EPA/540/R-94/520
March 1995

Geosafe Corporation In Situ Vitrification
INNOVATIVE TECHNOLOGY EVALUATION REPORT

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

NOTICE

The information in this document has been prepared for the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) Program under Contract No. 68-CO-0048. This document has been subjected to EPA's peer and administrative reviews and has been approved for publication as an EPA document. Mention of trade names of commercial products does not constitute an endorsement or recommendation for use.

FOREWORD

The Superfund Innovative Technology Evaluation (SITE) Program was authorized by the Superfund Amendments and Reauthorization Act (SARA) of 1986. The Program is administered by the EPA Office of Research and Development (ORD). The purpose of the SITE Program is to accelerate the development and use of innovative cleanup technologies applicable to Superfund and other hazardous waste sites. This purpose is accomplished through technology demonstrations designed to provide performance and cost data on selected technologies.

This project consisted of a demonstration conducted under the SITE Program to evaluate the In Situ Vitrification Technology developed by the Battelle Memorial Institute and exclusively licensed to Geosafe Corporation for treatment of soils contaminated with organic and inorganic materials. The Battelle Memorial Institute developed the ISV technology for the U.S. Department of Energy, Environmental Management Division, Office of Technology Develpment at Pacific Northwest Laboratory. The technology Demonstration was conducted at the former site of Parsons Chemical Works, Inc. in Grand Ledge, Michigan. This Innovative Technology Evaluation Report presents an interpretation of the performance and cost data gathered during the demonstration and discusses the potential applicability of the technology.

A limited number of copies of this report will be available at no charge from the EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio, 45268. Requests should include the EPA document number found on the report's cover. When the limited supply is exhausted, additional copies can be purchased from the National Technical Information Service (NTIS), Ravensworth Building, Springfield, Virginia, 22161, (703) 487-4600. Reference copies will be available at EPA libraries in the Hazardous Waste Collection. You can also call the SITE Clearinghouse Hotline at (800) 424-9346 or (202) 382-3000 in Washington, D.C. to inquire about the availability of other reports.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

The Geosafe In Situ Vitrification (ISV) Technology is designed to treat soils, sludges, sediments, and mine tailings contaminated with organic, inorganic, and radioactive compounds. The organic compounds are pyrolyzed and reduced to simple gases which are collected under a treatment hood and processed prior to their emission to the atmosphere. Inorganic and radioactive contaminants are incorporated into the molten soil which solidifies to a vitrified mass similar to volcanic obsidian.

This mobile technology was evaluated under the SITE Program on approximately 330 yd3 of contaminated soil at the Parsons site. Demonstration results indicate that the cleanup levels specified by EPA Region V were met and that the vitrified soil did not exhibit leachability characteristics in excess of regulatory guidelines. Process emissions were also within regulatory limits.

The Geosafe ISV Technology was evaluated based on seven criteria used for decision-making in the Superfund Feasibility Study (FS) process.

This report was submitted in fulfillment of Contract No. 68-CO-0048 by SAIC under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from March 1994 to April 1994, and work was completed as of April 1994.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Section Page

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

Table

LIST OF FIGURES

Figure

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

μg	Microgram
$\mu g/kg$	Micrograms per kilogram
$\mu g/L$	Micrograms per liter
$\mu g/m^3$	Micrograms per cubic meter
AQCR	Air Quality Control Regions
AQMD	Air Quality Management District
ARAR	Applicable or relevant and appropriate requirement
ATTIC	Alternative Treatment Technology Information Center
BDAT	Best Demonstrated Available Technology
BLS	Below land surface
CAA	Clean Air Act
CEM	Continuous emission monitors
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERI	Center for Environmental Research Information
CFR	Code of Federal RegulFR
CO	Carbon monoxide
CO_2	Carbon dioxide
CWA	Clean Water Act
DDT	Dichlorodiphenyltrichlorethane
DRE	Destruction removal efficiency
EPAU.S.	Environmental Protection Agency
EPA-RREL	EPA Risk Reduction Engineering Laboratory
HEPA	High efficiency particulate air
HSWA	Hazardous and Solid Waste Amendments
ICP	Inductively coupled plasma
ISV	In Situ Vitrification
ITER	Innovative Technology Evaluation Report
kg	Kilogram
lb/hr	Pounds per hour
LDR	Land Disposal Restriction
MCL	Maximum contaminant levels

ACRONYMS, ABBREVIATIONS, AND SYMBOLS (Continued)

MCLG	Maximum contaminant level goals
MDNR	Michigan Department of Natural Resources
mg/kg	Milligrams per kilogram
mg/L	Milligrams per liter
mg/m^3	Milligrams per cubic meter
MW	Megawatt
MWh	Megawatt hour
NAAQS	National Ambient Air Quality Standards
NaOH	Sodium Hydroxide
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
ND	Not detected
ng/kg	Nanograms per kilogram
NIST	National Institute Standards Technology
NO,	Nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NTIS	National Technical Information Service
OD	Outside diameter
ORD	EPA Office of Research and Development
OSHA	Occupational Safety and Health Act
OSWER	Office of Solid Waste and Emergency Response
OVA	Organic vapor analyzer
PAH	Polynuclear aromatic hydrocarbon
Parsons	Parsons Chemical Works, Inc.
PCB	Polychlorinated biphenyl
POTW	Publically-owned treatment works
PPE	Personal protective equipment
ppmv	Parts per million by volume
PVC	Polyvinyl chloride
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act

ACRONYMS, ABBREVIATIONS, AND SYMBOLS (Continued)

MCLG	Maximum contaminant level goals
MDNR	Michigan Department of Natural Resources
mg/kg	Milligrams per kilogram
mg/L	Milligrams per liter
mg/m^3	Milligrams per cubic meter
MW	Megawatt
MWh	Megawatt hour
NAAQS	National Ambient Air Quality Standards
NaOH	Sodium Hydroxide
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
ND	Not detected
ng/kg	Nanograms per kilogram
NIST	National Institute Standards Technology
NO_x	Nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NTIS	National Technical Information Service
OD	Outside diameter
ORD	EPA Office of Research and Development
OSHA	Occupational Safety and Health Act
OSWER	Office of Solid Waste and Emergency Response
OVA	Organic vapor analyzer
PAH	Polynuclear aromatic hydrocarbon
Parsons	Parsons Chemical Works, Inc.
PCB	Polychlorinated biphenyl
POTW	Publically-owned treatment works
PPE	Personal protective equipment
ppmv	Parts per million by volume
PVC	Polyvinyl chloride
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act

ACRONYMS, ABBREVIATIONS, AND SYMBOLS (Continued)

RREL	Risk Reduction Engineering Laboratory
SAIC	Science Applications International Corporation
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SITE	Superfund Innovative Technology Evaluation
SO_x	Sulfur oxides
SWDA	Solid Waste Disposal Act
TCDD	Tetrachlorodibenzo-p-dioxin
TCLP	Toxicity Characteristic Leaching Procedure
THC	Total Hydrocarbons
tons/yd3	Tons per cubic yard
TSCA	Toxic Substances Control Act
VISITT	Vendor Information System for Innovative Treatment Technologies
yd^3	Cubic yards

CONVERSIONS

Mass

1 pound (lb) = 0.4536 kg

1 ton = 2,000 lb = 907.18 kg

1 kilogram (kg) = 2.20 lb

Volume

1 cubic inch (in^3) = 5.78E-04 ft^3 = 2.14E-05 yd^3 = 0.0164 L = 1.64E-05 m^3 = 4.33E-03 gal

1 cubic foot (ft^3) = 1,728 in^3 = 0.0370 yd^3 = 28.32 L = 0.0283 m^3 = 7.48 gal

1 cubic yard (yd^3) = 46,656 in^3 = 27 ft^3 = 764.55 L = 0.7646 m^3 = 201.97 gal

1 cubic meter (m^3) = 61,023 in^3 = 35.31 ft^3 = 1.31 yd^3 = 1,000 L = 264.17 gal

1 liter (L) = 61.02 in^3 = 0.0353 ft^3 = 1.30E-03 yd^3 = 1.00E-03 m^3 = 0.2642 gal

1 gallon (gal) = 231 in^3 = 0.1337 ft^3 = 4.95E-03 yd^3 = 3.7854 L = 3.79E-03 m^3

Length

1 inch (in) = 0.0833 ft = 0.0278 yd = 0.0254 m

1 foot (ft) = 12 in = 0.3333 yd = 0.3048 m

1 yard (yd) = 36 in = 3 ft = 0.9144 m

1 meter (m) = 39.37 in = 3.28 ft = 1.09 yd

Temperature

1 degree Fahrenheit (°F) = 0.5556°C [x°C=0.5556*(y°F-32)]

1 degree Celsius (°C) = 1.8°F [x°F=1.8*(y°C)+32]

CONVERSIONS **(Continued)**

Pressure

1 pound per square inch (psi) = 27.71 in H_2O = 6894.76 Pa
1 inch of water (in H_2O) = 0.0361 psi = 248.80 Pa
1 Pascal (Pa) = 1.45E-04 psi = 4.02E-03 in H_2O

Viscosity

1 poise = .1 kg/m-see = 2.09E-03 **lb/ft-sec**
1 kg/m-set = 10.00 poise = 2.09E-03 Ib/ft-set
1 **lb/ft-sec** = 478.70 kg/m-set

Rate

1 Ib/hr = 2.20 **kg/hr**
1 **kg/hr** = 0.4536 Ib/hr

ACKNOWLEDGEMENTS

This report was developed under the direction of Ms. Teri Richardson, the EPA Technical Project Manager for this SITE Demonstration at the Risk Reduction Engineering Laboratory (RREL) in Cincinnati, Ohio. It was prepared by the Process Technology Division of Science Applications International Corporation (SAIC), San Diego, California under the direction of Mr. Raymond J. Martrano, the SAIC Work Assignment Manager. Contributors to the report were: Ms. Jamie Sue Winkelman, engineering and technical writing; Mr. Jonathan E. Rochez, engineering and data evaluation; and Ms. Ruth D. Alfasso, technical writing. Technical reviews were provided by Mr. Randy Parker and Ms. Laurel Staley of EPA-RREL and Dr. Victor S. Engleman, Mr. Joseph D. Evans, and Mr. Kyle R. Cook of SAIC. Special thanks are extended to Mr. Leonard N. Zintak, Jr. of EPA Region V for his technical review and assistance throughout this project.

EXECUTIVE SUMMARY

This report summarizes the findings associated with a Demonstration of the Geosafe Corporation (Geosafe) .In Situ Vitrification (ISV) Process. The Geosafe ISV technology was evaluated under the EPA Superfund Innovative Technology Evaluation (SITE) Program in conjunction with remediation activities associated with an EPA Region V removal action. The technology was assessed regarding its ability to treat pesticides (specifically chlordane, dieldrin, and 4,4'-DDT) and mercury to below Region V mandated limits. It was evaluated against the nine criteria for decision-making in the Superfund Feasibility Study process. Table ES-l presents the results of this evaluation.

The ISV technology uses electric power to heat contaminated soil past its melting point and thus thermally destroy organic contaminants in the soil. Once the entire treatment volume is molten, power is discontinued. As the molten mass solidifies, it incorporates inorganic contaminants within a glass and crystalline vitrified material. Off-gases that are generated during treatment are collected in a containment hood that is placed over the treatment area. The off-gases are processed by a treatment train which typically consists of a quencher, a wet scrubber, a demister, a heater, particulate filters, and activated carbon to process the gas before discharge to the atmosphere. In certain applications, a thermal oxidizer is used to polish the treated gases before release to the atmosphere. As part of the Region V removal action, Geosafe performed a total of eight melts which covered nine pre-staged treatment cells at the Parsons Chemical Works, Inc. (Parsons) site located in Grand Ledge, Michigan. The SITE Program studied one of these treatment settings (Cell 8) in detail to determine the technology's ability to meet the Region V removal criteria and to obtain cost and performance data on the technology. This Innovative Technology Evaluation Report focuses on the findings associated with the SITE Demonstration.

Results presented in this report for the treated soil are based on post-treatment sampling just below the surface of the melt alone. Complete post-treatment sampling of the solidified melt cannot be safely performed until at least one year after treatment at which time sampling of the melt core will take place. Because the technology is already being used in commercial applications, this report has been published prior to obtaining treated soil samples from the center of the study area. In this manner, the community may be provided with the information currently available regarding the operability and effectiveness of the technology. Results of the post-treatment soil samples collected from the core of Cell 8 will be reported at a later date in a published Addendum.

Table ES-l. Evalutation Criteria for the Geosafe In Situ Vitrification Process

Overall Protection of Human Health and the Environment	Compliance with ARARS	Long-Term Effectiveness and Performance	Short-Term Effectiveness	Reduction of Toxicity, Mobility, or Volume through Treatment
Provides both short- and long-term protection by destroying organic contaminants and immobilizing inorganic material. Developer also claims the technology can treat radioactive compounds. Remediation can be performed in situ, thereby reducing the need for excavation. Off-gas treatment system reduces airborne emissions. System is flexible and can be adapted for a variety of contaminant types and site conditions. Technology can simultaneously treat a mixture of waste types. Technology is applicable to combustible materials, but the concentration of such materials in the treatment zone must be carefully controlled and treatment prudently planned.	Requires compliance with RCRA treatment, storage, and land disposal regulations (for a hazardous waste). Successfully treated waste may be delisted or handled as non-hazardous waste. Operation of on-site treatment unit may require compliance with location-specific applicable or relevant appropriate requirements (ARARs). Emission control may be needed to ensure compliance with air quality standards depending upon local ARARs and test soil components. Scrubber water will likely require secondary treatment before discharging to publically owned treatment works (POTW) or surface bodies. Disposal requires compliance with Clean Water Act regulations.	Effectively destroys organic contamination and immobilizes inorganic material. Developer also claims the technology can treat radioactive compounds. Reduces the likelihood of contaminants leaching from treated soil. ISV glass is thought to have a stability similar to volcanic obsidian which is estimated to remain physically and chemically stable for thousands to millions of years. Allows potential re-use of property after treatment.	Treatment of a site using ISV destroys organic compounds and immobilizes inorganic contaminants. Vitrification of a single treatment setting may be completed in approximately ten days. This treatment time may vary depending on site-specific conditions. Presents potential short-term chemical exposure risks to workers operating process equipment. High voltage and high temperatures require appropriate safety precautions. Some short-term risks associated with air emissions are dependent upon test material composition and off-gas treatment system design. Staging, if required, involves excavation and construction of treatment areas. A potential for fugitive emissions and exposure exists during excavation and construction.	Significantly reduces toxicity and mobility of soil contaminants through treatment. Volume reductions of 20 to 50 percent are typical after treatment. Some inorganic contaminants, especially volatile metals, may be removed by the vitrification process, and require subsequent treatment by the off-gas treatment system. Some treatment residues may themselves be treated during the next vitrification setting. Residues from the final setting, including expended or contaminated processing equipment, may require special disposal requirements. Volume of scrubber water generated is highly dependent upon soil moisture content.

Table ES-1 (Continued)

Implementability	Cost	Community Acceptance	State Acceptance
Equipment is mobile and can be brought to a site using conventional shipping methods. Weight restrictions on tractors/trailers may vary from state to state. Support equipment includes earth-moving equipment for staging treatment areas (if required) and covering treated areas with clean soil. A crane is required for off-gas containment hood placement and movement. Chemical characterization of contaminated soil is required for proper off-gas treatment system design. A suitable source of electric power is required to utilize this technology. Technology not recommended for sites which contain organic content greater than 7 to 10% (by weight), metals content in excess of 25% (by weight), and inorganic contaminants greater than 20% (by volume). Sites with buried drums may only be treated if drums are not intact or sealed.	The cost for treatment when the soil is staged into nine 15-foot deep cells is approximately \$770/yd^3 (\$430/ton). Treatment is most economical when treating large sites to the maximum depth. Electric power is generally the most significant cost associated with ISV processing. Other factors (in order of significance) include labor costs, startup and fixed costs, equipment costs, and facilities modifications and maintenance costs. Moisture content of the media being treated directly influences the cost of treatment since electric energy must be used to vaporize water before soil melting occurs. Sites that require staging and extensive site preparation will have higher overall costs.	Technology is generally accepted by the public because it provides a permanent solution and because it is performed in situ. Potential reuse of land after treatment provides an attractive alternative to property owners. A public nuisance could be created if odorous emissions from the soil constituents are not properly controlled by the off-gas system.	State ARARs may be more stringent than federal regulations. State acceptance of the technology varies depending upon ARARs. The ISV system (especially the off-gas treatment portion) is somewhat modular, such that it may be modified to meet state-specific criteria.

CONCLUSIONS BASED ON CRITICAL OBJECTIVES

The studies conducted by the SITE Program suggest the following conclusions regarding the technology’s performance at the Parsons site based on the critical objectives stated for the Demonstration:

> The treated soil met the EPA Region V cleanup criteria for the target pesticides and mercury. Dieldrin and 4,4’-DDT were reduced to levels below their analytical reporting detection limits (< 16 $\mu g/kg$) in the treated soil. Chlordane was below its detection limit (80 $\mu g/kg$) before treatment commenced. Mercury, analyzed by standard SW-846 Method 7471 procedures, was below the specified cleanup level before treatment began, averaging 3,800 $\mu g/kg$. It was reduced to an average of less than 33 $\mu g/kg$ in the treated soil.
>
> Stack gas samples were collected during the Demonstration to characterize process emissions. There were no target pesticides detected in the stack gas samples. During the Demonstration, mercury emissions averaged 1.2 X 10” lb/hr (16 $\mu g/m^3$). The emissions were below the regulatory requirement of 5.93 x 10^{-4} lb/hr (88 $\mu g/m^3$) at all times. Other metal emissions in the stack gas (particularly arsenic, chromium, and lead) were of regulatory concern during process operations, but were found to be in compliance with the Michigan state applicable or relevant and appropriate requirements (ARARs).
>
> Emissions of total hydrocarbons (as propane) and carbon monoxide were’regulated at 100 parts per million by volume (ppmv) and 150 ppmv, respectively. Throughout the Demonstration, vapor emissions of these gases (measured downstream from the thermal oxidizer) were well below the regulatory guidelines. Total hydrocarbon and carbon monoxide emissions both averaged below 10 ppmv.

CONCLUSIONS BASED ON SECONDARY OBJECTIVES

The studies conducted by the SITE Program suggest the following conclusions regarding the technology’s performance at the Parsons site based on the secondary objectives stated for the Demonstration:

The technology successfully treated the soil in Cell 8, completing the test cell melt in ten days with only minor operational problems. During this time, approximately 330 yd^3 (approximately 600 tons) of contaminated soil were vitrified, according to Geosafe melt summaries. Approximately 610 MWh of energy was applied to the total soil volume melted (estimated to be 480 yd^3) during vitrification of Cell 8; power applied to the actual ***contaminated*** soil volume could not be independently measured because clean fill and surrounding uncontaminated soil are vitrified as part of each melt. Based on the total soil treated in Cell 8, the energy consumption was approximately 0.72 MWh/ton. System operation was occasionally interrupted briefly for routine maintenance such as electrode segment addition and adjustment.

The solid vitrified material collected was subjected to TCLP analysis for the target pesticides and mercury. Test results indicate that no target pesticides were detected in the post-treatment leachate. Chlordane was not detected in either the pre- or post-treatment leachate, so no definitive conclusions can be drawn about the technology's impact on the leachability of this compound based on this Demonstration. Levels of leachable mercury in both pre- and post-treatment soil leachates were well below the regulatory limit of 200 μg/L (40 CFR $261.24). Several other metals were also found to have passed the TCLP leaching test.

Scrubber water generated during the Demonstration contained volatile organics, partially oxidized semivolatile organics (phenolics), mercury, and other metals. The scrubber water underwent secondary treatment before ultimate disposal, and data suggest that secondary treatment of this waste stream will probably be required in most cases.

Pre-treatment soil ***dry*** density averaged 1.5 tons/yd^3, while post-treatment soil ***dry*** density averaged 2.1 tons/yd^3. Accordingly, a volume reduction of approximately 30 percent was observed for the test soil on a dry basis.

The cost for treatment when the soil is staged into nine cells is approximately $1 ,300/yd^3 ($740/ton) for 5-foot deep cells, $770/yd^3 ($430/ton) for 15-foot deep cells (like those at the Parsons site), and $660/yd^3 ($370/ton) for 20-foot deep cells. The costs presented are calculated based on the number of cubic yards of ***contaminated*** soil treated. Because clean fill and surrounding uncontaminated soil are treated as part of each melt, the amount of material treated is higher than the amount of contaminated soil treated. Costs per cubic yard based on total soil treated would, therefore, be lower than the costs per cubic yard based on contaminated soil treated presented in this report.

- Treatment is most economical when treating large cells to the maximum depth. The primary cost categories include utilities, labor, and startup and fixed costs.

The following sections of this report contain the detailed information which supports the items summarized in this Executive Summary. The site studied during this Demonstration was Geosafe's first large-scale commercial project, and the results presented in this report are based primarily on this application. Valuable lessons learned at this site have been put into practice in subsequent applications.

SECTION 1
INTRODUCTION

This section provides background information about the Superfund Innovative Technology Evaluation program, discusses the purpose Of this Innovative Technology Evaluation Report, and briefly describes the Geosafe In Situ Vitrification Technology. For additional information about the SITE Program, this technology, and the Demonstration site, key contacts are listed at the end of this section.

1.1 Background

ISV has been under development since 1980. When it was first researched by Battelle Memorial Institute (Battelle), ISV was designed to treat radioactive (transuranic) contaminated soil in situ to avoid problems associated with excavation or transportation of these soils. A successful pilot-scale demonstration of the technology on radioactive wastes was performed in 1983. It was soon recognized that the technology had applicability towards other wastes, including hazardous chemical contamination and mixed (chemical and radioactive) wastes. The Geosafe Corporation (Geosafe) was formed in the spring of 1988 and subsequently negotiated a sublicense from Battelle for the purpose of establishing ISV in the commercial marketplace. From this point forward in this report, Geosafe will be considered to be the technology developer.

In October 1990, EPA began a cleanup of the soil contamination at the former Parsons Chemical Works, Inc. site (currently occupied by ETM Enterprises) in Grand Ledge, Michigan. The site, designated as a Super-fund site by the EPA, is located approximately ten miles west of Lansing. Parsons operated at this location from 1945 until its closure in 1979. Parsons was engaged in the mixing, manufacturing, and packaging of agricultural chemicals including pesticides, herbicides, solvents, and mercury-based compounds. Prior to any remedial action, the site contained approximately 3,000 yd^3 (5,400 tons) of contaminated soil. The depth of contamination on-site was relatively shallow, five feet or less; therefore, contaminated soils from three target areas were excavated, consolidated, and staged on-site for treatment.

ISV was the cleanup technology selected for the Parsons site, and Geosafe Corporation of Richland, Washington was the EPA contractor selected to perform the ISV treatment (I). During remediation of the Parsons site, a SITE Demonstration of the full-scale Geosafe system was performed. Although

Geosafe Corporation applied and was accepted into the SITE Program in the late 1980s, they had to wait approximately two years for the signing of a remediation contract with EPA Region V. Geosafe also encountered some developmental problems such that the actual SITE Demonstration of this technology was delayed until March 1994.

1.2 Brief Description of Program and Reports

The SITE Program is a formal program established by the EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA). The SITE Program promotes the development, demonstration, and use of new or innovative technologies to clean up Superfund sites across the country.

The SITE Program's primary purpose is to maximize the use of alternatives in cleaning hazardous waste sites by encouraging the development and demonstration of new, innovative treatment and monitoring technologies. It consists of four major elements:

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

The Emerging Technology Program focuses on conceptually proven bench-scale technologies that are in an early stage of development involving pilot or laboratory testing. Successful technologies are encouraged to advance to the Demonstration Program.

The Demonstration Program develops reliable performance and cost data on innovative technologies so that potential users may assess the technology's site-specific applicability. Technologies evaluated are either currently available or close to being available for remediation of Superfund sites. SITE Demonstrations are conducted on hazardous waste sites under full-scale remediation conditions or under conditions that closely simulate full-scale remediation conditions, thus assuring the usefulness and reliability of information collected. Data collected are used to assess: (1) the performance of the technology, (2) the potential need for pre- and post-treatment processing of wastes, (3) potential operating problems, and (4) the approximate costs. The Demonstrations also allow for evaluation of long-term risks and operating and maintenance costs.

Existing technologies that improve field monitoring and site characterizations are identified in the Monitoring and Measurement Technologies Program. New technologies that provide faster, more cost-effective contamination and site assessment data are supported by this program. The Monitoring and Measurement Technologies Program also formulates the protocols and standard operating procedures for demonstration methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Emerging Technology Program, the Demonstration Program, and the Monitoring and Measurements Technologies Program through various activities. These activities increase the awareness and promote the use of innovative technologies for assessment and remediation at Superfund sites. The goal of technology transfer activities is to develop interactive communication among individuals requiring up-to-date technical information,

1.3 The SITE Demonstration Program

Technologies are selected for the SITE Demonstration Program through annual requests for proposals. ORD staff reviews the proposals to determine which technologies show the most promise for use at Superfund sites. Technologies chosen must be at the pilot- or full-scale stage, must be innovative, and must have some advantage over existing technologies. Mobile and in situ technologies are of particular interest,

Once the EPA has accepted a proposal, cooperative agreements between the EPA and the developer establish responsibilities for conducting the Demonstration and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site and is responsible for any costs for transport, operations, and removal of the equipment. The EPA is responsible for project planning, sampling and analysis, quality assurance and quality control, preparing reports, disseminating information, and transporting and disposing of treated waste materials.

The results of this evaluation of the Geosafe In Situ Vitrification Technology are published in two basic documents: the SITE Technology Capsule and this Innovative Technology Evaluation Report (ITER). The SITE Technology Capsule provides relevant information on the technology, emphasizing key features of the results of the SITE field Demonstration while the ITER provides an in-depth evaluation of the overall performance and applicability of the technology.

1.4 Purpose **of the Innovative Technology Evaluation Report**

This ITER provides information on the Geosafe In Situ Vitrification Technology for treatment of contaminated soils and includes a comprehensive description of this Demonstration and its results. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision-makers carrying out specific remedial actions. The ITER is designed to aid decision-makers in further evaluating specific technologies for further consideration as applicable options in a particular cleanup operation. This report represents a critical step in the development and commercialization of a treatment technology.

To encourage the general use of demonstrated technologies, the EPA provides information regarding the applicability of each technology to specific sites and wastes. The ITER includes information on cost and performance, particularly as evaluated during the Demonstration. It also discusses advantages, disadvantages, and limitations of the technology

Each SITE Demonstration evaluates the performance of a technology in treating a specific waste. The waste characteristics of other sites may differ from the characteristics of the treated waste. Therefore, a successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

1.5 Brief Technology Description

In situ vitrification uses electrical power to heat and melt soil and other earthen materials (e.g., dewatered sludge, mine tailings, buried waste, and sediments) contaminated with organic, inorganic, and radioactive compounds. Due to the intense heat of the process, organic contaminants within the treatment volume undergo pyrolysis (thermal decomposition in the absence of oxygen). The pyrolysis products then migrate to the surface of the treatment zone where they are oxidized under a collection hood. Large amounts of ambient air are used to cool the collection hood and to sweep the off-gases to the treatment system. An air pollution control system treats the off-gases generated prior to discharge. The remaining molten material cools to form a monolithic glass-like product that incorporates the thermally stable inorganic compounds present within the treatment zone. The glass material is claimed to have very low leaching characteristics (2,3,4)

The Geosafe ISV technology uses a square array of four graphite electrodes that allows a melt width of approximately 20 to 40 feet and a potential treatment depth of up to 20 feet. Multiple settings may be used for remediation of a larger contaminated area. Electric power is supplied to the electrodes through flexible conductors. Initially, the electrodes are inserted one to two feet below the soil surface, and a conductive starter path is laid between them. An electric potential is applied to the electrodes to establish an electrical current in the starter path. Upon melting (at temperatures in the vicinity of 2,000 to 2,500°F), the soil becomes electrically conductive. As the soil surrounding the electrodes becomes molten, the electrodes can be lowered until the desired treatment depth is attained.

In a single setting, the process can remediate contaminated soil at an estimated rate of four to six tons per hour until a maximum mass of 800 to 1,200 tons has been treated. After treatment, the vitrified mass is typically left in place, although it can be removed if necessary after cooling. Subsidence, resulting from the elimination of void volume and removal of humus and organic contaminants, is remedied by backfilling over the melt with clean material.

A more in-depth description of the process may be found in Section 4.4 of this report, “Detailed Process Description.” Appendix A, “Vendor’s Claims,” provides some additional information.

1.6 Key Contacts

Additional information about the Geosafe In Situ Vitrification Technology and the SITE Program can be obtained from the following sources

The Geosafe In Situ Vitrification Technology

Mr. James E. Hansen
Geosafe Corporation
Director of Business Development and Communications
2950 George Washington Way
Richland, Washington 99352
Phone: 509/375-07 10
Fax: 509/375-7721

The SITE Program

Ms. Teri L. Richardson
EPA SITE Technical Project Manager
U . S. Environmental Protection Agency
Risk Reduction Engineering Laboratory
26 West Martin Luther King Drive
Cincinnati, OH 45268
Phone: 5 13/569-7949
Fax: 5 13/569-7620

Information on the SITE Program is available through the following on-line information clearinghouses

- The Alternative Treatment Technology Information Center (ATTIC) System (operator: 703/908-2 137) is a comprehensive, automated information retrieval system that integrates data on hazardous waste treatment technologies into a centralized, searchable source. This database provides summarized information on innovative treatment technologies.
- The Vendor Information System for Innovative Treatment Technologies (VISITT) (hotline: 800/245-4505) database currently contains information on approximately 23 1 technologies offered by 141 developers.
- The OSWER CLU-IN electronic bulletin board contains information on the status of SITE technology Demonstrations. The system operator can be reached at 301/589-8368.

Technical reports may be obtained by contacting the Center for Environmental Research Information (CERI), 26 Martin Luther King Drive in Cincinnati, OH, 45268 at 513/569-7562.

SECTION 2

TECHNOLOGY APPLICATIONS ANALYSIS

This section of the report addresses the general applicability of the Geosafe ISV technology to contaminated soil sites. The analysis is based primarily on this SITE Demonstration, and conclusions are based exclusively on these data since only limited information is available on full-scale applications of the technology. This SITE Demonstration was conducted on approximately 400 cubic yards of soil, of which an estimated 330 cubic yards were contaminated with low levels of pesticides, dioxins/furans, mercury, and other metals,

2.1 Key Features

The Geosafe ISV system is an in situ technology that allows on-site treatment of contaminated wastes without excavation and with only limited site preparation. The technology is unique in that it can effectively treat a wide variety of contamination including hazardous chemical (both organic and inorganic), radioactive, and mixed (chemical and radioactive) wastes. ISV can treat sites that would otherwise require two or more technologies to handle the same range of contaminants. Although the application of this technology to radioactive and mixed wastes was not studied as part of the Demonstration, full-scale testing for this type of treatment has been successfully conducted.

In situ treatment is advantageous, especially when volatile organic compounds are present or when large quantities of contaminated soils are present since soil handling activities may be minimized. If the contamination is shallow or scattered, the soil may be excavated, consolidated, and staged for treatment.

Operation utilizes electric energy to melt the soil, driving off and decomposing organic contaminants and immobilizing thermally stable compounds in a matrix claimed to be relatively non-leachable. The residual product has very stable geological characteristics, similar to volcanic obsidian. Contaminants that are difficult to treat using other techniques can be bound into this glass and crystalline vitrified material. The vitrified mass is typically left in place, and thus the need for disposal of the treated material can be eliminated. The developer claims that the vitrified material is non-hazardous and can be delisted. Delisting procedures are very site-specific and could vary significantly from state to state.

Treatment by ISV effectively reduces the mobility of the contaminants and the toxicity and volume of the contaminated media. The mobility of contaminants is diminished when leachable constituents are incorporated into a non-leachable mass. The toxicity of the soil is reduced by the destruction and removal of organic contaminants and volatile metal compounds. The potential for lateral migration is restricted through the use of refractory walls when using staged treatment. Compounds that are vaporized but not destroyed by the vitrification process are passed through an off-gas treatment system. The removal of materials that can be vaporized and void space between soil particles as a result of the vitrification process produces a 20 to 50 percent volume reduction according to the developer.

2.2 Operability of the Technology

The Geosafe ISV technology operates using electrical energy to heat and melt soil, destroying organic contaminants by means of pyrolysis and oxidation, thermally decomposing some inorganic contaminants, and immobilizing thermally stable contaminants. The most important operational parameter for this technology is the electrical input to the melt. A maximum of 1.75 MW of power is supplied through each of the two phases of the electrical system (A and B), such that maximum total power to the electrodes during treatment is about 3.5 MW. Initially, the current applied to the soil is low (100 to 200 amps per phase) and the voltage is quite high (up to 4,000 volts per phase). However, as the melt progresses, the voltage is decreased and the current is increased as the molten soil becomes more conductive. The voltage applied to each of the two phases during full power operation averages only 600 volts while the current for each phase averages 2,900 amps. Treatment of a typical 15-foot deep single cell requires up to 1,200 MWh of energy; however, the cell treated during the Demonstration required only 610 MWh (approximately 0.72 MWh/ton), much less than other cells at the Parsons site. According to the vendor, normal energy consumption is approximately 1 MWh/ton. The high rates of consumption dictate that electricity is a primary factor when considering costs and availability of resources.

Although ISV can treat saturated soils, the presence of large amounts of water or a high water table hinders operation of the ISV technology. When water is present, electrical energy is initially used to vaporize this water instead of melting the contaminated soil, thus prolonging treatment time and increasing costs. The resulting water vapors must be handled by the off-gas treatment system and further increases project costs. An overabundance of water does not preclude treatment with ISV, but may make it prohibitively expensive. As with most thermal technologies, the cost of treatment increases with the amount of water that has to be removed; therefore, it is economically wise to keep the treatment zone as dry as possible prior to treatment

Weather is another factor which affects the operability of the Geosafe system. Rain or snow at the treatment site increases the amount of water in the soil and can lead to the difficulties discussed above. High humidity increases the amount of liquid handled by the off-gas treatment system. Moving the hood becomes more difficult in windy conditions, but may still be accomplished safely. Temperature is not a critical factor. Cold ambient temperatures may increase the amount of initial heating required but once the soil is in a molten state, the surrounding area stays warm due to the thermal insulating properties of the soil. Extreme temperatures (hot or cold) make working conditions less favorable for personnel and equipment. The ISV process was successfully operated at the Parsons site during a typical Michigan winter season.

When contaminated soil volumes are shallow or scattered, the soil can be excavated, consolidated, and staged in a treatment area. This was illustrated at the Parsons site where the contaminated soil was excavated from three selected areas and placed in nine pre-constructed treatment cells. The cell walls were constructed of concrete; a layer of cobble was placed outside of the concrete, and a sheet of plywood was used to separate the treatment cells from the surrounding uncontaminated soil. The bottom of the cells were constructed of cobble covered with a plastic liner. Some aspects of the cell structure used at the Parsons site proved unsuitable for effective implementation of the technology. This issue is further discussed in Section 4 of this report, “Treatment Effectiveness.”

For the SITE Demonstration, one of the nine treatment cells was vitrified. This cell contained approximately 400 cubic yards of soil, 330 of which was estimated to be contaminated. During the removal action supervised by EPA Region V at the Parson Chemical site, all nine cells (approximately 3,000 cubic yards of contaminated soil) were treated. Because of the way the melts grew during treatment, remediation of the nine cells was accomplished in eight melts rather than nine

2.3 Applicable Wastes

The ISV technology can treat a wide range of waste matrices contaminated with a variety or mixture of contaminant types. The technology can be used on soils, sludges, sediments, mine tailings, and similar assembly and shakedown) is approximately three weeks. If a more rapid setup is required, more than one shift of workers may be utilized per day.

2.5 Materials Handling Requirements

The amount of materials handling required depends mainly on whether the contaminated soil is staged or treated in situ. Treatment of soils that are not moved, and that do not require pre-treatment, does not necessitate much additional equipment. Earth-moving equipment (such as a backhoe and/or a dump truck) is required to backfill the subsidence of treated areas.

If soils are to be staged, or if mixing of wastes is required, soil excavation equipment is needed. The actual equipment used depends on the amount and characteristics of the contaminated soil. A backhoe is commonly used to move soil on a site, with or without an accompanying dump truck. A conveyor belt or similar device can be used to transport soil from a temporary staging area to treatment cells. Special equipment or modifications to existing equipment may be recommended for excavation of soils containing volatile contaminants in order to reduce volatilization and exposure of personnel or the community.

Sampling of soils before and after treatment may also require the use of materials handling equipment. Soil in situ can be sampled using a drill rig, a backhoe, a shovel, or another device depending on the characteristics of the soil and the depths to be sampled. After treatment, samples of the solidified matrix may need to be collected using a specially-equipped drill rig or jackhammer

During both setup and treatment, a crane and other support equipment are required. The crane is used to erect the hood during assembly, to move the hood over each melt before treatment, and to add electrodes during treatment. Other equipment, such as a forklift, may be needed to move drums and miscellaneous supplies on the site.

2.6 Site Support Requirements

The main site requirement for use of ISV is the availability of electricity. For the unit used during the Demonstration, 4 MW are required at a voltage of either 12,500 or 13,800 volts. These voltages are standard grid voltages available in the United States. Power can be supplied through trailer-mounted diesel generators in situations where building a connection to the power grid would be unfeasible. The costs of using diesel-generated power are generally higher than that for grid electricity.

If a thermal oxidizer is part of the treatment train, then a source of natural gas or fuel oil is required. A natural gas connection to the local utility was made at the Parsons site to supply natural gas during the Demonstration. It may be possible to obtain an electric secondary combustion device that provides the necessary off-gas treatment. Although this would eliminate the need for fuel, the use of natural gas or fuel oil would probably be more economical if it is available.

Other utilities required for the use of ISV include water for cleaning, for use in the scrubber, and for personnel needs. Only small amounts of potable water are required. Phone service to the site is required for general communications and to summon emergency assistance. A connection to the sewer may also be needed to discharge scrubber water or diverted groundwater. Portable toilets may be used as toilet facilities.

Access to the site must be provided over roads suitable for travel by heavy equipment. The trailers can travel over regular roads, but may not be allowed on low capacity bridges or especially steep grades. Personnel must also be able to reach the site without difficulty, since three shifts of personnel are utilized during treatment. Auxiliary facilities are needed for storage of supplies and tools, and for office and rest areas. Mobile trailers and storage containers can be brought on-site for these purposes. Because the ISV process is operated continuously, the top of the hood is equipped with floodlights which illuminate the work areas after dark. Additional site lighting may be required in other areas for nighttime operation.

When the ISV equipment is utilized in an inhabited area, site security measures are required both to protect the public from accidental exposures and to prevent accidental or intentional damage to the equipment. A fence surrounded the Parsons site to provide additional security.

2.7 Ranges **of Suitable Site Characteristics**

Because ISV can operate on soils in situ, applicable waste characteristics (discussed in Section 2.3) and suitable site characteristics overlap somewhat. The site characteristics described in this section provide additional information about items which require consideration before treatment of a site.

Apart from appropriate soil types discussed previously, the required geological conditions include stable formations which can support the treatment equipment. The treatment surface must be level to allow placement of the ISV equipment and facilitate effective sealing of the soil/hood interface to prevent escape of fugitive emissions. Groundwater present in the treatment area makes treatment more time consuming and costly (as described earlier). Diverting groundwater around the treatment area may make remediation more efficient.

The treatment area cannot contain utility lines or other underground facilities, since these would be destroyed by the treatment and may pose a safety hazard (e.g., buried gas lines). If the treatment soil or adjacent areas contain highly permeable natural or artificial conduits in the less permeable matrix, special precautions may need to be taken to prevent the melt from extending outside the planned treatment zone and to prevent fugitive emissions of toxic or odorous gases. These precautions may include removal of the more permeable material, mixing it with the other soil, or the construction of restraining walls, such as the refractory concrete walls used during the Demonstration.

The use of ISV requires space for placement of the process equipment, auxiliary equipment and buildings, and waste staging (when required). The process trailers occupy an area of approximately 10 feet by 120 feet. The off-gas hood is 60 feet in diameter, while the area treated in a single melt measures approximately 27 feet by 27 feet; therefore, sufficient space must be available around the perimeter of the treatment area to place and seal the hood. An extra buffer of space between the contaminated soil and any areas that are not a part of the site is also required so that unexpected melt growth does not have an adverse off-site impact.

The Geosafe equipment can operate in nearly any climate. Since soil is a good insulating material, very cold climates do not inhibit treatment other than perhaps slowing its initiation. Equipment can be climatized to prevent damage due to exposure to hot, cold, or wet conditions.

The ISV process can be used in fairly close proximity to inhabited areas, so long as appropriate measures are taken to prevent off-site emissions, odors, or noise. The presence of lights and noise may preclude use in some residential areas, since the system must be operated continuously for effective application. Heavy equipment must be transported to and from the site on occasion, however, once the equipment is operating, there is little additional traffic generated to the site. The small crew size limits the number of vehicles on-site.

2.8 Limitations of the Technology

The size of a melt which can be generated is limited to approximately 40 feet by 40 feet and a maximum depth of about 20 feet (800 to 1,200 tons) with the current ISV technology. For treatment of deeper contamination, Geosafe has proposed using a multi-layered staged approach in which the upper portion of contaminated soil may be excavated while the deeper portion of contaminated soil is treated in situ. The excavated soil would then be replaced and treated in situ atop the previously vitrified material. This would, however, increase the complexity of treatment and the cost per cubic yard. Demonstrations of this approach have not yet been performed.

Because the ISV process operates in situ, it may not be appropriate for sites where contaminated soil exists directly adjacent to buildings, other structures, or the property line. Staging or the use of insulating refractory walls can be used in some cases, but will probably increase the costs.

Costs per cubic yard are minimized when a sufficient amount of waste is treated at the site to distribute the costs of mobilization. Small amounts of contaminated soil may be more efficiently treated with other methods or at an off-site facility. ISV may not be the least expensive method to treat a waste with only one type of contamination (e.g., volatile organics or metals), but it may be favored when in situ treatment is desired. ISV also offers unique opportunities and potential cost savings when treating sites with multiple types of contamination-sites that would normally require the use of two or more technologies or a treatment train to accomplish treatment goals. In some instances, ISV may be the most cost-effective treatment alternative

After treatment with ISV, the soil is molten and very hot. The molten mass may take more than a year to fully cool. Although the surface of each completed melt is covered with a thick layer of clean fill, the heat may prevent re-use of the site until complete cooling has occurred. The monolith of solidified material is dense and hard, which minimizes leaching and breakdown. If required, the cooled vitrified mass may be removed from the site. Intentional rapid cooling of the melt may induce shrink-cracking of the surface, a desirable effect if the solidified block is to be broken apart and removed. Activities such as drilling through the treated material to install a building foundation or monitoring wells require state-of-the-art technology, but can be accomplished using appropriate techniques.

Limits on the amounts of contaminants which can be present in media suitable for treatment by ISV are determined by the heat removal capacity of the off-gas treatment system. The treatment soil is limited to a maximum of seven to ten percent organics by weight for effective remediation using the current off-gas treatment equipment. Additional or modified off-gas treatment components could allow treatment of a waste with a higher organic content.

Previous experience has indicated that safe, effective treatment becomes more difficult when pockets of flammable liquid or vapor in sealed containers exist beneath the soil surface. Combustible materials may also present treatment difficulties since the sudden release of gases may exceed the heat load and volumetric capacity of the off-gas treatment system, resulting in a loss of hood vacuum and a potential for fugitive emission releases. The sudden gas release may also cause bubbling and spattering of molten material which can damage the hood and may carry molten material away from the melt, creating a potential safety hazard. The most effective means of treatment exists when contaminants are evenly distributed throughout the soil and so will not cause sudden overload of gas-processing and other equipment. Buried drums also present potential problems if they are sealed and contain significant amounts of liquid

Metals in their reduced chemical state may sink to the bottom of the melt, concentrate there, and cause the electrodes to short-circuit. This metal-induced shorting may be encountered in soils that have high amounts of iron (or other similar metals). The developer claims that most metals are not reduced in an ISV melt and that short-circuiting of the electrodes can be prevented through use of the feeding mechanism which can retract the electrodes temporarily when a large metal object is encountered or when shorting is experienced

2.9 ARARS **for the Geosafe ISV Technology**

This subsection discusses specific federal environmental regulations pertinent to the operation of the Geosafe ISV technology including the transport, treatment, storage, and disposal of wastes and treatment residuals. Federal and state applicable or relevant and appropriate regulations (ARARs) are presented in

Table 2-l These regulations are reviewed with respect to the Demonstration results. State and local regulatory requirements, which may be more stringent, must also be addressed by remedial managers. ARARs include the following: (1) the Comprehensive Environmental Response, Compensation, and Liability Act; (2) the Resource Conservation and Recovery Act; (3) the Clean Air Act; (4) the Safe Drinking Water Act; (5) the Toxic Substances Control Act; and (6) the Occupational Safety and Health Administration regulations. These six general ARARs are discussed below.

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

The CERCLA of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 provides for federal funding to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or to the environment.

As part of the requirements of CERCLA, the EPA has prepared the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for hazardous substance response. The NCP is codified in Title 40 Code of Federal Regulations (CFR) Part 300, and delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination.

SARA states a strong statutory preference for innovative technologies that provide long-term protection and directs EPA to do the following:

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

Geosafe's ISV technology meets each of these requirements. Volume, toxicity, and mobility of contaminants in the waste matrix are all reduced as a result of treatment. Organic compounds are removed and destroyed; the vitrified product permanently immobilizes inorganic constituents. The need

Table 2-1. Federal and State Applicable or Relavant and Applicable Regulations (ARARs) for the Geosafe ISV Technology

PROCESS ACTIVITY	ARAR	DESCRIPTION OF REGULATION	GENERAL APPLICABILITY	SPECIFIC APPLICABILITY TO ISV
Waste characterization of untreated waste	RCRA: 40 CFR Part 261 (or state equivalent)	Standards that apply to identification and characterization of wastes	Chemical and physical analyses must be performed to determine if waste is a hazardous waste .	Chemical and physical properties of waste determine its suitability for treatment by ISV.
Soil excavation	CAA: 40 CFR Part 50 (or state equivalent)	Regulation governs toxic pollutants, visible emissions and particulates	If excavation is performed, emission of volatile compounds or dusts may occur.	Only applies to staged treatment. Handling practices should minimize volatilization and dust production.
Waste processing	RCRA: 40 CFR Part 264 (or state equivalent)	Standards that apply to treatment of wastes in a treatment facility	When hazardous wastes are treated, there are requirements for operations, recordkeeping, and contingency planning.	Applicable or appropriate for ISV operations.
	CAA: 40 CFR Part 50 (or state equivalent)	Regulation governs toxic pollutants, visible emissions and particulates	Stack gases may contain volatile organic compounds or other regulated gases.	During ISV treatment, stack gases must not exceed limits set for the air district of operation. Standards for monitoring and recordkeeping apply.

Table 2-1. (Continued)

PROCESS ACTIVITY	ARAR	DESCRIPTION OF REGULATION	GENERAL APPLICABILITY	SPECIFIC APPLICABILITY TO ISV
Storage of auxiliary wastes	RCRA: 40 CFR Part 264 Subpart J (or state equivalent)	Regulation governs standards for tanks at treatment facilities	If storing non-RCRA wastes, RCRA requirements may still be relevant and appropriate.	Storage tanks for liquid wastes (e.g., scrubber water) must be placarded properly, have secondary containment and be inspected daily.
	RCRA: 40 CFR Part 264 Subpart I (or state equivalent)	Regulation covers storage of waste materials generated	Applicable for RCRA wastes; relevant and appropriate for non-RCRA wastes	Containers of process stream residuals (e.g., filters) need to be labeled as hazardous waste. The storage area needs to be in good condition, weekly inspections are required, and storage should not exceed 90 days unless a storage permit is acquired.
Determination of cleanup standards	SARA: Section 121(d)(2)(A)(ii); SDWA: 40 CFR Part 141	Standards that apply to surface and groundwater sources that may be used as drinking water	Remedial actions of surface and groundwater are required to meet maximum contaminant level goals (MCLGs) or maximum contaminant levels (MCLs) established under SDWA	No specific applicability to ISV unless groundwater treatment is specified as part of the cleanup criteria.

Table 2- (Continued)

PROCESS ACTIVITY	ARAR	DESCRIPTION OF REGULATION	GENERAL APPLICABILITY	SPECIFIC APPLICABILITY TO ISV
Waste disposal	RCRA: 40 CFR Part 262	Standards that pertain to generators of hazardous waste	Generators must dispose of wastes at facilities that are permitted to handle the waste. Generators must obtain an EPA ID number prior to waste disposal.	Waste generated may include filters or other solid wastes not consumed in a melt.
	CWA: 40 CFR Parts 403 and/or 122 and 125	Standards for discharge of wastewater to a publically owned treatment works (POTW) or to a navigable waterway	Discharge of wastewaters to a POTW must meet pre-treatment standards; discharges to a navigable waterway must be permitted under national pollution discharge elimination system (NPDES).	Wastewater disposal most applicable to scrubber water discharge.
	RCRA: 40 CFR Part 268	Standards regarding land disposal of hazardous wastes	Hazardous wastes must meet specific treatment standards prior to land disposal, or must be treated using specific technologies.	May be applicable for off-site disposal of auxilliary wastes. May also be applicable to the solidified vitrified soil, if materials were staged for treatment. ISV may be a best demonstrated available technology (BDAT) for some wastes

for off-site transportation and disposal of solid waste is eliminated by in situ treatment. Scrubber water generated during the SITE Demonstration required secondary treatment before ultimate disposal at a permitted facility, and off-gas emissions were treated prior to release to the atmosphere. The developer claims that secondary wastes, including scrubber water, may be recycled to subsequent melts. In some cases, according to the developer, this may accomplished by filtering and discharging the water and treating the filter in a subsequent melt

In general, two types of responses are possible under CERCLA: removal and remedial action. Between 1986 and 1992, in situ vitrification was selected as the source control remedy at four Superfund sites in one removal action (the Parsons site) and three remedial actions (1). Superfund removal actions are conducted in response to an immediate threat caused by a release of hazardous substances. Removal action decisions are documented in an action memorandum. Many removals involve small quantities of waste or immediate threats requiring quick action to alleviate the hazard. Remedial actions are governed by the SARA amendments to CERCLA. As stated above, these amendments promote remedies that permanently reduce the volume, toxicity and mobility of hazardous substances, pollutants, or contaminants.

On-site removal and remedial actions must comply with federal and often more stringent state ARARs. AFURs are determined on a site-by-site basis and may be waived under six conditions: (I) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state AR4R has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund for other sites. These waiver options apply only to Superfund actions taken on-site, and justification for the waiver must be clearly demonstrated.

2.9.2 **Resource Conservation and Recovery Act (RCRA)**

RCRA, an amendment to the Solid Waste Disposal Act (SWDA), is the primary federal legislation governing hazardous waste activities and was passed in 1976 to address the problem of how to safely dispose of municipal and industrial solid waste. Subtitle C of RCRA contains requirements for generation, transport, treatment, storage, and disposal of hazardous waste, most of which are also applicable to CERCLA activities. The Hazardous and Solid Waste Amendments (HSWA) of 1984 greatly expanded the scope and requirements of RCRA.

RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. These regulations are only applicable to the Geosafe ISV Technology if RCRA-defined hazardous wastes are present. If soils are determined to be hazardous according to RCRA (either because of a characteristic or a listing carried by the waste), all RCRA requirements regarding the management and disposal of hazardous waste must be addressed by the remedial managers. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from specific and nonspecific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D. For this Demonstration, the technology was subject to RCRA regulations because the Parsons site is a Superfimd site contaminated with RCRA-listed wastes including dioxins/furans, chlordane, dieldrin, 4,4'-DDT, mercury, and arsenic. RCRA regulations do not apply to sites where RCRA-defined hazardous wastes are not present.

Unless they are specifically delisted through delisting procedures, hazardous wastes listed in 40 CFR Part 261 Subpart D remain listed wastes regardless of the treatment they may undergo and regardless of the final contamination levels in the resulting effluent streams and residues. This implies that, even after remediation, treated wastes are still classified as hazardous because the pre-treatment material was a listed waste.

For generation of any hazardous waste, the site responsible party must obtain an EPA identification number. Other applicable RCRA requirements may include a Uniform Hazardous Waste Manifest (if the waste is transported), restrictions on placing the waste in land disposal units, time limits on accumulating waste, and permits for storing the waste.

Requirements for corrective action at RCRA-regulated facilities are provided in 40 CFR Part 264, Subpart F (promulgated) and Subpart S (partially promulgated). These subparts also generally apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective action, remediating groundwater, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which particular RCRA requirements may be waived for temporary treatment units operating at corrective action sites and provides information regarding requirements for modifying permits to adequately describe the subject treatment unit.

2.9.3 Clean Air Act (CAA)

The CAA establishes national primary and secondary ambient air quality standards for sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. It also limits the emission of 189 listed hazardous pollutants such as arsenic, asbestos, benzene, and vinyl chloride. States are responsible for enforcing the CAA. To assist in this, Air Quality Control Regions (AQCR) were established. Allowable emissions are determined by the AQCR, or its sub-unit, the Air Quality Management District (AQMD). These emission limits are determined based on whether or not the region is currently within attainment for National Ambient Air Quality Standards (NAAQS).

The CAA requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards. Fugitive emissions from the ISV technology may come from (1) the untreated soil during sampling or staging (volatile organic compounds or dusts), (2) the area around the hood during treatment, (3) the treated air exhaust stack during treatment, or from (4) the still-molten treated soil. Under the CAA, the ISV treatment must not exceed the current standards for any pollutant that may be present in the waste soil or formed during treatment. Because of the thermal nature of the ISV process, the potential for generating regulated compounds exists. The off-gas treatment system must be designed to meet the current emission standards. State air quality standards may require additional measures to prevent emissions

2.9.4 Clean Water Act (CWA)

The objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of the nation’s waters. To achieve this objective, effluent limitations of toxic pollutants from point sources were established. Publically owned treatment works (POTWs) can accept waste water with toxic pollutants; however the facility discharging the waste water must meet pre-treatment standards and may need a discharge permit. A facility desiring to discharge water to a navigable waterway must apply for a permit under the National Pollutant Discharge Elimination System (NPDES). When an NPDES permit is issued, it includes waste discharge requirements for volumes and contaminant concentrations

The only waste water from the ISV process which may need to be managed is the scrubber water that is used to cool the off-gas and remove particulates and acid gases. The volume of waste water generated includes the original charge of liquid to the scrubber and water condensed from the gas stream. The amount of waste water to be managed depends on the water content of the soil undergoing treatment and the moisture content of the gas stream. Because of the presence of mercury in the soil, the waste water generated from the scrubber during the ISV Demonstration was not treated and discharged on-site, but was transported to an off-site facility for disposal. The CWA was therefore not an ARAR for the Demonstration site, but it could be in other applications where discharge to a POTW is performed.

Safe Drinking Water Act (SDWA)

The SDWA of 1974, as most recently amended by the Safe Drinking Water Amendments of 1986, requires the EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorized national drinking water standards and a joint federal-state system for ensuring compliance with these standards.

The National Primary Drinking Water Standards are found in 40 CFR Parts 141 through 149. These drinking water standards are expressed as maximum contaminant levels (MCLs) for some constituents, and maximum contaminant level goals (MCLGs) for others. Under CERCLA (Section 121(d)(2)(A)(ii)), remedial actions are required to meet the standards of the MCLGs when relevant. For the ISV Demonstration, treatment of contaminated groundwater was not a part of the removal actions. Leaching tests such as the toxicity characteristic leaching procedure (TCLP) or state-specific tests are often used to determine whether water may be impacted by contaminated soils. ISV immobilizes or encapsulates contaminants in a glass and crystalline structure. The TCLP is frequently used after treatment by ISV to determine the final leachability of contaminants within a vitrified mass.

Toxic Substances Control Act (TSCA)

The TSCA of 1976 grants the EPA authority to prohibit or control the manufacturing, importing, processing, use, and disposal of any chemical substance that presents an unreasonable risk of injury to human health or the environment. These regulations may be found in 40 CFR Part 761; Section 6(e) deals specifically with PCBs. Materials with less than 50 ppm PCB are classified as non-PCB; those containing between 50 and 500 ppm are classified as PCB-contaminated; and those with 500 ppm PCB or greater are classified as PCB. PCB-contaminated materials may be disposed of in TSCA-permitted landfills or destroyed by incineration at a TSCA-approved incinerator; PCBs must be incinerated. Sites where spills of PCB-contaminated material or PCBs have occurred after May 4, 1987 must be addressed under the PCB Spill Cleanup Policy in 40 CFR Part 761, Subpart G. The policy establishes cleanup protocols for addressing such releases based upon the volume and concentration of the spilled material.

TSCA may be relevant or appropriate for use of ISV, since the technology is capable of treating wastes containing or contaminated with PCBs. TSCA was not an ARAR at the ISV Demonstration at the Parsons site because no PCBs were detected in the treated waste

2.9.7 **Occupational Safety and Health Administration (OSHA) Requirements**

CERCLA remedial actions and RCRA corrective actions must be performed in accordance with the OSHA requirements detailed in 20 CFR Parts 1900 through 1926, especially $1910.120 which provides for the health and safety of workers at hazardous waste sites. On-site construction activities at Superfund or RCRA corrective action sites must be performed in accordance with Part 1926 of OSHA, which describes safety and health regulations for construction sites. State OSHA requirements, which may be significantly stricter than federal standards, must also be met.

All technicians operating the Geosafe ISV system and all workers performing on-site construction are required to have completed an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. Workers on hazardous waste sites must also be enrolled in a medical monitoring program. The elements of any acceptable program must include: (1) a health history, (2) an initial exam before hazardous waste work starts to establish fitness for duty and a medical baseline, (3) periodic (usually annual) examinations to determine whether changes due to exposure may have occurred and to ensure continued fitness for the job, (4) appropriate medical examinations after a suspected or known overexposure, and (5) an examination at termination.

For most sites, minimum PPE for workers will include gloves, hard hats, safety glasses, and steel-toe boots. Depending on contaminant types and concentrations, additional PPE, including respirators or supplied air may be required. Additional requirements for protective clothing are dictated by the use of high power electricity on the site, and these requirements should be used to specify the types of boots, gloves and hard hats which are used during operation.

The vapor hood of the Geosafe ISV system may be considered a confined space. If workers are required to enter beneath the hood while it is on the ground, the actions must comply with the recently promulgated OSHA requirements for confined spaces (29 CFR §1910.146), including requirements for stand-by personnel, monitoring, placarding, and protective equipment. If excavation of the waste is required on the site, trenches and excavations may be considered additional confined spaces (based on type and depth) and the same requirements would have to be met. Other construction- or plant-related OSHA standards may also apply during ISV operations, including shoring of trenches, and lock-out/tag-out procedures on powered equipment.

Noise levels are not expected to be high, with the possible exception of noise caused by soil handling activities. During these activities, noise levels should be monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels over an eight-hour day. If noise levels increase above this limit, workers will be required to wear ear protection. The levels of noise anticipated are not expected to adversely affect the community, depending on its proximity to the treatment site.

2.9.8 State Requirements

In many cases, state requirements supersede the corresponding Federal program, such as OSHA or RCRA, when the state program is Federally approved and the requirements are more strict. The state of Michigan had other regulatory requirements which are not covered under the major Federal programs including special requirements for operating on a floodplain.

SECTION 3
ECONOMIC ANALYSIS

The primary purpose of this economic analysis is to provide a cost estimate (not including profit) for full-scale application and use of the Geosafe ISV system. The costs associated with this technology are identified in 12 cost categories defined by EPA that reflect typical cleanup activities encountered on Superfund sites. Each of these categories is defined and discussed, thus forming the basis for this cost analysis,

Costs estimated in this economic analysis are largely based on actual conditions experienced at the Parsons site. The vendor claims to have made substantial improvements relative to these numbers and should be contacted for current cost estimates. Appendix A of this report presents the vendor's claims in detail.

3.1 Conclusions and Results of the Economic Analysis

This economic analysis estimates the cost of using the Geosafe ISV system for three cases-Case 1, Case 2, and Case 3 corresponding treatment of approximately 970, 3,200, and 4,400 cubic yards (1,700, 5,700, and 7,900 tons) of contaminated soil in nine staged treatment cells. This represents three different cell depths (5, 15, and 20 feet) for the same size site. The costs for Case 1, Case 2, and Case 3 are estimated to be $1,300, $770, and $660 per cubic yard ($740, $430, and $370 per ton), respectively. Costs presented in this report are order-of-magnitude estimates as defined by the American Association of Cost Engineers, with an expected accuracy within +50% and -30% ; however, because this is a new technology, the range may actually be wider. Table 3-l presents a summary of the 12 cost categories for each case. Table 3-2 presents a detailed summary for the cost associated with Case 2 (3,200 cubic yards) which most closely parallels conditions observed at the Demonstration site. Figure 3-l shows a graphical representation of the contributions of each of the categories to the total cost for Case 2.

The economic analysis for the case most similar to the conditions experienced at the Parsons site (Case 2) shows that the primary cost categories include utilities, labor, and startup and fixed costs, each contributing roughly 20% to the total cost (utilities slightly higher). Equipment costs and facilities and maintenance costs are each responsible for roughly 10% of the total treatment cost. The other two cases

Table 3-1. Summary of Economic Analysis Results for Three Treatment Scenarios

Cost Category	Case 1 970 yd^3		Case 2 3,200 yd^3		Case 3 4,400 yd^3	
	\$/yd^3	%	\$/yd^3	%	\$/yd^3	%
1. Site and Facility Preparation	51	4	18	2	13	2
2. Permitting and Regulatory Requirements	27	2	9	1	7	1
3. Equipment	190	15	98	13	83	13
4. Startup and Fixed	260	20	130	17	110	17
5. Labor	250	19	150	19	130	20
6. Consumables and Supplies	80	6	61	8	52	8
7. Utilities	180	14	170	22	160	24
8. Effluent Treatment and Disposal	0	0	0	0	0	0
9. Residuals and Waste Shipping and Handling	34	3	26	3	23	3
10. Analytical Services	52	4	19	2	14	2
11. Facility Modifications and Maintenance	170	13	86	11	69	10
12. Site Demobilization	37	3	13	2	9	1
TOTAL COST PER CUBIC YARD	1,300	100	770	100	660	100
TOTAL COST PER TON*	740		430		370	

*Assuming wet soil density of 1.8 tons/yd^3 based on SITE Demonstration results.

Note: All costs are based on contaminated soil treated.
Total costs are rounded to two significant figures and based on the sum of the individual costs before rounding. For this reason, the sum of the numbers presented in this table may not match the total precisely.

Table 3-2. Detailed Summary of Results for Case 2 (3,200 Cubic Yards of Contaminated Soil)

	Case 2 3,200 yd3	
	$/yd^3*	$
1. **SITE AND FACILITY PREPARATION**		
Site Design and Layout		
Survey and Site Investigations		
Legal Searches		
Access Rights and Roads		
Preparations for Support Facilities	0.00	0
Auxiliary Buildings	0.00	0
Utility Connections		
Transportation of Waste Feed	0.00	0
Technology-Specific Requirements		-----
Transportation	4.81	15,400
Assembly	12.95	41,400
TOTAL	17.76	56,800
2. **PERMITTING AND REGULATORY REQUIREMENTS**		
Permits		
Enviromnental Monitoring Requirements		
Development of Monitoring Protocols		-----
Stand-Down	9.50	30,400
TOTAL	9.50	30,400
3. **EQUIPMENT**		
Major Equipment (to estimate other costs)		4,000,000
Annualized Equipment (prorated)	***78.68***	251,800
Equipment Rental		
100-Ton Crane	4.05	13,000
25Ton Crane	0.85	2,700
Forklift	2.10	6,700
Front-End Loader	1.24	4,000
Dump Truck	0.43	1,400
Storage Tank	1.76	5,600
Thermal Oxidizer	8.25	26,400
Trailers	0.71	2,300
Toilets	0.24	800
TOTAL	98.31	314,700

(Continued)

Table 3-2. (Continued)

	Case 2 3,200 yd^3	
	$/yd^3*	$
4. STARTUP ANTI FIXED		
Startup	8.62	27,600
Working Capital	14.61	46,800
Insurance and Taxes	53.72	171900
Initiation of Monitoring Programs		-----
Contingency	53.72	171900
TOTAL	130.67	418,200
5. LABOR		
Total Melt Labor	75.95	243,100
Total Move Labor	25.93	83,000
Per Diem	23.88	76,400
Rental Cars	9.95	31,800
Airfare	10.61	34,000
TOTAL	146.33	468,300
6. CONSUMABLES AND SUPPLIES		
Consumables		
Electrodes	22.79	72900
Graphite and Glass Frit	0.15	500
Insulating Blanket	4.23	13,500
**Refractory Concrete	7.83	25,100
NaOH	1.28	4,100
HEPA Filters	11.04	35,300
Scrub Solution Bag Filters	0.57	1,800
**Carbon Filters	11.97	38,300
Office Supplies	0.24	800
Health and Safety Supplies	1.13	3,600
TOTAL	61.23	195,900
7. UTILITIES		
Natural Gas	1.02	3,300
Water	0.02	100
Electricity	166.05	531,400
TOTAL	167.10	534,800

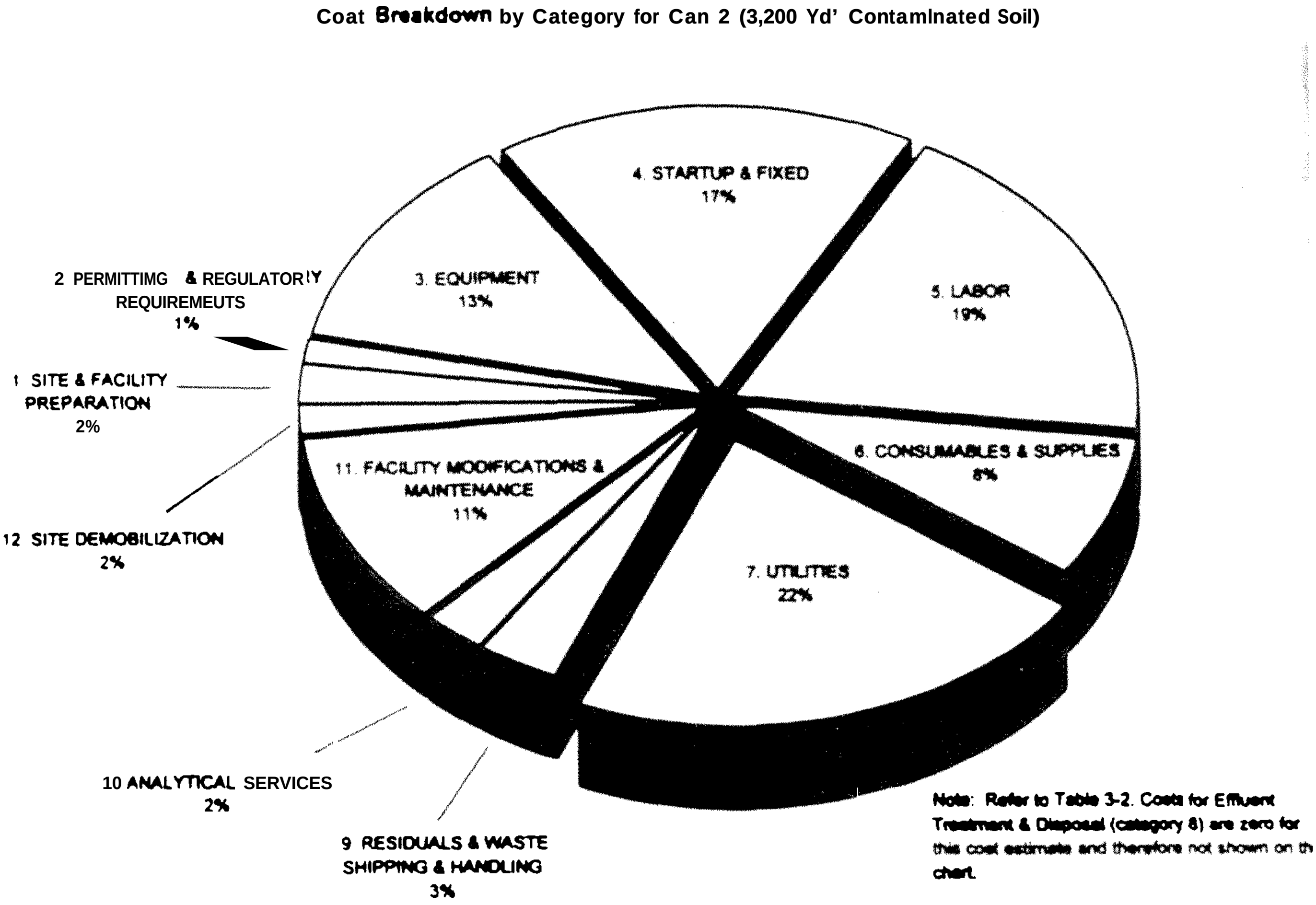
(Continued)

Table 3-2. (Continued)

	Case 2 3,200 yd^3	
	$/$yd^3$*	$
8. EFFLUENT TREATMENT AND DISPOSAL		
On-Site Facility	-----	-----
Off-Site Facility	----	-----
TOTAL	0.00	0
9. RESIDUALS AND WASTE SHIPPING AND HANDLING		
Preparation	1.77	5,700
Waste Disposal		
Scrubber/Decontamination Water	19.04	60,900
Solid Waste	4.86	15,500
TOTAL	25.67	82,100
10. ANALYTICAL SERVICES		
Soil Samples	4.27	13,700
Gas Samples	4.27	13,700
Scrubber Samples	4.27	13,700
Glass Samples	4.27	13,700
Operational Monitoring	1.42	4,500
TOTAL	18.52	59,300
11. FACILITY MODIFICATIONS AND MAINTENANCE		
Design Adjustments		
Facility Modifications		
Scheduled Maintenance (materials)	35.81	114,600
Equipment Replacement (hood panels)	50.56	161,800
TOTAL	86.38	276,400
12. SITE DEMOBILIZATION		
Disassembly	12.95	41,400
Site Cleanup and Restoration	0.00	0
Permanent Storage	0.00	0
TOTAL	12.95	41,400
TOTAL	774.40	2,478,000

*Costs presented are per yd^3 of *contaminated soil* treated.
Costs presented in the body of the report have been rounded to two significant figures. Additional significant figures have purposely been retained in this detailed table.

**May not be required at every site.



Note: Refer to Table 3-2. Costs for Effluent Treatment & Disposal (category 8) are zero for this cost estimate and therefore not shown on th chart.

Figure 3-l. Graphical Representation of 12 Cost Categories for Case 2

show similar cost distributions. Treatment is most economical when treating large soil volumes to the maximum depth, particularly since down-time between melts is minimal compared to actual treatment time. A high ratio of down-time to melt time results in increased costs per cubic yard for some categories (e.g., labor) because total treatment time is not linearly related to total treatment volume. On a per cubic yard basis, the contribution of utilities (as a percentage of total cost) increases markedly with increased treatment volume. As expected, the contributions of labor costs and consumables and supplies costs also increase with increased treatment volume. The contributions of all other cost categories as a percentage of total cost decrease with increased treatment volume.

3.2 Issues and Assumptions

This economic analysis was developed based primarily on information collected during the treatment of Cell 8 at the Parsons site. Costs have been extrapolated where necessary, and when treatment of Cell 8 did not yield representative data, information was obtained from Geosafe so that a fair estimate of typical treatment could be generated.

This cost analysis provides estimates for the three treatment scenarios described below. In each case, staged treatment is assumed to take place in nine treatment cells measuring 27 feet by 27 feet. Preliminary analysis indicated little variation in cost per cubic yard when treatment depth remained constant and the number of cells was varied. The contributions of categories such as site and facility preparation costs, startup and fixed costs, and, site demobilization costs (on a per cubic yard basis) decrease, as expected, when the number of cells is increased because their contributions can be amortized over a longer treatment period. However, the impact of varying the number of treatment cells appeared to have little effect on the overall cost per cubic yard of contaminated soil treated. Therefore, the three cases present data for treatment in which the number of cells remains constant and the treatment depth (and thus total volume) is varied. The depth of treatment is assumed to exceed the depth of contaminated soil by one foot. Although included in this cost estimate, the layer of clean fill on top of the contaminated soil may be less than specified or not required at all in some cases. If clean fill is not required, the overall treatment volume (and therefore treatment cost) may be reduced. The three cases presented in this report are as follows:

- Case 1: Cell depth of 5 feet with a 0.5foot layer of clean fill on top of the contaminated soil such that the depth of contaminated soil is 4.5 feet and the total treatment depth is 6 feet.

- Case 2: Cell depth of 15 feet with a 2-foot layer of clean fill on top of the contaminated soil such that the depth of contaminated soil is 13 feet and the total treatment depth is 16 feet.

- Case 3: Cell depth of 20 feet with a 2-foot layer of clean fill on top of the contaminated soil such that the depth of contaminated soil is 18 feet and the total treatment depth is 21 feet.

Case 1 was selected to present information representative of what may be considered to be a minimum treatment depth for economically feasible application of ISV. Case 2 was selected to present economic data representative of conditions observed during the Demonstration and ISV treatment at the Parsons site. It should be noted that treatment of the nine cells (approximately 3,000 cubic yards) at Parsons was actually accomplished in eight melts. This economic analysis assumes that, in each case, the process completes nine melts in nine settings. Case 3 was selected to provide information representative of the current maximum treatment depth for ISV.

The costs for each case of this economic analysis are presented per cubic yard of contaminated (not *total*) soil treated. When using ISV, the total volume of soil treated exceeds the contaminated volume of soil treated. Three factors must, therefore, be taken into account to determine the *total* volume of soil treated corresponding to the *contaminated* volume of soil treated. These factors are: 1) the layer of clean fill (one-half to two feet); 2) the actual treatment depth (one foot beyond the contaminated soil depth); and 3) an overmelt correction of 15% (by volume) to account for overmelting beyond the perimeter of the treatment zone and remelting to facilitate overlapping treatment. The amount of soil treated in excess of the amount of contaminated soil is dependent on the actual treatment configuration.

The focus of this cost estimate is on Case 2 which represents the Demonstration at the Parsons site. During the Demonstration, it was estimated by Geosafe that approximately 330 cubic yards of *contaminated* soil were treated in one treatment cell. In this cost analysis, a cell treatment volume of approximately 350 cubic yards of contaminated soil is used in the calculations for Case 2. When taking into consideration the three factors mentioned above, the volume of total soil treated is approximately 500 cubic yards per cell. Thus, Case 2 is based on treatment of approximately 3,200 cubic yards of *contaminated* soil and approximately 4,500 cubic yards of *total* soil. Because the total amount of soil treated exceeds the amount of contaminated soil treated, costs per cubic yard of total soil treated would necessarily be lower

Overall costs to the site owner would probably be less when staged cells are not used since excavation and cell construction costs may be eliminated, however, undocumented underground features (e.g., buried tanks, drums, telephone or electrical cables, etc.) may potentially increase treatment costs for in situ treatment

Important assumptions regarding operating conditions and task responsibilities that could significantly impact the cost estimate results are presented below:

- The cost estimates presented in this analysis are representative of charges typically assessed to the client by the vendor and do not include profit. Costs such as preliminary site preparation, permits and regulatory requirements, initiation of monitoring programs, and site cleanup and restoration are considered to be the responsible party's (or site owner's) obligation and are not included in the estimate presented. These costs tend to be very site-specific, and calculations are left to the reader. Whenever possible, applicable information is provided on these topics so that the reader may independently perform calculations to acquire economic data desired.

- It is assumed that the, contaminated soil will be staged into treatment cells by an independent contractor prior to Geosafe's arrival on-site.

- The density of the untreated soil (on a wet basis) is assumed to be 1.8 tons per cubic yard.

- Treatment is assumed take place 24 hours per day, 7 days per week, 52 weeks per year. An on-line efficiency factor of 80% has been incorporated to account for down-time due to scheduled and unscheduled maintenance and other unforeseen delays. Down-time to move the hood is accounted for separately.

- Capital costs for equipment are limited to the cost of the ISV system (off-gas hood, electrical transformers, power cables, and electrode feeders) the basic gas treatment system (quench tank, scrubber, demister, particulate filter system, activated carbon system, and glycol cooling *system),* and the backup gas treatment system. Percentages of the total equipment cost are used to estimate other costs.

- During treatment, three shifts of workers are assumed to work eight hours per day, seven days per week for three weeks. At the end of three weeks, one shift of workers is rotated out, and a new set replaces the former. The rotation of workers is set up so that each worker works for three weeks straight, and then rests for one week.

- Operations for a typical shift require two workers: one shift engineer and one operator. Additionally, one site manager and one project control specialist are present on-site during the day shift. Off-site office support corresponding to 50% of one person's full-time responsibilities is also required.

- The costs presented (in dollars per cubic yard) are calculated based on the number of cubic yards of *contaminated* soil treated. Because clean fill and surrounding uncontaminated soil are treated as part of each melt, the *total* amount of material treated may be approximately 35 to 55 percent higher. Costs per cubic yard based on total soil treated would, therefore, be lower than those presented in this estimate.

Many actual or potential costs that exist, including treatability studies, were not included as part of this estimate. They were omitted either because the costs were assumed to be the obligation of the responsible party or because site-specific engineering designs that are beyond the scope of the SITE project would be required. The costs of treatability studies could range from $40,000 to $80,000 depending on the application (2,3,4). Analytical costs can be a major factor in treatability studies, depending on the number and type of analyses required

3.3 **Basis of the Economic Analysis**

This cost analysis was prepared by breaking down the overall cost into 12 categories defined by EPA. The categories, some of which do not have costs associated with them for this particular technology, are:

- Site and Facility Preparation Costs
- Permitting and Regulatory Requirements Costs
- Equipment Costs
- Start-up and Fixed Costs
- Labor Costs
- Consumables and Supplies Costs
- Utilities Costs
- Effluent Treatment and Disposal Costs
- Residuals and Waste Shipping and Handling Costs
- Analytical Services Costs

- Facility Maintenance and Modifications Costs
- Site Demobilization Costs

The 12 cost factors examined as they apply to the Geosafe ISV system, along with the assumptions employed, are described in detail below.

3.3.1 Site and Facility Preparation Costs

For these cost calculations, “site” refers to the location of the contaminated waste. Site design and layout, survey and site investigations, legal searches, and access rights and roads are assumed to be the responsibility of the site owner. Support facilities and auxiliary buildings are not required for this technology because the system is self-contained with mobile trailers used for auxiliary buildings. Utility connections may or may not be required; the specific characteristics of the site may cause this cost to fluctuate greatly, and therefore, costs are not included in this estimate. It should be noted that utility connections, while normally available from standard United States electrical grids, may be of particular importance for this technology because of the high power demands of the system. Because ISV is an in situ technology, the location of the contaminated waste is assumed to be the same as the location of the treatment facility; thus, there are no costs for transportation of the contaminated waste.

For the purposes of this cost estimate, it is assumed that the contaminated soil will be excavated and staged into treatment cells by an independent contractor prior to Geosafe’s arrival on-site. Although the costs of this activity are not included in this estimate because they are site-specific, typical excavation and placement costs may be assumed here. If staging is not required, a reduction in site preparation costs may be experienced; however, if the contaminated soil is not excavated and consolidated, unidentified buried items may be encountered and must be handled appropriately

Transportation charges are only assessed for travel to a treatment site since it is anticipated that, once a job is completed, the equipment will be transported directly to the next site without returning to Geosafe’s home office. Trucking charges include drivers and are based on an 80,000-pound legal load. The ISV process equipment is contained on or in three mobile trailers: a process trailer, a support trailer, and an electrical trailer. The three process trailers are typically moved by two tractors (two of the trailers are towed together). An overweight permit is necessary for transport of the electrical trailer. This is the only trailer that requires a permit. Three additional trailers are required for transportation of the hood, electrode feeders, backup gas treatment system, and other associated piping and equipment. Thus, transportation of the ISV system requires a total of five tractors and six trailers. It is assumed that overweight permits can be obtained for under $50 per state and that permits will be required for an average of four states per trip. Using a 1,000-mile basis as a typical transportation distance and an estimated cost per mile of $3.00, the total transportation cost is approximately $15,000, Depending on the number of states that are traversed and the amount of state fees that are assessed for permits and road usage, this cost may vary. The transportation cost from Geosafe Corporation in Richland, Washington to the Parsons site in Grand Ledge, Michigan was higher than this estimate (approximately $34,000 total) due in part to the great distance travelled and to the peculiar weight limitations of Michigan roads. The $15,000 figure has been used for this cost estimate to present what may be anticipated as typical transportation costs.

Assembly of the Geosafe ISV system requires a full crew of eight Geosafe employees plus three local workers working eight hours per day for ten days. Office support from the home office is also required for four hours per day (one person). Two cranes are required: a 25-ton crane for one week (seven days) and a 100-ton crane for half of one day (four hours). Assembly costs are limited to labor charges (including rental cars and per diem) and crane rental fees. Information on labor rates may be found under "Labor Costs."

3.3.2 Permitting and Regulatory Requirements Costs

The cost of permitting and regulatory requirements is generally the obligation of the responsible party (or site owner), not that of the vendor. These costs may include actual permit costs, system monitoring requirements, and the development of monitoring and analytical protocols. Modifications to the system may also be required to maintain compliance with the regulations. Permitting and regulatory costs can vary greatly because they are very site- and waste-specific. No permitting costs are included in this analysis, however, depending on the treatment site, this may be a significant factor since permitting activities can be very expensive and time consuming. The costs of environmental monitoring (including the development of monitoring protocols) are determined by the requirements imposed by the local governing agency. Because they are site- and waste-specific, these costs are not included here.

Stand-down costs (costs incurred while the system is not in use) for this technology, which are included in the cost estimate, are in the vicinity of $5,000 per day. It is therefore advisable that, to the maximum extent possible, permitting and regulatory requirements are carefully researched and appropriate permits obtained prior to the initiation of treatment. Even so, it is likely that some stand-down time will occur while samples are being analyzed to determine compliance. It is assumed that one day of stand-down time will be incurred for each sampling episode and that one sampling episode will be required for every three cells treated.

3.3.3 Equipment Costs

Equipment costs include major pieces of equipment, purchased support equipment, and rental equipment. Support equipment refers to pieces of purchased equipment and/or subcontracted items that will only be used for one project.

The major pieces of equipment are the off-gas hood, the electrode feeders, electrical cables, the off-gas treatment system (including quencher, scrubber, mist eliminator, particulate filter system, and activated charcoal system), the back-up off-gas treatment system, the glycol cooling system, and the electrical system. The electrodes themselves are considered consumables. No support equipment is purchased or sub-contracted for operation of this system. Rental equipment includes a 25-ton crane, a 100-ton crane, a forklift, a front-end loader, a dump truck, a storage tank, one mobile office trailers, one mobile decontamination trailer, and two portable toilets. In some cases, rental of modular additions to the gas treatment system may also be necessary. At the Parsons site, a rented thermal oxidizer was required to fully treat the off-gases. To remain consistent throughout the analysis, it is assumed that a thermal oxidizer is required in each case.

The capital cost of the complete system is assumed to be $4,000,000. Although the client does not purchase the system, the cost of remediation must account for the annualized cost of the equipment. The capital equipment costs are presented as annualized equipment costs, prorated for the amount of time the equipment is used for the project. The annualized equipment cost is calculated using a ten-year equipment life and 10% annual interest rate. The annualized equipment cost is based upon the writeoff of the total initial capital equipment cost and scrap value (5,6), assumed to be 10% of the original equipment cost. The following equation is used:

$$\textit{Capital recovery} = (V - V_s)\ \frac{i(1 + i)^n}{(1 + i)^n}$$

where V = the cost of the original equipment ($4,000,000),
V_s = the salvage value of the equipment ($400,000),
n = the equipment life (10 years), and
i = the annual interest rate (10%) (4,5).

The capital cost of equipment is the same for each case. The annualized cost of the equipment is prorated over the assembly time, startup time, total treatment time, and disassembly time. In each case, assembly and disassembly time remain constant at ten days each; startup time remains constant at seven days. Total treatment time for nine settings, including soil melt time and hood move time, is estimated to be 73 days when the depth of the cell is 5 feet, 130 days when the depth of the cell is 15 feet (as during the Demonstration), and 150 days when the depth of the cell is 20 feet.

A 25-ton crane is rented at a rate of $95 per hour to provide assistance with hood movement and electrode addition. The 25-ton crane is required for an estimated two hours per cell when the cell depth is 5 feet, for four hours per cell when the cell depth is 15 feet, and for an estimated six hours per cell when the cell depth is 20 feet. A 100-ton crane is rented at a rate of $200 per hour for eight hours (one day) each time the hood is moved. Crane rental charges for assembly and disassembly are included under "Site and Facilities Preparation Costs" and "Site Demobilization Costs," not "Equipment Costs." A forklift is rented at a rate of $1,300 per month for assembly time, startup time, total treatment time, and disassembly time. A front-end loader ($440 per day) and a dump truck ($150 per day) are each rented for one day to backfill the melt subsidence each time the hood is moved, nine days total. A 20,000-gallon Baker ® storage tank is rented at a rate of $38 per day for the total treatment time; the costs for delivery and pickup of the tank are each $350. One mobile office trailer and one mobile decontamination trailer are rented at a rate of $150 per month for assembly time, startup time, total treatment time, and disassembly time; the costs for delivery and pickup are each $180. Two portable toilets are rented at a rate of $60 per month for assembly time, startup time, total treatment time, and disassembly time; the costs for pickup and delivery are $40 each. A thermal oxidizer is rented at a rate of $5,000 per month for assembly time, startup time, total treatment time, and disassembly time; the costs for pickup and delivery are each $300.

3.3.4 Start-up and Fixed Costs

Start-up and fixed costs are considered to include such things as startup operations, security, working capital, insurance and taxes, and contingency. For the most part, these costs are independent of the length of treatment time. Working capital varies slightly with treatment depth and the time required to treat each cell. Insurance and taxes and contingency costs are prorated over the assembly time, startup time, total treatment time, and disassembly time

Startup costs are limited to labor charges (including rental cars and per diem) for a full crew (eight persons) working eight hours per day for one week (seven days). Operations will not take place 24 hours per day during startup since melting is not initiated until after the startup and shakedown processes are complete. Information on labor rates may be found under “Labor Costs.”

To protect both the site and the public, site security is required whenever Geosafe personnel are not on-site. Since 24-hour operations are assumed to take place only during treatment (actual melting), security is required overnight during all other phases of the project (i.e., assembly, startup, hood moves, and disassembly). At these times, one security guard is required for eight hours per day. The labor rate for a security guard is assumed to be $10 per hour.

Working capital is the amount of money currently invested in consumables and supplies. The working capital cost of consumables and supplies is based on maintaining a one-month inventory of these items. (See “Consumables and Supplies Costs” for the specific amounts required for the operation of the system. Note that the cost of consumables and supplies varies slightly with treatment depth and the time required to treat each cell.) The total cost of consumables and supplies divided by the total number of treatment months yields the monthly cost of consumables and supplies. This dorresponds to the amount of money required to maintain a one-month inventory of consumables and supplies.

Insurance is usually 1% and taxes are usually 2 to 4% of the total purchased equipment capital costs (approximately) on an annual basis. The cost of insurance for a hazardous waste process can be several times more. Together, annual insurance and taxes are assumed to be 10% of the purchased equipment capital costs (7) for the purposes of this estimate. The cost is prorated over the assembly time, startup time, treatment time and disassembly time.

The cost of the initiation of monitoring programs is very site- and waste-specific. Requirements for the initiation of monitoring programs are generally determined by the state agency governing hazardous waste operations. Applicable costs would be assessed prior to treatment and would not likely extend into the treatment phase of remediation. The cost of environmental monitoring is discussed under "Permitting and Regulatory Requirements Costs" above.

An annualized contingency cost of 10% of the total purchased equipment capital costs is allowed for any unforeseen or unpredictable cost conditions, such as strikes, storms, floods, and price variations (5,6). This cost is prorated over the assembly time, startup time, treatment time and disassembly time.

3.3.5 **Labor Costs**

Labor costs include overhead and administrative costs and are limited to hourly labor rates, per diem, daily transportation, and travel. Labor charges are assessed only during the total treatment time since labor costs for other activities (such as assembly, startup and disassembly) are included elsewhere. Labor charges during treatment are broken down into two categories: soil melts and hood moves.

During a melt, operations take place in three shifts. The day shift (8 A.M. to 4 P.M.) requires a site manager, an engineer, a project control specialist, and an operator. The swing shift (4 P.M. to 12 A.M.) and the graveyard shift (12 A.M. to 8 A.M.) each require an engineer and an operator. During hood moves, the full crew (a site manager, three engineers, a project control specialist, and three operators) is present. Operations are eight hours a day during hood moves. To coordinate on-site operations with the home office, it assumed that office support requirements total 50% of one person's full-time responsibilities.

Hourly labor rates are as follows: site manager, $60; engineer, $40; project control specialist, $30; operator, $30; local worker, $20; office support, $40. .Per diem (daily meals and accommodations) is estimated at $75 per day per person. Daily transportation includes a rental car and fuel at $50 per day. One rental car is provided for the site manager; a second rental car is provided for the process control specialist. One additional rental car is provided for each shift of workers for a total of five rental cars. Round trip travel costs are assumed to be $1,000 per person, and it is assumed that, based on a rotating schedule of three weeks on and one week off, each person will travel home and back to the site once each month during treatment. Regular trips home are not scheduled during assembly, startup, and disassembly.

The site manager, project control specialist, engineers, and operators require per diem, daily transportation to the site, and round trip travel to the site. Local workers are only employed during assembly and disassembly and do not require per diem, daily transportation to the site, or round trip travel to the site. Office support personnel provide assistance from the home office and are not required to be present on-site; hourly labor is the only applicable charge for office support.

3.3.6 Consumables and Supplies Costs

The Geosafe ISV process utilizes a square array of four electrodes to melt soil. The electrodes used are solid graphite and supplied in 12-inch outside diameter (OD) six-foot threaded sections. The cost of the graphite electrodes is approximately $1 per pound, and each six-foot section weighs approximately 500 pounds, resulting in an electrode cost of $500 per section. The total cost for electrodes is based on whole (six-foot) sections used during each melt. That is, even if the melt is only sixteen feet deep, electrode usage is assumed to be eighteen feet (three six-foot electrode sections). Geosafe shears the electrodes near the surface at the conclusion of a melt for reuse, but the location of the cut with respect to the threads determines the usefulness of the sheared electrodes.

A conductive mixture of graphite and glass frit is laid in a pattern on the untreated soil surface between the electrodes to provide a starter path for the electrical current. Approximately 75 pounds of frit, available for about $1 per pound, are required for every melt.

A synthetic material is used to insulate the untreated soil surface and to protect the hood from undesirable contact with molten soil during the early stages of treatment. This insulating "blanket" is available by the roll at a cost of $1.70 per square foot. Approximately 900 square feet are required to cover the soil surface beneath the hood for each cell

Refractory concrete is a material that can be used to prevent convective melt erosion of the soil wall and limit melt width. This material has recently been employed to restrict melt growth to the desired areas Prefabricated sheets can be used to form the walls of the cells constructed for staged treatment

Refractory concrete may be considered a staging cost rather than a consumable, but for this cost estimate, it is categorized as a consumable item. Refractory concrete is available at a cost of $0.25 per pound. The use of refractory concrete is not required when the cell depth is 5 feet because melt width is not a problem at such shallow depths. When the cell depth is 15 feet (based on experience at Parsons), approximately 11,000 pounds of refractory concrete are required per cell, and an estimated 15,000 pounds when the cell depth is 20 feet. The need for and the use of refractory concrete may vary from site to site and even from cell to cell. Using a conservative approach, the quantities in this estimate assume that refractory concrete is used in every cell treated over the entire cell depth. Geosafe proposes that refractory concrete may only be required at the "beltline" (widest point) of the melt and not over the full depth.

Sodium hydroxide (NaOH) is utilized as a caustic in the scrubbers. For this process, a 50% NaOH solution is used. It is available for $150 per 55-gallon drum. The amount of NaOH required depends on the volume and characteristics of soil treated. It is also influenced by the performance of the scrubber and the ambient weather conditions. It is estimated that one drum per cell is required when the cell depth is 5 feet, three drums per cell when the cell depth is 15 feet, and four drums per cell when the cell depth is 20 feet.

High efficiency particulate air (HEPA) filters are used in the off-gas treatment system to collect fine particulate matter. These filters are consumed at a rate dependent on the soil characteristics, the treatment time, and the performance of the off-gas treatment system. In some cases, it may not be necessary to use HEPA filters to meet state particulate limits. Demonstration results indicate that approximately 25 HEPA filters were used during treatment of each 15-foot cell. It is assumed that an estimated 10 HEPA filters are required for each 5-foot cell, and 35 filters are required for each 20-foot cell. Each HEPA filter costs approximately $160. The high cost and high rate of consumption of HEPA filters motivated Geosafe to develop techniques whereby the filters could be reused and recycled, reducing the overall cost of HEPA filters.

Bag filters used by the scrubber portion of the off-gas treatment system are available at $2.50 per filter. The number of filters used during treatment of each cell is dependent on the amount volume of scrubber water generated. This volume is highly variable. Approximately 80 filters were required per cell during treatment at the Parsons site (15foot cells). It is estimated that 25 filters are required for treatment of 5-foot cells and 100 filters are required for treatnient of 20-foot cells.

Carbon filters, employed to process the off-gas before release to the atmosphere, are used for normal operations in the absence of a thermal oxidizer. In some instances, such as at the Parsons site, carbon filters may be used in addition to a thermal oxidizer. Carbon filters were consumed at a rate of four per 15-foot cell at Parsons. The number of carbon filters is variable and dependent on the volume and nature of off-gas generated as well as the performance of the off-gas system. It is assumed that an estimated two filters are required per 5-foot cell and five filters are required per 20-foot cell

General office supplies are required to maintain efficient operation at the site from the time of assembly and startup through treatment and disassembly. The monthly cost for office supplies is approximately $150.

Health and safety supplies are required for all phases of the project including assembly, startup, treatment, and disassembly. The monthly cost of health and safety supplies varies slightly with the phase of treatment but averages approximately $700.

3.3.7 Utilities Costs

Electricity is a primary cost for this technology. Rates substantially lower than typical residential rates are often available for industrial purposes, particularly when usage is as high as it is for this technology. The industrial or commercial cost of high voltage line power varies greatly with location ranging from as low as $0.025 per kilowatt-hour on the west coast to as much as $0.08 per kilowatt-hour in the Midwest and east coast (3). At the time of the Demonstration in Grand Ledge, Michigan, the commercial cost of electricity was slightly higher-$0.089 per kilowatt-hour. There was an additional monthly service fee of $6.50. These charges reflect the local cost for electricity. At other sites, this cost may differ. Based on information gathered during the Demonstration, the Geosafe ISV process requires approximately 0.37 kWh of electricity for each pound of soil melted (approximately 0.72 MWh per ton). This value is used in the cost estimate presented although it is slightly lower than the typical value reported by Geosafe of 0.50 kWh per pound (1 MWh per ton). The total electrical usage for the system when treating nine five-foot deep cells at a rate of 370 MWh per pound of soil is approximately 2,200 MWh. When the cell depth is increased to 15 feet, approximately 5,900 MWh are required for nine cells, and when the cell depth is 20 feet, approximately 7,700 MWh are required for nine cells. The power consumption per pound of soil reported here is based on Demonstration results-soil with a density of approximately 3,600 pounds per cubic yard (1.8 tons per cubic yard) and 16 percent moisture. The density and moisture content of the actual soil treated may cause this value to vary. Additional electricity is required for power in the office and process trailers. However, this is negligible compared to the amount of power required to melt the soil and has therefore been ignored in these calculations. A diesel generator may be utilized when power lines are inaccessible. Cost for use of diesel generators is equivalent to approximately $0.083 to $0.13 per kilowatt-hour *(3)*

Natural gas is utilized by the thermal oxidizer. Approximately one million cubic feet of natural gas are required to treat the off-gas generated from each B-foot cell when using a thermal oxidizer with a capacity of 10,000 standard cubic feet per minute. This amount will vary slightly with the time required to treat a cell, but the overall effect on the total cost is negligible, and thus the same natural gas requirements have been assumed for each of the three cases. The local cost for natural gas in Grand Ledge, Michigan at the time of the Demonstration was $10 per month plus approximately $0.00040 per cubic foot.

Locally, water rates were $21 per quarter (three months) plus a sewage fee of $0.0029 per gallon at the time of the Demonstration. Water usage fluctuated throughout treatment based on system performance, soil moisture content, and current weather conditions. On the average, approximately 3,500 gallons of water were required for each cell treated during the Demonstration (cell depth 15 feet). When the cell depth is 5 feet, water consumption per cell is estimated to be 2,000 gallons per cell, and when the cell depth is 20 feet, water consumption is estimated to be 4,500 gallons per cell.

Effluent Treatment and Disposal Costs

The stack gas and the scrubber liquor are the only effluent streams anticipated to be generated as a result of typical treatment using the Geosafe ISV process. Depending on the on-site contamination and the ARARS, these streams may be permitted for discharge. In most instances, when a thermal oxidizer is part of the off-gas treatment train, emissions may be released directly to the atmosphere without further treatment. A likely scenario for the scrubber liquor is collection and disposal as a residual waste although

Geosafe claims that scrubber liquor may be recycled to subsequent melts. During the Demonstration, scrubber liquor was collected as disposed of as a residual waste, therefore these costs are covered under "Residuals and Waste Shipping and Handling Costs." At the Parsons site, an additional effluent stream was encountered when the logistics of treatment required a groundwater diversion system to be installed. This diverted water was permitted for discharge after carbon filtration. The costs for treatment of this additional effluent stream were unique to the Parsons site and have been excluded from this cost estimate.

3.3.9 Residuals and Waste Shipping and Handling Costs

The primary process residual generated by the Geosafe ISV technology is the vitrified mass. This material is generally left intact and in place at the conclusion of treatment. The molten mass may take one to two years to cool completely. There are no costs associated with the disposal of the vitrified mass. In some instances, the treated material may be left uncovered in order to cool more rapidly and thus induce crystallization and fracturing of the mass. This may be a desirable practice if the vitrified mass is to be removed from the treatment site. Costs for the removal of the vitrified mass are dependent on the ease of handling the material (which is in turn dependent on the degree of fracturing achieved) and have not been included in this cost estimate.

A number of secondary process residuals and waste streams are generated by the Geosafe technology. The disposal of these streams requires approximately one week (seven days) of preparation (eight hours per day). Personnel requirements are limited to three local workers and the off-site assistance of one person from the Geosafe home office. (See "Labor Costs" for specific labor rates.)

The liquid waste streams include scrubber liquor and decontamination liquid. The scrubber liquor was discussed briefly above as an effluent stream, but since the scrubber liquor was not discharged at the Parsons site, the cost of its disposal is included in this category. The amount of scrubber liquor generated is dependent on the nature of the treatment media. High levels of contamination and/or soil moisture content may result in large quantities of scrubber liquor. For treatment of 5-foot cells, it is estimated that approximately 3,000 gallons of scrubber water (including the initial charge of water to the scrubber) are generated per cell. The amount of scrubber liquor generated at the Parson site was highly variable from cell to cell, but an average of approximately 8,000 gallons of scrubber water (including the initial charge) were generated for treatment of 15-foot cells. It is estimated that approximately 10,000 gallons of

Geosafe claims that scrubber liquor may be recycled to subsequent melts. During the Demonstration, scrubber liquor was collected as disposed of as a residual waste, therefore these costs are covered under "Residuals and Waste Shipping and Handling Costs. " At the Parsons site, an additional effluent stream was encountered when the logistics of treatment required a groundwater diversion system to be installed. This diverted water was permitted for discharge after carbon filtration. The costs for treatment of this additional effluent stream were unique to the Parsons site and have been excluded from this cost estimate.

3.3.9 Residuals and Waste Shipping and Handling Costs

The primary process residual generated by the Geosafe ISV technology is the vitrified mass. This material is generally left intact and in place at the conclusion of treatment. The molten mass may take one to two years to cool completely. There are no costs associated with the disposal of the vitrified mass. In some instances, the treated material may be left uncovered in order to cool more rapidly and thus induce crystallization and fracturing of the mass. This may be a desirable practice if the vitrified mass is to be removed from the treatment site. Costs for the removal of the vitrified mass are dependent on the ease of handling the material (which is in turn dependent on the degree of fracturing achieved) and have not been included in this cost estimate.

A number of secondary process residuals and waste streams are generated by the Geosafe technology. The disposal of these streams requires approximately one week (seven days) of preparation (eight hours per day). Personnel requirements are limited to three local workers and the off-site assistance of one person from the Geosafe home office. (See "Labor Costs" for specific labor rates.)

The liquid waste streams include scrubber liquor and decontamination liquid. The scrubber liquor was discussed briefly above as an effluent stream, but since the scrubber liquor was not discharged at the Parsons site, the cost of its disposal is included in this category. The amount of scrubber liquor generated is dependent on the nature of the treatment media. High levels of contamination and/or soil moisture content may result in large quantities of scrubber liquor. For treatment of 5-foot cells, it is estimated that approximately 3,000 gallons of scrubber water (including the initial charge of water to the scrubber) are generated per cell. The amount of scrubber liquor generated at the Parson site was highly variable from cell to cell, but an average of approximately 8,000 gallons of scrubber water (including the initial charge) were generated for treatment of 15-foot cells. It is estimated that approximately 10,000 gallons of scrubber water (including the initial charge) are generated for treatment of 20-foot cells. The scrubber liquor may require special handling depending upon the types and levels of contaminants being treated. Decontamination liquid will only be generated at the conclusion of treatment when the process equipment is decontaminated prior to transport to the next treatment site. It is estimated that approximately 5,000 gallons of decontamination water will be accumulated for disposal. Two profile samples are assumed to be collected from each 20,000 gallons of liquid waste accumulated. A full range of analyses will be performed on these samples to characterize the waste stream for disposal. The analytical cost per sample is estimated at $1,500. An additional one-time $150 profile cost is also assumed for the liquid waste stream. Disposal costs for the liquid waste stream are assumed to be $0.75 per gallon, typical for liquid waste disposal.

Solid secondary wastes include carbon filters, scrub solution bag filters, HEPA filters, used hood panels, and personal protective equipment (PPE). Carbon filters and HEPA filters may be recycled to maximize their use. Other process residuals (such as used scrub solution bag filters, used HEPA filters, and PPE) can be disposed in future melt settings to reduce the volume of these materials requiring ultimate disposal.

The number of used hood panels requiring disposal is dependent on the type and extent of contamination at the site, the corrosiveness of the off-gases generated during treatment (as well as the corrosion-resistance of the hood panels), and the. duration of treatment. The vendor claims that under some treatment conditions, the life expectancy of hood panels may increase, and disposal of the panels may not be required. The solid wastes may be combined into a single waste stream for disposal. Approximately two 20-cubic yard roll-off bins of solid waste are generated for treatment of nine 5-foot cells; four roll-off bins for treatment of nine 15-foot cells; and five roll-off bins for treatment of nine 20-foot cells. Disposal costs are assumed to be $800 per 20-cubic yard roll-off bin. Profile samples are collected to characterize the waste for disposal (two per roll-off bin), and a full range of analyses performed ($1,500 per sample) An additional one-time $150 profile cost is also assessed to the solid waste stream.

3.3.10 Analytical Services Costs

Sampling and analysis of the system is performed on a routine basis to ensure proper performance and compliance with regulatory limitations. It is assumed that samples are collected from every third cell treated. Three samples of each of the following matrices are collected during each sampling episode for test soil, off-gas, scrubber liquor, and treated soil. A full range of analyses ($1,500) is performed on each sample. If sampling is performed by an outside contractor, additional costs will be incurred, particularly for gas sampling. Daily monitoring for fugitive emissions is also performed using a photoionization detector or organic vapor analyzer. This monitoring equipment is available for approximately $250 per week and is required only during treatment.

3.3.11 Maintenance and Modifications Costs

Maintenance costs are assumed to consist of maintenance labor and maintenance materials. Maintenance labor and materials costs vary with the nature of the waste and the performance of the equipment. For estimating purposes, the annual maintenance labor and materials costs are assumed to be 10% of the purchased equipment capital costs. Of this, 33% is estimated to be maintenance labor and 67% is estimated to be maintenance materials. Costs for design adjustments, facility modifications, and equipment replacements are not included in this cost estimate. Maintenance labor is assumed to be accounted for under “Labor Costs, ” and therefore scheduled maintenance costs are limited to maintenance. materials

In addition to typical maintenance materials, the Geosafe hood panels may require replacement during and at the conclusion of treatment. Although the panels were stainless steel, the harsh environment beneath the treatment hood at the Parsons site demanded frequent replacement of the panels. There are approximately 120 panels (approximately $100 each) on the hood. It is estimated that 33 % of these panels will need replacement during treatment of nine 5-foot cells, 50% during treatment of nine 15-foot cells, and 58% during treatment of nine 20-foot cells. Due to difficulties in decontaminating the hood panels at the conclusion of treatment, it is Conservatively estimated that 67% of the hood panels will need replacement for after treating nine 5-foot cells, and all 120 hood panels will need replacement after treating nine 15- or 20-foot cells. The frequency of hood panel replacement depends on operating conditions during treatment; Geosafe claims that the typical life expectancy of the panels is greater than that exhibited during the Demonstration. See Appendix A of this report (“Vendor’s Claims”) for additional details

3.3.12 Site Demobilization Costs

Site demobilization is limited to the removal of all equipment from the site. Disassembly of the Geosafe ISV system holds the same cost requirements as assembly. The disassembly process is identical to assembly, merely performed in the reverse order. Any other requirements of the site will vary depending on the future use of the site and are assumed to be the obligation of the responsible party. Therefore, site cleanup and restoration costs are limited to disassembly labor charges for this cost estimate.

SECTION 4

TREATMENT EFFECTIVENESS

4.1 Site History and Contamination

From 1945 to 1979, Parsons Chemical Works, Inc. was engaged in the mixing, manufacturing, and packaging of agricultural chemicals at a 6.5-acre site located in Grand Ledge, Michigan. Sanitary sewage and wash water were discharged from the packaging plant to a septic tank and tile field system. Wash water from the operations was also released to the septic tank system, which was hydraulically connected to a storm drain emptying into an unnamed creek near the site. Chemicals in the wash water contaminated the soil in three areas on the site. The site, now a Superfund site, is currently owned and occupied by ETM Enterprises, Inc., a manufacturer of fiberglass parts. ETM purchased the site from Parsons in 1979.

A total of about 3,000 cubic yards of soil were found to be contaminated with chlordane, 4,4’-DDT, dieldrin, and mercury. Dioxins were also found on the site at very low levels. The areas of contamination on the site were relatively shallow, reaching a maximum depth of only five feet.

4.2 Treatment Approach

After a feasibility study was conducted at the Parsons site, ISV was selected as the treatment remedy Treatability tests on the site soil were completed by Geosafe Corporation in January 1990. The results confirmed the suitability of the site soil and contamination for remediation by ISV, and thus ISV was selected as the Removal Action for the Parsons Superfund site.

Because the contaminated soil at the Parsons site was shallow and located in several small areas on the site, the soil was excavated and staged into two adjacent trenches. The trenches were constructed near two of the contaminated soil areas, and also close to the original Parsons building. One trench was 168 feet long, and the adjacent trench was 84 feet long. Each trench was approximately 27 feet wide. A total of nine ISV treatment cells were planned for the trenches, each a total of 27 feet by 27 feet by 15 feet deep (See Figure 4-l)

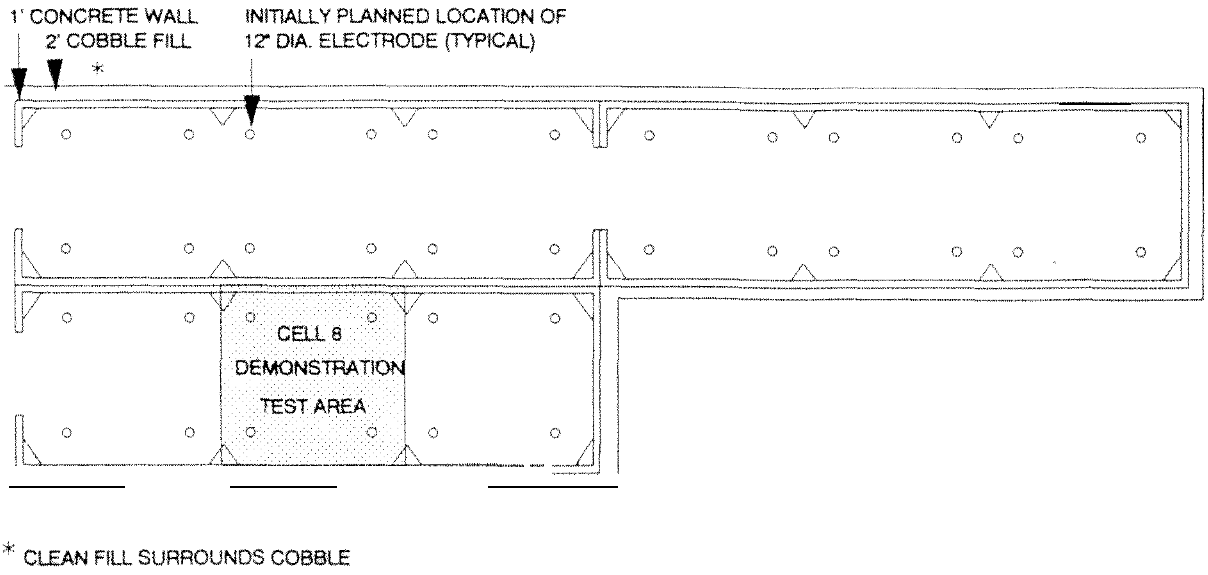


Figure 4-l. Plan View of Treatment Cells

The cells were built using concrete, cobble, and wood as shown in Figure 4-2. They were constructed by trenching an area of the site, installing wooden concrete forms, and pouring concrete into the forms to create the nine cell settings. The concrete walls were one-foot thick and 16 feet high; the top of the walls were at ground level. A one-foot layer of cobble (which sloped up to approximately three feet in the comers) was placed in the bottom of each cell, and approximately two feet of cobble was used to surround the exterior of the cell forms. The cobble was used to provide a drainage pathway for water that was known to be present on-site; the resultant flow of water was directed to two sumps and was pumped from there to a drainage trench. After construction, the cells were lined with plastic sheeting, and then filled with contaminated soil from the site. A layer of clean soil approximately two feet deep was placed on top of the contaminated soil to act as a barrier between the contaminated soil and the surrounding area.

It was planned that the treatment would progress through the nine cells in a designated order. Each cell was anticipated to require approximately seven to ten days to treat, with an additional three days required to move the hood and off-gas treatment system between settings and start the next cell.

4.3 Treatment Objectives

The treatment objectives for the ISV remediation at Parsons were set by EPA Region V. Final cleanup levels for the soil were set at 1,000 μg/kg for chlordane; 4,000 μg/kg for 4,4'-DDT; 80 μg/kg for dieldrin; and 12,000 μg/kg for mercury. A major claim of the ISV developer is that the process can significantly reduce the leaching potential of heavy metals and other inorganics from the solidified mass. Leachability was therefore tested by conducting the toxicity characteristic leaching procedure (TCLP) on pre- and post-treatment samples of the soil. The Federal TCLP limits (40 CFR 9261.24) were used for comparison with test results.

4.4 Detailed Process Description

The ISV process is designed to treat soil and other earthen materials (e.g., sludge, sediments, and mine tailings) contaminated with a wide variety of contaminants. The technology uses joule heating to melt the waste matrix, destroying organic compounds in the process, and encapsulating the inorganic constituents in a monolithic and leach-resistant form. In joule heating, electric current flows through the material and transfers heat energy to the material (3)

ISV involves the heating and melting of the lithological matrix in which contamination is present. The Geosafe process uses a square array of four 12-inch OD graphite electrodes spaced up to 18 feet part. This allows formation of a maximum melt width of about 35 to 40 feet and a maximum melt depth of approximately 20 feet. The electrode spacing is somewhat dependent on the soil characteristics, and the electrodes are lowered gradually as the melt progresses. Figure 4-3 shows a typical ISV equipment layout.

A conductive mixture of flaked graphite and glass frit is placed just below the soil surface between the electrodes to act as a starter path since dry soil is usually not electrically conductive. The soil surface beneath the hood is then covered by a layer of insulation. The starter path facilitates the flow of current between the electrodes until the ground matrix reaches a temperature and viscosity to conduct the current and produce melting. At this stage, the soil warms to approximately 2,900 to 3,600°F (1,600 to 2,000°C), well above the initial melting temperature of typical soils (2,000 to 2500°F or 1,100 to 1,400°C). Temperatures at an individual electrode can reach as high as 3,300°F (1,800°C). The graphite and glass starter path is eventually consumed by oxidation. Upon melting, most soils become electrically

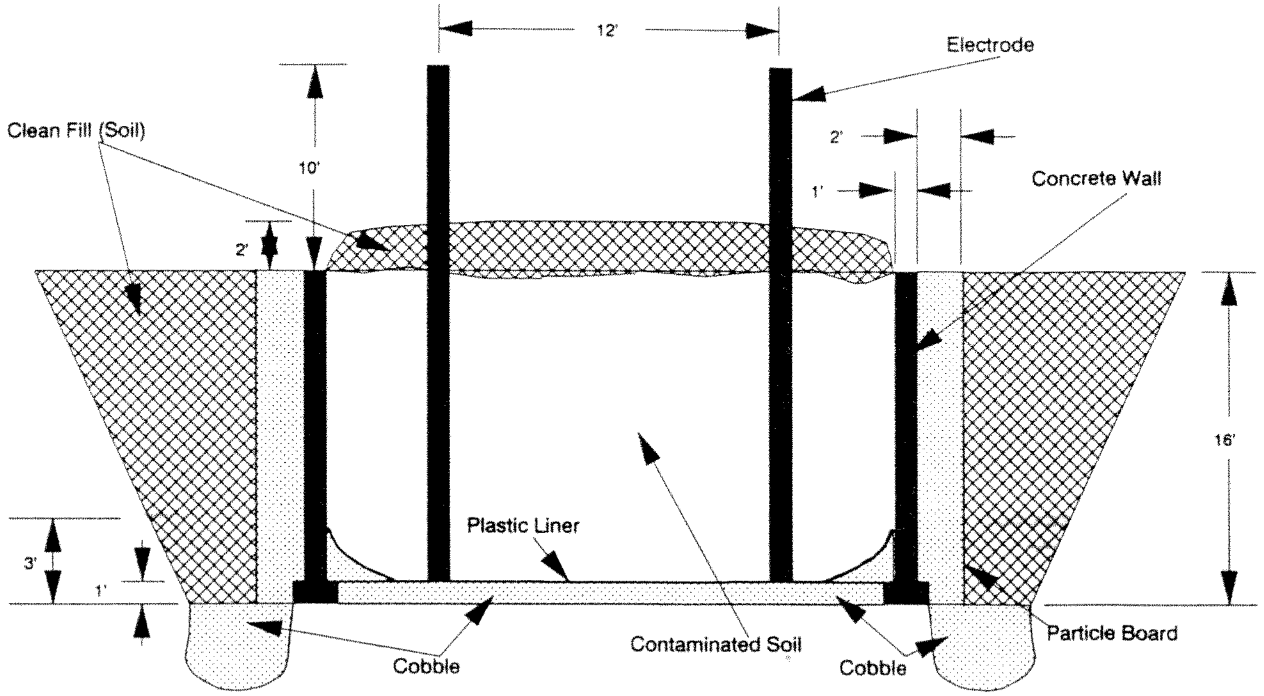


Figure 4-2. Cut-Away View of Treatment Cells

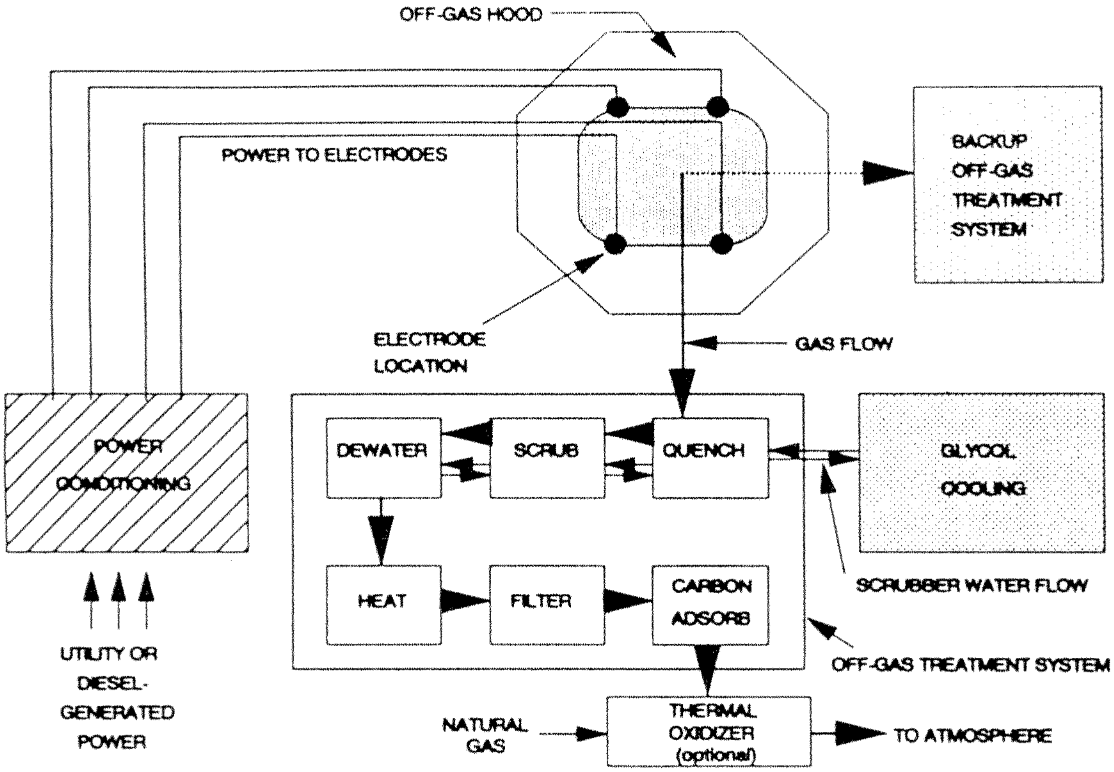


Figure 4-3. Geosafe In Situ Vitrification Process

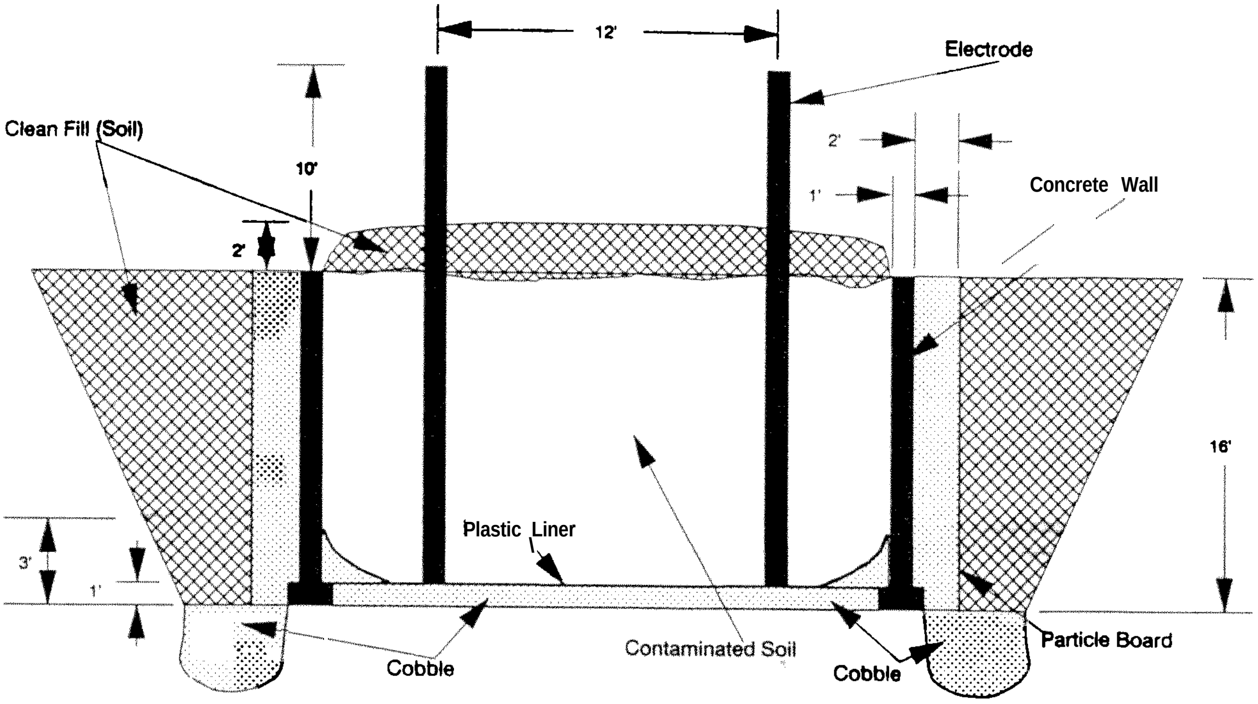


Figure 4-2. Cut-Away View of Treatment Cells

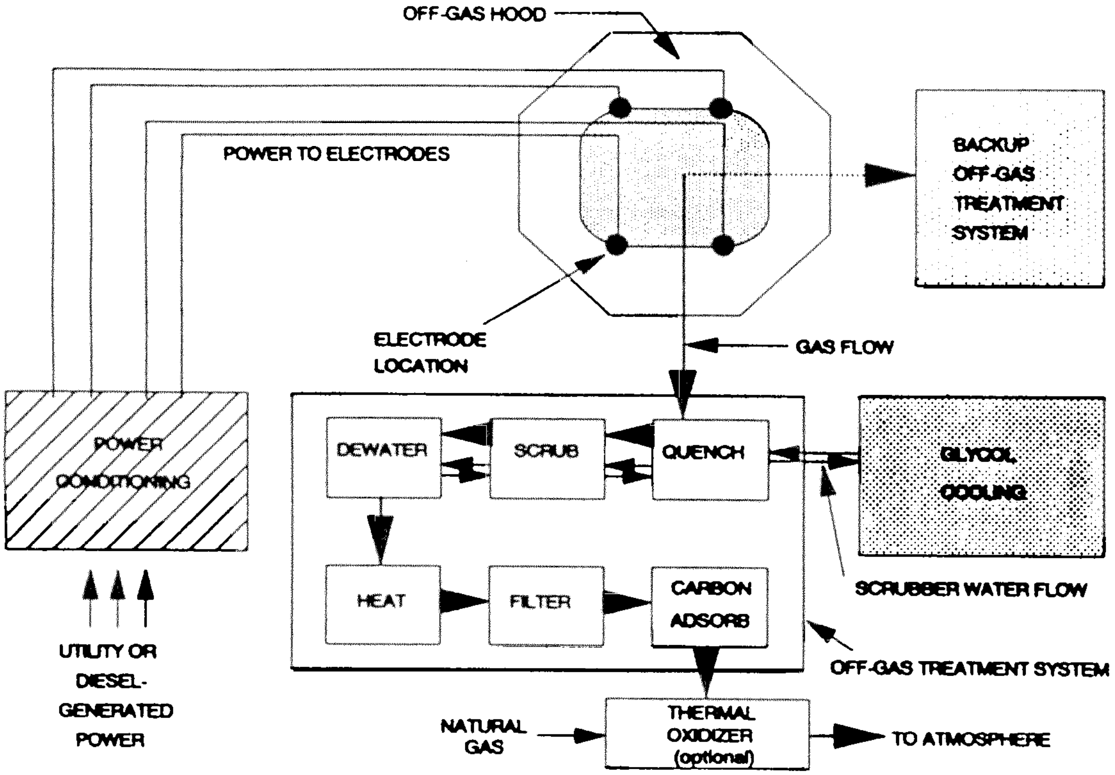


Figure 4-3. Geosafe In Situ Vitrification Process

conductive; thus, the molten mass becomes the primary conductor and heat transfer medium. As a result of the joule heating, the inherent viscosity is lowered to approximately 100 poise. At this point, the melt begins to grow within the soil matrix, extending radially and downward. Power is maintained at levels sufficient to overcome heat losses from the surface and to the surrounding soil. Heating of the melt is aided by convection currents within the melt. Heat is transferred to the adjacent soil by conduction from the melt.

Electric power is supplied to the array of electrodes through flexible conductors. The ISV hood is equipped with an electrode feed system that gravity feeds the electrodes downward as the melt progresses. Initially, the electrodes are inserted approximately one to two feet below grade. As the melt becomes established and is no longer subject to any failure in its conduction of the applied current, the four electrodes are released and allowed to descend into the lithological matrix according to their respective individual weights. Ideally, this will proceed until the targeted contaminants are completely enveloped in the melt and the desired treatment depth is attained. Graphite extensions are added to the top of each electrode according to the intended depth penetration of the melt. If processing difficulties are encountered, the electrode feed system may “grasp” the electrodes and thus prevent their downward movement until the difficulty is addressed.

The process can remediate contaminated soil at a rate of four to six tons per hour until a maximum mass of 800 to 1,200 tons has been treated. The downward growth rate of the melt is in the range of one to two inches per hour. Because soil typically has low thermal conductivity, a very steep thermal gradient of 300 to 480°F (150 to 250°C) per inch precedes the advancing melt front. This produces a 212°F (1OO’C) isotherm less than one foot away from the molten mass. The soil volume between the 212°F isotherm and the melt is termed the “dry zone.” This zone has maximum vapor permeability because it exists without the presence of liquid water.

As the melt grows, the electrical resistance of the melt decreases. The ratio between the voltage and the current must, therefore, be adjusted periodically to maintain operation at an acceptable power level. Generally, the melt grows outward to a width approximately 50 percent wider than the electrodes spacing. The molten zone is roughly a cube with slightly rounded corners on the bottom and sides; this shape reflects the higher power density around the electrodes. Figure 4-4 presents typical process conditions.

During processing, ISV removes the void volume present in particulate materials resulting in a volume reduction. Further volume reduction also occurs, since some of the material present in the soil such as humus and organic contaminants are removed as gases and vapors during processing. The overall volume reduction (typically 20 to 50 percent), creates a subsidence volume above the melt (see Figure 4-4).

At appropriate temperature regimes within the soil surrounding the melt, or within the melt itself, the solids and contaminants undergo changes of physical state .and decomposition reactions. The possible dispositions of contaminants resulting from ISV processing include:

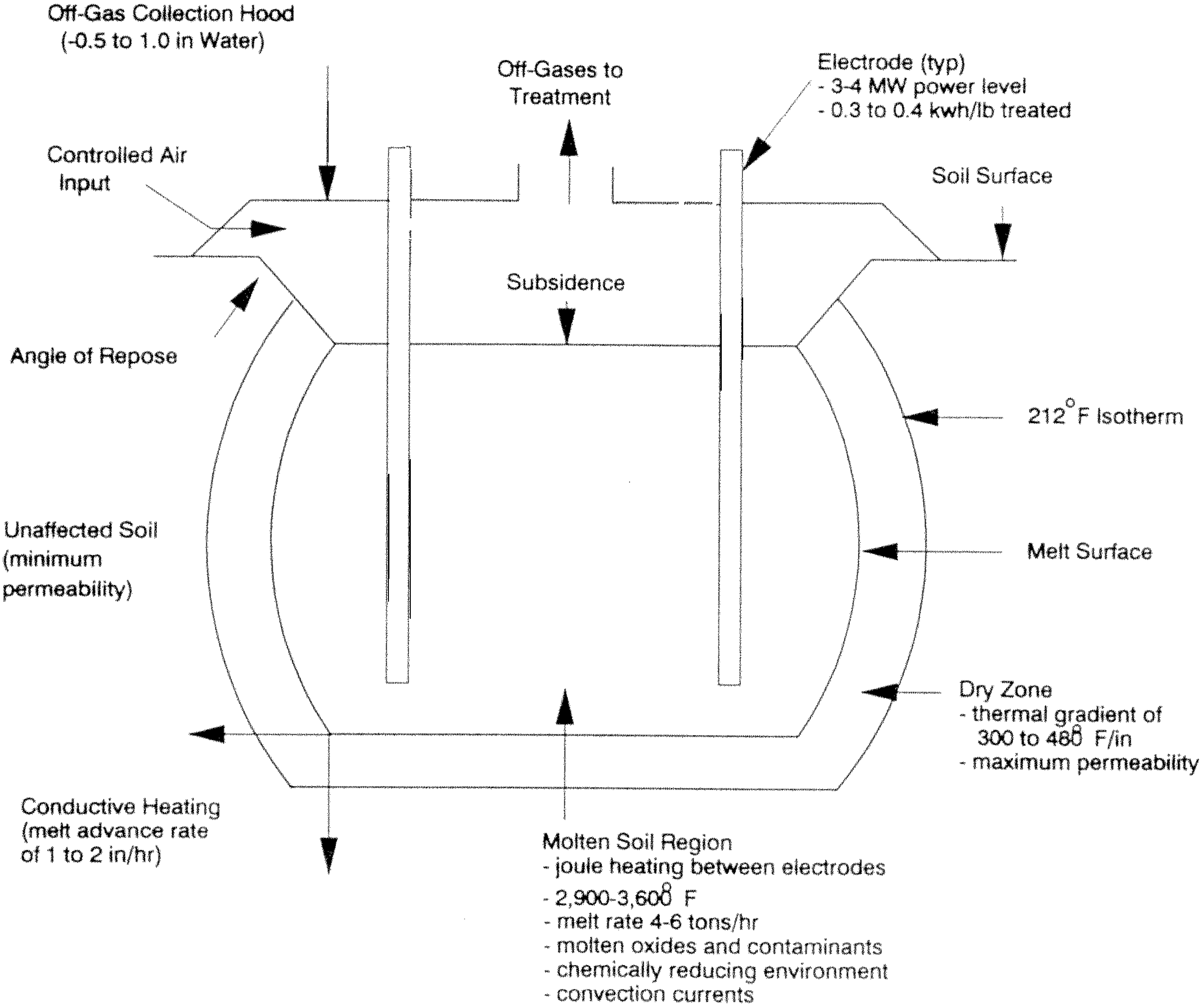


Figure 4-4. Typical ISV Process Conditions for the Geosafe Technology

- chemical and thermal destruction;
- removal from the treatment volume to the off-gas treatment system;
- chemical and physical incorporation within the residual product;
- lateral migration ahead of the advancing melt; and
- escape to the environment.

As the thermal gradient advances on solid or liquid organic materials, these materials are either drawn into the melt or laterally migrate into the dry zone where the are vaporized and ultimately pyrolyzed. Only a small fraction of vapor passes through the melt itself. The predominant pathway for vapor movement from the treatment zone is through the dry zone adjacent to the melt. Because of gas-phase permeability differences, the dry zone is the path of least resistance and the adjacent wet soil acts as a barrier to outward movement of vapors. Organic pyrolysis products are typically gaseous; because of the high viscosity of the molten material, these gases move slowly through the melt, usually on a path adjacent to the electrodes, toward the upper melt surface. While some of these gases may dissolve into the molten mass, the remainder move to the surface where those that are combustible react in the presence of air. Pyrolysis and combustion products are collected in an off-gas collection hood and are subsequently treated in the off-gas treatment system. Because of the high temperature of the melt, no residual organic contaminants are expected to remain in their original compound form within the vitrified product

The behavior of inorganic materials upon exposure to the advancing thermal gradient is similar to that of the organics. Inorganic compounds may thermally decompose or otherwise enter into reactions with the melt. Typically, the metals originally present are incorporated into the vitrified residual. Immobilization may occur when the contaminants are incorporated into the glass network or encapsulated (surrounded) by the glass. If large amounts of non-volatile metals are present, they may sink to the bottom of the melt and concentrate there.

During treatment, a “cold cap” forms over the surface of the melt. This cold cap, a surface layer of viscous molten material at the air/melt interface, helps to contain radiative heat loss. The cold cap also performs the important function of holding volatilized wastes for possible re-incorporation into the melt. The cold cap is penetrated by the electrodes which, themselves, are usually hot enough to maintain fluid behavior in directly adjacent areas. These highly fluid surface areas are common vent locations for release of vapors and gases from the melt.

Once a melt is established, the process may be restarted after a power shutdown or loss, as long as a molten path remains between the electrodes. If this is not the case, it will be necessary to lay a new starter path of graphite and glass frit between the electrodes. The amount of time allowed for restart depends on the size of the melt. A large melt (e.g., 500 tons) could allow restart even after several days. Shutdowns during the first 48 hours of treatment are more difficult to restart and more sensitive to the length of the outage.

The processing area is covered by an octagonal off-gas collection hood with a maximum width between the flat edges of 60 feet. Footers, which support the hood, extend five feet past the maximum width of the hood. The large distance between the edge of the hood and the edge of the melt is designed to enable off-gas containment, even under worst-case subsidence conditions. Flow of air through the hood is controlled to maintain a vacuum of 0.5 to 1 inches of water on the system. The vacuum prevents the escape of fugitive emissions from the hood and ground surface interface. Air provides oxygen for combustion of pyrolysis products and organic vapors. The off-gases, pyrolysis products, and air are drawn from the hood by an induced draft blower into the off-gas treatment system. The off-gas is treated by quenching, pH-controlled scrubbing, mist elimination, particulate filtration, and activated carbon adsorption. A thermal oxidizer was added to the gas treatment train midway through the remediation at the Parsons site to complete combustion of organic compounds from the melt and help reduce odors. A backup gas treatment system is also present and is designed to be activated automatically in case of power interruption. The backup system employs a diesel-powered generator, blower, mist cooler, filter, and activated carbon column.

Once power to the electrodes is shut off, the melt begins to cool. In most cases, no attempts are made to force cooling of the melt; slow cooling is expected to produce a vitreous (amorphous) and micro-crystalline structure. Removal of the hood is normally accomplished within 24 hours after power to the electrodes is discontinued. The used graphite electrodes are severed near the melt surface and are left within the treated monolith. After the off-gas hood is removed and the electrodes are severed, the subsidence volume is filled to the desired depth with clean backfill. When melt locations are contiguous, a single large monolith will ultimately be produced. In instances where removal of the vitrified mass is anticipated, the treated area may be left uncovered to speed the cooling process and induce shrink-cracking of the surface. This aids the fracturing of the mass prior its removal.

4.5 Testing Methodology

The EPA Risk Reduction Engineering Laboratory (EPA-RREL) chose the former operational site of Parsons Chemical Works, Inc. (the Parsons site) in Grand Ledge, Michigan for the evaluation of the Geosafe ISV process as part of the SITE Program. The site was known to be contaminated with low levels of pesticides and metals and was the first full-scale implementation of the ISV technology to treat hazardous wastes. Region V of the EPA had also selected the Geosafe technology as part of a removal action for the Parsons site. The SITE Program, under the direction of EPA-RREL, used this opportunity to gain additional valuable information regarding the ISV technology. The SITE Demonstration and the Region V cleanup operations were implemented in conjunction with one another during treatment. The sampling analysis and process monitoring performed as part of the SITE Demonstration were designed to supplement those already planned and performed by Region V. For informational purposes, some data from EPA Region V is presented in this report; these data were not used to evaluate the SITE Demonstration objectives

Under the SITE Program, the goal of this Demonstration was to determine the effectiveness of treatment and to evaluate the technology from an economic and performance standpoint. The developer of this technology (Geosafe) claimed that the ISV system could obtain a destruction and removal efficiency (DRE) of 99.99% for organic compounds within the soil and can incorporate inorganic compounds and metals within the residual vitrified product. Pre-treatment chemical concentrations were too low to evaluate this claim appropriately. Instead, the objectives presented in the following paragraphs were established.

The primary objective of the Demonstration was to determine whether EPA Region V cleanup criteria could be met. The Demonstration of the ISV technology was designed to allow evaluation of the ability of the technology to meet regulatory criteria for the major pesticides present and mercury. In addition, the leaching characteristics of the untreated and the treated waste were evaluated.

Critical objectives are those objectives which are important to developer's claims and those which **can be** evaluated at this site. Secondary (or non-critical) objectives are those which are of interest to future applications of ISV technology but do not relate directly to the developer's claims. Other objectives, such as DRE, are not considered here but are expected to be included at future sites where levels of contamination are higher. The Demonstration objectives as specified in the QAPP were:

Critical Objective:

- To determine if final soil cleanup levels set by the EPA Region V were achieved. These specified cleanup levels were 1,000 μg/kg for chlordane, 4,000 μg/kg for 4,4'-DDT, 80 μg/kg for dieldrin, and 12,000 μg/kg for mercury.

Secondary Objectives:

- To evaluate the leachability characteristics of chlordane, 4,4'-DDT, dieldrin, and mercury in the test soil using the TCLP and determine whether the leachability characteristics of these compounds in the vitrified residue met the regulatory limits specified in 40 CFR $261.24. (Note: Only mercury and chlordane are listed in 40 CFR $261.24.)
- To determine the approximate levels of dioxins/furans, pesticides (specifically chlordane, 4,4'-DDT, and dieldrin), mercury, and moisture in the test soil.
- To characterize the liquid residues (scrubber water) of the process with respect to pesticide and mercury concentrations.
- To evaluate emissions from the process
- To identify the operational parameters of the technology
- To develop operating costs and assess the reliability of the equipment
- To examine potential impediments to the use of this technology including technical, institutional, operational, and safety impediments.

A Demonstration Plan and Quality Assurance Project Plan (QAPP) were prepared to specify technical project objectives to be used in evaluating the Geosafe ISV technology at the Parsons site under the SITE Program. The QAPP specified the procedures for sampling and analysis to evaluate project objectives. The sampling plan required test soil sampling before and after treatment, scrubber water sampling before and after treatment, and gas sampling of the emissions to the atmosphere during treatment.

To evaluate the critical objective for this project, the treated soil samples analyses for pesticides and mercury were designated as critical analyses. Other non-critical measurements were performed to characterize the process. The following sections present a discussion of the data collected in support of this evaluation.

Soil placed into the treatment cells was sampled by EPA Region V while the cells were being filled. These samples were composites collected from random locations throughout the cells. Based upon Region V data, Cell 8 contained the highest levels of organic and inorganic contaminants, therefore this cell was selected for evaluation by the SITE Program. In May 1993, five additional grab samples were collected by EPA Region V, three of which were analyzed by the SITE Program for pesticides and mercury. The TCLP was also performed on these samples, and the leachate was analyzed for pesticides and mercury. These samples were intended to provide information for use in development of SITE Demonstration objectives. The results are presented in Table 4-l. The data suggest that the staged soil is not very homogeneous before treatment, exhibiting wide variations in contamination levels.

Based upon these results, it was noted that the contaminant levels were not high enough to warrant a full statistical-based sampling strategy to determine the average soil concentration of target contaminants for use in DRE, mass balance, or percent removal calculations. Therefore, the SITE Program elected to collect a limited number of soil samples (three plus one field duplicate) from the test cell to evaluate pre-treatment soil conditions. Pre-treatment soil conditions were not as significant as post-treatment soil conditions since determination of DRE was not an objective, so the heterogeneity of the pre-treatment soil was not a concern.

Composite samples of the soil in Cell 8, the cell treated during the Demonstration, were collected and analyzed before treatment was initiated on this cell at a time when sampling did not interfere with Region V activities in adjacent cells. A drill rig equipped with a 2-inch diameter split spoon sampler was used to collect sample cores from three separate boreholes at three locations within the cell. An additional borehole was drilled to obtain the field duplicate samples. This boring was located as close as possible to the primary boring. All samples were collected from depths between 4 and 15 feet below land surface. The soil recovered from all split spoons of a particular boring were composited together and aliquoted for the selected analyses. Samples from the cell were analyzed for pesticides (chlordane, 4,4’-DDT, and dieldrin), dioxins/furans, mercury, glass formers (alumina and silica), and conductive cations (lithium,

Table 4-l. Results of Analysis of Pre-Treatment Screening Samples Collected from Cell 8

Sample	Units	Analytical Parameter			
		4,4’-DDT	Dieldrin	Chlordane	Mercury
Composite*	μg/kg	72,000 J	12,000 J	2,000 J	12,000
1[†]	μg/kg	1,100	2,600	< 8.0	3,900
3[†]	μg/kg	4,800	2,800	< 8.0	15,000
5’	μg/kg	830	180	< 8.0	1,400
TCLP 1[†]	μg/L	0.11	4.4	< 0.26	< 0.00048
TCLP 2[†]	μg/L	1.2	6.3	< 0.26	<0.00048
TCLP 3[†]	μg/L	< 0.087	1.5	< 0.26	< 0.00048

* Random composite collected during filling of the cell. Sample collected in February 1991 by Ecology and Environment.

[†] Samples collected in May 1993 for SAIC by EPA Region V representatives. Five samples were collected, but only three were analyzed.

J Value reported is less than the reporting detection limit but greater than the method detection limit. Value is an estimate.

Compound not detected at or above presented value (detection limit).

potassium, sodium). Samples were also subject to the TCLP for the target pesticides and mercury. During sampling, the geological characteristics of the borings were recorded. The physical parameters of grain size and permeability were determined. To evaluate the volume reduction from treatment, moisture content and test soil density (on a dry basis) were measured using a drive cylinder method. In this procedure, the sample is obtained in situ by driving a cylinder of known volume into the sample matrix. The cylinder is weighed to determine density and then analyzed for moisture content. Using this information, dry density can be calculated.

During treatment of Cell 8, the process was visually observed and monitoring of the system was conducted. Data were recorded at regular intervals. Stack sampling was conducted as specified in the QAPP.

Gaseous emissions from the stack downstream of the gas treatment equipment were evaluated using both sample collection and continuous emission monitoring techniques. Stack gas samples were collected using Summa canisters for volatile organic compounds, and sampling trains for semivolatile organics, pesticides, dioxins/furans, metals, hydrogen chloride, and particulate matter. Continuous emission monitoring for oxygen, carbon monoxide, and total hydrocarbons was conducted using the on-line equipment utilized by Geosafe to comply with operating permits. The original intent of the stack gas sampling was to provide an indication of the composition of the gases emitted to the atmosphere. All of the stack gas measurements were designated as non-critical. During the first few treatment settings at the Parsons site, an offensive odor was emitted from the process. To remedy this, Geosafe modified the off-gas treatment train to include a thermal oxidizer, thereby oxidizing the odorous compounds. Local regulatory agencies also closely monitored process emissions and specified emission criteria. As a result of these developments, the stack gas sampling objectives for the SITE Demonstration were modified to evaluate if the process could operate within regulatory guidelines. The emissions of pesticides and mercury, along with arsenic, chromium, lead, carbon monoxide, and total hydrocarbons, were designated critical measurements. Samples of the gases emitted to atmosphere were collected after exiting the thermal oxidizer

After treatment of Cell 8 was complete, the off-gas treatment system was allowed to run for approximately 24 hours to remove any fugitive emissions from the melt. After this 24-hour period, the containment hood was moved and the ambient air was monitored with an organic vapor analyzer and a mercury analyzer. When airborne contaminant levels were determined to be safe, samples of the treated material were collected from just below the surface of the melt. These samples were intended to provide immediate information regarding the effectiveness of the ISV treatment.

The surface material sampled was part of the “cold cap” and was already solidified by the time the treatment hood was moved. Samples were collected by a member of the developer’s staff who, wearing heat-insulating boots and other appropriate personal protective equipment, stood upon the subsided surface of the melt. The sampler was supported by a lifeline held by personnel outside the melt area. Samples of the surface material were then obtained using a decontaminated hammer to chip pieces from the cold cap. After collection, the samples were placed in a cotton cloth and further crushed using the decontaminated hammer. The sample pieces were thoroughly homogenized and aliquoted into sample containers for analysis. These post-treatment surface samples were analyzed for pesticides (chlordane, 4,4'-DDT, and dieldrin), dioxins/furans, and metals. They were also subject to the TCLP for the target pesticides and metals. In addition, density measurements were performed on the treated material. Admittedly, these surface samples are not representative of the entire melt, but they do provide immediate information about the treated surface material.

Additional samples of the post-treatment soil will be collected from the core of the vitrified mass after it has completely cooled and solidified. The number of samples collected will exceed then number of samples required to ensure statistical credibility. These samples may be collected up to two years after the completion of treatment. It is anticipated that these samples will be collected from the center of the treatment area using a rotary drill rig equipped with a diamond-tipped drill bit or another appropriate method. The samples will again be analyzed for pesticides (chlordane, 4,4'-DDT, and dieldrin), dioxins/furans, and metals and subjected to the TCLP for target pesticides and metals. The density of these samples will also be measured. The data will be reviewed by a statistician as required. If the samples display significant variability or the levels are higher than the cleanup objectives, then additional samples will be analyzed. Future samples are anticipated to confirm the results obtained from the surface samples. The results from these sample analyses will be published as an Addendum to this report.

To account for contaminants removed by the scrubber, grab samples of the scrubber water were collected before, during, and after treatment of Cell 8. Two samples (primary and field duplicate) of water charged to the scrubber were collected before treatment of Cell 8 (but after treatment of the preceding cells) to provide baseline data regarding the type and quantity of contaminants present. The scrubber liquor was also sampled to evaluate the amount and types of material accumulating during treatment. Two sets of samples were collected after treatment commenced-one (primary and field duplicate) during a discharge sequence, and one at the end of the test. Since the scrubber liquor waste stream may require secondary disposal, samples were collected to characterize this liquid and to gain information on the type of material being treated by the off-gas treatment system. All scrubber samples were analyzed for volatile organics, semivolatile organics, target pesticides, dioxins/furans, and total metals including mercury and arsenic. These sample analyses were not considered critical objectives for the Demonstration.

4.6 Performance Data

Table 4-2 presents the post-treatment soil sample results for target pesticides, mercury, and target TCLP analytes in comparison to regulatory limits. The table also presents summary stack emission data in comparison with the ARARs in place at the time of the Demonstration. Standard deviations are not presented in this table since only a limited number of samples were collected. The summary clearly indicates that Region V cleanup objectives for the target contaminants were achieved. It should be noted that some ARARs were achieved prior to treatment, without implementation of the technology. Both chlordane and mercury were below the specified cleanup objectives before treatment even began. As shown in the table, the TCLP results were well within the regulatory limits. Stack emissions were also below the ARARs. The technology was not rigorously challenged by the low levels of contaminants at this site, and therefore, the ability of the technology to remediate highly contaminated soil has not yet been demonstrated. Detailed discussions regarding the analytical data in this table are presented in the following sections.

4.6.1 Test Soil

The test soil was subjected to the chemical and physical analyses specified in the QAPP both before and after treatment. A discussion of the results of these analyses is presented below.

4.6.1.1 Pre-Treatment Test Soil Chemical Characteristics

The results of chemical analyses of the soil are presented in Tables 4-3 through 4-6. Standard deviations are not presented because only a limited number of samples were collected. The pesticide target analytes were detected in the pre-treatment samples at the average levels shown in Table 4-3. Chlordane was below the EPA Region V cleanup criteria of 1,000 μg/kg and was not detected in any of the samples. 4,4'-DDT averaged 13,000 μg/kg, with a range of 2,400 to 23,000 μg/kg. Dieldrin ranged from 1,200 to 8,300 μg/kg and averaged 4,600 μg/kg. Levels of mercury in the test soil were below the Region V cleanup criteria of 12,000 μg/kg, ranging from 2,200 to 4,700 μg/kg and averaging 3,800 μg/kg.

The pre-treatment soil was also evaluated for the presence of dioxins and furans since these compounds had been detected in low levels by EPA Region V at various locations of the Parsons site. The results

Table 4-2. Performance Data During Demonstration Versus ARARs

Analyte	Units	Test Result (Average)	Regulatory Limit	
Treated Soil				
Chlordane	µg/kg	< 80	1,000	*
4,4-DDT	µg/kg	< 16	4,000	*
Dieldrin	µg/kg	< 16	80	*
Mercury	µg/kg	110	12,000	*
Treated Soil TCLP				
Chlordane	µg/L	< 0.50	30	**
Mercury	µg/L	0.18	200	**
Arsenic	µg/L	13	5,000	**
Barium	µg/L	440	100,000	**
Cadmium	µg/L	< 5.0	1,000	**
Chromium	µg/L	< 10	5,000	**
Lead	µg/L	1,100	5,000	**
Selenium	µg/L	< 300	1,000	**
Silver	µg/L	< 10	5,000	**
Stack Emissions				
Arsenic	lb/hr	< 1.9E-06	-----	†
Chromium	lb/hr	2.1E-05	-----	†
Lead	lb/hr	2.8E-05	-----	†
Mercury	lb/hr	1.1E-04	5.9E-04	‡
Carbon Monoxide	ppmv	< 10	150	‡
Total Hydrocarbons	ppmv	< 10	100	‡

* Cleanup level specified by EPA Region V.
** 40 CFR §261.24.
† No regulatory limits specified.
‡ Emission level specified by Michigan Department of Natural Resources.

Table 4-3. Geosafe Test Soil Pesticides and Metals Data Summary*

Analyte	Pre-Treatment	Post-Treatment [a]	Post-Treatment [b]
Pesticides +	(µg/kg)	(µg/kg)	(µg/kg)
Chlordane	< 80	< 80	NA
4,4'-DDT	13,000	< 16	NA
Dieldrin	4,600	< 16	NA
Metals ++	(µg/kg)	(µg/kg)	(µg/kg)
Aluminum	3.1E+07	3.1E+05	3.0E+07
Arsenic	9.0E+03	3.1E+03	6.4E+03
Barium	3.1E+05	3.6E+03	2.8E+05
Calcium	2.6E+07	1.0E+06	4.8E+07
Chromium	4.1E+04	1.3E+04	5.0E+04
Cobalt	1.0E+04	1.9E+03	5.5E+03
Copper	7.1E+03	7.1E+03	1.4E+04
Iron	2.4E+07	2.6E+06	1.6E+07
Lead	5.0E+04	8.6E+03	2.5E+04
Magnesium	8.7E+06	3.2E+05	1.5E+07
Manganese	6.7E+05	1.1E+04	3.4E+05
Mercury	3.8E+03	3.3E+01	1.1E+02
Nickel	3.4E+04	1.1E+04	1.6E+04
Potassium	1.3E+07	1.1E+05	1.1E+07
Sodium	6.2E+06	1.2E+05	6.7E+06
Vanadium	5.6E+04	1.9E+03	4.3E+04
Zinc	5.6E+04	4.5E+04	9.2E+04
Physical Parameters ++	(ton/yd^3)	(ton/yd^3)	(ton/yd^3)
Density (wet basis)	1.8	NA	NA
Density (dry basis)	1.5	2.0	NA

* - Complete data are presented in the Technology Evaluation Report.

[a] - Digestion of metals by SW-846 Method 3050 and mercury by SW-846 Method 7471.

[b] - Digestion by HF acid total dissolution.

\+ - Data reported are average values from three primary and one duplicate sample collected.

++ - Pre-treatment data reported are average values from three primary samples collected.
Post-treatment data reported are average values from three primary and one duplicate sample collected.

< - Analyte not detected at or above presented value (detection limit).

NA - Sample not analyzed for this parameter.

Table 4-4. Geosafe Test Soil **Dioxins/Furans** Data Summary*

Analyte	Pre-Treatment ** (ng/kg)	Post-Treatment ** (ng/kg)
2,3,7,8-TCDF	< 0.88	< 0.49
Total TCDF	17	< 0.49
2,3,7,8-TCDD	6.4	< 0.47
Total TCDD	9.2	0.011
1,2,3,7,8-PeCDF	< 1.7	< 0.51
2,3,4,7,8-PeCDF	4.5	< 0.31
Total PeCDF	52	< 0.51
1,2,3,7,8-PeCDD	1.4	< 0.34
Total PeCDD	7.4	< 0.34
1,2,3,4,7,8-HxCDF	< 6.2	< 0.51
1,2,3,6,7,8_HxCDF	< 5.4	< 0.43
2,3,4,6,7,8-HxCDF	3.6	0.40
1,2,3,7,8,9_HxCDF	0.78	< 0.49
Total HxCDF	53	0.20
1,2,3,4,7,8-HxCDD	1.5	< 0.49
1,2,3,6,7,8_HxCDD	6.3	< 0.63
1,2,3,7,8,9-HxCDD	3.2	< 1.0
Total HxCDD	56	0.0067
1,2,3,4,6,7,8_HpCDF	32	< 0.60
1,2,3,4,7,8,9_HpCDF	< 2.5	< 0.55
Total HpCDF	130	0.081
1,2,3,4,6,7,8_HpCDD	240	0.78
Total HpCDD	430	0.80
OCDF	200	< 0.77
OCDD	2,900	4.3
2,3,7,8-TCDD Equivalence	17	0.034

* - Complete data are presented in the Technology Evaluation Report.

** - Data reported are average results from one primary and one duplicate sample collected.

< - Analyte not detected at or above presented value (detection limit).

Table 4-5. **Geosafe Soil TCLP Pesticides and Metals Data Summary***

	Pre-Treatment			Post-Treatment		
Analyte	Sample 1 (µg/L)	Sample 2 (µg/L)	Sample 3 (µg/L)	Sample 1 (µg/L)	Sample 2 (µg/L)	Sample 3 (µg/L)
Pesticides						
Chlordane	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50
4,4'-DDT	0.17	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Dieldrin	8.2	8.9	6.5	< 0.10	< 0.10	< 0.10
Metals						
Arsenic	NA	NA	NA	< 4.0	13	31
Barium	NA	NA	NA	330	540	550
Cadmium	NA	NA	NA	< 5.0	2.9	4.1
Chromium	NA	NA	NA	11	< 10	5.8
Lead	NA	NA	NA	< 50	4,300	15
Mercury	0.050	0.035	0.010	0.20	0.23	0.090
Selenium	NA	NA	NA	< 300	< 300	< 300
Silver	NA	NA	NA	< 10	< 10	< 10

* - Complete data are presented in the Technology Evaluation Report.
NA - Sample not analyzed for this compound.
< - Analyte concentration is less than or equal to presented value (detection limit).

in Table 4-4 indicate that dioxin/furan contamination was extremely low with a 2,3,7,8-TCDD equivalency, averaging 17 ng/kg with a range between 14 and 19 ng/kg.

The pre-treatment soil samples were subjected to the toxicity characteristic leaching procedure to evaluate the leachability of the critical target analytes before treatment (see Table 4-5). Only chlordane and mercury are listed in 40 CFR §261.24 where TCLP limitations are specified. Chlordane was not detected in any of the TCLP samples, and mercury was well below regulatory limits. However, low levels of 4,4'-DDT were detected between less than 0.10 and 0.17 μg/L, and dieldrin was detected between 6.5 and 8.9 μg/L.

Table 4-6. Geosafe Pre-Treatment Test Soil Conductive Cations and Ultimate Analysis Data*

Analysis	Result	units
Conductive Cations* *		
Aluminum	33,000	**mg/kg**
Lithium	18	mgfl<g
Potassium	12,000	mgn<g
Silicon	280,000	m!#g
Sodium	6,600	**mg/kg**
Ultimate Analysis* * *		
Carbon	**1.3**	**%**
Nitrogen	0.23	%
Oxygen	7.0	%
Sulfur	0.010	%

• - Complete data are presented in the Technology Evaluation Report.
• * - Data reported arc average values from one primary and one duplicate sample collected.
• ** - Data reported are average values from three primary samples collected.

An important consideration when using the in situ vitrification technology is the confirmation of sufficient amounts of conductive cations and glass-forming metal oxides in the test soil to allow soil melting and subsequent formation of a stable monolith. For the SITE Demonstration, inductively coupled plasma (ICP) analyses using standard SW-846 procedures were conducted on the pre-treatment test soil to evaluate these parameters. The results are summarized in Table 4-6. Geosafe typically uses an X-ray diffraction technique rather than ICP analyses to evaluate these parameters before treatment. Before the onset of remediation at Parsons site, Geosafe independently determined that the concentrations of these materials were high enough to allow the Parsons soil to be vitrified without supplemental oxide addition.

During the processing of the test cells prior to the cell selected for the Demonstration, odor problems were observed. Because of the odor, Region V and Geosafe investigated potential sources of the problem. Geosafe suspected sulfur as the culprit since site records indicated that sulfur was previously used at the Parsons site, and low concentrations of sulfur-based compounds in the exhaust gas are often very odorous. The SITE Program analyzed some of the pre-treatment samples using an ultimate elemental analysis technique to evaluate the sulfur content of the soil. These analyses were not originally planned

Table 4-6. Geosafe Pre-Treatment Test Soil Conductive Cations and Ultimate Analysis Data*

Analysis	Result	units
Conductive Cations**		
Aluminum	33,000	mg/kg
Lithium	18	mg/kg
Potassium	12,000	mg/kg
Silicon	280,000	mg/kg
Sodium	6,600	mg/kg
Ultimate Analysis* * *		
Carbon	1.3	%
Nitrogen	0.23	%
Oxygen	7.0	%
Sulfur	0.010	%

- - Complete data are presented in the Technology Evaluation Report.
- * - Data reported arc average values from one primary and one duplicate sample collected.
- ** - Data reported are average values From three primary samples collected.

An important consideration when using the in situ vitrification technology is the confirmation of sufficient amounts of conductive cations and glass-forming metal oxides in the test soil to allow soil melting and subsequent formation of a stable monolith. For the SITE Demonstration, inductively coupled plasma (ICP) analyses using standard SW-846 procedures were conducted on the pre-treatment test soil to evaluate these parameters. The results are summarized in Table 4-6. Geosafe typically uses an X-ray diffraction technique rather than ICP analyses to evaluate these parameters before treatment. Before the onset of remediation at Parsons site, Geosafe independently determined that the concentrations of these materials were high enough to allow the Parsons soil to be vitrified without supplemental oxide addition.

During the processing of the test cells prior to the cell selected for the Demonstration, odor problems were observed. Because of the odor, Region V and Geosafe investigated potential sources of the problem. Geosafe suspected sulfur as the culprit since site records indicated that sulfur was previously used at the Parsons site, and low concentrations of sulfur-based compounds in the exhaust gas are often very odorous. The SITE Program analyzed some of the pre-treatment samples using an ultimate elemental analysis technique to evaluate the sulfur content of the soil. These analyses were not originally planned

as part of the **Demonstration. As noted in Table 4-6,** some sulfur was present in the pre-treatment soil, but at very low levels. To solve the odor problem, Geosafe added a thermal oxidizer to the end of the off-gas treatment train to polish and completely combust partially oxidized melt gases. The thermal oxidizer was effective in removing melt odors. The ultimate source of the odor was never positively identified.

Additional studies were conducted on the pre-treatment test soil after learning that arsenic, lead, and chromium were being detected in stack gas samples collected by EPA Region V and in HEPA filter samples. The SITE Program elected to make these metals critical analytes in the stack gas samples since their emission to the atmosphere may be a human health risk. Because of this decision, samples of the pre-treatment test soil were analyzed to evaluate metal content within the soil. The soil was analyzed for standard ICP metals and arsenic (using a graphite furnace method). The results of these analyses are presented in Table 4-3.

4.6.1.2 Post-Treatment Test Soil Chemical Characteristics

In the laboratory, all vitrified soil samples were ground into a fine powder before digestion and/or leachability testing was performed. The samples were ground in a comminution device specifically designed to prepare laboratory samples by minimizing heat effects (friction of grinding) and sample contamination. The laboratory was instructed to grind portions of the treated soil that were most representative of the center of the treated area, not the cold cap. The cold cap was easily distinguished by the amount of entrained bubbles in the vitrified sample. Solid (bubble-free) portions of the melt were selected for analyses since they probably best represent the final product.

Samples of the ground vitrified material were extracted and analyzed for pesticides using SW-846 Method 8080. The results of these analyses are summarized in Table 4-3. The results indicate that the technology met the removal criteria for the organic contaminants of interest. As noted by the data, all pesticides were below their detection limits in each of the samples. Table 4-3 shows that 4,4'-DDT was reduced from an average concentration of 13,000 μg/kg to less than 16 μg/kg. Dieldrin was reduced from 4,600 μg/kg to less than 16 μg/kg. Since chlordane was not detected in any of the pre-treatment samples, the ability of the technology to treat this compound cannot be evaluated as part of this Demonstration.

Metal analyses were performed using two different digestion procedures—SW-846 Method 3050 (7471 for mercury) and a microwave procedure using a mixture of hydrofluoric, nitric, and hydrochloric acids to obtain total dissolution of the sample. The data for both of these analyses are summarized in Table 4-3. As noted in the table, the metal concentrations detected by the microwave digestion procedure are much greater than those found in the standard procedure since the microwave digestion with hydrofluoric acid is more aggressive and provides a better dissolution of the vitrified soil. Comparison between the two samples is assumed to be valid because aliquots from the same sample were used for both analyses. The only metal which does not appear to have been recovered at higher concentrations in the microwave procedure was lead. Lead recoveries may have been impacted by sample detection limits. The data suggest that most of the metals are retained within the vitrified solid after treatment. However, due to the limited data set, it is difficult to accurately draw this conclusion pertaining to any specific metal because of sample and analytical variability. Metals were not the primary focus of this Demonstration.

Mercury concentrations that were determined using the microwave-digested samples may not be accurate. During the QA review of these data, it was noted that some signal enhancement or depression may have occurred. A National Institute of Standards and Technology (NIST) fly ash sample was analyzed with routine samples. This sample exhibited high recovery and matrix spike samples were biased low using the microwave procedure. Therefore, mercury concentrations obtained using standard SW-846 digestion and analytical procedures may provide a better indication of mercury concentrations since all associated quality control data was acceptable. The data from either procedure, however, clearly indicate that the regulatory limits for mercury levels in soil were easily achieved. Other metal concentrations closely match the pre-treatment soil samples (hydrofluoric acid digestion method) with the exception of mercury and perhaps arsenic (see Table 4-3). This is not surprising given the relative volatility of these metals at high temperatures. It was not possible to thoroughly evaluate the ability of the process to retain other metals due to the limited number of samples collected.

Some of the ground vitrified samples were subjected to the TCLP to evaluate the leachability of the critical analytes after treatment. TCLP results are presented in Table 4-5 (target pesticides and regulated metals only). As noted by the results, all samples were below the regulatory criteria for the listed metals and chlordane, however, no firm conclusion can be stated regarding chlordane since this compound was below its detection limit before treatment. Leachable levels of the pesticides dieldrin and 4,4'-DDT were reduced to non-detectable levels in the leachate. One of the three samples contained leachable levels of lead at 4,300 μg/L which is close to the regulatory limit of 5,000 μg/L. The reason for this single data outlier is not clear, especially since lead was not present at high levels in the test soil and was 50 μg/L or less in the other two samples. The TCLP was not performed for regulated metals other than mercury during the pre-treatment sampling event. Therefore, no conclusive statements can be made regarding the technology's impact on leachability characteristics of these metals (pre- and post-treatment comparison).

Dioxin/furan samples of the treated material collected suggest that these compounds were reduced to levels much lower than those found in the samples of the soil before treatment. This evaluation can be made by comparing the 2,3,7,8-TCDD equivalence calculations on pre- and post-treatment soil (see Table 4-4). The data table indicates that 2,3,7,8-TCDD equivalences were reduced from an average of 17 ng/kg to 0.034 ng/kg. The decrease of the equivalences appears to be real since the concentrations of the individual isomers seem to have been reduced.

4.6.1.3 **Pre-Treatment Test Soil Physical Characteristics**

Physical properties of the test soil were investigated as part of the Demonstration. The soil was a sandy clay-like material containing approximately 45 % of material with a grain size greater than 0.1 mm. The remainder of the test soil consisted of some finer grain sands. The detailed results of the grain size measurements and the geological information gathered during sampling are found in an appendix of the accompanying Technology Evaluation Report. Table 4-3 presents the results of the soil density measurements on both a wet and a dry basis. It should be noted that the pre-treatment samples were collected in July 1993 and the Demonstration did not commence until late March 1994. It is unlikely that the percent moisture values (used to determine soil density on a dry basis) obtained from the pre-demonstration samples are identical to the actual moisture content of the soil at the time of treatment. However, sampling logistics required pre-treatment samples to be collected well in advance of treatment, while the test cell was not covered by the hood and before directly adjacent cells were treated.

4.6.1.4 Post-Treatment Test Soil Physical Characteristics

Samples of the post-treatment soil were also collected to evaluate the density of the treated material. These data, along with pre-treatment dry density information were used to evaluate the volume reduction upon treatment (Table 4-3). Dry density was used in these calculations in order to compare pre- and treatment data. It was assumed that sample moisture was contained in the porosity of the soil and, upon driving the moisture off during treatment, no appreciable volume reduction would occur. The result of this evaluation indicated that, on a dry basis, a volume reduction of approximately 30% occurred as a result of treatment. Vendor claims for volume reduction as a result of treatment are calculated somewhat differently; the vendor should be contacted if additional information regarding this claim is desired.

4.6.2 **Scrubber Liquor**

At the time of the SITE Demonstration, Geosafe had completed five melt settings. Before the start of the SITE Demonstration (treatment of Cell 8), the off-gas treatment system was prepared with fresh HEPA filters and activated carbon. The scrubber system was also drained, cleaned, and charged with fresh water. The results of analysis of the scrubber water samples for organics, metals, and dioxins/furans are presented in Tables 4-7, 4-8, and 4-9, respectively.

4.6.2.1 Pre-Treatment Scrubber **Liquor**

The pre-treatment scrubber samples, obtained from the scrubber tap, were slightly brown and cloudy from suspended and dissolved solids which remained after cleaning. The results of the pesticide analyses (Table 4-7) indicated that there were no traces of chlordane or 4,4'-DDT in the scrubber solution. The primary and duplicate samples both showed approximately 3.0 $\mu g/L$ of dieldrin before treatment. These results indicate that some of the dieldrin was escaping the vitrification process during treatment of cells previously remediated. This loss can probably be attributed to volatilization of the pesticide within the dry zone of the approaching melt

Volatile and semivolatile scrubber water data that were obtained before the start of the Demonstration are summarized in Table 4-7. The volatile pre-treatment scrubber samples contained ketones (specifically acetone and methyl ethyl ketone) and some benzene. Benzene was detected in the scrub solution at a concentration of approximately 15 $\mu g/L$. Samples analyzed for semivolatile organics before testing indicated that there were low levels (approximately 2.0 to 50 $\mu g/L$) of polynuclear aromatic hydrocarbon (PAH) compounds along with some moderate levels (approximately 100 to 400 $\mu g/L$) of phenolic compounds in the scrubber before the test.

Table 4-7. Gcosafe Scrubber Water **Organics** Analysis Summary **Data***

Analyte	**Pre-Treatment**** (µg/L)	During **Treatment**** (µg/L)	**Post-Treatment***** (µg/L)
Pesticides			
Chlordane	< 5.0	< 50	< 50
4,4'-DDT	C 1.0	< 10	< 10
Dieldrin	3.0	< 10	10
Volatiles			
Ace tone	450	1,500	2.000
Benzene	15	21	24
Methyl ethyl ketone	90	200	310
Semivolatiles			
Acenaphthylene	2.1	< 100	< 100
Anthracene	9.3	< 100	< 100
Bcnz(a)anthracene	21	11	18
Bcnz(a)pyrene	3.2	< 100	< 100
Bcnzo(b)fluoranthene	17	< 100	< 100
Benzo(g,h,i)perylene	1.5	< 100	< 100
Benzo(k)fluoranthene	17	< 100	< 100
Benzoic acid	< 50	22.000	11.000
chrysene	39	20	33
Di-n-butylphthalatc	1.2	< 100	< 100
Dibcnzofuran	13	8.0	15
2,4-Dimethylphcnol	34	< 100	< 100
bis(2-cthylhexyl)phthalate	6.6	< 100	C 100
Fluoranthene	33	29	53
Fluorcnce	6.5	6.1	10
Indenol 1,, 2,3cd)pyrcne	1.2	< 100	< 100
2-Methylnaphthalene	7.3	< 100	< 100
4-Methylphenol/3-Methylphenol	150	690	3,100
2-Methylphenol	90	345	660
Naphthalene	33	31	31
4-Nitrophenol	3.6	6,100	2,6QO
Phenanthrene	41	43	78
Phenol	380	5.100	11,000
Pyrene	24	2Q	36

• - Complctc dara are presented in **the** Technology Evaluation Report.

• * - **Data reported are average values from one** primamy an one duplicate sample collected.

*** - Data reported are from one primary sample collcctcd.

< - **Analyte** not detected at or above **presented** value (detection limit).

Table 4-8. Geosafe Scrubber Water Metals Analysis Summary Data*

Analyte	Pre-Treatment** (µg/L)	During Treatment** (µg/L)	Post-Treatment*** (µg/L)
Aluminum	590	3,800	3,600
Antimony	52	470	450
Arsenic	1,400	320	540
Barium	96	8.0	7.2
Beryllium	< 2.0	1.1	1.2
Cadmium	170	58	110
Calcium	97,000	850	2,100
Chromium	570	< 10	< 10
Cobalt	65	39	26
Copper	120	130	180
Iron	7,400	890	1,300
Lead	5,400	5,700	5,900
Magnesium	34,000	830	2,200
Manganese	1,600	220	340
Mercury	310	62	800
Nickel	3,600	1,100	1,000
Potassium	9,700	950,000	260,000
Selenium	36	570	400
Silver	13	< 10	< 10
Sodium	110,000	18,000,000	7,100,000
Thallium	59	1,600	900
Vanadium	8.0	12	9.0
Zinc	8,600	27,000	22,000

* - Complete data are presented in the Technology Evaluation Report.

** - Data reported are average values from one primary and one duplicate sample collected.

*** - Data reported are from one primary sample collected.

< - Analyte not detected at or above presented value (detection limit).

Table 4-9. Geosafe Scrubber Water Dioxins/Furans Analysis Data*

Analyte	Pre-Treatment** (μg/L)	During Treatment* (μg/L)	Post-Treatment*** (μg/L)
2,3,7,8-TCDF	2.1E-04	1.4E-04	3.5E-04
Total TCDF	4.6E-03	3.0E-03	7.8E-03
2,3,7,8-TCDD	3.2E-04	1.4E-04	3.0E-04
Total TCDD	1.6E-02	4.7E-03	1.4E-02
1,2,3,7,8-PeCDF	< 5.7E-04	< 2.6E-04	2.3E-04
2,3,4,7,8-PeCDF	2.5E-04	1.3E-04	3.3E-04
Total PeCDF	1.9E-03	1.3E-03	4.3E-03
1,2,3,7,8-PeCDD	8.3E-04	2.8E-04	6.2E-04
Total PeCDD	1.6E-02	4.7E-03	9.5E-03
1,2,3,4,7,8-HxCDF	2.1E-04	< 1.0E-04	< 1.7E-04
1,2,3,6,7,8-HxCDF	2.1E-04	5.3E-05	< 1.5E-04
2,3,4,6,7,8-HxCDF	1.4E-04	4.3E-05	1.2E-04
1,2,3,7,8,9-HxCDF	< 1.0E-04	< 1.0E-04	< 1.0E-04
Total HxCDF	1.4E-03	2.6E-04	6.6E-04
1,2,3,4,7,8-HxCDD	4.2E-04	1.2E-04	2.8E-04
1,2,3,6,7,8-HxCDD	5.6E-04	1.8E-04	4.1E-04
1,2,3,7,8,9-HxCDD	3.9E-04	1.7E-04	1.8E-04
Total HxCDD	1.3E-02	3.6E-03	6.9E-03
1,2,3,4,6,7,8-HpCDF	4.1E-04	9.0E-05	2.6E-04
1,2,3,4,7,8,9-HpCDF	< 1.0E-04	< 1.0E-04	< 1.0E-04
Total HpCDF	4.5E-04	9.0E-05	2.6E-04
1,2,3,4,6,7,8-HpCDD	2.7E-03	9.3E-04	2.3E-03
Total HpCDD	6.6E-03	2.2E-03	5.3E-03
OCDF	1.5E-04	3.0E-05	8.3E-05
OCDD	3.7E-03	1.6E-03	4.0E-03
2,3,7,8-TCDD Equivalence	1.0E-03	4.2E-04	9.5E-04

* - Complete data are presented in the Technology Evaluation Report.

** - Data reported are average values from one primary and one duplicate sample collected.

*** - Data reported are from one primary sample collected.

< - Analyte not detected at or above presented value (detection limit).

The pre-treatment scrubber water was also analyzed for the presence of dioxins and furans. There were no appreciable levels of these compounds detected (2,3,7,8-TCDD equivalence was 1.0 x 10^{-3} µg/L).

The metals data for the scrubber water is summarized in Table 4-8. Some residual metals were present in the scrubber solution in the form of either dissolved or precipitated salts. As noted by the data, moderate levels of arsenic, chromium, lead, and mercury were present at the beginning of the Demonstration. Sodium hydroxide was used in the scrubber to neutralize acid vapor from the melt and to assist in the precipitation of dissolved metals; therefore, the average sodium concentration in the pre-treatment scrubber water was 110,000 µg/L.

4.6.2.2 Scrubber **Liquor During and After Treatment**

No target pesticides were detected in samples collected from the scrubber sump discharge during treatment. These results are summarized in Table 4-7. The samples required a dilution, and the detection limits achieved for the pre-treatment samples could not be achieved due to chromatographic interferences. The sample collected at the end of the Demonstration contained dieldrin at a concentration of 10 µg/L. This value was the same as the reporting detection limit of this sample. The positive identification of dieldrin suggests that some of this compound is not thermally decomposed by the vitrification process and must be treated by the off-gas treatment system.

Post-treatment scrub solution samples analyzed for volatile and semivolatile compounds required dilution to reduce chromatographic interferences (see Table 4-7). The concentration of benzene in the scrubber liquor did not appear to change significantly during treatment while increases in concentrations of other volatile analytes (especially acetone and methyl ethyl ketone) were observed. The post-treatment samples showed increases in the concentrations of the phenolic compounds and nitrophenols. These compounds were present in the post-treatment scrubber liquor in concentrations ranging from approximately 650 to 11,000 µg/L. Benzoic acid was also detected at 11,000 µg/L.

The post-treatment scrubber water was also analyzed for the presence of dioxins and furans. No appreciable levels of these compounds were detected in the samples (see Table 4-9), and in most cases, the concentrations detected would not be a regulatory concern. The scrubber concentrations were on the order of 1.0 x 10^{-3} $\mu g/kg$ 2,3,7,8-TCDD equivalence for pre-treatment, blowdown, and post-treatment samples

The metal analyses of the scrubber water during and after treatment indicated that some mercury (a target analyte) was present in the scrub solution (Table 4-8). However, in comparison to pre-treatment samples, there was no net increase beyond what may be attributed to analytical error. Reductions and/or no significant change were observed for many of the metals. This was most likely due to the addition of sodium hydroxide to the scrubber solution which was used to neutralize acid gases and assist in the precipitation of dissolved metals. Treatment of metal vapors by the scrubber probably resulted in precipitable salts which were removed in the scrubber filtration system. Significant increases were noted in aluminum, antimony, potassium, selenium, thallium, and zinc. These metals do not readily form precipitable salts at the pH conditions under which the scrubber was operating.

4.6.3 **Stack Gas**

Stack gas samples for the parameters specified in the QAPP were collected during treatment of Cell 8. The stack gas was also monitored continuously for oxygen, carbon monoxide, and total hydrocarbons.

Because pesticides were known to be present in the soil, pesticide emissions were evaluated by the analysis of samples collected by three primary and one duplicate sample train. The soil concentrations were too low to allow evaluation of a destruction and removal efficiency (DRE) claim. Even so, any detectable quantity of pesticides in the stack gas would indicate a low DRE for these compounds. The results of the pesticide stack samples are presented in Table 4-10. As shown in the table, none of the target pesticides were detected in the stack gas.

Samples collected for volatile and semivolatile analyses did not contain any significant target compound hits. The volatile samples were obtained using a time-integrated Summa@ canister sampling technique. The results of these analyses are summarized in Table 4-10. Since both volatile and semivolatile samples were analyzed using gas chromatography/mass spectrometry, a search of the 10 largest non-target compounds were conducted. None of the unknown responses were positively identified; these compounds were, therefore, classified as unknown hydrocarbons. The unknown compounds were present at negligible levels. The emission data corresponds well with the total hydrocarbon measurements.

The stack emissions of dioxins/furans was very low during testing. Most of the target isomers were not detectable in the stack samples. For the two samples (primary and duplicate), the 2,3,7,8-TCDD equivalences were 1.0×10^{-6} and 2.8×10^{-8} $\mu g/m^3$. Complete data are presented in the Technology Evaluation Report.

To characterize metal emissions, samples were collected using three primary and one field duplicate multiple metals sample train. The results of these samples are presented in Table 4-11. Total metals emissions were calculated by summing the vapor phase and solid phase contributions. In cases where the vapor phase or solid phase emissions were not detected at or above the detection limit, the detection limit was used in the calculations. All metals emissions were in compliance with the established regulatory guidelines. The majority of the mercury emitted from the process was in the vapor phase; levels near

Table 4-10. Geosafe Organic Stack Emissions Summary Data*

	Result	
Analyte	($\mu g/m^3$)	(lb/hr)
Pesticides**		
Chlordane	< 1.4	< 1.0E-05
4,4'-DDT	< 0.28	< 2.0E-06
Dieldrin	< 0.28	< 2.0E-06
Semivolatiles***		
Benzoic acid	23	1.6E-04
Di-n-butylphthalate	1.0	7.2E-06
Diethylphthalate	0.73	5.0E-06
bis(2-ethylhexyl)phthalate	2.5	1.7E-05

* - Complete data are presented in the Technology Evaluation Report.

** - Data reported are results from three primary and one duplicate sample collected

*** - Data reported are results from one primary and one duplicate sample collected.

< - Analyte not detected at or above presented value (detection limit).

Table 4-11. Geosafe Metal Stack Emissions Summary Data*

	Vapor Phase**		Solid Phase**		Total Metals**	
Analyte	($\mu g/m^3$)	(lb/hr)	($\mu g/m^3$)	(lb/hr)	($\mu g/m^3$)	(lb/hr)
Aluminum	< 4.7	< 3.4E-05	41	2.9E-04	44	3.1E-04
Antimony	< 2.3	< 1.7E-05	< 2.9	< 2.1E-05	< 2.8	< 2.0E-05
Arsenic	< 0.057	3.8E-07	< 0.22	< 1.6E-06	< 0.27	< 1.9E-06
Barium	0.069	4.9E-07	1.8	1.3E-05	1.9	1.3E-05
Beryllium	< 0.047	c 3.4E-07	< 0.058	< 4.2E-07	< 0.058	< 4.2E-07
Cadmium	0.14	1.0E-06	0.13	9.4E-07	0.20	1.5E-06
Calcium	13	9.3E-05	410	2.9E-03	420	3.0E-03
Chromium	0.52	3.7E-06	2.4	1.7E-05	2.9	2.1E-05
Cobalt	0.49	3.5E-06	< 0.28	< 2.0E-06	0.51	3.6E-06
Copper	0.62	4.4E-06	0.84	6.0E-06	1.5	1.0E-05
Iron	3.0	2.2E-05	43	3.1E-04	46	3.2E-04
Lead	1.2	8.9E-06	1.5	1.0E-03	2.1	1.5E-05
Magnesium	3.5	1.9E-05	5.6	4.0E-05	8.2	5.9E-05
Manganese	140	1.0E-03	1.4	9.9E-06	140	1.0E-03
Mercury	16	1.2E-04	0.0046	3.3E-08	16	1.2E-04
Molybdenum	< 1.2	< 8.5E-06	5.5	3.9E-05	5.5	3.9E-05
Nickel	0.43	3.0E-06	1.1	7.6E-06	1.3	9.5E-06
Potassium	110	8.1E-04	18	1.3E-04	130	9.3E-04
Selenium	2.7	1.9E-05	4.7	3.3E-05	3.2	2.2E-05
Silver	0.69	4.9E-06	< 0.29	< 2.1E-06	< 2.3	< 1.6E-05
Sodium	32	2.3E-04	73	5.2E-04	76	5.4E-04
Strontium	0.042	3.0E-07	0.74	5.3E-06	1.7	1.3E-05
Thallium	< 2.3	< 1.7E-05	< 2.9	< 2.1E-05	< 2.9	< 2.1E-05
Vanadium	< 0.47	< 3.4E-06	< 0.57	< 3.9E-06	< 0.57	< 3.9E-06
zinc	1.7	1.2E-05	5.7	4.0E-05	7.4	5.3E-05

* - Complete data are presented in the Technology Evaluation Report.

** - Data reported are average values from three primary and one duplicate sample collected.

< - Analyte not detected at or above presented value (detection limit).

non-detect were found on particulate filters. Arsenic was below reporting detection limits in all samples. Chromium emissions were mostly in the particulate form, as were most of the remaining metal emissions. It was not determined whether the chromium emissions were in the hexavalent or trivalent form. The emission of lead was close to the detection limit in of the samples collected. Stack gas modeling performed by the local regulatory agencies indicated that metal emissions were at levels that did not pose a significant human health risk.

The hydrogen chloride emissions during the Demonstration were about 5.0 X 10” lb/hr, well below the 4 lb/hr performance standard of 40 CFR $264.343. This standard is established for an incinerator burning hazardous waste. Although it may not be directly applicable, this standard does provide a background for evaluating these emissions.

Particulate emissions averaged approximately 3.0 mg/m^3. This value was not corrected for oxygen content in the stack since supplemental oxygen was supplied to the thermal oxidizer. Even if the particulate emissions were corrected, they would still be below the referenced performance standard for incineration (see 40 CFR $264.343).

During the entire Demonstration, oxygen, carbon monoxide, and total hydrocarbons (as propane) were monitored by Geosafe. The emissions of both total hydrocarbons and carbon monoxide were well within the operational limits of the process and were each consistently below 10 ppmv throughout the Demonstration

4.6.4 Limitations of the Data Results

The conclusions presented in this report have been based upon the information gathered during the Demonstration. Great care was taken to ensure that the measurements collected were accurate and representative. However, in some instances, engineering and analytical limitations restrict the use and interpretation of some of these data. This section discusses some of these limitations.

After treatment, samples of the vitrified soil were collected from the surface of the treatment area. There are some limitations associated with these samples. Although the vendor claims that the molten mass becomes well-mixed by thermal gradients within the melt, a “cold cap” typically forms on the upper surface of the melt. Upon cooling, the upper surface of the melt may have been incorporated into the cold cap and therefore is probably not representative of the center of the treatment area. It is highly likely that all organic material within the test soil was destroyed by the intense heat generated during treatment. Mercury and other metals may be found in higher concentrations at the center of the treatment area due to a higher amount of vapor entrainment than that present at the melt surface. Additionally, the test soil was covered with two feet of clean fill. It is possible that some of the post-treatment samples collected may have been treated fill material. It should be noted that great care was taken to select samples that represented the center of the treatment area. Large rock-like samples were collected from the melt surface; the bottom portions of these samples were placed in containers for analysis. Given the volume reduction upon treatment, it is highly probable that these samples were obtained from a depth that contained contaminated soil. Future sampling is planned to obtain material closer to the center of the treatment area after the soil has cooled. These samples will be used to verify the results presented in this report. When obtained, the final results and conclusions of the Demonstration will be published in an Addendum to this report.

Although the currently available data indicate that the technology was successful in achieving the Region V cleanup criteria, it should be noted that some of the contaminants were already below the established limits before treatment. This was especially true for chlordane which was not detected in any of the pre-treatment soil samples collected during the SITE Demonstration. However, data collected by Region V indicate that chlordane was present in the soil at the time the cells were filled (see Table 4-l). Mercury levels were also below the target criteria before treatment. The data collected during this Demonstration do indicate that substantial reductions occurred in contaminant concentrations after treatment.

The TCLP measurements were performed using standard SW-846 procedures. The method specifies that the samples must be ground before leaching. This analytical procedure exposes a much greater leachable surface area than would be present after actual remediation since practical applications of ISV create a single large monolith. Therefore, the results of the TCLP analyses presented in this report most likely represent a worst-case scenario. Actual leachability of a treated area is conservatively estimated to be as good as or better than the results present in this report. The TCLP data presented for chlordane is inconclusive because chlordane was not detected at or above its detection limit in the pre-treatment TCLP samples

Although dioxins and furans were known to be present in the test soil, they were not the primary focus of this study because their concentrations in the soil were very low. The dioxin/furan results are limited since only a few samples were collected from each matrix. The data collected suggest that the process does not generate significant quantities of dioxins/furans during treatment.

Stack sampling activities concentrated on pesticide and metals emissions. Other stack samples were performed at a limited frequency. It was not possible to collect stack samples throughout the entire ten-day Demonstration. This would have been technically difficult and cost prohibitive. Therefore, the samples collected represent emissions over a shorter time period than the average emissions throughout the Demonstration. The investigators believe that these samples are representative of typical emissions since sampling occurred while contaminated soil was being treated.

Volume reductions were calculated based upon density information gained from the surface samples. It is possible that samples collected from the center of the treatment area may be more dense due to the weight of the melt upon itself. During cooling, the material may form a more crystalline structure and entrained gases (bubbles) may redissolve in the material during cooling. The volume reductions will be confirmed during the future sampling event.

4.6.5 **Process Operability and Performance at the Parsons Site**

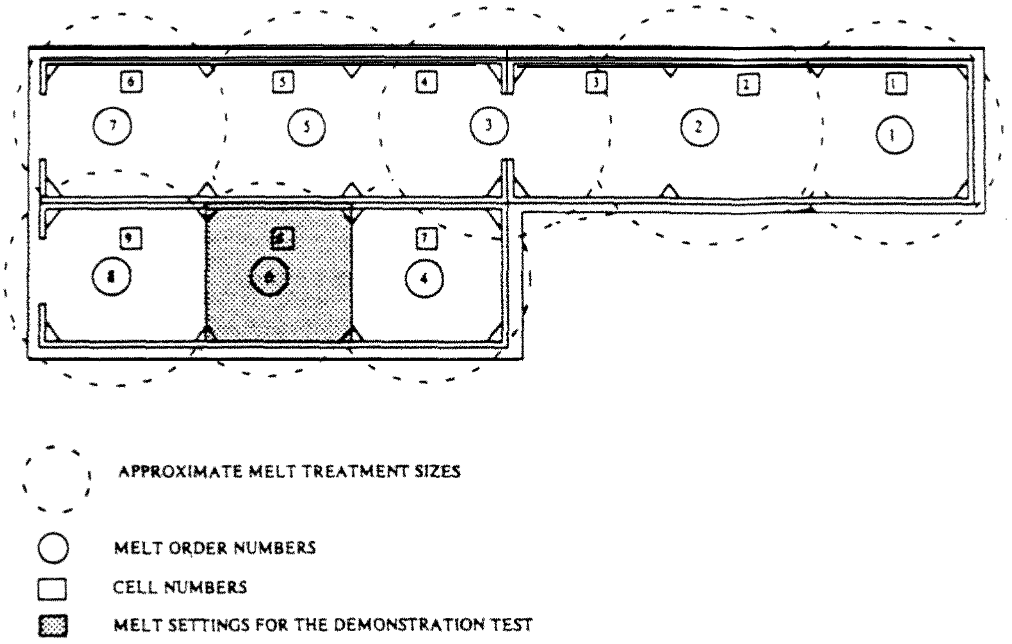
This section summarizes the operability of the process and the overall performance of the Geosafe ISV system at the Parsons site. It includes discussions about developments and problems encountered, along with the manner in which these items were resolved.

The in situ vitrification of the staged cells at Parsons improved with the progression of treatment. Although the initial cells presented some treatment difficulties, during the Demonstration (treatment of Cell 8), the system ran continuously for approximately ten days with only minor operational problems. System operation was only interrupted for routine maintenance such as electrode segment addition and adjustment. Throughout the remediation project, problems encountered were minor and limited to those associated with the replacement of scrubber system heater cores (due to solids buildup), periodic replacement of the hood panels, and final disassembly of the hood panels

Originally, remediation of the nine cells at the Parsons site was scheduled to be completed in three months. Treatment began in June 1993. Treatment time for the early cells exceeded the average treatment time, as well as the expected treatment time. The amount of water that was present in the soil and close proximity of shallow perched water contributed to longer treatment times in the early cells. Additionally, unexpected lateral growth of the early melts increased treatment times when the original cell walls did not effectively contain the treatment area. By early March 1994, Geosafe had completed five melts and treated six cells. These five melts had unusually large overlap areas; the fourth and fifth melts extended slightly into the Demonstration cell (Cell 8). Because of this overlap (and additional overlap in future melts), the Parsons site was completely remediated in eight melts rather than nine (see Figure 4-5). In late March and early April of 1994, the Demonstration was conducted on the sixth melt (Cell 8). All eight melts were completed by June 1994, nine months after the original anticipated finish date. Data in the economic analysis presented in this report is based on the planned treatment of nine melts in nine cells.

Geosafe did not meet the schedule for treatment at the Parsons site. This may be attributed to a number of factors-some due to problems with the process, others due to constraints imposed by regulatory agencies. EPA Region V and the Michigan Department of Natural Resources (MDNR) required Geosafe to modify treatment procedures so that the emissions and odors from the stack were controlled. Because the Parsons site is in a residential area, the offensive odor drew public attention. Further treatment was halted until new permit conditions were established and process modifications were completed. The technical requirements of an Air Quality Permit were specified by MDNR in a document entitled "General and Special Conditions." Because Geosafe was required to comply with these conditions, this document became a (Superfund site) ARAR for the State of Michigan. Verification of emissions rates (including volatiles, semivolatiles, pesticides, dioxins/furans, metals, particulate matter, hydrogen chloride, sulfur dioxide, carbon monoxide, nitrogen oxides, carbon monoxide, and total hydrocarbons) was stipulated. All changes and modifications to the Geosafe equipment were required to be approved by the EPA Region V. Because the system could not operate during this period, the permitting and approval process added significantly to the time required to complete treatment.

Sulfur compounds in the scrubber liquor were suspected by Geosafe as the source of the odors. To alleviate this problem, the scrubber water was changed at a higher frequency to reduce the amount of sulfur compounds accumulating in the scrub solution. Additionally, Geosafe added a thermal oxidizer to the end of the off-gas treatment system as a final treatment step prior to release of the gas stream to the



atmosphere. This solved the odor problems and reduced emissions to levels within the regulatory limits, The oxidizer operated between 1,400 and 1,600°F (760 and 870°C).

Cell construction, as initially designed at Parsons, proved to be the source of numerous problems during treatment. The cobble outside the cells created porous paths in the vicinity of treatment, thereby increasing the likelihood for vapor or steam to escape from areas outside the confines of the hood. It is possible that the porous paths within the cobble also caused irregular melt shapes. In addition, phenolic compounds and epoxies, not originally present in the contaminated soil, were released into the melt and the groundwater from thermal decomposition of the treated plywood. The presence of new contaminants in the groundwater caused setbacks while regulatory agencies intervened and modifications to the current cell construction were considered.

Geosafe responded to these developments by excavating the area outside of the remaining treatment cells and removing the wooden forms. Refractory concrete with a very high melting temperature was strategically positioned adjacent to the exterior of the concrete cell walls. This helped to control melt shapes, limit emissions of vapor or steam, and restrict the melt energy inside the cell boundaries. Based upon the experience Geosafe gained at Parsons, the design and construction of staged treatment cells will be modified for future projects. It should be noted that the use of cobble in treatment cell construction was unique to the Parsons site where the configuration and flow of the on-site groundwater dictated its application.

During the treatment of Cell 2, a fire occurred as a result of a melt disruption. The fire was caused by a rapid volatilization of 12-foot by l-foot polyvinyl chloride (PVC) casing which had been left in the treatment area to accommodate the previous electrode design. The PVC casing was empty and open at the surface similar to an open-cased well. Four of these casings were located within each test cell. Geosafe determined that the molten soil had contacted the PVC casing and melted a hole in it. This allowed molten material to flow into the casing. The molten material immediately volatilized the PVC casing and caused the expulsion of a small amount of molten material onto the surface soil within the hood. This resulted in an excessive temperature rise on the hood surface and the subsequent burning of combustible hood components. Although very smokey because of burning rubber materials, the fire was small and did not cause the release of any hazardous materials or loss of off-gas containment. The fire caused a disruption of Cell 2 treatment for over 100 hours while Geosafe repaired and replaced damaged equipment. After the damaged equipment was replaced, the treatment of Cell 2 was continued. Geosafe was successful in restarting and continuing the melt without the addition of a new starter path.

During the treatment of Cell 3 another small fire was encountered. This fire was caused by a molten area that was exposed due to a collapsed portion of the cold cap. The radiant energy released was close to the hood surface and caused excessive heating. The instrument lines leading to the electrode feeders began to smolder and bum. This fire was quickly extinguished by Geosafe personnel and had little effect upon treatment of Cell 3.

As a result of the fires, Geosafe removed all PVC casings from future melts and removed all combustible materials from the hood. These corrective actions solved the fire-related problems, and no further incidents of this nature were recorded during the treatment of the Parsons site.

Vitrification of some of the early cells at Parsons required considerably more time and power than anticipated, and large amounts of scrubber water were generated. This was due in part to the high moisture content of the soil and the close proximity of shallow perched water. The perched water flowed intermittently through a sand lens located eight to ten feet below the surface. Because of the large amounts of water encountered during treatment of the early cells, Geosafe constructed an intercept system to collect the perched water at the upgradient end of the treatment zone in a cobble wall. The collected water ran under and beside the treatment zone in cobble and was then directed to two sump locations from which it was pumped to a surface drainage ditch. The amount of water entering subsequent cells was substantially reduced as a result of this action. A permit was obtained for discharge of water and some liquid wastes generated during treatment after minor on-site treatment; however, all scrubber water was collected and sent off-site for treatment and ultimate disposal, and therefore the on-site treatment permit was not used.

Cells treated later in the remediation of the Parsons site required less energy than those treated in the early stages of the project. Cell 8 was the sixth of eight melts performed at the Parsons site. Figure 4-6 graphically depicts the power input applied to Cell 8 during treatment. From this figure, it is apparent that power levels were low during startup. Once the starter path melts enough of the surrounding soil, power can gradually be increased. After the melt was established, power levels were maintained at approximately 3 MW.

Some of the first few cells treated at the Parsons site did not achieve the desired treatment depth of approximately 16 feet, possibly because of the accumulation of water at the bottom of the treatment areas. This was observed during the first three melts, with melt three only reaching a depth of approximately 14 to 15 feet below land surface (BLS). During these initial melts, the rate of electrode penetration slowed noticeably as the depth increased. Treatment of these cells was discontinued because further depth progression could not be achieved in an economical manner. Large quantities of scrubber water were also generated during these melts. During cell construction, thermocouples were strategically placed in the treatment area to provide an indication of melt progress. Geosafe monitored temperatures indicated by the thermocouples during treatment, and their data suggest that sufficient temperatures were achieved at the bottom and corners of each setting such that, theoretically, mercury would volatilize and organic contaminants would thermally decompose by pyrolysis. Since the contaminated soil was located at a depth of 15 feet BLS, it is highly probable that all of the soil in these cells was vitrified or experienced temperatures high enough to treat the soil. Depth objectives were met for all subsequent melt settings after improvements were made to the groundwater intercept system.

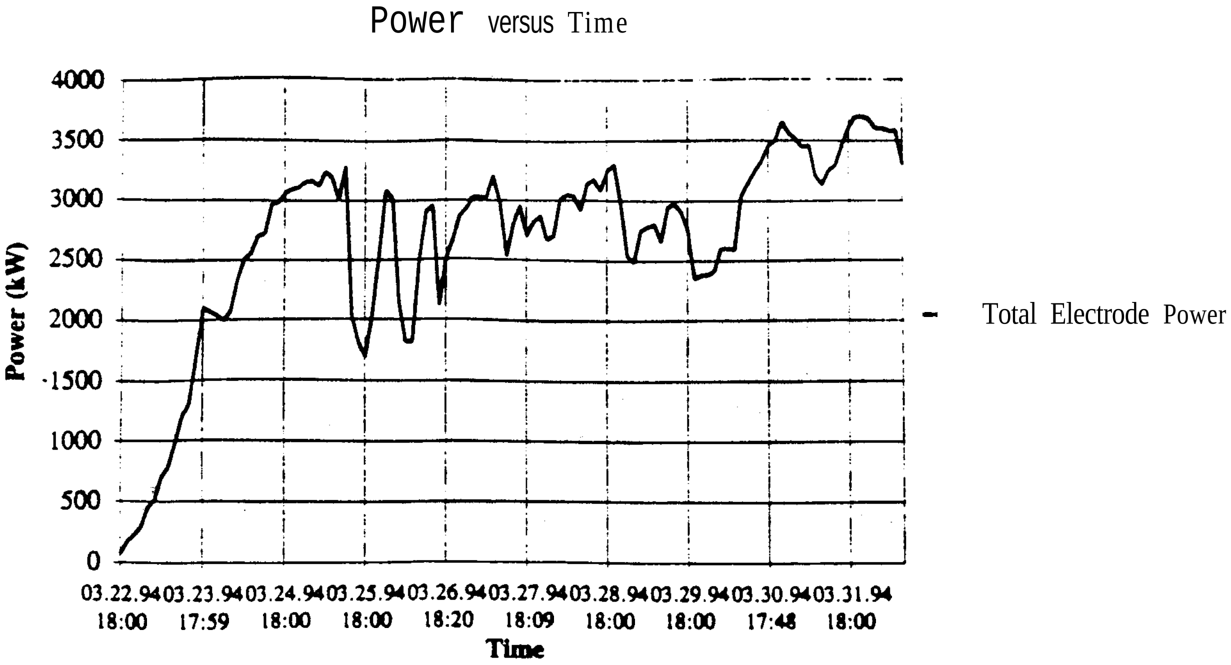


Figure 4-6. Power Input to Cell 8 During the Demonstration

In some of the early treatment settings (melts 1 and 2), the quencher outlet section exhibited significant fouling. This was caused by a particulate build-up of sodium sulfate. To correct this problem, flushing nozzles were installed, and a mechanical vibrator was mounted to the housing of the quencher to minimize particulate buildup in the off-gas treatment system.

After the process underwent the modifications described above and the cells were restaged with refractory concrete, overall operability of the system was very good. Performance during the Demonstration melt was exceptional with no major operational problems or stoppages. Minor adjustments, such as the addition of electrode sections, were conducted quickly and smoothly. A graphical representation of treatment time versus electrode depths is presented in Figure 4-7.

4.7 Process **Residuals**

The major process residual from treatment with ISV is the vitrified monolith produced from the treated soil. At the Parson site, this monolith will be allowed to cool and will most likely remain in place

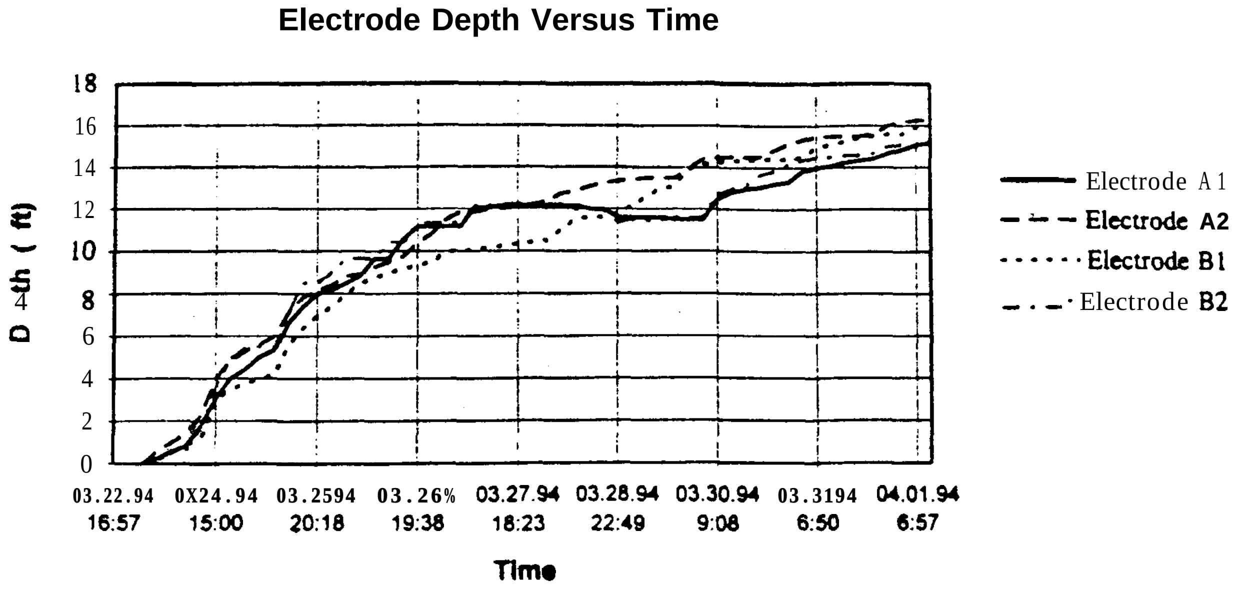


Figure 4-7. Treatment Time Versus Electrode Depth During the Demonstration (Cell 8)

indefinitely. As each melt was completed, the surface was covered with several feet of clean fill soil. This soil cover minimized emissions from the still-hot molten mass, and allowed equipment to travel over the previously treated areas. After all of the melts were completed, the entire site was graded for future use to be determined by the site owner. This is generally the disposal method that will be used for ISV, especially when contaminated soils are treated without excavation and staging. If the material is not removed from the ground, it cannot be subject to any RCRA land disposal restrictions. Additionally, since there is a significant volume reduction from the original material, the layer of clean fill placed on top can be deep enough to support grass or other ground cover without increasing the overall height of the area.

At some sites, it may be desirable to remove the vitrified material. In this case, the monolith can be excavated and removed by breaking it into pieces. Because of its immense size and weight, it is only practical to remove the vitrified mass in pieces. Fracturing the mass may be aided by rapid cooling of the molten material as described previously. The vitrified material can then disposed of elsewhere.

The characteristics of the treated soil were found to meet the developer's expectations based on the sampling of the treated soil surface. Visual inspection and physical analyses showed that the material was hard, dense, and glassy. Leachability was insignificant for any target compounds (see Table 4-2 and 4-5). Based on these characteristics, the material is believed to have a lifespan similar to natural obsidian, a material known to last for'thousands to millions of years. Over the long term, it should be safe to place this material in landfills or leave it in place at the site. Because this technology is still new and unproven over the long term, this projection cam-tot be supported with any data at this time.

The ISV process generates a waste water stream during treatment. Some of the water removed from the soil undergoing treatment may be reintroduced to the exhaust stream in the form of condensed humidity. This occurs when lower operating temperatures are used in the off-gas treatment system or when the amount of water removed from the soil exceeds the amount of water than can be passed through the off-gas treatment system as humidity. When the soil undergoing treatment has a high moisture content, the amount of water removed can be significant. During the Demonstration, the scrubber water generated contained small quantities of the compounds previously identified; it was transported off-site for treatment and ultimate disposal at a permitted facility. Decontamination liquid is produced at the conclusion of treatment. Depending on contaminant levels, it is likely that this waste stream must be transported off-site for disposal at a permitted facility. A third liquid stream generated at the Parsons site was diverted groundwater. This waste stream was unique to the Parsons facility and was due to the close proximity of shallow perched water. A discharge permit was obtained to carbon filter this water and discharge it to a local drainage ditch.

The ISV system uses filters and activated carbon to remove particulates and vapors from the scrubber and the gas stream. These materials may be recycled, however, when they are spent, they require disposal. The filters and carbon can be treated in a subsequent ISV melt or they can be removed to an off-site disposal facility. The amount of these materials generated is dependent on the soil characteristics (moisture content, in particular) and the performance of the off-gas system

Miscellaneous wastes are also generated during treatment with ISV. These include used personal protective gear (such as gloves and coveralls). These materials can sometimes be decontaminated and disposed of as non-hazardous waste. Alternatively, they too can be placed in a new melt setting and treated with the waste. Miscellaneous waste generated from the last melt setting may need to be containerized and disposed of as hazardous waste in an appropriate facility.

SECTION 5
OTHER TECHNOLOGY REQUIREMENTS

5.1 Environmental Regulation Requirements

Federal, state, and local regulatory agencies may require permits before mobilization and operation of the ISV technology. Most federal permits will be issued by the authorized state agency. Federal and state requirements may include obtaining a hazardous waste treatment permit or modifying an existing permit. Air emission permits may be required for any unit that could emit a hazardous substance. The Air Quality Control Region may also have restrictions on the types of process units and fuels that would be used. Local agencies may have permitting requirements for excavation, land treatment, and health and safety. In addition, if waste water is disposed via the sanitary sewer, then the local water district would have effluent limitations and sampling requirements, Finally, state or local regulatory agencies may also establish cleanup standards for the remediation.

At the Parsons site, federal and state permits included a National Pollutant Discharge Elimination System (NPDES) permit to discharge diverted groundwater to a nearby waterway. Air permits were acquired from the state of Michigan. These permits specified changes in stack gas treatment monitoring that were carried out before the Demonstration began. A thermal oxidizer was added to the treatment train to ensure that permitting requirements were met. Sampling and monitoring was required for volatile organic compounds, pesticides, mercury and other metals, total hydrocarbons, carbon monoxide, particulates, sulfur dioxide, and nitrogen oxides. The requirements also specified the afterburner temperature, calibration frequencies for continuous emission monitoring and discharge limits for components of the stack gas

Local permits included various construction and operation permits from the Department of Building and Safety, and permission to operate granted by the local Fire Department.

Transportation of the ISV process units across state lines requires permits; one of the trailers is overweight. Current specifications for placarding, warning lights, and load limitations must be followed during transportation of the system

Personnel Issues

During treatment, the ISV system operated continuously. Three shifts of workers are required for operation. Each shift has at least two people: a shift engineer and an operator. One site manager and one project control specialist are also employed during the day shift to oversee operations. A rotating system is used such that, each shift of workers is on-site for three continuous weeks. This is followed by one week off, during which the workers may return home, if desired. A replacement shift of workers is sent out each week to relieve the shift completing their three-week cycle.

Personnel operating the ISV technology must be trained in both the process operation and in health and safety practices associated with hazardous material. Each worker must have completed the OSHA-mandated 40-hour training course for hazardous waste work, and have an up-to-date refresher certification. At least one member of each shift team must be certified in CPR and First Aid, and additional high voltage training is required. Personnel must be enrolled in a medical monitoring program to ensure that they are fit to perform their job duties and to detect any symptoms of exposure to hazardous materials

Community Acceptance

A Visitor's Day meeting was held in March 1994 to distribute information to the public on the remediation project and on the SITE Demonstration of the ISV technology. The meeting included presentations by Geosafe and the EPA SITE project manager, along with a brief tour of the site and technology. Participants in the Visitor's Day included regulatory personnel, remediation contractors, and members of the local public. The turnout at the Visitor's Day was high, indicating strong interest in the ISV technology and its application for remediation at Parsons and similar sites.

The ISV technology can operate on soils in situ, reducing the need for excavation, and the accompanying noise, traffic, and dust generation. Treatment of a small area can be completed rapidly if no technical or regulatory delays are encountered. After backfilling the subsidence with clean soil, the site can be landscaped or converted for another beneficial use. ISV remediation at the Parsons site was conducted near inhabited areas; a church and residences were located within a few hundred feet of the treatment

5.2 Personnel Issues

During treatment, the ISV system operated continuously. Three shifts of workers are required for operation. Each shift has at least two people: a shift engineer and an operator. One site manager and one project control specialist are also employed during the day shift to oversee operations. A rotating system is used such that, each shift of workers is on-site for three continuous weeks. This is followed by one week off, during which the workers may return home, if desired. A replacement shift of workers is sent out each week to relieve the shift completing their three-week cycle.

Personnel operating the ISV technology must be trained in both the process operation and in health and safety practices associated with hazardous material. Each worker must have completed the OSHA-mandated 40-hour training course for hazardous waste work, and have an up-to-date refresher certification. At least one member of each shift team must be certified in CPR and First Aid, and additional high voltage training is required. Personnel must be enrolled in a medical monitoring program to ensure that they are fit to perform their job duties and to detect any symptoms of exposure to hazardous materials.

5.3 Community **Acceptance**

A Visitor's Day meeting was held in March 1994 to distribute information to the public on the remediation project and on the SITE Demonstration of the ISV technology. The meeting included presentations by Geosafe and the EPA SITE project manager, along with a brief tour of the site and technology. Participants in the Visitor's Day included regulatory personnel, remediation contractors, and members of the local public. The turnout at the Visitor's Day was high, indicating strong interest in the ISV technology and its application for remediation at Parsons and similar sites.

The ISV technology can operate on soils in situ, reducing the need for excavation, and the accompanying noise, traffic, and dust generation. Treatment of a small area can be completed rapidly if no technical or regulatory delays are encountered. After backfilling the subsidence with clean soil, the site can be landscaped or converted for another beneficial use. ISV remediation at the Parsons site was conducted near inhabited areas; a church and residences were located within a few hundred feet of the treatment area. Other than during mobilization and demobilization activities, the treatment neighborhood did not experience any significant increase in traffic at the site dut; to the remediation activities.

There are potential inconveniences associated with treatment operations. The hood to cover the treatment melt is large, lighted, and therefore conspicuous. Since operation must occur continuously once a melt has staled, lights and noise will be present at all hours, This may not be acceptable in residential areas. boring the first melt, porous pathways in the cobble walls of the treatment cells caused minor problems adjacent to the site. Odors from the operation were also a source of public complaint. During the second melt, a fire occurred which required the response of the local fire department and attracted public attention to the site, Construction and operational changes were made during treatment so that these problems were no longer occurring at the time of the SITE Demonstration. These solutions will be implemented at subsequent treatment operations, thus reducing the potential for recurrence. The ISV process consumes a great deal of electrical dower" During the treatability phase of ISV application, the electrical infrastructure should be examined and augmented as necessary to avoiid any negative impact on the community

Prior to the SITE Demonstration, EPA Region V had already performed sampling events on the Geosafe system to evaluate the cleanup effort at the Parsons site. Data were also gathered in response to odor complaints and problems identified during the first five melts prior to the Demonstration. These data were provided to the SITE investigators, and this information was used to refine sampling strategies used during the Demonstration. This section presents some of the Region V data and discusses some conclusions which are suggested from the interpretation of these data.

On December 1 and 2, 1993, Region V conducted stack sampling both before and after the off-gas treatment system to evaluate its effectiveness. At that time, the Geosafe system was fully operational and was performing the fourth melt at the Parsons site. The inlet data represents samples collected from the piping connecting the off-gas hood to the off-gas treatment system. A special section of piping was constructed to facilitate stack sampling at this location. The thermal oxidizer had not been added to the off-gas system prior to this sampling event, so the outlet data represents the exhaust to the atmosphere immediately after the blower. Subsequent modifications to the off-gas treatment system, including the installation of the thermal oxidizer, were made to improve system performance in cleanup of gaseous emissions. The sampling indicated that the VOC levels at the stack were below state ARAR values.

Table 6-l presents volatile organic compound emissions for the two sampling days at both the inlet and outlet of the off-gas treatment system. Approximately five samples were taken per day from these locations; the values presented are the averages of those results. The data indicate that there is some variation in the emissions generated during treatment. In some cases (Day Two), the data indicate that some of the volatiles were removed from the air stream by the off-gas treatment system. However, the Day One data suggest that the treatment train did not reduce these compounds. This is not surprising since the treatment system was not specifically designed to treat volatile organic emissions. Although activated carbon was part of the treatment train, the data suggest that it was ineffective in eliminating volatile organic emissions

Presented in Table 6-2 is the semivolatile organic compounds emission summary data. The data suggest that the off-gas treatment system is effective in treating semivolatile organic compounds as all concentrations detected at the inlet were reduced at the outlet sampling location. Most concentrations were reduced by two to three orders of magnitude

Table 6-l. Region V Geosafe Stack **Volatile** Organic Compound **Emissions** Summary Data

VOST Emissions	Day 1 Inlet (ppmv)	Day 1 outlet (ppmv)	Day 2 Inlet (ppmv)	Day 2 outlet (ppmv)
Acetone	2.6	1.9	3.4	3.4
Benzene	**0.92**	1.3	14	7.5
Bromomethane (Methyl Bromide)	0.076	0.0060	0.045	0.034
2-Butanone (MEK)	0.29	0.35	2.0	1.0
Carbon Disulfide	0.069	0.12	0.27	0.18
Chloromethane (Methyl Chloride)	0.55	0.51	0.60	0.57
Ethylbenzene	0.014	0.26	0.94	0.20
Methylene Chloride	1.3	1.4	8.0	2.9
4-Methyl-2-Pentanone **(MIBK)**	0.0012	0.11	0.64	0.29
Styrene	0.014	0.11	0.44	0.33
Toluene	0.12	0.34	6.3	4.0
Vinyl Chloride	0.0031	**0.0040**	1.6	0.55
Xylenes (Total)	0.00050	0.45	1.5	0.30

< - Compound not detected at or above presented value (detection limit).

Metals stack emission summary data is presented in Table 6-3. As with semivolatile compounds, all metal concentrations were significantly reduced after being treated by the off-gas treatment system. Specifically, mercury concentrations were reduced by slightly more than three orders of magnitude to indicate the effectiveness of the off-gas treatment system on metals

At the time these samples were collected, Region V monitored the stack gases using continuous emission monitors (CEMs) to evaluate the concentrations of carbon monoxide, carbon dioxide, nitrogen oxides, sulfur oxides, and total hydrocarbons. Typical results are presented in Table 6-4. As noted, the gas treatment system was effective in removing the nitrogen and sulfur oxide emissions. The carbon monoxide emissions ranged between 33 and 53 lb/hr which was significantly below the state ARAR level of 638 Ib/hr. The total hydrocarbon data verified the organic stack emission data, confirming that organics were not being completely removed by the off-gas treatment system.

Table 6-2. Region V Geosafe Stack Semivolatile Organic Compound Emissions Summary Data

	Day 1		Day 2	
Semivolatile Organic Emissions	Inlet (ppmv)	Outlet tppmv)	Inlet (ppmv)	Outlet (ppmv)
Acenaphthene	0.010	< 4.2E-04	0.014	< 4.2E-04
Acenaphthylene	0.0080	< 4.3E-04	0.0080	< 4.3E-04
Anthracene	0.010	< 3.6E-04	0.013	< 3.7E-04
Chrysene	0.0030	< 2.8E-04	0.0030	< 2.9E-04
Dibenzofuran	0.059	< 3.8E-04	0.071	< 3.9E-04
Di-n-butylphthalate	0.0070	4.OE-04	0.0050	< 2.3E-04
2,4-Dimethylphenol	0.075	< 5.3E-04	0.07 1	< 5.3E-04
Fluoranthene	0.015	1.6E-05	0.022	< 3.2E-04
Fluorene	0.038	< 3.9E-04	0.048	< 3.9E-04
2-Methylnaphthalene	0.17	2.7E-05	0.18	< 4.6E-04
2-Methylphenol	0.35	< 6.OE-04	0.28	1.8E-04
4-Methylphenol	0.55	< 6.OE-04	0.59	2.4E-04
Naphthalene	0.49	l.lE-03	0.51	< 5.1E-04
2-Nitrophenol	0.010	< 4.7E-04	0.019	< 4.7E-04
Phenanthrene	0.087	7.3E-05	0.12	< 3.7E-04
Phenol	2.0	2.9E-03	2.1	4.2E-03
Pyrene	0.010	< 3.2E-04	0.013	< 3.2E-04

< - Compound not detected at or above presented value (detection limit).

Table 6-3. Region V Geosafe Stack Metals Emissions Summary Data

	Day 1		Day 2	
Metals Emissions	Inlet **(lb/dscf)**	Outlet **(lb/dscf)**	Inlet **(lb/dscf)**	Outlet **(lb/dscf)**
Arsenic	5.2E-05	< 3.6E-08	l.lE-04	< 3.6E-08
Chromium	1.6E-06	2.8E-07	5.5E-06	5.4E-07
Lead	7.2E-05	2.2E-06	7.3E-05	5.2E-07
Mercury	4.1E-06	1.3E-09	5.5E-06	3.4E-09

< - Metal not detected at or above presented value (detection limit).

Table 6-4. Region V Geosafe Typical CEM Emissions

Analyte	Emission Rate (lb/hr)
Carbon Monoxide	43
Nitrogen Oxides	0.21
Total Hydrocarbons	3.0
Sulfur Oxides	0.050

Part of the investigation into the process emissions included sampling a portion of one of the used high efficiency particulate air (HEPA) filters. The HEPA filter was analyzed for semivolatile organics, pesticides, dioxins/furans, metals, and sulfur. The results are summarized in Table 6-5. As noted in the table, high levels of arsenic (1,700 mg/kg), lead (1,600 mg/kg) and mercury (1,200 mg/kg) were detected. Chromium was also present at 57 mg/kg. All other detectable target organic compounds were present at moderately low levels. The metals arsenic, lead, and mercury can be classified as somewhat volatile, and therefore their detection in the particulate form on the HEPA filters is not surprising. Chromium may have come from the melt and from deterioration of the hood panels and other parts of the stainless steel off-gas treatment system since this metal is relatively non-volatile. The results presented in Table 6-5 indicate that the filters performed very well.

Region V also performed various analyses pertaining to the off-gas hood itself. These tests included an interior wipe of the hood after treatment of a cell, and analysis of deposits of the off-gas hood wall itself. By wiping the interior of the off-gas hood and analyzing the residue, Region V hoped to gain insight about equipment contamination and contamination buildup during operation. An analysis of the Region V samples for semivolatile organic compounds and pesticides yielded concentration values below the detection limits for the wipe residue. Mercury was detected in the wipe sample.

When moving the hood at the completion of a melt, flaky deposits from the interior of the hood fell off and were deposited on top of the clean soil surrounding the treated area. Analysis of these deposits

Table 6-5. Region V Geosafe HEPA Filter Analysis

Analysis	Units	Result	
Total Solids	% Solids	92	
Metals			
Arsenic	mg/kg	1,700	
Chromium	m&g	57	
Lead	mg/kg	1,600	J
Mercury	mg/kg	1,200	
Semivolatile Organics			
Benzo(a)anthracene	µg/kg	220	J
Benzo(b)fluoranthene	µg/kg	380	
Benzo(g,h,i)perylene	µg/kg	160	J
Bis(2ethylhexyl)phthalate	µg/kg	500	
Butyl benzyl phthalate	µg/kg	150	
Chrysene	µg/kg	300	
Fluoranthene	µg/kg	230	
Phenanthrene	µg/kg	270	
Pyrene	µg/kg	370	
Organochlorine Pesticides and PCBs			
4,4’-DDE	µg/kg	22	J
Polychlorinated Dioxins			
HxCDDs (total)	µg/kg	0.41	
HpCDDs (total)	µg/kg	0.78	
1,2,3,4,6,7,8_HpCDD	µg/kg	0.33	
OCDD	µg/kg	0.83	

J - Value reported is less than the reporting detection limit but greater than the method detection limit. Value is an estimate.

showed metals concentrations at the levels presented in Table 6-6. Region V expressed concern over the chips since they flaked easily from the interior surface of the hood during movement. The problem was easily remedied by using a vacuum to remove the deposits from the ground surface and the hood interior panel surfaces. The flakes and associated dust were placed into subsequent melt settings for treatment. After treatment was completed at Parsons, the hood panels were disposed of as secondary waste since the cost of decontamination activities would have exceeded the value of the panels. Because the hood panel corrosion at the Parsons site was much more rapid than anticipated, Geosafe investigated the situation and found that high levels of sulfur at the site resulted in unexpected and increased rates of corrosion. In addition, Geosafe determined that the long periods of inactivity experienced between the first few melts resulted in exposure to moisture conditions that enhanced corrosion. When the corrosion rate was noted to be of concern, Geosafe initiated "coupon" testing directed at identifying alternative materials for improved hood panel performance. The coupon testing at the Parsons site has identified hood materials that are currently being testing as part of full-scale treatment at another site.

Region V also performed a limited number of analyses on treated soil obtained from melts completed prior to the SITE Demonstration. Some of these samples were analyzed using neutron activation analysis. This is a non-intrusive procedure that can eliminate interferences and recovery bias associated with standard sample digestion procedures for metals. In this procedure, neutrons produced during nuclear fission are used to activate a sample to form radioactive isotopes. As these isotopes decay, the energy is quantized and related to a particular element. By counting the disintegrations per unit of time, a statistically valid concentration of elemental abundances can be determined. There were no published EPA methods pertaining to this procedure at the time of testing, and therefore this procedure was not used during the Dimonstration. Results of the Region V treated soil metal data are presented in Table 6-7.

Table 6-7. Region V Geosafe Neutron Activation Analysis on Treated Soil

Metal	Concentration (mg/kg)
Arsenic	2.3
chromium	48
Mercury	< 5.0

Region V conducted an excavation of the first melt to determine the extent of treatment and to evaluate if migration of site contaminants into adjacent clean soil had occurred as a result of treatment. The samples collected during this excavation were analyzed for volatile organics, semivolatile organics, dioxins/furans, pesticides, and metals. The results of these data are presented in Table 6-8. There were no semivolatile or dioxin/furans detected in these samples. All Region V target analytes were well below the cleanup criteria. Traces of the pesticides were detected. Because pre-treatment sampling was not conducted outside the treatment area, the source of these pesticides is unknown. It may stem from existing contamination from previous chemical activities at the Parsons site or migration from other contaminated area of the site via rainwater runoff. It is inappropriate to assume that these low levels of pesticides were a result of ISV treatment. In most instances, the concentrations detected are considered insignificant.

Current information regarding the status of Geosafe's commercial activities have been provided by the vendor and is presented below. After completion of vitrification operations at the Parsons site, Geosafe mobilized its equipment to a General Electric Company site in Spokane, Washington for performance of a TSCA demonstration project in support of an application for a National TSCA Operating Permit. The GE/TSCA demonstration involved treatment of 3,500 tons of soil contaminated with polychlorinated biphenyls (PCBs) to a maximum level of 17,000 mg/kg. The soil was staged in five treatment cells to a depth of 15 feet. In addition to the contaminated soil, the treatment volume contained approximately 80 unsealed steel drums and significant quantities of asphalt and concrete debris.

The TSCA demonstration project was performed under a permit issued by EPA's TSCA authorities. EPA personnel witnessed critical melting operations and participated in the acquisition, analysis, and evaluation of performance data. The five melts were performed without difficulty, and Geosafe was able to complete the project on schedule. Preliminary off-gas treatment data indicated that the level of PCBs in the stack outlet was less than the detectable limit. The ISV equipment operated without difficulty during the complete project. Geosafe was able to make further improvements in operations efficiency and reduced hood movement time to less than two days. Geosafe expects to receive a National TSCA Operating Permit for treatment of PCBs at the conclusion of EPA's evaluation process.

Geosafe completed the GE/TSCA project in early October 1994. The ISV equipment was then mobilized to the Wasatch Chemical Superfund Site in Salt Lake City, Utah where it is being used to treat approximately 7,000 tons of soil and debris contaminated with dioxins, pentachlorophenol, several pesticides, and other organics. Vitrification operations began at the Wasatch site late in 1994.

6.2 Scaling Capabilities

Geosafe has stated that ISV can be used to treat contaminated soil in situ in several configurations. They have proposed to treat soils that are deeper than the 20-foot maximum depth of a single ISV melt in stages. There are two approaches. The shallower intervals can be treated initially, and the vitrified product can be removed, allowing the deeper intervals to then be treated. Alternately, the top layers of soil can be removed and stored separately until the deeper soils are vitrified. The soils can then be replaced and vitrified on top of the first set of melts. Due to the volume reduction, additional soil from other areas can be added in the same space. These methods have not been fully demonstrated, however future activities are planned.

Geosafe's existing full-scale equipment is the largest ISV equipment that has been developed. A single system is in existence. Battelle Memorial Institute has studied larger units for the U.S. Department of Energy and has determined that significantly larger ISV systems can be designed and fabricated. To date, this has not been performed.

In the future, more than one full-scale ISV system may be used to expedite treatment of large sites in an economic fashion. Cost savings may also be incurred by the use of an ISV system two to three times larger than the current 4 MW system. A larger system would not only have a higher throughput rate and lower operating cost, but would also be able to produce larger melts and process to greater depths.

Table 6-8. Region V Geosafe Melt 1 Excavation Soil Analysis

Metals

Analyte	Sample 1 Concentration (mg/kg)	Sample 2 Concentration (mg/kg)
Arsenic	4.1	3.4
Lead	7.4	5.0
Mercury	< 0.050	0.12

Organochlorine Pesticides

Analyte	Sample 1 Concentration (µg/kg)	Sample 2 Concentration (µg/kg)
B-BHC	3.4	2.7
G-BHC	2.7	1.7
4,4’-DDD	< 3.3	7.9
4,4’-DDE	9.2	13
4,4’-DDT	< 3.3	9.6
Dieldrin	2.7	3.6
Endrin	3.6	< 3.3
Heptachlor	1.8	< 1.7
Heptachlor epoxide	3.2	< 1.7

Volatile Organics

Analyte	Sample 1 Concentration (µg/kg)	Sample 2 Concentration (µg/kg)
Benzene	4.0	< 4.0
2-Butanone (MEK)	< 10	16
Methylene chloride	49	11
Toluene	3.0	1.0
Xylenes	1.0	< 1.0

REFERENCES

1 U.S. Environmental Protection Agency. 1993. ***Innovative Treatment Technologies: Annual Status Report;*** Fifth Edition. EPA 542-R-93-003. U.S. Environmental Protection Agency. Office of Solid Waste and Emergency Recovery. Washington, D.C.

2 Hansen, J.E. 1993. "In Situ Vitrification (ISV) for Remediation of Contaminated Soil Sites. Geosafe Corporation. Richland, Washington.

3 Timmons, D.M., V. Fitzpatrick, and S. Liikala. 1990. "Vitrification Tested on Hazardous Wastes." ***Pollution Engineering,*** June 1990. pp. 76-81.

4 U.S. Environmental Protection Agency. 1992. ***Handbook on Vitrification Technologies for Treatment of Hazardous and Radioactive Waste.*** EPA/6225/R-92/002. U.S. Environmental Protection Agency. Office of Research and Development. Washington D.C.

5 Douglas, J.M. ***Conceptual Design of Chemical Processes;*** McGraw-Hill, Inc. New York, 1988

6 Peters, M.S. ; Timmerhaus, K. D. ***Plant Design and Economics for Chemical Engineers;*** Third Edition. McGraw-Hill, Inc. New York, 1980.

7 Garrett, D.E. ***Chemical Engineering Economics;*** Van Nostrand Reinhold, New York, 1989.

8. Liikala, S.C. 1991. "Applications of In Situ Vitrification to PCB-Contaminated Soil." Presented at the 3rd International Conference for the Remediation of PCB Contamination, Houston, Texas, March 25-26, 1991.

9 U.S. Environmental Protection Agency. 1986. ***Test Methodsfor Evaluating Solid Waste. SW-846.*** U.S. Environmental Protection Agency. Office of Solid Waste. Washington D.C.

10. Geosafe Corporation. 1992. "Whole Rock Analysis." In Situ Vitrification Technology Update Geosafe Corporation. Richland, Washington.

11 Timmons, D.M. and V. Fitzpatrick. 1990. "In Situ Vitrification: Heat and Immobilization are Combined for Soil Remediation." ***Hazmut World,*** December 1989.

12 Dragun, J. 1991. "Geochemistry and Soil Chemistry Reactions Occurring During In Situ Vitrification." J. ***Hazardous Materials,*** 1991. pp.343-363.

13 Science Applications International Corporation. 1993. "Geosafe In Situ Vitrification Demonstration Plan." Science Applications International Corporation. Process Technology Division. San Diego, California.

14 Office of Federal Register. 1993. ***Code of Federal Regulations Title 40, Protection of Environment.*** U.S. Government Printing Office, Washington, D.C. July 1993.

APPENDIX A

VENDOR'S CLAIMS

This appendix presents the claims made by the vendor, Geosafe Corporation, regarding In Situ Vitrification (ISV), the technology under consideration. This appendix was written solely by Geosafe, and the statements presented herein represent the vendor's point of view based on over 190 tests, demonstrations, and commercial melts performed since 1980. Publication here does not indicate EPA's approval or endorsement of the statements made in this section; EPA's point of view is discussed in the body of this report

A.1 Summary

Geosafe considers that the SITE demonstration performed at the Parsons Chemical site was very successful. Geosafe believes that the SITE demonstration, together with the other seven melt settings of the Parsons project, over 190 other tests and demonstrations of the technology, and large-scale remediation work that has been performed since the demonstration, have clearly shown the efficacy of the ISV technology for treatment of contaminated soil sites. The technology has been shown effective for the treatment of soil and other earthen materials contaminated with a broad range of organic, inorganic, and radioactive materials. This Vendor Claims section summarizes the capabilities of the ISV process that have been developed to date; it also comments on the results of the Parsons Project and the SITE demonstration performed there.

The ISV technology is a unique on-site and in situ thermal treatment technology with specific advantages relative to alternative technologies, including:

- ability to simultaneously process mixtures of all contaminant types
- ability to attain high destruction, removal, and/or immobilization treatment effectiveness
- production of a vitrified residual product with unequalled chemical, physical, and weathering properties
- maximum permanence of treatment, including geologic life expectancy of the vitrified product

- maximum volume reduction
- good public acceptance related to on-site and in situ safety benefits and quality of treatment and residual vitrified product
- cost effectiveness that increases with increasing site difficulty and stringency of cleanup standards.

Numerous application configurations are available to allow application of ISV to a wide range of site conditions. The equipment system has been demonstrated to be highly reliable, and to be adaptable to specific site needs. There are few site conditions that cannot be handled by adaptation of the site and/or the process and equipment. The process is now available for contaminated soil site remediation on a large-scale commercial basis. The process continues to be developed for buried wastes and other advanced applications.

The Parsons Site Project was Geosafe's first large-scale remediation project performed on a commercial basis. The site presented several challenges that had not been previously experienced during large-scale ISV operations. It was necessary for Geosafe to make several adaptations to the technology, which allowed successful demonstration both of the technology's and Geosafe's ability to adapt to site-specific challenges

The SITE demonstration was performed on the sixth of eight melts performed during the Parsons , Project. Demonstration results confirmed the capabilities of the ISV technology where relevant site conditions existed. The demonstration confirmed that all performance criteria for the site were met.

A.2 **Introduction**

The ISV process involves electric melting of soil and other earthen materials for purposes of removing, destroying, and/or permanently immobilizing hazardous and radioactive contaminants. The patented process was originally developed by Battelle Memorial institute for the U.S. Department of Energy (DOE), with the intent of possibly treating transuranic-contaminated soils in situ at DOE sites. Developmental testing of the process proved it to be highly effective for a broad range of hazardous and radioactive contaminant types, earthen media types, and application configurations.

The ISV process, which has been described in more detail elsewhere in this report, involves the melting of a solid media. It is the molten media that conducts the electricity, and converts it to heat (joule heating). The high melt temperature results in removal and/or destruction of organic and other vaporizable contaminants. Immobilization of heavy metals, whether radioactive or non-radioactive, occurs as the heavy metals are incorporated into the residual vitrified product that forms upon cooling of the melt. Because of these simultaneous removal, destruction, and immobilization treatment mechanisms, EPA has variously classified ISV as a thermal treatment, a solidification/stabilization treatment , and a physical/chemical treatment process.

A.3 **Applicability to Contaminated Soil and Other Earth-Like Materials**

ISV may be applied to any media that is capable of forming and supporting a joule-heated melt. Such materials include most natural soils, sediments, mill tailings, and other earthen materials. These materials consist predominantly of metal oxides (e.g., SiO_2, Al_2O_3, Fe_2O_3) that have adequate electrical conductivity in the molten state and will produce a vitrified product upon cooling. In relatively infrequent cases, some natural earthen materials do not contain adequate alkali materials to provide the desired molten state electrical conductivity. In such cases, fluxant materials may be added to obtain the desired melt properties.. In similar manner, some natural earthen materials, e.g., limestone, may not produce the desired vitrified product properties upon cooling. In such cases, typical silicate type soils may be added to produce a good quality vitrified product.

Because of these features, ISV is most often applied to contaminated earthen materials. It may also be applied to various non-soil waste materials (e.g., process sludges, incinerator ash) by combining them with earthen media for treatment. For example, non-soil sludges may be processed by intermixing with soil for treatment, or by forming a melt in soil placed above the sludge and allowing it to melt down through the sludge. Waste lagoons and evaporation ponds may be treated in this manner

In some cases, the waste material itself may be analogous to earthen materials and be processed without modification. Municipal incinerator and coal power plant ashes are examples of such materials; their origin lies in other earthen materials (e.g., coal, metal ores), and they possess essentially the same chemical composition as earthen materials.

Application Configurations

ISV is applied to contaminated media in place where it presently exists (termed in situ melting), as opposed to bringing the media to, and feeding it into, the melting equipment (termed ex situ melting). The materials subject to ISV may be undisturbed soil deposits that have inadvertently become contaminated, or they may be earthen materials that have become contaminated through some engineered waste treatment and/or disposal process (e.g., buried/landfilled waste, sludge lagoons and evaporation ponds). In many cases, ISV may be applied to these materials where they presently exist; alternatively, the configuration of the materials may be changed if desired to allow more efficient or cost-effective ISV treatment. For example, soils from a shallow evaporation pond may be reconfigured (staged) to a greater depth to allow for more economic ISV treatment. Figure A-l illustrates some of the reconfiguration options that allow ISV application to most situations involving contaminated earthen materials.

A.5 Contaminant Treatment Effectiveness and Permanence

Organics are completely removed from the media volume melted due to their inability to exist within the typical soil melt temperature range of 2,900 to 3,600°F (1,600 to 2,000°C). During ISV, organic contaminants are vaporized by heat from the thermal gradient present in front of the melt. Upon vaporization, the organics move toward the ground surface, either through the melt or very closely adjacent to it. The specific soil gas-phase permeability has a direct bearing on the pathway of gases and vapors to the surface.

Several options exist for the final treatment of the organic vapors, including: 1) destruction by pyrolytic thermal decomposition below grade, 2) oxidation upon contacting air at the ground surface, and/or 3) entry into the off-gas volume followed by removal and/or thermal destruction during off-gas treatment. Typically, substantially all of the organics are destroyed during ISV processing, with the possibility of very small amounts becoming part of the off-gases which are subsequently removed or destroyed by the off-gas treatment system

Heavy metals are predominantly immobilized by ISV processing to the extent of their solubility in the molten media. The immobilization mechanisms are chemical and physical incorporation into the vitrified

IN SITU VITRIFICATION

Configuration Alternatives

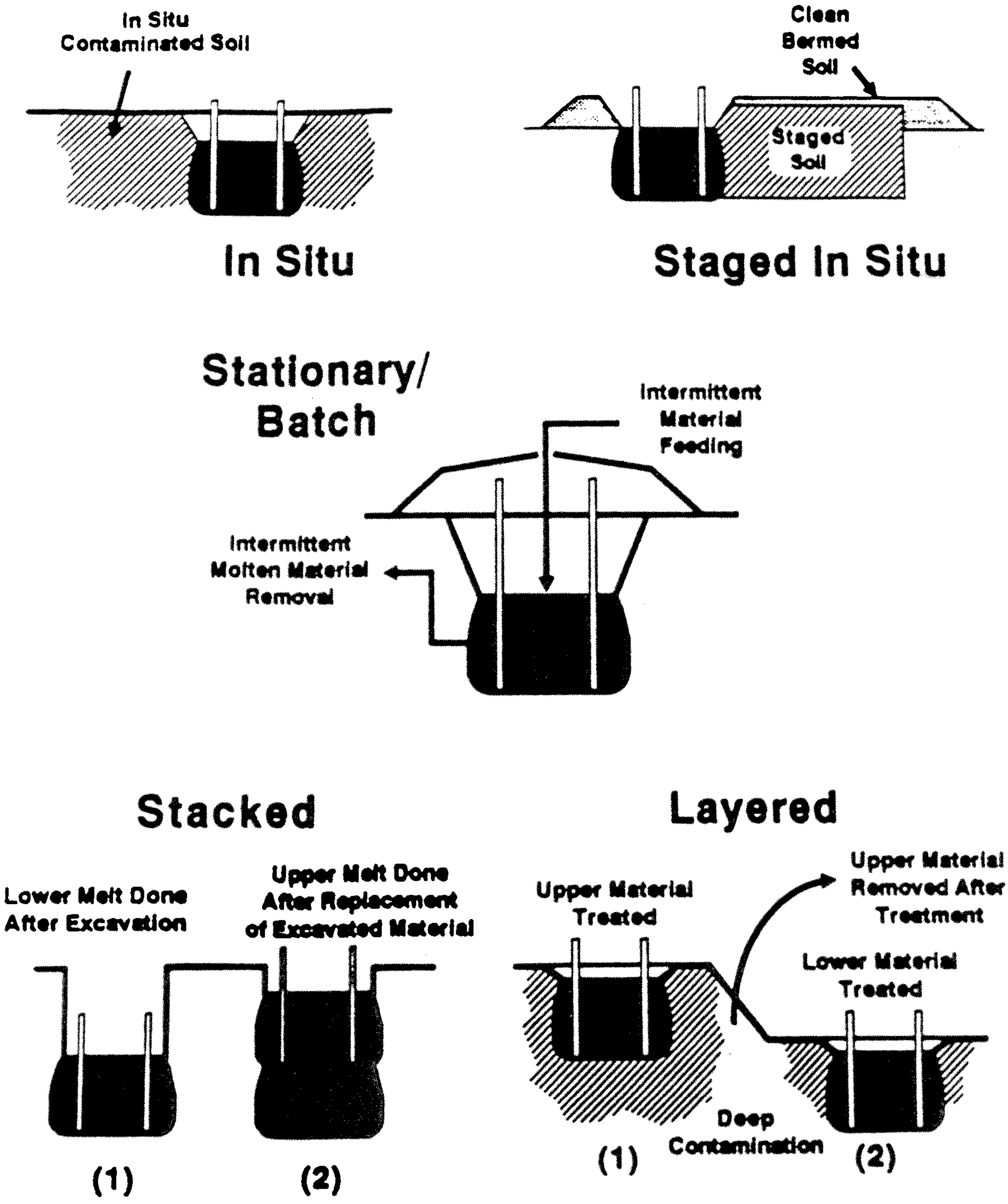


Figure A-l. Various Configuration Options for ISV Processing product. The retention efficiency (i.e., percentage entering the melt as opposed to volatilizing to the off-gases) is a function of many variables which can be analyzed in advance of treatment to determine expected performance. Most priority pollutant metals, including semivolatiles like lead and arsenic, are retained at very high levels, with the remainder being subject to removal during off-gas treatment. At the other extreme, ISV is a removal process for mercury due to its high vapor pressure and low solubility in typical silicate melts. The quality of heavy metal immobilization within the vitrified product, as measured by TCLP testing, is unequalled compared to other immobilization/stabilization/solidification technologies.

Radioactive materials of interest are typically heavy metals (e.g., plutonium, uranium, cesium, strontium) and are immobilized like heavy metals during ISV as described above. ISV may also be employed to prevent radon release to the environment (air pathway). Radon, a gas that is formed by decay of radium within a vitrified material, is contained by the material until such time that it decays further, back to a solid. Several orders of magnitude reduction in the radon emanation rate can be achieved.

A.6 **Residual Vitrified Product**

ISV treatment of natural earthen materials results in a single, large, monolithic, rock-like mass that is predominantly vitreous (glassy) in nature. Some amount of microcrystallinity may exist within the vitrified mass depending on the mixture of metal oxides that were melted together and the cooling time experienced. Vitrified product from natural soil melts possesses the following characteristics: 1) it is typically about 10X the strength of unreinforced concrete in both tension and compression, 2) it is unaffected by wet/dry and/or freeze/thaw cycling, 3) it has acceptable biotoxicity (i.e., not toxic to near-surface life forms), 4) it is unequalled compared to other treatment products in its ability to withstand weathering for a geologic time period.

Conversion of treated media into a vitrified product results in a large volume reduction (e.g., 25 to 50% for most natural soils). The volume reduction results from removal of void volume present between solid particles, the removal of vaporizable materials present, and the thermal decomposition of some mineral materials (e.g., limestone will calcine to lime while giving off COJ. Volume reductions on the order of 70 to 80% or more are achievable for certain sludges and buried wastes. The resulting density of vitrified product from soil melts is typically in the range of 2.5 to 2.8 g/cc.

Because the vitrified material contains zero organics, and it securely immobilizes the heavy metals present, the vitrified material is no longer hazardous and should be suitable for “delisted” regulatory status. Given such status, the vitrified monolith should be suitable for leaving on-site, and the land should be available for other uses without restriction.

A.7 **Air Emissions and Other ARARs**

The existing ISV off-gas treatment system design has been demonstrated capable of meeting air emission standards for the states of Washington, Michigan, and Tennessee (see results for Parsons Project in later section). It is important to note that the system can be modified if necessary to meet specific state standards. Geosafe is not aware of any state or federal air emissions standards that would preclude its use within the U.S.

In similar manner, Geosafe is not aware of any other state or federal ARARs that would prohibit the use of ISV compared to other alternative technologies. The technology is quite flexible regarding application configurations, and the remedial design can be adapted as necessary to comply with typical ARARs.

A.8 **Application Limitations**

ISV is subject to eight (8) basic types of limitations as defined below

A.8.1 Media Melting Characteristics

The contaminated media must be suitable for melting within the operating capabilities of the equipment system. This suitability for melting relates primarily to the geochemical composition of the media, which determines melting properties (e.g., melt temperature, viscosity) and molten state electrical conductivity. Most natural soils can be efficiently melted by ISV without any modification. In relatively rare cases (e.g., highly leached soils), the addition of alkali materials may be desirable to increase melt electrical conductivity and to lower melting temperature or melt viscosity.

Vitrified Product Quality

The media composition and melt cooling rates are the primary determinants of vitrified product quality. Most natural soils and other earthen materials possess sufficient glass forming minerals (e.g., silica, alumina) to produce an excellent residual product. Note that it is a common misconception that sandy soil is required to obtain a vitreous product. In fact, most soil types (e.g., gravel, sand, clay, silt) possess glass forming materials in abundance. Limestone and dolomite soils are possible exceptions to this. Whereas these soil types typically contain some amount of silica, they may require some addition of good glass forming soil to produce the desired quality of vitrified product.

The ISV process typically produces a higher quality vitrified product than do other vitrification technologies because ISV can be operated at a higher temperature than melter- or furnace-based technologies. Because glass at high temperatures can corrode the refractory linings of ex situ melters, furnaces, kilns, and similar devices, fluxants are added in such applications to lower the melting temperature, which also results in some diminishing of vitrified product quality. Such “fluxing down” is not required in ISV since there is no refractory lining to be concerned about. Therefore, the higher melting temperature of ISV produces the highest possible vitrified product quality.

A high quality vitrified product is necessary if heavy metals immobilization is a desired objective. If ISV is employed only to destroy/remove organic contaminants, then the vitrified product quality is not important because no organics continue to exist within the vitrified mass

A.8.3 Water Recharge

ISV may be applied to fully saturated, even supersaturated, media. This is possible because the thermal gradient in front of the advancing melt simply dries the wet media out before melting it. Water can be a limitation to ISV processing if site conditions allow recharge to the treatment zone at a rate faster than the drying and melting rate. In such cases, ISV cannot be applied without some engineered provision for limiting recharge (e.g., slurry wall, intercept trench, temporarily lowering the water table by pumping).

Since water removal by ISV consumes energy (about the same amount as melting soil), it is desirable to maintain the material to be treated at as low a water content as possible. During cooling, completed ISV melts will dry out the surrounding soil to a distance of 8 to 10 feet from the melt.

A.8.4 **Processing Depth**

The maximum practical depth of processing for a given site is dependent upon many factors including media melting properties, water content and recharge conditions, and processing equipment capabilities. The greatest single melt depth attained by Geosafe to date is slightly over 22 feet. If deeper vitrification depths are desired, application concepts are available that involve multiple melts to achieve increased depth (reference the "stacked" and "layering" concepts of Figure A-l). Increased single melt depth capability is under development.

A.8.5 Total Organic Content

Treatment of organic materials results in heat generation due to the pyrolytic decomposition of organics followed by oxidation of the pyrolysis products. This heat enters the off-gases and must be removed by the quenching stage of the off-gas treatment system. The heat removal capability of the existing large-scale equipment is capable of removing the heat produced from a treatment zone containing about 10 wt % organic content. This is a much higher organic loading than exists at most contaminated sites.

If it is desired to employ ISV for higher organic loadings, it would be necessary to employ equipment with additional heat removal capacity, or to "average down" the organic loading. This can be done by intermixing high and low contamination level media, or by adding more lowly contaminated or clean soil to the contaminated media.

A.8.6 Debris Content

The ISV process is unique in its ability to accommodate large amounts of various types of debris in the treatment volume. Organic debris (e.g., plants, roots, tires, PPE, trash) will be disposed in a manner similar to that of organic contaminants discussed above. Inorganic debris (e.g., concrete, rocks, scrap metal) will behave similarly to earthen materials and heavy metals (i.e., dissolve into the melt).

Such debris within the treatment zone normally does not limit ISV if it is not present in such a way as to physically interfere with the melting process, or is not present at such high quantities as to adversely affect the melt properties. Such extreme conditions are rare at most sites, with the exception of landfills, and particularly construction debris landfills. With proper remedial design, including the possibility of removing or reconfiguring some debris content, the ISV process is capable of processing significant quantities of organic and inorganic debris

Large quantities of metallic debris can also be accommodated. Metals in the reduced state (e.g., iron scrap) normally remain in the reduced state and sink to the bottom of the ISV melt. The presence of molten metal at the bottom of a melt actually enhances downward melt growth. By maintaining the electrodes a short distance above the molten metal, ISV processing can continue without electrical shorting diffkulties being caused by the presence of the metal.

A.8.7 Sealed *Containers*

Whereas ISV has been demonstrated capable of processing sealed containers possessing a variety of waste materials, the conditions under which such processing can be safely and reliably accomplished have not yet been fully defined. Therefore, at this time Geosafe does not treat sites containing sealed containers of vaporizable materials (e.g., organic liquids) on a commercial basis. Geosafe will consider such applications on a research, development, and demonstration basis with the objective of eventual commercial application.

A.8.8 Media Gas-Phase Permeability

During ISV processing, gases and vapors are generated in advance of the melt and move to the surface through the dry zone adjacent the melt and/or through the melt itself. It is necessary that each application be analyzed and, if necessary, designed to ensure that the gases and vapors may move to the surface without causing excessive levels of melt disturbance.

A.9 cost

The cost of ISV is defined as Geosafe's price for ISV-related services, including treatability testing, technical support of remedial design, and remedial action. Geosafe's price includes its direct costs for materials, supplies, electricity, and labor; indirect costs including subcontracted services and labor burdens; corporate overhead; and profit margin. Geosafe's price covers all activities it performs for the client. It does not cover other activities the client may perform or have performed at a site (e.g., site characterization, site preparation, remedial design, etc.).

The cost of treatability testing usually falls in the range of $40,000 to $80,000 of which $25,000 to $30,000 is for performance and evaluation of the test, and the remainder ($15,000 to $50,000) is for analytical chemistry services. The cost of treatability testing is highly dependent upon the number of contaminants and number and types of chemical analyses that must be performed. Treatability testing is usually performed at engineering-scale and produces a 150- to 200-pound vitrified mass. Actual contaminated media from the site is employed in such testing at Geosafe's facilities in Richland, Washington. In most cases, Geosafe is able to utilize engineering-scale treatability test data for large-scale remedial design and cost estimation purposes. Geosafe also has the capability to perform one-ton melts for larger treatability tests. Such testing can be performed in situ on the client's site if desired.

The combined cost of mobilization and demobilization of Geosafe's large-scale ISV equipment system usually falls in the range of $300,000 to $400,000. Transportation distance from the prior site location is a large variable determining the level of cost in this range. The mob/demob cost covers all activities associated with transporting, setting up, readiness testing, decontamination, disassembly, and transport away from the site.

The equipment system is permanently mounted on three over-the-road trailers so that it is truly mobile as opposed to transportable. The off-gas hood is transported on an additional trailer and must be erected at the site. Additional trailers (typically two to four) are employed to transport materials and supplies to the site (e.g., electrodes, cables, tools). Mobilization and demobilization costs are fixed costs that should be allocated to all the tonnage involved in a remediation project.

The cost of vitrification operations currently falls in the range of $350 to $450/ton (wet density basis) for typical non-radioactive U.S. projects. The three primary factors impacting vitrification costs are: 1) the local price of electrical power, 2) rate and depth of processing, and 3) the amount of water requiring removal during processing. Electrical power is usually obtained at large consumer industrial rates. Costs are less for deeper and drier sites than for shallow, wet sites. These cost estimates are based on Geosafe's current use of a single large-scale ISV system. It is anticipated that costs will come down as additional machines are added, which will provide a larger revenue base over which to allocate indirect corporate costs. Costs involved with treatment of radioactive sites will be higher due to radiological safety requirements.

A.10 Regulatory and Public Acceptance

The ISV process has received good support from regulatory authorities that recognize its potential for satisfying regulatory cleanup objectives and the regulatory preference for implementation of innovative, on-site, in situ treatment technologies. It is noted that this support is sometimes countered by potentially responsible party resistance against use of innovative technologies. Geosafe acknowledges the fine support given to ISV by EPA's Technology Innovation Office, the SITE Program, and Regions IV, V, VI, VIII, and X; and by the States of North Carolina, Michigan, Illinois, Texas, Utah, Idaho, and Washington. Geosafe recognizes that no innovative technology may be successfully commercialized without solid regulatory support.

ISV has also received excellent public acceptance to date. We believe that this high acceptance is due primarily to the on-site and in situ public and environmental safety benefits of the technology, and recognition of the superior safety and permanence of the residual vitrified product. The robustness (i.e., broad capabilities) of the technology, and the large volume reduction it produces are also well received by the public. Public acceptance for ISV is also attributable to the technical credibility of the organizations who developed and continue to support the technology: Battelle Memorial Institute and DOE.

A.11 Development Status and Commercial Implementability

ISV is commercially available for contaminated soil/sludge/sediment/tailings type applications. It continues to be developed for buried waste, underground tank, barrier wall, and construction-related applications.

The Parsons Chemical/ETM Enterprises Superfund Site was the first large-scale commercial application of ISV. After completion of vitrification operations there, the equipment was mobilized to Spokane, Washington for performance of a 3,500-ton TSCA demonstration project involving PCB contamination to 17,000 mg/kg in soil that was staged to a depth of 16 feet in five treatment cells. The demonstration was completed very successfully and on schedule. Preliminary results at the time of this writing (November 1994) indicated very effective treatment of PCBs and full compliance with air emission standards. PCB levels in the off-gas stack emissions were below detection limits. This demonstration was performed in support of Geosafe's application for a National TSCA Operating Permit from EPA. Based on the preliminary results, Geosafe is quite confident that the desired permit will be forthcoming after EPA has completed their evaluation of the project.

After completion of the TSCA demonstration project, Geosafe mobilized its equipment to the Wasatch Chemical Superfund Site in Salt Lake City, Utah. Here the process will be employed for treatment of approximately 6,000 tons of soil and debris contaminated with dioxin, pentachlorophenol, numerous pesticides, and other organics. In addition, Geosafe has obtained contracts for significant test work involving hazardous, radioactive, and mixed waste applications for sites in Australia and Japan.

The ISV technology was originally developed for the U.S. Department of Energy (DOE), Office of Technology Development, at the Pacific Northwest Laboratory (operated by Battelle Memorial Institute). DOE continues to fund an ISV development program directed to exploring many possible applications for ISV within the DOE Weapons Complex. Tests and demonstrations are being performed at engineering-, pilot-, and large-scale. The technology is scheduled for demonstration at large-scale on buried cesium- and strontium-bearing waste at the Oak Ridge National Laboratory during the 1995 fiscal year.

A.12 Review of Parsons Chemical Site Experience

Geosafe considers the Parsons Chemical project to have been highly successful, while recognizing that there were difficulties associated with it that had to be overcome. The site posed many challenges that had not been previously experienced by Geosafe or the ISV technology. These challenges had the effect of slowing the project down during the first few melts; however, they were all overcome and the ISV technology was further advanced from the experience.

A.12.1 Unusual Challenges

The site soil conditions posed the biggest challenges. Treatability testing at engineering-scale had been successfully performed on soil from the site prior to initiation of large-scale activities. Although the testing was useful for indicating expected treatment effectiveness, it did not provide indication of the challenges that would be posed by the very high moisture content, high clay content soil at the site. This soil proved to be very difficult to work with in either the wet (fully saturated, highly fluid) or dry (concrete-like) conditions. These characteristics required special provisions for the placement of starter paths and the operation of wheeled equipment on the site. These provisions included establishing a dry area over the wet soil to allow proper starter path placement, stabilizing high traffic personnel and vehicle pathways with rock, and using wood “floats” to support crane outriggers.

The saturated soil and high ambient humidity conditions resulted in unusually high moisture removal loadings on the off-gas treatment equipment. Whereas moisture removed from the treatment zone usually can be passed through the treatment system as humidity (water vapor), without accumulation as liquid, the quantity of water encountered at times during the project resulted in water accumulation. It was necessary to send this water off-site for treatment and disposal.

Water from the soil also contained dissolved solids at high enough levels to cause solids buildup problems between the quencher and scrubber stages of the off-gas treatment system. This problem was solved by modifying the quencher in a manner that prevented the occurrence of deposits.

When wet, the soil exhibited a noticeable sulfurous odor. In addition, a nonhazardous but noticeable odor developed during ISV processing that was due to sulfur and organic materials in the soil. The odor was initially minimized during operations by minimizing the level of sulfurous buildup in the scrub solution. The odor was eliminated midway through the project by the addition of a thermal oxidizer as a final polishing stage of the off-gas treatment system.

The last challenge was due to site soil conditions which resulted in a greater melt width to depth ratio than had previously been experienced with the ISV technology. This resulted in melting more clean soil than desired adjacent to the treatment trench; it also resulted in difficulties attaining the desired depth in the early melts. The cobble rock walls that had been placed around the designated melting region to minimize overmelting into clean adjacent soil were found to be only partially effective for this purpose; they slowed the lateral melt growth but did not stop it. This challenge was overcome by using refractory barriers that effectively controlled melt width and helped attain the desired depth. A significant benefit from the wider than expected melts was that the number of melts was reduced from nine to eight.

A.12.2 Performance Results

The project statement of work stipulated the following performance criteria for the vitrification treatment portion of the project:

- organic DRE of 99.999%
- production of a high integrity vitrified monolith that: 1) is highly resistant to erosion, 2) is substantially chemically inert, and 3) permanently immobilizes toxic metals and radionuclides present in the soil;
- volume reduction of at least 10% ; and
- compliance with Michigan State air emission standards

Large amounts of performance data were acquired during the project. The SITE demonstration performance results reported in this document are typical for the project overall. The results indicate attainment of all the technical performance criteria, as discussed further below.

Relative to organic DRE, chemical analyses and TCLP testing confirmed the absence of organics in the vitrified product. It is reasonable to assume zero levels of organics in the vitrified material, regardless of analytical method detection limit capabilities due to the fact that organics cannot exist at the temperatures experienced in molten soil. Therefore, relative to the treatment zone itself, essentially 100% destruction and/or removal of organics was attained.

Relative to removal of organics from the off-gases, typical stack emission values for the target pesticides were at less than detectable levels as indicated in Table A-l. Assuming the presence of contaminants at the detection limit values, and considering the low concentrations of contaminants in the starting soil, it was not possible to compute organic DREs with a mathematical significance beyond three nines. Geosafe recognizes this result as an analytical limitation rather than an actual performance measure for the ISV process. Geosafe's off-gas treatment system is qualified to produce a minimum of three nines itself, and numerous prior tests have indicated that another two to three nines of destruction efficiency may be expected within the treatment zone before entering the off-gases.

Relative to the vitrified monolith, a typical high integrity, chemically inert vitrified product was produced. TCLP testing indicated full compliance for organics and all priority pollutant metals. The required 10% minimum volume reduction was far exceeded by an actual volume reduction of about 35%.

The process was found to be in full compliance with air emission standards. Stack gas sampling was performed many times during the project. Typical results are presented in Table A-l.

A.12.3 **Notable Achievements**

Geosafe recognizes that the project had value for the ISV technology far beyond the meeting of site cleanup and performance objectives. Since this was Geosafe's first commercial large-scale remediation project, this project was very important for demonstrating the capabilities of Geosafe and the ISV technology in many related areas, including:

- demonstrated applicability to high moisture (fully saturated), high clay content soils;
- demonstrated ability to process soil contaminated with organics and heavy metals;
- demonstrated ability to process debris (drum lids, tires, roots and vegetation, PPE);

Table A-l. Off-Gas Emission Performance

Comuonent	ARAR Level (lb/hr)	ISV Level (lb/hr)
Mercury	5.9 x 10”	1.2 x 10^{-4}
Chlordane	2.5 x 10^{+1}	<1.1 x 10^{-7}*
Dieldrin	2.8 x 10”	<2.2 x 10^{-5}*
DDT	1.0 x 10^{-2}	<2.2 x 10^{-5}*

* Detection limit value

- demonstrated ability to comply with typical state ARARs, especially air emission standards;
- ability to control/eliminate odors;
- demonstrated high equipment reliability;
- demonstrated flexibility/adaptability of the off-gas treatment system to accommodate varying site conditions;
- demonstrated process equipment controllability;
- verification of staff capabilities and remote site staffing policies;
- developed methods of melt width control;
- developed method of startup in fully saturated soils;
- verification of thermal efficiencies;
- acquisition of soil vapor pressure data adjacent to the melt, and confirmation that such pressures do not pose problems to application of the process in tight (high clay) soils;
- ability to operate during severe winter weather;

- a good level of public acceptance for the project; and
- acquisition of cost related performance information.

Geosafe notes that overall operations efficiencies improved throughout the project. Whereas the first four melts required about six months to complete (due somewhat to technical and regulatory delays), the final four melts were performed in less than three months. This is indicative of the advancement of ISV processing capability that was developed during the project.

A.13 Review of SITE Demonstration Results

Geosafe has reviewed the SITE demonstration results presented in this document and does not take significant issue with the information reported. Geosafe operations staff noted that the demonstration melt was performed without any notable difficulties, and that the equipment performed flawlessly throughout the demonstration.

Geosafe does note that the economic analysis portion of the document makes a number of assumptions that are based on the Parsons experience but which do not represent Geosafe's current capabilities with the ISV technology. We understand the standardized approach used for this analysis, and the necessity to use the demonstration results as the primary basis for projections. However, we note that the Parsons project was the first large-scale commercial remediation project performed with the ISV technology. Geosafe made significant improvements to the equipment and process efficiencies throughout the project. Further advances have been made since completion of the Parsons project, most notably in the areas of reduced hood movement time and ability to control melt width and the amount of overmelting into clean soil. Geosafe did not perform well in these two areas during the first half of the Parsons project. That resulted in excessive time and costs which are not a good basis for estimating Geosafe's current capabilities

Geosafe also notes that the ISV technology is quite adaptable to unusual site conditions, and that there are many engineering means by which apparent limitations can be accommodated. Geosafe does not fault the SITE Program for the analysis presented. However, given these considerations, Geosafe encourages potential users to request an applicability analysis and cost estimate for specific applications rather than assuming that the application limitations and cost estimates presented by the SITE Program are correct for all applications

A.14 Acknowledgement

Geosafe acknowledges the support provided by EPA, and the fine work by Science Applications International Corporation (SAIC), and EPA's other contractors throughout the Parsons Project and the SITE demonstration. Geosafe believes that such support is critical to the development, demonstration, and commercial implementation of innovative technologies.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1995 651-342