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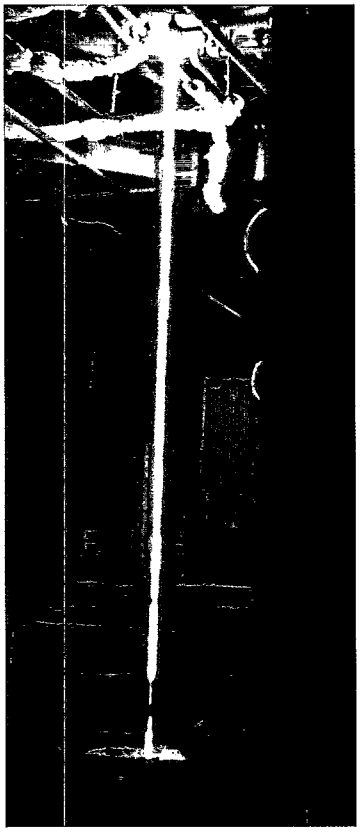
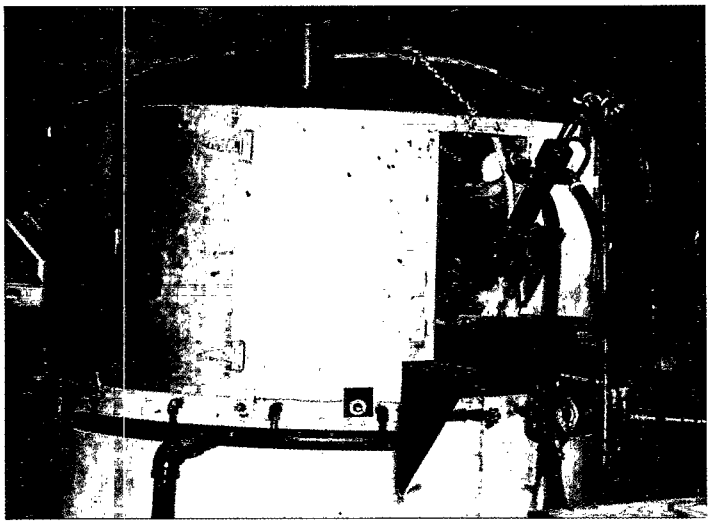
Geotech, Inc. Cold Top *Ex-Situ* Vitrification System

Innovative Technology Evaluation Report





SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

EPA/540/R-97/506
December 1999

Geotech, Inc.

Cold Top *Ex-Situ* Vitrification System

Innovative Technology Evaluation Report

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

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NOTICE

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FOREWORD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet these mandates, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the EPA center for investigation of technical and management approaches for reducing risks from threats to human health and the environment. The focus of the NRMRL research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goals of this research effort are to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the NRMRL strategic, long-term research plan. It is published and made available by the EPA Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

ABSTRACT

A Superfund Innovative Technology Evaluation (SITE) technology demonstration was conducted in February and March 1997 to evaluate the potential applicability and effectiveness of the Geotech Development Corporation (Geotech) Cold Top *ex-situ* vitrification technology on chromium-contaminated soils. The demonstration was conducted using the vitrification furnace at Geotech's pilot plant in Niagara Falls, New York.

Chromium-contaminated soil from two state Superfund sites in the Jersey City, New Jersey area was collected, crushed, sieved, dried, mixed with carbon and sand, and shipped to the Geotech pilot plant. The SITE demonstration consisted of one vitrification test run on soil from each site. During each test, solid and gas samples were collected from various locations in the Cold Top system and analyzed for several chemical and physical parameters. In addition, process monitoring data were recorded. During the demonstration, the Cold Top system treated about 10,000 pounds of soil contaminated with trivalent and hexavalent chromium and other metals.

One primary and five secondary objectives were identified for the SITE demonstration. The primary objective was to develop test data to evaluate whether waste and product streams from the Cold Top vitrification system pilot plant were capable of meeting the U.S. Environmental Protection Agency (EPA) Resource Conservation and Recovery Act (RCRA) definitions of a nonhazardous waste, based on the stream's leachable chromium content. Secondary objectives were to determine the following: (1) partitioning of chromium and hexavalent chromium from the contaminated soil into various waste and product streams; (2) the ability of the vitrified product to meet New Jersey Department of Environmental Protection (NJDEP) criteria for use as fill material (such as road construction aggregate); (3) the system's ability to meet applicable compliance regulations for air emissions of dioxins, furans, trace metals, particulates, and hydrogen chloride; (4) uncontrolled air emissions of the oxides of nitrogen, sulfur dioxide, carbon monoxide, and total hydrocarbons from the vitrification unit; and (5) projected operating costs of the technology per ton of soil.

Observational demonstration results showed that the Cold Top system vitrified chromium-contaminated soil from the two New Jersey sites, yielding a product meeting RCRA toxicity characteristic leaching procedure (TCLP) standards. From soil excavated at one of the New Jersey sites, the system yielded a potentially recyclable metallic product referred to as "ferrofurnace bottoms" that also met the RCRA

TCLP chromium standard. Demonstration results also showed that the chromium content of the vitrified products did not differ significantly from that of the untreated soils, but that the baghouse dusts were higher in chromium content than the untreated soils. Hexavalent chromium concentrations in the untreated soil were generally not detected (reduced at least two to three orders of magnitude) in the vitrified product and ferrofurnace bottoms. The hexavalent chromium concentration in the baghouse dust was about the same as that in the untreated soil.

Results of emissions modeling indicate that the concentration of metals in stack emissions depend on soil characteristics, the APCS, and detection limits of various analytes. Analysis of operating costs indicates that Cold Top treatment of chromium-contaminated soil, similar to that treated during the SITE demonstration, is estimated to cost from $83 to $213 per ton, depending on disposal costs and potential credits for sale of the vitrified product.

The results of all sample analyses and quality assurance and quality control data from the SITE demonstration were evaluated with respect to the project objectives specified by the quality assurance project plan (QAPP). The conclusions of the demonstration are being reported as observational, meaning that although the authors feel the conclusions are supported, some data are not statistically valid at the levels specified in the original data quality objectives.

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ACRONYMS AND ABBREVIATIONS

AGC	Annual guideline concentration
APCS	Air pollution control system
ARAR	Applicable or relevant and appropriate requirement
ATTIC	Alternative Treatment Technology Information Center
b	Blank contamination
B	Estimated result is less than reporting limit
BIF	Boilers and industrial furnace
C	Co-eluting isomers/congeners
CAA	Clean Air Act
°C	Degree Celsius
CEM	Continuous emissions monitor
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERI	Center for Environmental Research Information
CFR	Code of Federal Regulations
CO	Carbon monoxide
CO_2	Carbon dioxide
Cr^{+6}	Hexavalent chromium
cy	Cubic yard
dscf	Dry standard cubic foot
dscf/hr	Dry standard cubic foot per hour
dscm	Dry standard cubic meter
EPA	U.S. Environmental Protection Agency
°F	Degree Fahrenheit
ft/s	Foot per second
Geotech	Geotech Development Corporation
g/hr	Gram per hour
HCl	Hydrogen chloride gas
ID	Induced draft
ITER	Innovative Technology Evaluation Report
kVA	Kilovolt-amp
kWh	Kilowatt hour
LDR	Land disposal restriction
lb	Pound
μg/dscm	Microgram per dry standard cubic meter
μm	Micrometer
MDL	Method Detection Limit
mg/dscm	Milligrams per dry standard cubic meter
mg/kg	Milligrams per kilogram
mg/L	Milligram per liter
MS	Matrix spike
MSD	Matrix spike duplicate
NA	Not analyzed
NAAQS	National Ambient Air Quality Standards

ACRONYMS AND ABBREVIATIONS (Continued)

ND	Not detected
ng/dscm	Nanograms per dry standard cubic meter
NJDEP	New Jersey Department of Environmental Protection
NJIT	New Jersey Institute of Technology
NO_x	Nitrogen oxides
NRMRL	National Risk Management Research Laboratory
NR	Not recorded
NYSDEC	New York State Department of Environmental Conservation
O_2	Oxygen
ORD	U.S. EPA Office of Research and Development
OSHA	Occupational Safety and Health Administration
OSWER	U.S. EPA Office of Solid Waste and Emergency Response
QAO	Quality Assurance Objective
PCDD	Polychlorinated dibenzo-p-dioxin
PCDF	Polychlorinated dibenzofuran
%V	Percent by volume
PGC	Potential annual guideline concentration
PPE	Personal protective equipment
ppm	part per million
PSD	Prevention of significant deterioration
Q	Estimated maximum possible concentration
QA	Quality assurance
QAPP	Quality assurance project plan
QC	Quality control
RCRA	Resource Conservation and Recovery Act of 1976
SARA	Superfund Amendments and Reauthorization Act of 1986
SD	Standard Deviation
SGC	Short-term guideline concentration
SIT	Stevens Institute of Technology
SITE	Superfund Innovative Technology Evaluation
SO_2	Sulfur dioxide
SPLP	Synthetic Precipitation Leaching Procedure
	Target analyte list
TCLP	Toxicity characteristic leaching procedure
TEQ	2,3,7,8-TCDD equivalents
THC	Total hydrocarbons
TSCA	Toxic Substances Control Act
VISITT	Vendor Information System for Innovative Treatment Technologies
XPS	X-ray photoelectron spectroscopy

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EXECUTIVE SUMMARY

This report summarizes the findings of an evaluation of the Cold Top *Ex-Situ* Vitrification technology developed by Geotech Development Corporation (Geotech). The Cold Top technology was demonstrated at the Geotech pilot-plant facility in Niagara Falls, New York, under the EPA Superfund Innovative Technology Evaluation (SITE) program and in conjunction with the New Jersey Institute of Technology (NJIT) and the New Jersey Department of Environmental Protection (NJDEP) in 1997.

The purpose of this Innovative Technology Evaluation Report is to present and summarize information from the SITE demonstration of the Cold Top technology. The information is intended for remedial managers, environmental consultants, and other potential users who may consider using the technology to treat Superfund and Resource Conservation and Recovery Act of 1976 (RCRA) hazardous wastes. Section 1.0 presents an overview of the SITE program, describes the Cold Top technology, and lists key contacts. Section 2.0 discusses information relevant to the technology's application, including an assessment of the technology related to the nine feasibility study evaluation criteria, potential applicable environmental regulations, and operability and limitations of the technology. Section 3.0 summarizes the costs associated with implementing the technology. Section 4.0 presents the waste characteristics, demonstration approach, demonstration procedures, and the results and conclusions of the demonstration. Section 5.0 summarizes the technology status, and Section 6.0 includes a list of references. The Appendices include several technical reports concerning the technology, prepared by NJIT. The first report presents the findings of a bench-scale study of the technology and the second presents the results of a study on the use of the vitrified product from the SITE demonstration as fill for road aggregate.

The remainder of this executive summary provides an overview of the Cold Top technology; its waste applicability; demonstration objectives, approach, and conclusions; other case studies; and technology applicability.

The Cold Top Technology

Geotech of King of Prussia, Pennsylvania, has developed an *ex-situ*, submerged-electrode, resistance-melting technology designed to convert contaminated soil into an essentially monolithic, vitrified mass. According to Geotech, a development engineering firm holding four patents in the field of applied electrical power, vitrification transforms the physical state of contaminated soil from assorted, crystalline matrices into a glassy, amorphous solid comprised of interlaced polymeric chains that typically consist of alternating oxygen and silicon atoms. Geotech claims that chromium can readily substitute for silicon in these chains, thus rendering the chromium immobile to leaching by aqueous solvents and, therefore, nontoxic.

For the past 15 years, Geotech has operated a pilot plant that has vitrified a wide variety of materials, including granite, blast-furnace slag, fly ash, spent catalyst, and flue dust. Several production plants based on the Geotech technology are now being used to produce mineral fiber and other commercial products. The heart of the system is an electric resistance furnace capable of operating at melting temperatures of up to 5,200 °F (2,870 °C). The furnace is cooled by water circulating within its hollow jacket and is equipped with an off-gas treatment system, which may include a baghouse, cyclone, and wet scrubbers, depending on waste characteristics.

Prior to treatment, the furnace is initially charged with a mixture of sand and alumina/silica clay. Through electrical resistance heating, a molten pool forms; the voltage to the furnace is properly adjusted; and, finally, contaminated soil is fed into the furnace by a screw conveyor. Geotech removes the furnace plug from below the molten-product tap when the desired soil-melt temperature is achieved. As the soil melts, additional soil is added to maintain a "cold top." During the demonstration test, the outflow was poured into refractory-lined and insulated molds for slow cooling. Excess material was discharged to a water sluice for immediate cooling and collection before off-site disposal.

Waste Applicability

According to Geotech, the Cold Top Vitrification process has been used to treat soils contaminated with hazardous heavy metals such as lead, cadmium, and chromium; asbestos and asbestos-containing materials; and municipal solid waste combustor-ash residue. Waste material must be sized to pass through a 3/8-inch screen. The Cold Top Vitrification process is most efficient when feed materials have been dewatered to less than 5 percent water and organic chemical concentrations have been minimized.

Wastes similar to those treated during the demonstration may require the addition of sand to ensure that the vitrification process produces a glass-like product. According to Geotech, in the molten state, inorganic contaminants fuse with the sand to become an integral part of the fused material. The vitrified product from the Cold Top process is designed to cool slowly to form a high-density, noncrystalline glass with physical properties suitable for commercial use.

Geotech claims that the vitrified product has many uses, including shore erosion blocks, decorative tiles, roadbed fill, and cement or blacktop aggregate, and that radioactive wastes can be treated with this technology.

Demonstration Objectives and Approach

Key participants in the planning and execution of the Cold Top demonstration included the Geotech, NJIT, NJDEP, and the EPA SITE Program. Additional support was provided by the New York State Department of Environmental Conservation (NYSDEC) and Stevens Institute of Technology.

Demonstration tests were performed on soils from two sites, representing residue from two types of chromite-ore-processing procedures. The sites were selected by NJDEP under an ongoing program to clean up over 150 hexavalent-chromium-contaminated sites. Excavated soils from Liberty State Park and NJDEP Site 130 were crushed, sieved, dried, and amended with carbon and sand at a facility in New Jersey. "Supersacs" containing the pretreated material were then shipped to the Geotech facility in Niagara Falls, NY, where separate demonstration runs were conducted on February 1 and March 11, 1997. The SITE team collected samples of untreated soil, offgas generated during treatment, and baghouse dust. Cooled castings were transported to NJIT, where samples were crushed and ground for chemical analyses. Chemical analyses were performed in triplicate by NJIT and by SITE-contracted laboratories.

Demonstration Conclusions

The primary objective of the SITE demonstration was to determine if the waste and products produced by the Cold Top Vitrification system meet the Resource Conservation and Recovery Act (RCRA) definition of a characteristic waste because of their chromium content. The Toxicity Characteristic Leaching Procedure was performed on both treated product and untreated waste to evaluate this objective.

Secondary objectives of the demonstration were as follows: 1) evaluate the partitioning of total chromium from the waste feed into the various waste and product streams; 2) determine costs for treating the type of waste treated during the demonstration; 3) determine if the vitrified product meets NJDEP criteria for fill material, such as road construction aggregate, based on chromium, antimony, beryllium, cadmium, nickel, and vanadium concentrations; 4) determine if process air emissions meet NYSDEC compliance requirements and determine the uncontrolled air emissions of oxides of nitrogen, sulfur dioxide, carbon monoxide, and hydrogen chloride; and 5) determine if the high chlorine concentrations in the untreated soils causes formation of dioxins and furans in the exhaust gases.

Due to a system shutdown during the first run and unanticipated changes made to the off-gas collection and treatment system during the second test run, data from the two runs are not directly comparable. Therefore, all demonstration data are presented as observational data. Observational data are data which are analytically sound but that did not meet the predetermined data quality objective goals.

Demonstration findings included:

<u>RCRA TCLP Chromium Standard</u>

The Cold Top technology vitrified chromium-contaminated soil from two New Jersey sites, producing a product meeting the RCRA TCLP total chromium standard at the 95 percent confidence level. Vitrification of soil from one of the two sites also produced ferrofurnace bottoms, a potentially

recyclable metallic product, that also met the RCRA TCLP total chromium standard.

Chromium Partitioning

With the exception of the baghouse dust and the ferrofurnace bottoms sample, the total chromium content of the vitrified product did not differ significantly from that of the untreated soil. The concentrations of total chromium in the vitrification baghouse dust and ferrofurnace bottoms samples were approximately two and five times greater, respectively, than those found in the untreated soil.

Hexavalent chromium was not detected in the ferrofurnace bottoms samples and was only detected in one of six vitrified-product samples. The hexavalent chromium concentrations ranged from one-half to approximately the same in the vitrification baghouse dust as in the untreated soil. The baghouse dust was presumed to be mainly fine-sized, untreated soil that was generated when soil was added to the vitrification furnace and then carried through the air pollution control system (APCS).

Cost

Cold Top treatment of chromium-contaminated soil, similar to that treated during the SITE demonstration, is estimated to cost from $83 to $213 per ton, depending on disposal costs and potential credits for the vitrified product. The three scenarios evaluated included (1) use of the vitrified product as aggregate, (2) backfilling of the vitrified product on site, and (3) landfilling of the vitrified product. Costs for these three scenarios were $83, $98, and $213 per ton, respectively. Because of the uncertainty of their formation, potential credits for ferrofurnace bottoms were not considered in this economic analysis.

NJDEP Interim Cleanup Standards

Comparison of metal concentrations in the vitrified product to the NJDEP interim soil cleanup standards indicated that the vitrified product met the interim standards for antimony, beryllium, cadmium, vanadium, and hexavalent chromium, but did not for nickel and total chromium.

Stack Emissions

Although the Cold Top technology is not an incineration technology, the stack emissions from the demonstration were compared to Subpart O incinerator regulations, and the results were mixed. The data collected during the SITE demonstration were input into complex modeling calculations supplied by New York State. The modeling required site- and waste-specific analyses to assess the impact of the Cold Top stack emissions. Results of the modeling were found to depend on the soil, the APCS, and the detection limits of the various analytes. Results of emissions modeling indicate that the concentrations of metals in

stack emissions depend on the characteristics of the soil, the air pollution control system, and the detection limits of the various analytes. Emissions of dioxins, particulate, oxides of nitrogen, sulfur dioxide, carbon monoxide, and hydrogen chloride were all below the appropriate New York limits, based on appropriate measurement and calculation procedures.

Dioxin and Furan Formation

Exhaust gas concentrations of dioxins and furans were generally below the laboratory reporting limits. The high concentrations of chloride in the site soils could not be correlated with dioxin and furan formation.

Other Observations

Field observations and measurements made during the demonstration indicate that several operational issues must be addressed during technology scale-up. First, a consistent and controlled feed system needs to be developed that spreads the waste feed uniformly over the surface of the molten soil. This feed system must also minimize dust generation. Second, an emission control system needs to be configured to control any particulate and gaseous emissions from the furnace and feed system.

Other Studies

A bench-scale study of the Cold Top technology was performed at NJIT . After completion of this demonstration, NJIT studied the feasibility of using the vitrified product from the SITE demonstration as road aggregate.

SECTION 1
INTRODUCTION

This section provides background information on the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program, discusses the purpose of this Innovative Technology Evaluation Report (ITER), and describes the Cold Top vitrification system developed by Geotech Development Corporation (Geotech) of Niagara Falls, New York. Additional information about the SITE program, the Geotech technology, and the demonstration can be obtained by contacting the key individuals listed at the end of this section.

1.1 THE SITE PROGRAM

The SITE program was established by the EPA 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's primary purpose is to promote the use of alternative technologies in cleaning up hazardous waste sites. The various component programs under SITE are designed to encourage the development, demonstration, and use of new or innovative treatment and monitoring technologies. The program is designed to meet four primary objectives:

- Identify and remove obstacles to the development and commercial use of alternate technologies
- Structure a development program that nurtures emerging technologies
- Demonstrate promising innovative technologies to establish reliable performance and cost information for site characterization and cleanup decision-making
- Develop procedures and policies that encourage the selection of available alternative treatment remedies at Superfund sites as well as other waste sites and commercial facilities

Technologies are selected for the SITE Demonstration Program through annual solicitations. ORD staff review 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 or transportable technologies are of particular interest. Once EPA has accepted a proposal, cooperative agreements between EPA and the developer establish

responsibilities for conducting the demonstrations and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site and is expected to pay any costs of transporting, operating, and removing the equipment. EPA is responsible for project planning; transporting the material to be treated to a fixed facility for off-site demonstrations; sampling and analysis; quality assurance and quality control; preparing reports; disseminating information; and transporting and disposing of treated waste materials.

For this Geotech technology demonstration, New Jersey Institute of Technology (NJIT) has a contract with New Jersey Department of Environmental Protection (NJDEP) to evaluate the Geotech Cold Top technology. EPA and NJIT have a formal agreement to cooperate in this evaluation. NJDEP is the lead agency for the evaluation, and EPA is furnishing additional resources to enhance the overall results. EPA's responsibilities for this demonstration are limited to the evaluation of the vitrification unit itself, while NJDEP will have primary responsibility for evaluating necessary pre- and post-vitrification treatment activities.

The results of the demonstration are published in two basic documents: the SITE Technology Capsule and the ITER. The SITE Technology Capsule provides relevant information on the technology, emphasizing key results of the SITE demonstration. Both documents are intended for use by remedial managers who need a detailed evaluation of the technology for a specific site and waste.

1.2 INNOVATIVE TECHNOLOGY EVALUATION REPORT

This ITER provides information on the Geotech technology and includes a comprehensive description of the demonstration and its results. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision makers who must implement specific remedial actions. The ITER is designed to aid decision makers in further evaluating specific technologies for consideration as an applicable option for a particular cleanup operation.

To encourage the general use of demonstrated technologies, the ITER provides information regarding the applicability of each technology to specific sites and wastes. In particular, the report includes information on (1) cost and site-specific characteristics and (2) the advantages, disadvantages, and limitations of the technology.

Each SITE demonstration evaluates a technology's performance in treating a specific material. Because the characteristics of other materials may differ from the characteristics of the treated material, 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.

1.3 PROJECT DESCRIPTION

About 3 tons of contaminated soil were excavated from each of two chromium-contaminated sites. The soil was screened to remove material larger than one inch in diameter and placed in drums for shipment to a facility in Camden, New Jersey, where it was dried, crushed, sieved, and blended with several additives. This soil pretreatment was performed because the developer claims that effective vitrification by the Cold Top system requires soil that is dried to less than 5 percent moisture and sized to less than 0.375-inch diameter particle size. The addition of sand aids in the vitrification and improves the physical strength and other properties of the vitrified product. The soils from the two sites were handled separately. A continuous-loop or toroidal-flash dryer, operating at 300 to 450 °F (150 to 230 °C) inlet temperature with approximately 175°F (80°C) outlet or exhaust temperature, was used to dry the soils. A baghouse captured dust emitted by the drying process. During the drying operation, the soil was mixed with (1) sand to increase the silica content and facilitate vitrification, (2) carbon to increase the electrical conductivity of the mixture, and (3) dust from the baghouse. The resulting mixture was dry and well blended; it was placed in one-half-filled 2,000-pound-capacity polypropylene bags, called "supersacs," and transported to Geotech in Niagara Falls, New York.

At the Geotech facility, soil from each of the sites was placed in the vitrification furnace, which produced a vitrified product and, in one case, a by-product referred to as ferrofurnace bottoms. Off-gases from the vitrification oven and dust from the vitrification baghouse were collected. The products and waste streams of the vitrification process were sampled and analyzed as part of the demonstration. The vitrified product was then subjected to various tests by NJIT to determine if it is suitable for use in concrete or asphalt.

1.4 TECHNOLOGY DESCRIPTION

Geotech, the developer of the *ex-situ*, submerged-electrode, resistance-melting technology known as "Cold Top," claims its technology converts contaminated soil particles into an essentially monolithic, vitrified mass. According to Geotech, vitrification transforms the physical state of contaminated soil from assorted crystalline matrices to a glassy, amorphous, solid state comprised of interlaced polymeric chains. These chains typically consist of alternating oxygen and silicon atoms. Chromium is expected to readily substitute for silicon in the chains. According to Geotech, the chromium would then be immobile to leaching by aqueous solvents, and as a result, it would be biologically unavailable and nontoxic.

The main unit of the system is a 1,350-kilovolt-amps (kVA) electric resistance furnace capable of operating at melting temperatures up to 5,200 °F (2,900 °C). Once the voltage is properly adjusted, the furnace operates continuously. The furnace is initially charged with a mixture of sand and alumina-silica clay. When subjected to electrical resistance heating, the mixture forms a molten pool; the voltage to the furnace is then adjusted; and the contaminated soil is fed into the furnace by a screw conveyor. As the soil melts, additional soil is added to maintain a "cold top." When the desired soil-melting temperature is achieved, Geotech removes the furnace plug from below the molten-product tap. During the demonstration, the outflow was poured into refractory-lined and insulated molds for slow cooling. Material not collected in the molds for physical or chemical testing was discharged to a water sluice for immediate cooling and collection before off-site disposal. Other configurations of a full-scale system allow outflow to be converted to pellets and fibers. The furnace is equipped with an off-gas treatment system (which can include a baghouse, cyclone, and wet scrubbers) to control emissions.

1.5 KEY CONTACTS

Additional information on the Geotech technology and the SITE program can be obtained from the following sources:

The Geotech Development Corporation

Dr. Thomas R. Tate
President
Geotech Development Corporation
1150 First Avenue, Suite 630
King of Prussia, Pennsylvania 19406
(610) 337-8515
FAX: (610) 768-5244

The SITE Program

Marta K. Richards
EPA SITE Project Manager
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
26 West Martin Luther King Drive
Cincinnati, Ohio 45268
(513) 569-7692
FAX: (513) 569-7676

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

- The Alternative Treatment Technology Information Center (ATTIC) System is a comprehensive, automated, information retrieval system that integrates data on hazardous waste treatment technologies into a centralized source. The system operator can be reached at 301-670-6294.
- The Vendor Information System for Innovative Treatment Technologies (VISITT) database contains information on 154 technologies offered by 97 developers. The hotline number is 800-245-4505.
- The OSWER CLU-In electronic bulletin board contains information on the status of SITE technology demonstrations. The system operator can be reached at 301-585-8368.
- Other on-line Internet information sources.

Technical reports may be obtained by contacting the EPA Center for Environmental Research Information (CERI) at 26 West Martin Luther King Drive, Cincinnati, Ohio 45268; telephone 513-569-7562.

SECTION 2
TECHNOLOGY APPLICATIONS ANALYSIS

This section assesses the general applicability of the Geotech Cold Top system to remediate waste and contaminated soils from Superfund sites. This assessment is based on results from the SITE Program demonstration of the technology.

Demonstration tests were performed on soils from two sites contaminated with residues from two types of chromite-ore processing: NJDEP Site 130 and the NJDEP-owned Liberty State Park site. The sites were selected by NJDEP under an ongoing program to clean up more than 150 sites contaminated with hexavalent chromium. Excavated soils were crushed, sieved, dried, and blended with carbon and sand at a facility in Camden, New Jersey. Supersacs containing the pretreated material were then shipped to the Geotech facility in Niagara Falls, New York, where separate demonstration runs were conducted.

2.1 FEASIBILITY STUDY EVALUATION CRITERIA

This section assesses the Geotech technology relative to nine evaluation criteria used to conduct detailed analyses of remedial alternatives in feasibility studies performed under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Table 1 summarizes the evaluation criteria as they relate to the performance of the technology.

2.1.1 Overall Protection of Human Health and the Environment

This criterion addresses whether or not a remedy provides adequate protection and describes how risks posed by each pathway are eliminated, reduced, or controlled through treatment, engineering controls, or institutional controls.

The Geotech technology provides both short- and long-term protection of human health and the environment by eliminating exposure to hazardous inorganic constituents; the process fuses hazardous constituents into a noncrystalline, glass-like product. Exposure to air emissions is minimized by removing contaminants with an off-gas treatment system. Potential accidental releases could temporarily affect air quality in the vicinity of the site. Site workers may be exposed to air emissions on a short-term basis when preparing the waste feed , dumping the waste feed from the supersacs into the feed hopper, and manually

Table 1. Feasibility Study Evaluation Criteria for the Geotech Technology

CRITERION	GEOTECH TECHNOLOGY PERFORMANCE
1 Overall Protection of Human Health and the Environment	The Geotech technology fuses hazardous inorganic constituents into a noncrystalline, glass-like product. Air emissions are reduced by using an air pollution control system (APCS).
2 Compliance with Federal ARARs	Compliance with chemical-specific applicable or relevant and appropriate requirements (ARARs) depends on the treatment efficiency of the vitrification system and the chemical constituents of the waste. Compliance with chemical-, location-, and action-specific ARARs must be determined on a site-specific basis. For most sites, the following environmental regulations will be applicable to Cold Top operations: Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); Resource Conservation and Recovery Act (RCRA); the Clean Air Act; the Clean Water Act; and the Occupational Safety and Health Act.
3 Long-Term Effectiveness and Permanence	As the vitrified products met RCRA Toxicity Characteristic Leaching Procedure requirements, these fused wastes were considered to be permanently treated. Treatment residuals from the APCS can be recycled through the system, and the vitrified product and ferrofurnace bottoms may be recycled or may require proper off-site disposal.
4 Reduction of Toxicity, Mobility, or Volume Through Treatment	Vitrification reduces the mobility of the waste feed by fusing hazardous inorganic constituents into a high-density, noncrystalline, glass-like product. Toxicity is also reduced by the chemical reduction of hexavalent chromium to less toxic species, such as trivalent chromium.
5 Short-Term Effectiveness	Short-term risks to workers, the community, and the environment are present during waste-handling activities and from potential exposure to process air emissions. Adverse impacts from both activities can be mitigated with proper personnel safety and waste-handling procedures and air pollution system control.
6 Implementability	The Cold Top system vitrifies a wide variety of materials. Geotech plans to establish a full-scale fixed facility in the northern New Jersey area. Currently, Geotech does not operate a transportable system, so only transportation of the waste feed needs to be evaluated for this criterion.
7 Cost	Costs for treatment by the Cold Top technology depend on waste- and location-specific factors such as the volume of material to be treated, physical properties of the material to be treated, transportation costs, electricity costs, and economic value or cost to dispose of the vitrified product and ferrofurnace bottoms. For the treatment scenarios evaluated in the economic analysis contained in this Innovative Technology Evaluation Report, costs ranged from $83 to $213 per ton.
8 State Acceptance	State acceptance to the full-scale, fixed Cold Top facility is likely to be favorable.
9 Community Acceptance	The minimal short-term risks presented to the community along with the permanent fusing of hazardous waste constituents in the waste, producing a usable product, should increase the likelihood of community acceptance of this technology. Additionally, as treatment by this technology takes place off site, acceptance by the community from where the waste is removed should be favorable.

removing the ferrofurnace bottoms after cool down.

2.1.2 Compliance with ARARs

This criterion addresses whether or not a remedy will meet all of the applicable or relevant and appropriate requirements (ARARs) of federal and state environmental statutes. General and specific ARARs identified for the Geotech technology are presented in Section 2.2. Compliance with chemical-, location-, and action-specific ARARs should be determined on a site-specific basis; however, location-, and action-specific ARARs generally can be met. Compliance with chemical-specific ARARs depends on the chemical constituents of the waste and the treatment efficiency of the vitrification system.

2.1.3 Long-Term Effectiveness and Permanence

This criterion refers to the ability of a remedy to maintain reliable protection of human health and the environment over time. Vitrification is a proven treatment technology for hazardous wastes contaminated with inorganic constituents. Vitrification transforms the physical state of contaminated soil from assorted crystalline matrices to a glassy, amorphous, solid state comprised of interlaced polymeric chains. These chains typically consist of alternating oxygen and silicon atoms. Chromium is expected to readily substitute for silicon in the chains. According to Geotech, the chromium would then be immobile to leaching by aqueous solvents, and as a result, it would be biologically unavailable and nontoxic over time.

2.1.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

This criterion refers to the anticipated performance of the treatment technology potentially employed in a Superfund remediation. With vitrification, the toxicity of the waste feed is reduced by permanently fusing hazardous inorganic constituents into a high-density, noncrystalline, glass-like product that may be used as shore erosion block, decorative tile, roadbed fill, and cement or blacktop aggregate. The density and volume of the vitrified product depends on the desired product. If high-density blocks are desired, the volume would be decreased. When the Cold Top system is run the way that was planned for the SITE demonstration, there would be no waste product planned for disposal as it would be completely recyclable.

Results of Toxicity Characteristic Leaching Procedure (TCLP) and Synthetic Precipitation Leaching Procedure (SPLP) tests indicated that the Cold Top process reduced leachable chromium concentrations

in the hazardous waste feed to below the regulatory limit defined for a characteristic waste as defined by the Resource Conservation and Recovery Act (RCRA).

Air emissions from the treatment process are controlled by an off-gas treatment system. The iron-rich ferrofurnace bottoms may be recycled. Any treatment residual (such as or baghouse dust) can be recycled through the system or shipped off site to a permitted treatment, storage, and disposal facility.

2.1.5 Short-Term Effectiveness

This criterion addresses the period of time needed to achieve lasting protection of human health and the environment as well as any adverse impacts that may be posed during the construction and implementation period before cleanup goals are achieved. During system operation, potential short-term risks presented to workers, the community, and the environment may include exposures to hazardous substances during waste-handling activities and exposures to air emissions. Adverse impacts during waste-handling activities should be minimized by properly operating the Geotech technology, properly handling waste streams, and properly using appropriate personal protection equipment (PPE). Adverse impacts from the emissions are mitigated by using an off-gas treatment system.

2.1.6 Implementability

This criterion considers the technical and administrative feasibility of a remedy, including the availability of materials and services needed to implement a particular option. Geotech operates a pilot plant in Niagara Falls, New York, that vitrifies a wide variety of materials. Currently, Geotech does not operate a transportable system; therefore, only the transportation of the waste feed needs to be evaluated for this criterion.

2.1.7 Costs

This criterion addresses estimated capital and operation and maintenance costs as well as net present worth costs. Costs for treatment by the Geotech technology will depend on site-specific factors such as the volume of material to be treated, physical properties of the material, contaminant types and concentrations, and site location. For the treatment scenarios evaluated in the economic analysis, costs ranged from $83 to $213 per ton. Section 3 of this report provides a detailed discussion of costs for the application of this technology.

2.1.8 State Acceptance

This criterion addresses the technical or administrative issues and concerns the support agency may have regarding the technology. EPA and NJIT, as a contractor to NJDEP, have a formal agreement to cooperate on the evaluation of the Geotech Cold Top technology. NJDEP is the lead agency for the evaluation, and EPA is furnishing additional resources to enhance the overall results. EPA responsibilities for this demonstration are limited to the evaluation of the vitrification unit itself; NJDEP will have primary responsibility for evaluating necessary pre- and post-vitrification treatment activities. Acceptance by other states must be evaluated on a site-specific basis, although state acceptance is expected to be favorable.

2.1.9 Community Acceptance

This criterion addresses any issues or concerns the public may have regarding the technology. Public acceptance of this technology should be positive for two reasons: (1) the technology presents minimal short-term risks to the community and (2) it permanently fuses hazardous constituents in the waste to produce a material that may be used as shore erosion block, decorative tile, roadbed fill, and cement or blacktop aggregate.

2.2 TECHNOLOGY PERFORMANCE REGARDING ARARs

This section discusses specific environmental regulations pertinent to the demonstration and operation of the Geotech Cold Top system, including the transportation, treatment, storage, and disposal of wastes and treatment residuals. CERCLA, as amended by SARA, requires the consideration of ARARs; CERCLA issues, although not true ARARs, are also considered.

Regulations that apply to a particular remediation activity depend on the type of remediation site and the type of waste treated. State and local regulatory requirements, which may be more stringent, must also be addressed by remedial managers. ARARs for the Geotech demonstration include the following: (1) CERCLA, (2) RCRA, (3) Clean Air Act (CAA), (4) Toxic Substances Control Act (TSCA), and (5) Occupational Safety and Health Administration (OSHA) regulations. Table 2 summarizes these regulations, which are discussed in greater detail below.

2.2.1 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA, as amended by SARA, provides for federal authority to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or the environment. Remedial alternatives that significantly reduce the volume, toxicity, or mobility of hazardous materials and provide long-term protection are preferred. Selected remedies must also be cost-effective and protective of human health and the environment.

Due to the large number and relatively small size of most of the New Jersey chromium-contaminated sites in New Jersey, the Geotech Cold Top system may likely be constructed in a central location to treat wastes from the various sites. In addition, for sites that contain large quantities of contaminated soil, Geotech is considering constructing a transportable unit for on-site operation. Disposal of residual wastes generated during on-site application might require off-site disposal or treatment. All on-site actions must meet all substantive state and federal ARARs. Substantive requirements pertain directly to actions or conditions in the environment (for example, air emission standards). Off-site actions must comply with legally applicable substantive and administrative requirements; administrative requirements, such as permitting, facilitate the implementation of substantive requirements.

On-site remedial actions must comply with all federal ARARs as well as more stringent state ARARs. ARARs are determined on a site-by-site basis and may be waived under six conditions: (1) 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 ARAR has not been consistently applied elsewhere; and (6) fund balancing, where ARAR compliance would entail such cost in relation to the added degree of protection or reduction of risk afforded by that ARAR that remedial action at other sites would be jeopardized. These waiver options apply only to Superfund actions taken on site, and justification for the waiver must be clearly demonstrated. Off-site remediations are not eligible for ARAR waivers, and all substantive and administrative applicable requirements must be met.

Table 2. Potential Federal ARARs for the Geotech Cold Top Vitrification System

Process Activity	ARAR	Description	Basis	Requirements
Waste feed characterization	RCRA 40 CFR Part 267 or state equivalent	Identify and characterize the waste to be treated	A RCRA requirement must be met before managing and handling the waste.	Chemical and physical analyses must be performed.
Transportation for off-site treatment	RCRA 40 CFR Part 262 or state equivalent	Mandate manifest requirements, packaging, and labeling prior to transporting	The waste may need to be manifested and managed as a hazardous waste.	An identification number must be obtained from EPA.
	RCRA 40 CFR Part 261 or state equivalent	Set transportation standards	The waste may need permits for transportation as a hazardous waste.	A transporter licensed by EPA must be used to transport the hazardous waste.
Storage prior to processing	RCRA 40 CFR Part 264 or state equivalent	Apply standards for the storage of hazardous waste	Prior to treatment, the hazardous waste may require on-site storage in a waste pile, tank, or container.	The material should be placed in a waste pile on plastic and covered with additional plastic that is secured to minimize fugitive air emissions, volatilization, and water infiltration. Tanks or containers must be well maintained; the container storage area, if used, must be constructed to control run-on and run-off. The time between storage and treatment should be minimized.
Waste processing - smelting, melting, and refining furnace	RCRA 40 CFR Parts 264, 265, 266 (Boilers and Industrial Furnaces [BIF] Rule in Subpart H), and 270	Apply standards for the melting of hazardous waste at permitted and interim status facilities	Processing of hazardous waste must be conducted in a manner that meets the RCRA operating and monitoring requirements.	Equipment must be operated and maintained daily. Air emissions must be characterized by continuous emissions monitoring (CEM). Equipment must be decontaminated when operations are complete.
Storage after processing	RCRA 40 CFR part 264 or state equivalent	Apply standards for the storage of hazardous waste: requirements for storage of hazardous waste in tanks and containers will apply	If vitrified product and byproducts are derived from the treatment of a RCRA-listed waste, requirements for storage of hazardous waste in tanks and containers will apply.	The vitrified product must be stored in tanks or containers that are well maintained; container storage area, if used, must be constructed to control run-on and run-off.

Table 2. Potential Federal ARARs for the Geotech Cold Top Vitrification System

Process Activity	ARAR	Description	Basis	Requirements
On- or off-site disposal	RCRA 40 CFR Part 264 or state equivalent	Apply standards for landfilling hazardous waste	Byproducts may need to be managed as a hazardous waste if they are derived from treatment of hazardous waste.	Wastes must be disposed of at a RCRA-permitted hazardous waste facility, or approval must be obtained from EPA to dispose of wastes on site.
	RCRA 40 CFR Part 268 or state equivalent	Apply standards that restrict the placement of certain hazardous wastes in or on the ground	The hazardous waste may be subject to federal land disposal restrictions (LDR).	Wastes must be characterized to determine if LDRs apply; treated wastes must be tested and results compared to standard.
Transportation for off-site disposal	RCRA 40 CFR Part 262 or state equivalent	Apply manifest requirements and packaging and labeling requirements prior to transporting	Byproducts may need to be manifested and managed as a hazardous waste if they are derived from treatment of hazardous waste.	An identification number must be obtained from EPA.
	RCRA 40 CFR Part 263 or state equivalent	Apply transportation standards	Byproducts may need to be transported as a hazardous waste if they are derived from treatment of hazardous waste.	A transporter licensed by EPA must be used to transport the hazardous waste according to EPA regulations.
Flue Gas Emissions	CAA or equivalent State Implementation Plan	Control air emissions that may impact attainment of ambient air quality standards	The Geotech technology system can incorporate an off-gas treatment system to treat emissions. Treated air is emitted to the atmosphere.	Treatment of contaminated air must adequately remove contaminants so that air quality is not impacted.
Worker Safety	OSHA 29 CFR Parts 1900 through 1926; or state OSHA requirements	Apply worker health and safety standards	CERCLA remedial actions and RCRA corrective actions must follow requirements for the health and safety of on-site workers.	Workers must have completed and maintained OSHA training and medical monitoring; use of appropriate PPE is required.

2.2.2 Resource Conservation and Recovery Act

RCRA, as amended by the Hazardous and Solid Waste Disposal Amendments of 1984, regulates the management and disposal of municipal and industrial solid wastes. EPA and certain RCRA-authorized states [listed in 40 Code of Federal Regulations (CFR) Part 272] implement and enforce RCRA and state regulations.

RCRA regulations may vary according to the specific use of the Geotech system. For example, the Cold Top process may also be used with pretreatment process units to remove extensive organic contamination before vitrification. In such cases, pertinent RCRA regulations would need to be determined for each specific application.

The presence of RCRA-defined hazardous waste determines whether RCRA regulations apply to the Geotech technology. If hazardous wastes are treated or generated during the operation of the technology, all RCRA requirements must be addressed regarding the management and disposal of hazardous wastes. RCRA regulations define hazardous wastes and regulate their transport and treatment, storage, and disposal. Wastes defined as hazardous under RCRA include characteristic and listed wastes. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes generated from nonspecific and specific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D.

If hazardous wastes are treated by the Geotech system, the owner or operator of the treatment or disposal facility must obtain an EPA identification number and a RCRA permit from EPA or the RCRA-authorized state. RCRA requirements for permits are specified in 40 CFR Part 270.

The Geotech Cold Top system is classified as a smelting, melting, and refining furnace by the boiler and industrial furnace (BIF) rule (as defined in 40 CFR Part 260.10). If the treatment waste feed has a high organic content, the Geotech system may burn or process wastes as a BIF; in such cases, the BIF rule outlined in 40 CFR Part 266 Subpart H may become an ARAR.

Treatment residuals generated during the operation of the system, such as baghouse dust, must be stored and disposed of properly. If the treatment waste feed is a listed waste, treatment residuals must be considered listed wastes (unless RCRA delisting requirements are met). If the treatment residuals are not listed wastes, they should be tested to determine if they are RCRA characteristic hazardous wastes. If the residuals are not hazardous and do not contain free liquids, they can be disposed of on site or at a nonhazardous waste landfill. If the treatment residuals are hazardous, the following RCRA standards apply:

> Standards and requirements for generators of hazardous waste, including hazardous treatment residuals, are outlined in 40 CFR Part 262. These requirements include obtaining an EPA identification number, meeting waste-accumulation standards, labeling wastes, and keeping appropriate records. Part 262 allows generators to store wastes up to 90 days without a permit and without having interim status as a treatment, storage, or disposal facility. If treatment residuals are stored on site for 90 days or more, 40 CFR Part 265 requirements apply.
>
> Any on- or off-site facility designated for permanent disposal of hazardous treatment residuals must be in compliance with RCRA. Disposal facilities must fulfill permitting, storage, maintenance, and closure requirements provided in 40 CFR Parts 264 through 270. In addition, any state RCRA requirements must be fulfilled. If treatment residuals are disposed of off site, 40 CFR Part 263 transportation standards apply.

The waste feed mixture used during the Geotech demonstration included chromium-contaminated soil from two types of chromite-ore processing sites. Soils classified as hazardous waste are subject to land disposal restrictions (LDR) under both RCRA and CERCLA. Applicable RCRA requirements may include (1) a Uniform Hazardous Waste Manifest if the treated soils are transported, (2) restrictions on placing soils in land disposal units, (3) time limits on accumulating treated soils, and (4) permits for storing treated soils.

Requirements for corrective action at RCRA-regulated facilities are provided in 40 CFR Part 264, Subpart F (promulgated) and Subpart S (proposed). These subparts also apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective actions, 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. Thus, RCRA mandates requirements similar to CERCLA, and as proposed, may allow units such as the Geotech treatment system to operate with partial waivers of permits.

2.2.3 Clean Air Act

The CAA and its 1990 amendments establish (1) primary and secondary ambient air quality standards for the protection of public health and (2) emission limitations on certain hazardous air pollutants.

CAA permitting requirements are administered by each state as part of State Implementation Plans developed to bring each state into compliance with National Ambient Air Quality Standards (NAAQS). Ambient air quality standards for specific pollutants apply to the operation of the Geotech system, because the technology ultimately results in an emission from a point source to the ambient air. Allowable emission limits for the operation of a Geotech system will be established on a case-by-case basis depending on the type of waste treated and whether or not the site is in a NAAQS attainment area. Allowable emission limits may be set for specific hazardous air pollutants, particulate matter, hydrogen chloride, or other pollutants. If the site is in an attainment area, the allowable emission limits may still be curtailed by the increments available under prevention of significant deterioration (PSD) regulations. Typically, an air pollution control system (APCS) similar to the type used during the SITE demonstration will be required to control the discharge of emissions to the ambient air.

ARARs pertaining to the CAA must be determined on a site-by-site basis. In attainment (or unclassified) areas, remedial activities involving the Geotech technology may be subject to PSD requirements in Part C of the CAA. The PSD requirements will apply when remedial activities involve a major source or modification as defined in 40 CFR Section 52.21; remedial activities subject to review must apply the best available control technologies and demonstrate that the

activity will not adversely affect ambient air quality.

2.2.4 Toxic Substances Control Act

Although the waste material treated during the SITE demonstration of the Cold Top technology did not contain asbestos, successful treatment of asbestos-contaminated materials is a claim of the technology. Asbestos regulations are described in the Toxic Substances Control Act (TSCA) and 40 CFR Part 763. If the system is used to treat asbestos-contaminated material, the remediation will require TSCA authorization that defines operational and disposal constraints. If the asbestos-contaminated material contains RCRA wastes, RCRA compliance is also required.

2.2.5 Occupational Safety and Health Administration Requirements

CERCLA remedial actions and RCRA corrective actions must be performed in accordance with OSHA requirements detailed in 20 CFR Parts 1900 through 1926, especially Part 1910.120, which provides for the health and safety of workers at hazardous waste sites. On-site construction activities at Superfund or RCRA corrective actions sites must be performed in accordance with Part 1926 of OSHA, which provides 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 Geotech treatment system are required to have completed an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. For most sites, minimum PPE for technicians will include gloves, hard hats, steel-toe boots, and coveralls. Depending on contaminant types and concentrations, additional PPE may be required.

2.3 OPERABILITY OF THE TECHNOLOGY

A schematic of the Cold Top system is shown in Figure 1. The system is controlled by an operator working at a control panel. The operator can control the power supplied to each of the vitrification electrodes. The amount of power supplied to the electrodes determines the rate at which contaminated soil is vitrified and also the rate at which untreated soil must be added to the furnace. Prior to startup, the

furnace is lined with sand to insulate its bottom and walls. A clay material, Mulcoa, is added on top of the sand. The energy required to melt Mulcoa is well characterized by Geotech and they use this information to determine the initial setting of the furnace. Contaminated soil is placed on top of the Mulcoa and, once the Mulcoa begins to melt and the power to the electrodes is properly determined, the soil begins to melt also. By visualizing the vitrified effluent from the reactor, the operator can tell when the Mulcoa has been completely melted and discharged. At this point, the discharge rate of the vitrified soil is closely monitored using a ladle, and power to the electrodes is adjusted, as necessary, to maintain the desired flow rate. This flow rate is maintained throughout the test run. A skilled operator is required to monitor and run the system.

2.4 APPLICABLE WASTES

Geotech has operated a pilot plant that has vitrified a wide variety of materials, including granite, blast furnace slag, fly ash, spent catalyst, and flue dust. In addition, the Cold Top vitrification process has been used to treat soils contaminated with hazardous heavy metals such as lead, cadmium, and chromium; asbestos and asbestos-containing materials; and municipal-solid-waste-incinerator-ash residue. Waste material must be sized to pass through a 0.375-inch mesh screen.

The Cold Top vitrification process is most efficient when (1) feed materials have been dewatered to less than 5 percent water and (2) organic chemical concentrations have been minimized. The demonstration wastes required the addition of carbon and sand to ensure that the vitrification process produced a durable glass-like product.

2.5 KEY FEATURES OF THE GEOTECH COLD TOP SYSTEM

The system is a 1,350-kVA electric resistance furnace capable of operating at melting temperatures of up to 5,200 °F (2,870 °C). The furnace is cooled by water circulating within its hollow jacket and is equipped with an off-gas treatment system, which may include a baghouse, cyclone, and wet scrubbers, depending on waste characteristics. Once the operating temperature is attained, contaminated soil is continuously fed to the furnace by a screw conveyor, while vitrified product is tapped from the middle of the furnace.

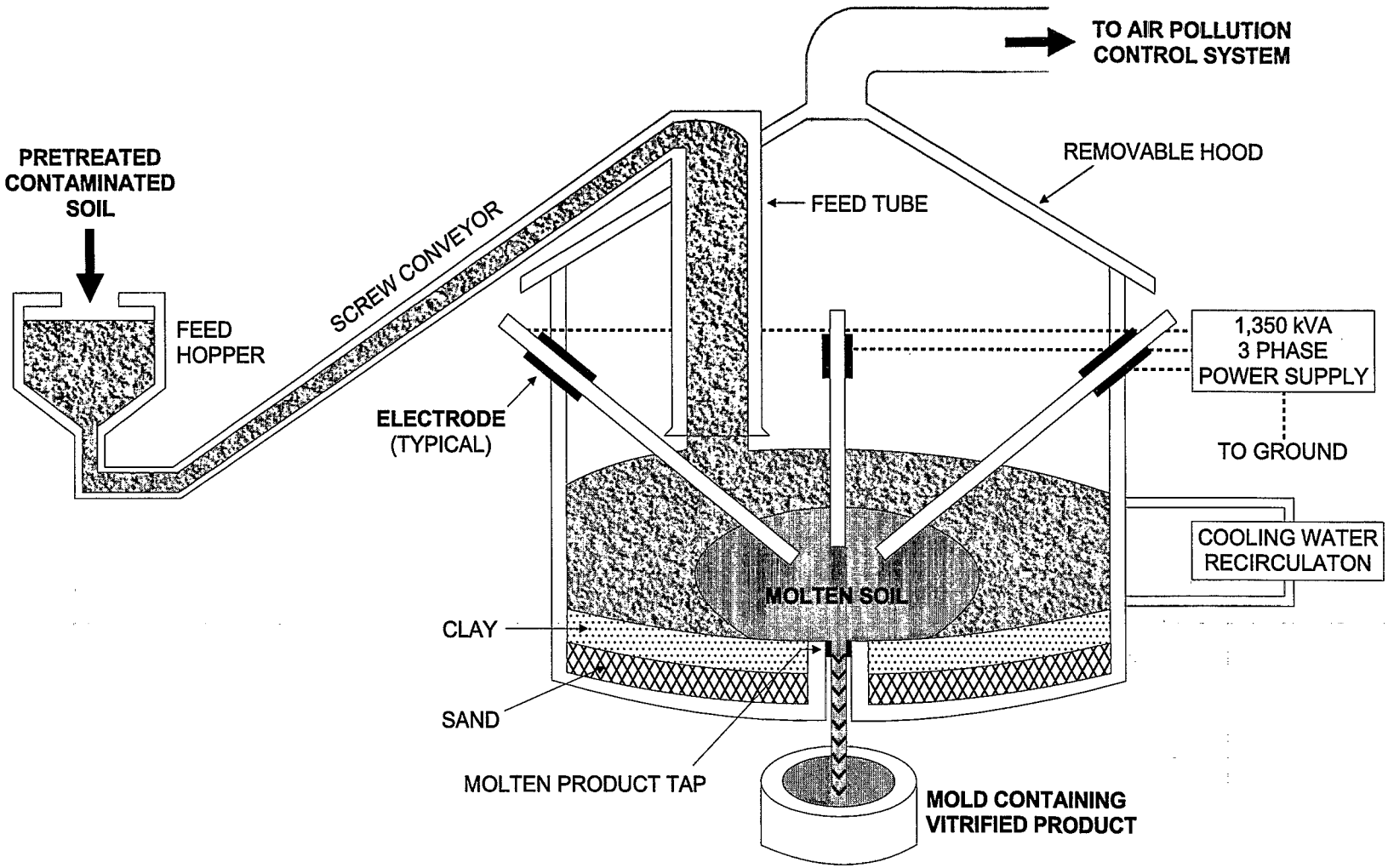


Figure 1. Cold Top *Ex-Situ* Vitrification System

2.6 AVAILABILITY AND TRANSPORTABILITY OF EQUIPMENT

For the past 15 years, Geotech's pilot plant in Niagara Falls, New York, has vitrified a wide variety of materials. A Geotech system may be constructed and centrally located for the more than 150 chromium-contaminated sites in New Jersey. Although Geotech does not currently operate a transportable system, it is considering constructing a transportable unit for sites that contain large quantities of contaminated soil. Several production plants based on the Geotech technology are now being used to produce mineral fiber and other commercial products. These plants could be converted to the treatment of hazardous wastes.

2.7 MATERIALS-HANDLING REQUIREMENTS

Waste feed must be sized to pass through a 0.375-inch mesh screen. The Cold Top vitrification process is most efficient when (1) feed materials have been dewatered to less than 5 percent water and (2) organic chemical concentrations have been minimized. Waste feed may require the addition of carbon (to increase the electrical conductivity of the mixture) and silica (to increase the silica content and facilitate vitrification). Demonstration waste feed pretreatment consisted of reducing the particle size, drying, and blending with 0.2 percent carbon and 25 percent sand by weight. Following pretreatment, the waste feed was placed in supersacs for transport to the Cold Top furnace. The waste feed was then emptied from the supersacs into a feed hopper where it was metered into the furnace by screw conveyor.

When the desired soil melt temperature is achieved, Geotech removes the furnace plug from below the molten-product tap. During the demonstration, the outflow to be used for chemical and durability testing was poured into refractory-lined and insulated molds for slow cooling. Excess material was discharged to a water sluice for immediate cooling and collection for off-site disposal.

2.8 LIMITATIONS OF THE TECHNOLOGY

The Geotech Cold Top system has several limitations. At the present time, waste material must be transported for treatment at the Geotech facility in Niagara Falls, New York, although other Cold Top facilities may be constructed in the future. Geotech is also considering constructing a transportable unit.

At the conclusion of a waste-feed run, ferrofurnace bottoms may be present in the furnace. This material must be analyzed prior to recycling or off-site disposal. The material may have significant value for recycling, therefore its formation as a by-product may be a benefit. Other limitations of the process, such as waste feed organic chemical content, dryness, and particle size, are discussed above.

SECTION 3
ECONOMIC ANALYSIS

This economic analysis presents cost estimates for using the Cold Top *ex-situ* vitrification system to treat contaminated soil. Cost data were compiled during the SITE demonstration at the Geotech test facility in Niagara Falls, New York, and from information obtained from Geotech. Costs have been placed in 12 categories applicable to typical cleanup activities at Superfund and RCRA sites (Evans 1990). Costs were estimated using data in R.S. Means Environmental Restoration Unit Cost Book (1996) and R.S. Means Building Construction Cost Data: 55th Edition (1997). Estimated costs are considered to be order-of-magnitude estimates with an expected accuracy within 50 percent above and 30 percent below the actual costs.

This section describes three scenarios selected for economic analysis (Section 3.1), summarizes the major issues involved and assumptions made in performing the analysis (Section 3.2), discusses costs associated with using the Cold Top *Ex-Situ* Vitrification process to treat contaminated soil (Section 3.3), and presents conclusions of the economic analysis (Section 3.4).

3.1 INTRODUCTION

There are more than 150 chromium-contaminated sites in the northern New Jersey area. The amount of contaminated soil at most of the sites ranges from 100 to 500 cubic yards (cy); two or three of the sites have more than 1 million cy. The number and close proximity of these many sites presents a large market potential in the area for a treatment system such as the Cold Top process. This economic analysis presents costs based on treating contaminated soil at a newly constructed, fixed vitrification facility located in or near Jersey City, New Jersey. As costs for a transportable vitrification system may vary and the cost-effectiveness of such a system would depend on each site's size, the economics of a transportable system are not addressed in this analysis.

Table 3 presents estimated costs per ton for soil treatment under three disposal scenarios. Under scenario 1, treated material is sold as road aggregate and clean backfill is used at the excavated site. This is the most economic scenario, and NJIT is conducting a concurrent investigation of the efficacy of this scenario. Under scenario 2, treated material is suitable for use as backfill at the excavated site, thus saving

Table 3. Summary of Costs for the Geotech Cold Top Vitrification Process

Cost Categories	Sell Treated Material as Aggregate and Use Clean Backfill ($/ton)	Backfill Treated Material ($/ton)	Landfill Treated Material and Use Clean Backfill ($/ton)
Site Preparation			
-Excavation	$ 5.72	$ 5.72	$ 5.72
-Waste preparation	5.00	5.00	5.00
Permitting and regulatory requirements	2.02	2.02	2.02
Capital costs	8.03	8.03	8.03
Fixed costs	6.79	6.79	6.79
Labor	11.75	11.75	11.75
Materials	9.67	1.67	9.67
Utilities	23.28	23.28	23.28
Disposal	(12.50)	0.00	107.00
Transportation			
-Excavated material	10.00	10.00	10.00
-Treated material	-----	10.00	10.00
Analytical costs	7.11	7.11	7.11
Equipment repair and replacement	5.50	5.50	5.50
Site demobilization	1.11	1.11	1.11
Total cost per ton	$83	$98	$213

costs associated with obtaining and using clean backfill material and off-site disposal of treated material. Under scenario 3, treated material is landfilled at a nonhazardous solid waste disposal facility, and clean backfill is used at the excavated site; this is obviously the most costly scenario.

3.2 ISSUES AND ASSUMPTIONS

This section summarizes major issues and assumptions regarding site-specific factors, equipment, and operating parameters used in this economic analysis of the Cold Top vitrification process. Key assumptions are summarized as follows:

- The primary contaminant of concern is chromium, at concentrations up to 100,000 mg/kg.
- Contaminated soil has a moisture content of about 15 percent, and less than 5 percent of the material will be retained on a 1-inch screen.
- The typical site contains 450 tons (or 300 cy) of contaminated soil and is located about 20 miles from the vitrification facility.
- Geotech will construct and operate the vitrification facility at one of the contaminated sites near Jersey City, New Jersey.
- The proposed vitrification facility will process 300 tons per day (200 cy/day), or approximately 109,000 tons per year, of contaminated soil, including pretreatment as needed (such as crushing, drying, and mixing with additives).

3.3 BASIS OF ECONOMIC ANALYSIS

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

- Site preparation costs
- Permitting and regulatory costs
- Capital costs

- Fixed costs
- Labor costs
- Materials costs
- Utilities
- Disposal costs
- Transport costs
- Analytical costs
- Facility modification, repair, and replacement costs
- Site demobilization costs

The 12 cost factors and any related assumptions for the Cold Top process are examined below. As shown in Table 3, costs for many of the categories are the same for each scenario.

3.3.1 Site Preparation Costs

Typical site preparation costs associated with setting up a waste treatment system at a hazardous waste site include site design, planning and management, legal searches, access rights, and construction work. Since the Cold Top facility in this analysis is a stationary unit, requiring waste to be brought to the facility for treatment, these costs are not incurred on a site-specific basis, and they are included within the capital cost category.

For this analysis, site preparation costs are associated with excavating contaminated soil. Mobilization costs for excavation, including clearing light brush, installing temporary fencing, establishing working zones, and mobilizing equipment to the site, are estimated to be $1,000 for the small sites considered in this analysis. Excavation costs of $5.25 per cy are based on using a two-person crew with a backhoe or

front-end loader for one 8-hour day, or approximately $1,575 to excavate the typical 300-cy (450-ton) site. This cost includes equipment, fuel, and labor costs. Therefore, the total site preparation cost for the typical site is approximately $2,575. For each of the three scenarios the site preparation cost is $8.58 per cy or $5.72 per ton.

Waste preparation is assumed to be required before treatment in the Cold Top system. Geotech expects to provide waste pretreatment services at its fixed facility and would include any costs associated with this activity in its contract price. However, for this analysis, it is assumed that this waste preparation will be a separate operation that may be conducted at the contaminated site. Furthermore, it is assumed that contaminated material will require screening, magnetic separation, and drying. Approximately 50 percent of the material will require crushing. Finally, silica will be added to the material, up to 25 percent by volume, and the material will be blended. Based on the SITE demonstration and published costs for these individual operations, the estimated cost for waste preparation is $5.00 per ton.

3.3.2 Permitting and Regulatory Costs

Permitting and regulatory costs will vary depending on whether treatment is performed on a Superfund or a RCRA corrective action site and the fate of the treated waste. Section 121(d) of CERCLA, as amended by SARA, requires that remedial actions be consistent with ARARs of environmental laws, ordinances, regulations, and statutes. ARARs include federal standards, as well as more stringent standards promulgated under state or local jurisdictions. ARARs must be determined on a site-specific basis. For this analysis, the cost for permits associated with construction activities at the site are estimated to be $500 or $1.67 per cy ($1.11 per ton).

For most pollution control facilities, the cost of keeping up with applicable regulations and permits is substantial. However, in this economic analysis, sincethe Cold Top facility will not use contact cooling water and air emissions are expected to be low, the permitting cost for the facility are estimated to be about $100,000 per year, which includes professional services and regulatory fees. Based on the projected facility throughput of 109,000 tons per year, the permitting and regulatory cost is estimated to be $0.92 per ton for all cases. The total cost for this category is, therefore, $2.02 per ton.

3.3.3 Capital Costs

Capital costs are based on information provided by Geotech. Specifically, Geotech provided this information as annual costs of $400,000 for depreciation and $475,000 for debt service on capital expenditures. Based on 109,000 tons per year, the estimated capital cost is $8.03 per ton.

3.3.4 Fixed Costs

Fixed costs for the Cold Top system include other annual expenses not directly related to waste treatment. Geotech has estimated the annual costs for these to be $110,000 for building utilities; $155,000 for insurance; $200,000 for general maintenance; and $275,000 for general administration. Based on 109,000 tons per year, the estimated fixed costs are $6.79 per ton.

These costs do not include any profit. To establish a price for treatment, Geotech will add such profit as a fixed cost per ton, based on market conditions. As a result, actual fixed costs may be significantly higher per ton.

3.3.5 Labor Costs

For 24-hour per day operation, Geotech expects to employ a 21 full-time personnel. Based on observations during the SITE demonstration, a five-person crew during each shift should be adequate to safely operate the system. The crew would consist of a field engineer (approximately $25 per hour), an equipment operator ($20 per hour), and three laborers ($15 per hour each). Four crews plus one overall supervising engineer ($1,300 per week) would complete the 21-person operating staff. Adding 50 percent for fringe benefits, including worker training, the total annual labor costs for the vitrification facility are estimated to be $853,840. Based on 109,000 tons per year, the estimated labor costs are $11.75 per ton.

3.3.6 Materials Costs

Materials costs are associated with site cleanup and treatment. The costs associated with this treatment

include carbon and silica addition during pretreatment, kaolin clay and glass frit addition during startup, and electrode replacement. Pretreatment and startup material costs are generally minimal; electrode replacement costs are addressed in Section 3.3.11.

For the three scenarios, the primary materials costs are associated with site backfilling, including labor, backfill material, spreading, and compaction. For the first and third scenarios, clean backfill will be used at the excavation. The estimated cost for supplying, spreading, and compacting clean borrow and backfill material will be $14.50 per cy or $9.67 per ton of soil treated. For the second, it is assumed that treated material will be replaced as backfill at the individual sites excavated. The estimated cost for spreading and compacting this material is $2.50 per cy or $1.67 per ton.

3.3.7 Utilities Costs

Electricity is the primary utility required for the Cold Top process. Only minimal drinking and service water is required for the system. Based on the SITE demonstration and other information provided by Geotech, the technology uses about 776 kilowatt-hours (kWhr) per ton of soil treated. Geotech expects to obtain a highly competitive rate of 3 cents per kWhr for its facility; however, this rate could be as high as 6 or 7 cents per kWhr (see Section 3.4.3). Therefore, the utility cost for the system could range from $23.28 to $54.32 per ton of soil treated.

3.3.8 Disposal Costs

Disposal costs represent the most significant difference among the three scenarios. In scenario 1, treated material is assumed to have a salable value as road aggregate. Standard costs for sand and stone aggregate are approximately $12.50 per ton, which will be assumed as a credit for this scenario. In scenario 2, treated material will be used as backfill at the site excavations; therefore, disposal costs are assumed to be zero. In scenario 3, disposal costs for landfilling the treated material would be $107 per ton, assuming a nonhazardous solid bulk waste.

3.3.9 Transportation Costs

Transportation costs will be incurred to transport soil from the contaminated sites to the vitrification facility. This analysis assumes an average distance of 20 miles from the site to (40 miles round trip),

with 300 cy of soil removed from the typical site. Based on these assumptions, it will take five 20-cy dump trucks four trips to remove the excavated soil. Transportation costs are estimated to be $15.00 per cy ($10.00 per ton) for each of the three scenarios.

The same assumptions are used to estimate costs to (1) transport the treated material back to the site for backfilling in scenario 2 and (2) transport this material to a landfill in scenario 3. Again, these costs are estimated to be $15.00 per cy ($10.00 per ton). Transportation costs for scenario 1 are assumed to be born by the purchaser.

3.3.10 Analytical Costs

Analytical costs are associated with confirmation of site excavation activities and evaluation of treatment effectiveness. While site-specific requirements may vary considerably, this analysis assumes that a total of 20 confirmation samples will be analyzed for metals at a cost of $100 per sample. Therefore, the cost for site confirmatory samples is $6.67 per cy or $4.44 per ton.

At a minimum, three samples of treated material should be collected for each site and analyzed for total metals and TCLP metals. These analyses will cost about $400 per sample. For the typical site, total analytical costs to evaluate treatment effectiveness will be $1,200, or $4.00 per cy ($2.67 per ton). Therefore, total analytical costs for the technology are $10.67 per cy or $7.11 per ton.

3.3.11 Facility Modification, Repair, and Replacement Costs

This cost category covers the general maintenance for the facility and the period replacement of electrodes and orifices for the vitrification units. Because the scope of the SITE demonstration limits the technology evaluation to a short time frame, costs under this category are based on information supplied by Geotech. For this analysis, costs are estimated based on a typical treatment campaign of 90 days, at which time the system would be shut down for 1 day to replace equipment, as needed. Geotech has estimated the annual repair and maintenance cost to be $400,000 for electrode and orifice replacement and $200,000 for general maintenance and ancillary equipment replacement. Therefore, the total cost to treat 109,000 tons of contaminated soil is $600,000, or $5.50 per ton of treated soil.

3.3.12 Site Demobilization Costs

Site demobilization and restoration are limited to the removal of equipment from the site. The cost for excavation demobilization at the typical site is estimated to be $500. Requirements regarding the backfilling, grading, and recompaction of the material in the excavation are included in Section 3.3.6. Therefore, demobilization costs are $1.67 per cy or $1.11 per ton.

3.4 SUMMARY OF ECONOMIC ANALYSIS

This section summarizes the costs for the Cold Top system for the three scenarios and the 12 cost categories. This section also presents an analysis of the impact of electricity rates on the technology's cost.

3.4.1 Total Cost for a Typical Site under Three Scenarios

The distinguishing factor in identifying the three treatment scenarios are based on the options for handling the contaminated soil after treatment: (1) reuse it as construction material, (2) return it to the excavated area, or (3) dispose of it at a landfill. Figure 2 compares the total costs for the three scenarios.

3.4.2 Cost Breakdown by Category

Costs for each of the twelve cost categories are summarized in Table 3 and shown in Figure 3 as costs per ton of soil treated, which range from $83 to $213 per ton of contaminated soil.

3.4.3 Cost Sensitivity to Electricity Rates

Electricity accounts for as much as 26 percent of the total technology treatment costs. Geotech expects to negotiate a preferred rate of $0.03 per kWhr during development of the New Jersey facility. However, electricity rates vary considerably based on location and market conditions. Figure 4 depicts the impact of electricity rates on total cost per ton for each of the three scenarios.

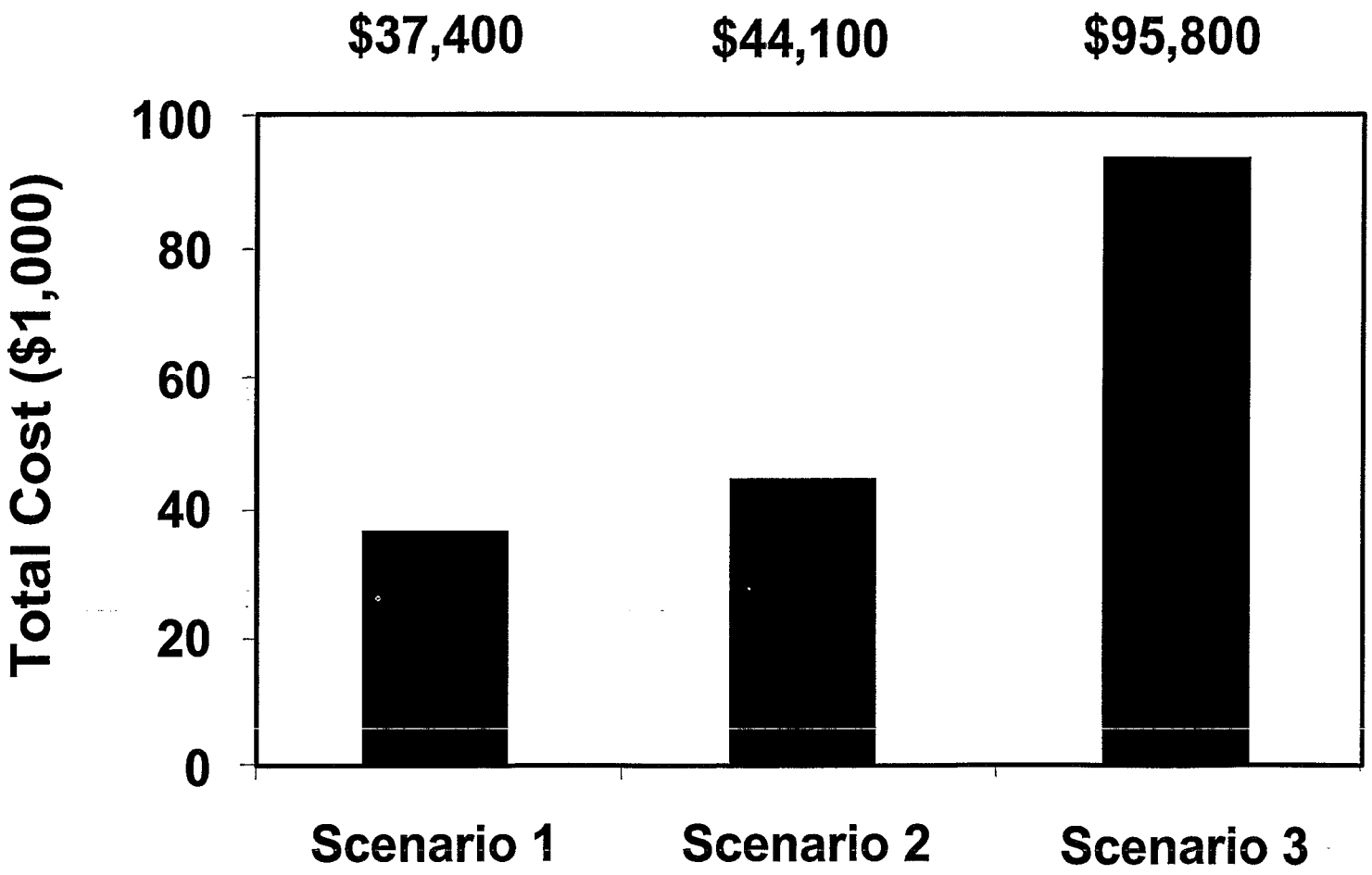
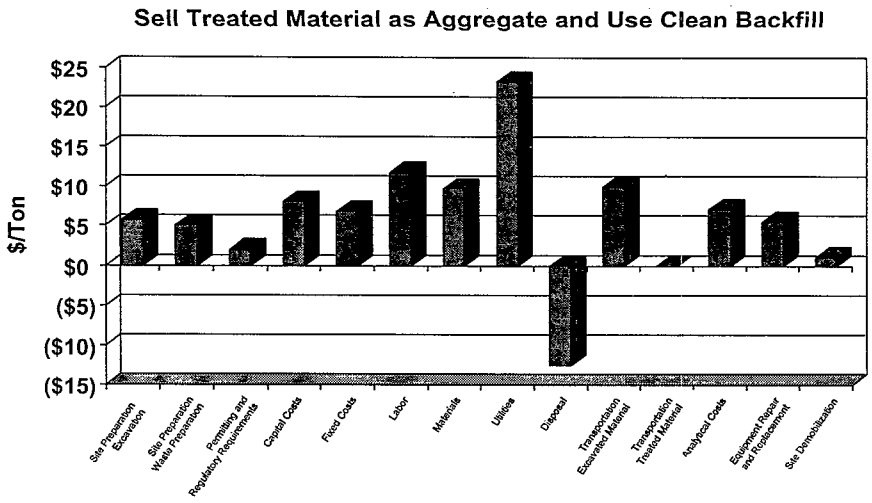
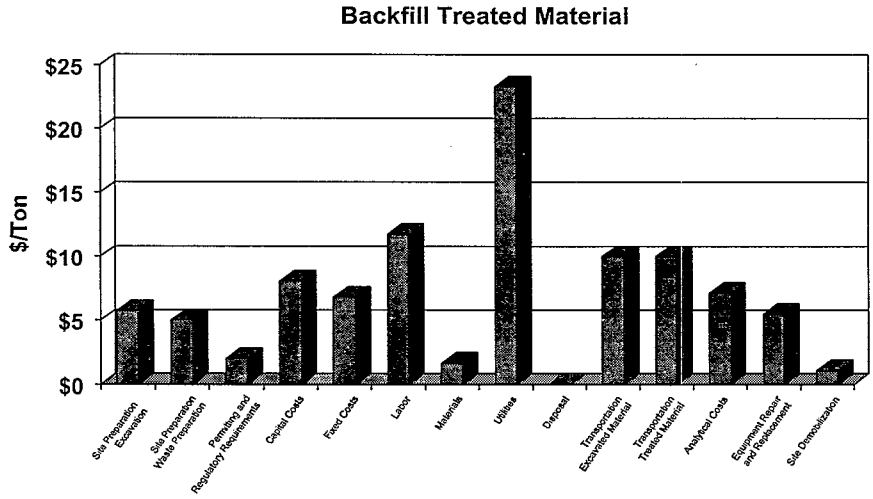


Figure 2. Total Treatment Cost for Typical Site



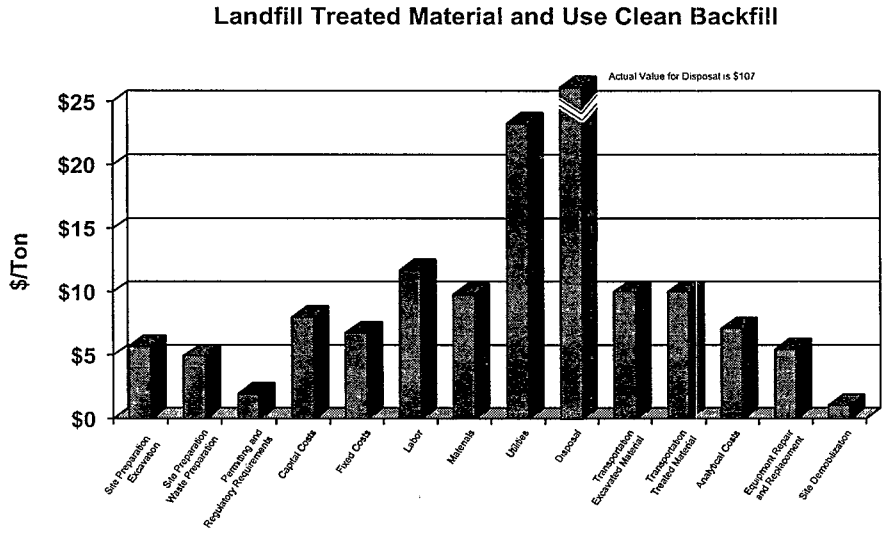
Total Cost $83/ton

Figure 3a. Cost Breakdown for Scenario No. 1



Total Cost $98/ton

Figure 3b. Cost Breakdown for Scenario No. 2



Total Cost $213/ton

Figure 3c. Cost Breakdown for Scenario No. 3

Figure 3. Cost Breakdown for Scenarios No. 1, 2, and 3

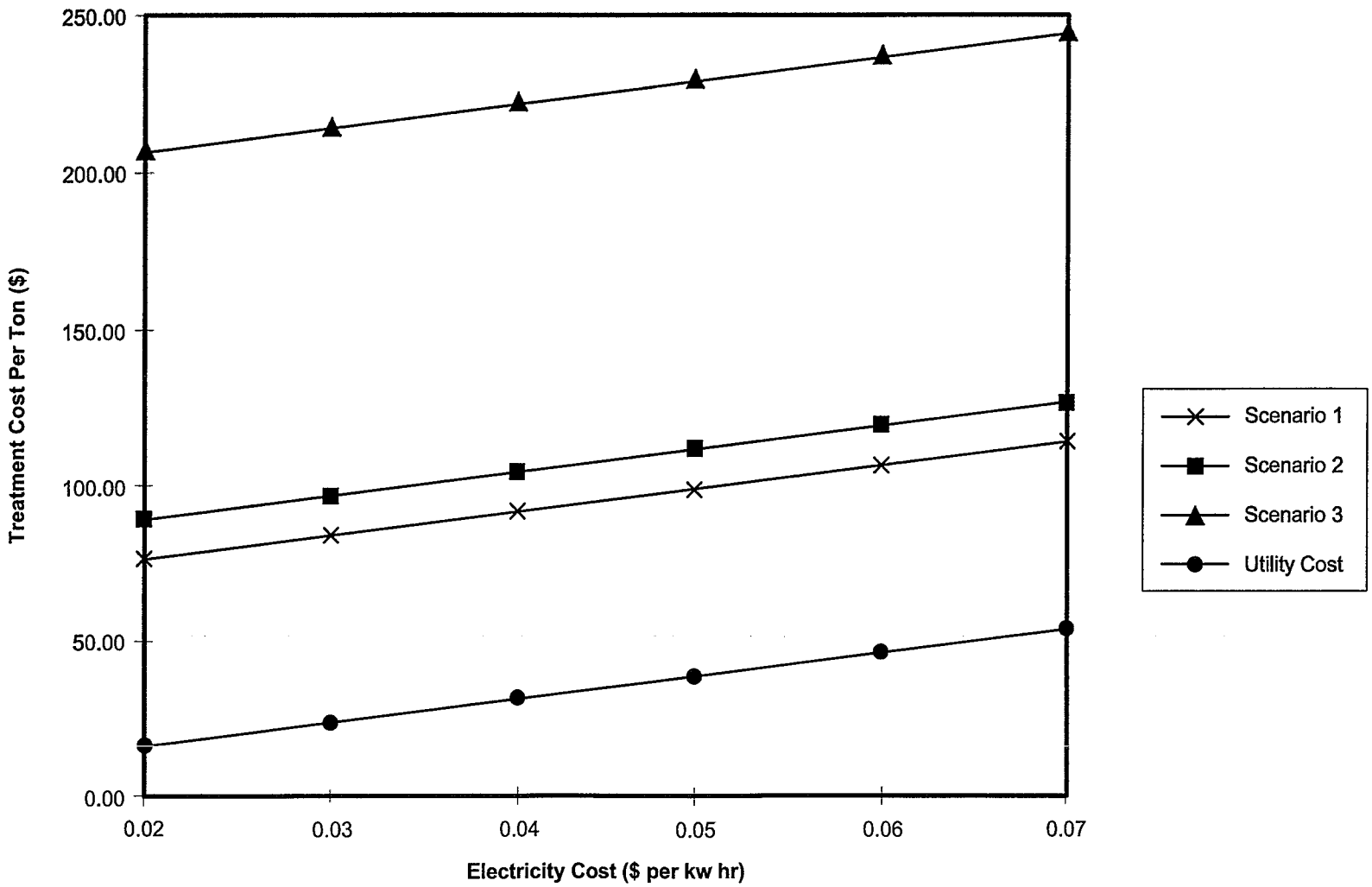


Figure 4. Impact of Electricity Cost on Total Treatment Cost

SECTION 4
TREATMENT EFFECTIVENESS

In 1994, the Stevens Institute of Technology (SIT), one of 2 universities involved in this project, conducted a bench-scale study to determine the performance of the Cold Top vitrification process based on the leachability of chromium and the concentration of hexavalent chromium in the glass product. The study included the collection and subsequent analysis of soils from nine chromium-contaminated sites in northern New Jersey (see Table 4 and Meegoda 1995). The soils were analyzed for total chromium, hexavalent chromium, and pH; the soils also underwent TCLP analyses for chromium. The concentrations of hexavalent chromium in the soils ranged from less than 5.8 milligrams per kilogram (mg/kg) to 4,800 mg/kg. The pH of the soils varied from 8.1 to 11.4, with three sites having a pH above 10. The results of the evaluation indicated that concentrations of chromium in the TCLP leachate of the vitrified samples were generally less than 1.1 milligram per liter (mg/L), which is below the regulatory threshold concentration of 5 mg/L that would define the vitrified product as a hazardous waste.

Contaminated soils from Liberty State Park and Site 130, both New Jersey Superfund sites, were selected for the Cold Top demonstration based on site access and the concentrations of chromium in untreated soils. The two sites are located in Hudson County in northern New Jersey. Table 4 summarizes the results of chromium analyses conducted before and after the SIT bench-scale treatment of soil from these two sites. Contaminated soils from the sites were treated at the Geotech vitrification pilot plant in Niagara Falls, New York.

4.1 DEMONSTRATION OBJECTIVES AND APPROACH

The general objective of the Cold Top SITE demonstration was to develop data needed to allow an unbiased, quantitative evaluation of the effectiveness and cost of this technology. To ensure the attainment of data that would allow such an evaluation, specific, performance-based objectives were developed. This technology demonstration had both primary and secondary SITE program objectives. Primary objectives (P) are considered critical for the technology evaluation. Secondary objectives (S) provide additional information that is useful but not critical. To obtain the data required to meet the

specified demonstration objectives, samples were collected and process measurements were made at the locations described in Section 4.3. The primary objective of this demonstration was as follows:

Table 4. Results of Chromium Analyses of Soils from Bench-Scale Study (Stevens Institute of Technology Data)

Site	Untreated Soil			Treated Soil		
	TCLP Chromium (mg/L)	Hexavalent Chromium (mg/kg)	Total Chromium (mg/kg)	TCLP Chromium (mg/L)	Hexavalent Chromium (mg/kg)	Total Chromium (mg/kg)
Site 130	48.6	4,800	5,294	0.0254	<5.2	48.4/15.2[1]
Liberty State Park	32.4	1,240	1,544	0.0934	<5.2	40.8/111.2[1]

Note:

[1] The two results are obtained from duplicate analyses.

P-1 Determine if the waste and product streams from the vitrification unit meet the RCRA definitions of a characteristic waste due to their chromium content; this determination should be made based on a 95 percent confidence level. For comparison, the chromium concentrations in the untreated soils was determined.

For wastes from each site, the demonstration evaluated the TCLP concentrations of chromium in the dried, blended soil mixture; the process residuals; and the vitrified product from the treatment process. This evaluation determined if the untreated soil, the process waste streams, and the vitrified product met the regulatory definition of a hazardous waste, specifically whether they exhibited the toxicity characteristic for chromium. To achieve this objective, the dried, crushed, blended, (but untreated) soil mixture; process residuals (including vitrification baghouse dust and ferrofurnace bottoms); and the vitrified product were subjected to TCLP testing, and the extracts were analyzed to determine total chromium concentrations. Chromium concentrations of 5.0 mg/L or less in the TCLP extracts would indicate that the residuals would not be defined as hazardous wastes due to the presence of chromium. Samples of untreated soil from each site were composited during soil collection; and one sample from each site was analyzed to determine the approximate chromium levels in the TCLP extract. The data show that chromium concentrations in the TCLP extract, of the contaminated site soils exceeded the RCRA hazardous waste criteria of 5.0 mg/L by factors of six to ten.

There were problems attaining these objectives. The problems are discussed in Sections 4.3 and 4.4. Another purpose of the SITE demonstration was to accomplish the following five secondary objectives:

S-1 Determine the partitioning of total and hexavalent chromium from the dried waste into various waste and product streams.

Mass balances were to be performed around the vitrification process for both total and hexavalent chromium to determine the relative partitioning of chromium into baghouse dust, stack emissions, ferrofurnace bottoms, and vitrified product. The total chromium mass balance was attempted by analyzing the following seven streams using the rigorous hydrofluoric acid digestion method: (1) the sand (silicon) and carbon additives; (2) the baghouse dust from the drying process; (3) the dried, crushed, and sieved, untreated soil blended with baghouse dust from the drying process and the sand and carbon additives; (4) the vitrification baghouse dust; (5) stack emissions (filter and impinger solution); (6) ferrofurnace bottoms; and (7) vitrified product. The weight of each material was to be determined, and the weights would then be multiplied by each material's respective concentration to determine the total amount of chromium in each stream. The weights of the above numbers (3) and (7) were not accurately determined due to weighing error and an inadequate supply of molds for the vitrification product.

The mass balance for hexavalent chromium was to be accomplished by sampling and analyzing for hexavalent chromium in the same seven streams. The analytical results for hexavalent chromium were to be compared to the results for total chromium to determine if hexavalent chromium is converted to other oxidation states of chromium.

S-2 Evaluate the operating costs of the Geotech technology per ton of soil

This objective was achieved by estimating the total costs of utilities, labor, maintenance, supplies, and other necessary equipment or activities to treat a soil similar to those used in the demonstration (Evans 1991). Once these costs were estimated, the cost per ton for treatment for a typical chromium-contaminated site was estimated for several treatment scenarios with different quantities of contaminated soil.

S-3 Determine whether the vitrified product from the treatment process met NJDEP criteria as fill material, such as for use as road construction aggregate. This involved sampling and subsequent analysis of the vitrified product for (1) total chromium and the target analyte list (TAL) minor metals using EPA-approved methods and (2) hexavalent chromium using a proposed EPA method.

As a matter of policy, the State of New Jersey has employed soil cleanup standards for the TAL minor metals (antimony, beryllium, cadmium, nickel, and vanadium) and for chromium and hexavalent chromium. New Jersey applies these standards to materials that will be placed on the land, such as the vitrified product. When applied to the vitrified product, the present cleanup standards specify that it contain less than 500 parts per million (ppm) of chromium when analyzed by appropriate EPA methods. To determine if the vitrified product contains less than 500 ppm chromium, a sample of the product was ground to pass through a 200-mesh sieve (75 micrometers [0.0029 inch]), digested, and analyzed for chromium by appropriate EPA SW-846 methods. To determine the applicability of the technology to soil containing other TAL minor metals, the digested vitrified product was analyzed for antimony, beryllium, cadmium, nickel, and vanadium using EPA SW-846 methodology. The State of New Jersey also recommends that the treated vitrified product contain less than 10 ppm of hexavalent chromium when analyzed using a modified version of proposed SW-846 Method 7196A.

NJDEP cleanup criteria are established for both residential and non-residential direct contact scenarios for five TAL minor metals. According to NJDEP, the appropriate are criteria are 14 and 340 ppm for antimony, 1 and 1 ppm for beryllium, 1 and 100 ppm for cadmium, 250 and 2400 ppm for nickel, and 370 and 7100 ppm for vanadium for the residential and non-residential direct contact scenarios, respectively.

S-4 Determine the final air emissions of dioxins, furans, trace metals, particulate, and hydrogen chloride to determine adherence to compliance requirements.

With one exception, exhaust gas sampling was performed downstream of the APCS during both of the demonstration test runs to fulfil this objective. During the second test run, the dioxin and furan sample was only collected before the APCS as data from the first test run showed that the dioxin and furan data did not differ before and after the APCS. Stack gas samples were collected and analyzed for dioxins and furans, trace metals, particulate and hydrogen chloride by EPA test methods. Data to meet this

objective were considered to be observational.

S-5 Determine the uncontrolled air emissions of oxides of nitrogen (NO_X), sulfur dioxide (SO_2), and carbon monoxide (CO) from the vitrification unit.

Continual on-line analyses of the flue gases, using continuous emissions monitors (CEMs), was conducted upstream of the system baghouse to determine the emissions of nitrogen oxides, sulfur dioxide, and carbon monoxide from the vitrification furnace. During the second demonstration test run, total hydrocarbon emissions were also monitored. Data to meet this objective were considered to be observational.

4.2 DEMONSTRATION PROCEDURES

During the demonstration, two tests were performed, one for each of the two chromium-contaminated sites (Liberty State Park and Site 130). To evaluate the developer's claims, the test matrix was designed to yield the following types of data for each of the tests:

- Emissions
- Chromium leachability
- Chromium partitioning
- Operating cost estimate per ton of soil

The primary objective of the SITE demonstration was to determine if waste and products produced by the Cold Top technology meet the RCRA definition of a characteristic waste because of their chromium content. The TCLP was performed on both treated product and untreated soil to meet this objective. Data were also obtained from other waste components, including sand and carbon additives and baghouse dust, and oven preparatory components, including sand and Mulcoa, to assess treatment efficiency of the technology and to obtain process information.

This section summarizes activities performed before and during the demonstration, procedures required to evaluate the Cold Top process, and discusses the types of samples and measurements collected during

the demonstration. The section also describes sampling locations, sampling frequency, collection procedures, decontamination, sample designation and tracking, and deviations from the demonstration QAPP.

4.2.1 Predemonstration Activities

About 3 tons of contaminated soil were excavated from each of the two chromium-contaminated sites. After screening to pass through a 1- to 1.5-inch sieve, the soil was placed in drums for initial shipment to Chem Pro Inc., the crushing-drying-and-blending facility. At this facility, the soils from the two sites were handled separately. Geotech claimed that the soil feed must be sized to a powder to be effectively vitrified. Additionally, for the drying furnace feed to operate without clogging, the soil had to be ground to approximately 0.375 inch. After removal of the soil from the drums and grinding, the soil was screened through a 0.375-inch sieve. In addition, Geotech claimed that the vitrification furnace could not handle the large mass of steam that would be produced during treatment of the soil, which was estimated to be about 20 percent water. Therefore, the crushed-and-sieved soil was dried to less than 5-percent moisture. A continuous-loop or toroidal-flash dryer, operating at 300 to 450 °F (150 to 230 °C) inlet temperature with approximately 175°F (80°C) outlet or exhaust temperature, was used to dry the soils. A baghouse captured the dust emitted by this drying process. After drying, the soil was mixed with sand (to increase the silica content and facilitate vitrification), carbon (to facilitate reduction of metals in the mixture), and the dust from the soil-dryer baghouse. The mixing provided a dried, well-blended mixture. The dried, blended soil mixture was placed in polypropylene bags (called "supersacs") and transported to the Geotech facility in Niagara Falls, New York.

4.2.2 Demonstration Activities

The soil collected from NJDEP Site 130 and Liberty State Park was prepared as discussed in Section 4.2.1 and shipped to the Geotech pilot plant in Niagara Falls, New York. Two separate test runs were planned, each using the soil from one of the two New Jersey chromium sites. Geotech determined the operating conditions for their system based on their vitrification experience and the flow characteristics of the molten Mulcoa and contaminated soil.

The furnace was prepared for each test run by lining it with sand and Mulcoa and then adding contaminated soil. The furnace was turned on and when it was at the proper temperature, as determined by the characteristics of molten Mulcoa, first molten Mulcoa and then molten soil were tapped and allowed to flow into either a water-cooled sluice or into carbon-lined molds for slow cooling and testing. Each of the two test runs was planned to last for 10 hours. After all the Mulcoa was vitrified and discharged, molten soil samples for analysis were collected at the beginning, middle, and end of each test run. Stack gas sample collection was to begin one hour after vitrified soil started to flow from the furnace.

4.3 SAMPLING PROGRAM

This section describes procedures for collecting representative samples at each of the 11 EPA SITE sampling locations. These locations include sampling points for dryer baghouse dust; carbon additive; sand additive; dried, blended soil mixture; vitrification furnace baghouse dust; stack emissions; ferrofurnace bottoms; vitrified product; sand added to the vitrification furnace; and Mulcoa. These are presented in Table 5.

4.3.1 Soil Dryer Baghouse Dust (Sampling Location S4)

Soil was collected from two New Jersey chromium sites, placed in drums, and shipped to Chem Pro Inc., in Camden, New Jersey, for crushing, sieving, drying, and blending. The drying apparatus included a baghouse to collect any particulate dust. The baghouse dust was then blended back into the dried soil. Using a plastic scoop, one sample of the baghouse dust was collected for each of the soils being treated. These two samples were analyzed for chromium and hexavalent chromium.

4.3.2 Carbon Additive (Sampling Location S5)

Carbon powder was used as an additive to the vitrification process to promote reduction of metals in the vitrification furnace. The carbon was added to the process during blending of the dried soil. The carbon produced by burning methane gas was certified by the producer as pure carbon; nevertheless, one bag of carbon was opened and sampled, using a plastic scoop. This sample was analyzed for chromium and hexavalent chromium.

4.3.3 Sand Additive (Sampling Location S6)

Sand (silica) powder was used as an additive to the vitrification process to promote vitrification in the furnace. The sand was added to the process during blending of the dried soil. The sand was certified by the producer as pure silicon dioxide; nevertheless, several bags were opened and sampled, using a plastic scoop. This composited sample was analyzed for chromium and hexavalent chromium.

4.3.4 Dried, Blended Soil Mixture (Sampling Location S7)

The soil was crushed, sieved, dried, and blended with carbon and sand additives and the dust collected in the soil-dryer baghouse was then placed in supersacs for transport to the Geotech facility. Four composite soil samples were collected from the Site 130 dried, blended soil mixture, and three composite soil samples were collected from the Liberty State Park dried, blended soil mixture. Each composite soil sample was composited from 10 or 15 grab samples from two or three supersacs, respectively. After each supersac was filled, five grab samples were collected by taking five cores over the entire depth of each supersac (one core in each corner and a fifth core in the center) using a grain thief; the grab samples were then placed in a 2-gallon Ziploc™ bag. Two or three supersacs were sampled and composited in the Ziploc™ bag, thoroughly mixed, and placed into appropriate sample containers, resulting in a single composite sample. This procedure was repeated for all of the supersacs for both of the soil types. Samples were analyzed for chromium and hexavalent chromium. Samples also were extracted by the TCLP, and the extract was analyzed for chromium.

4.3.5 Vitrification Furnace Baghouse Dust (Sampling Location S8)

The vitrification furnace included a baghouse to collect particulate dust from the vitrification furnace. At the end of each vitrification test run, the baghouse was shaken down, and all dust was removed. A plastic scoop was used to collect three samples of the dust. These samples were analyzed for chromium and hexavalent chromium. For each soil, three samples also were extracted using the TCLP, and the extract was analyzed for chromium.

Table 5. Sampling Locations

Matrix	Sampling Location	Method of Collection	Purpose
Soil dryer baghouse dust	S4	Grab sample	Determine partitioning of chromium and Cr^{+6}.
Carbon additive	S5	Grab sample	Assess whether additive contains chromium or Cr^{+6}.
Sand additive	S6	Composite sample	Assess whether additive contains chromium or Cr^{+6}.
Dried, blended soil mixture	S7	Composite sample	Determine partitioning of chromium and Cr^{+6}, and RCRA characteristic for chromium.
Vitrification furnace baghouse dust	S8	Grab sample	Determine partitioning of chromium and Cr^{+6}; and RCRA characteristic for chromium.
Stack emissions	S9 and S13	Composite and grab samples	Determine partitioning of chromium and Cr^{+6}; the final air emissions of dioxins, furans, and trace metals; particulate and HCl; and uncontrolled air emissions of O_2, CO_2, NO_x, SO_2, CO, and THC.
Ferrofurnace bottoms	S10	Grab sample	Determine partitioning of chromium and Cr^{+6} and RCRA characteristic for chromium.
Vitrified product	S11	Grab sample	Determine partitioning of chromium and Cr^{+6} and RCRA characteristic for chromium.
Sand added to vitrification furnace	S14	Grab sample	Assess whether additive contains chromium or Cr^{+6}.
Mulcoa	S15	Grab sample	Assess whether additive contains chromium or Cr^{+6}.

Notes:

CO Carbon monoxide
CO_2 Carbon dioxide
Cr^{+6} Hexavalent chromium
NO_x Nitrogen oxides
O_2 Oxygen
SO_2 Sulfur dioxide
THC Total hydrocarbons
RCRA Resource Conservation and Recovery Act

4.3.6 Stack Gas (Sampling Locations S13 and S9)

Stack gas sampling occurred at two locations in the APCS; the first location was at the baghouse inlet (Sampling Location S13), and the other location was at the baghouse outlet (Sampling Location S9). Furthermore, sampling was conducted at two places at Sampling Location S9: upstream (Sampling Location S9A) and downstream (Sampling Location S9B) of the induced draft (ID) fan. These sampling locations are discussed below.

4.3.6.1 Sampling Location S13 - Vitrification Hood Exhaust - APCS Inlet

The vitrification unit exhaust was modified to provide a sampling location meeting the minimum requirements of EPA Method 1. A circular duct, with a diameter of 15 inches, was inserted horizontally between the vitrification hood and the APCS. Three sampling locations were placed on this length of duct so that upstream and downstream disturbances could be minimized. A schematic of the circular duct showing the sampling locations is presented in Figure 5. Sampling ports were located on the bottom and the side of the duct. Sampling was conducted using a 2 by 6 sampling matrix (12 sampling points in each sampling axis) at all locations. The stack-emissions traverse layout, determined following EPA procedures, is shown in Figure 6 and the locations presented in Table 6.

4.3.6.2 Sampling Location S9A and B - APCS Outlet

Sampling was performed at the APCS outlet before and after the ID fan for Run 1 and before the ID fan for Run 2. The Method 23 sampling train at the APCS outlet was eliminated for dioxins and furans during Run 2 because the results from Run 1 were nearly identical, as expected, for both locations. Sampling was conducted at both locations using a 2 by 6 sampling matrix. More information regarding traverse points is presented in Table 6.

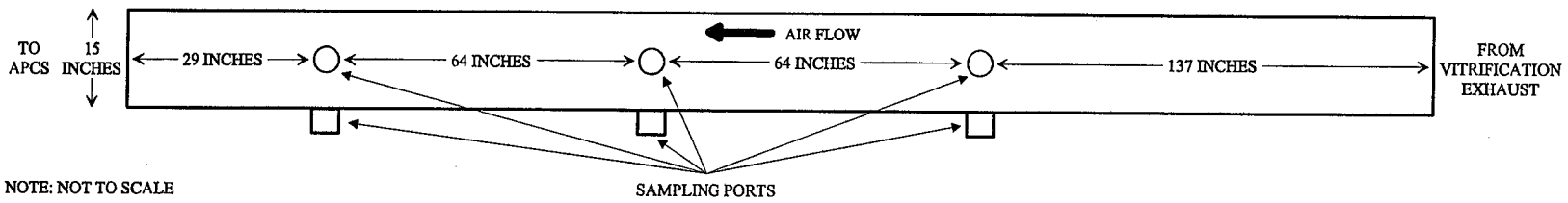


Figure 5. Sampling Locations S13 in Circular Duct after Vitrification Furnace

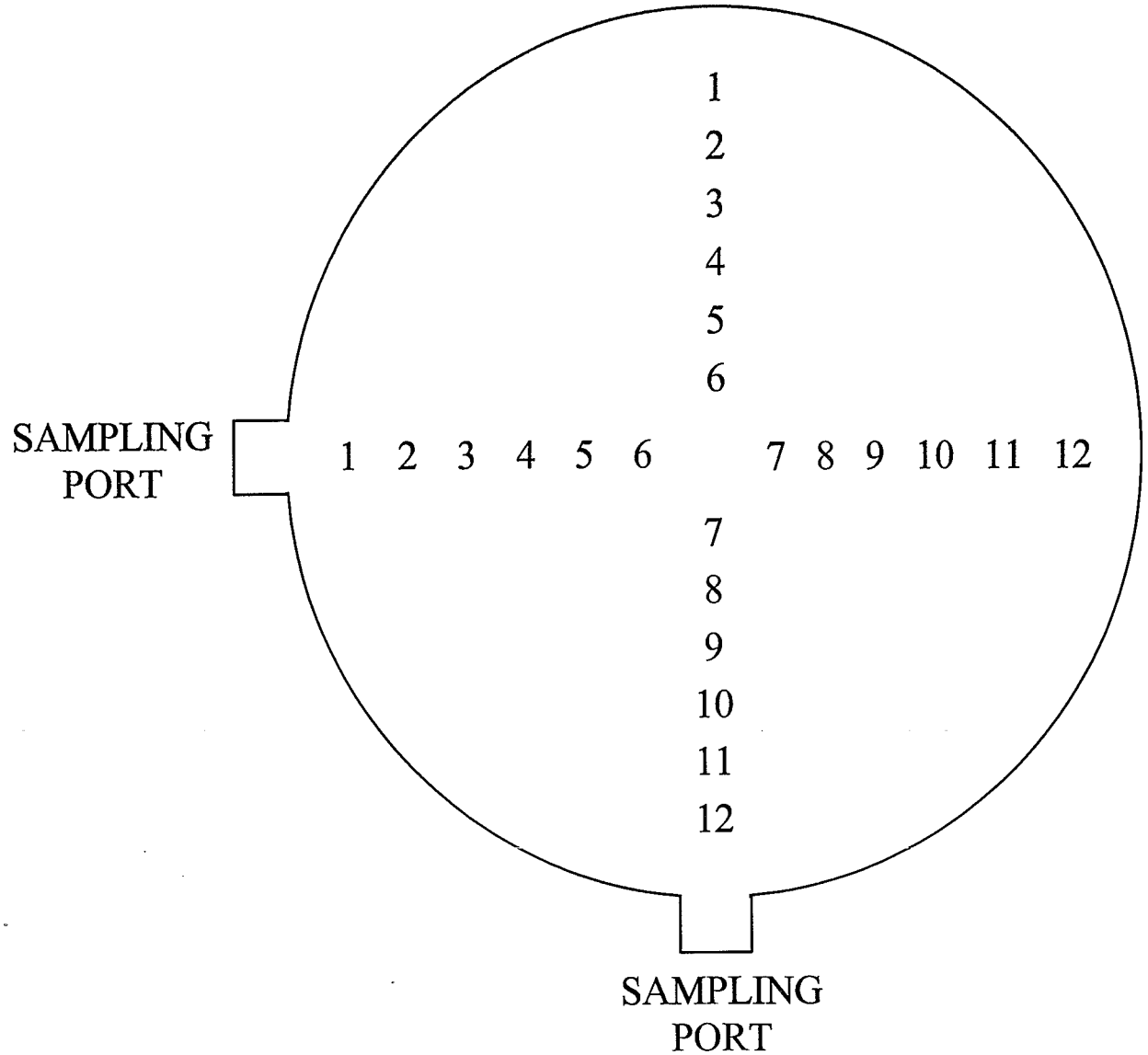


Figure 6. Traverse Point Layout for Sampling Locations S13 and S9

S9A - Upstream of the ID Fan

Sampling was performed on the upstream side of the ID fan through two ports 90° to one another on an 18-inch-diameter vertical duct exiting the APCS. Prior to the test program, a "honeycomb" flow straightener was inserted between this sampling location and the ID fan to eliminate any swirl or cyclonic flow that may be imparted on the flue gas by the ID fan. The nearest downstream disturbance was the bend before the ID fan, which was 36 inches away (2 diameters), and the nearest upstream disturbance was the APCS, which was 49 inches away (2.7 diameters). Figure 7 illustrates the layout of the location. Prior to testing, flow in this duct was checked for cyclonic flow, and none was found to be present at greater than 20°.

S9B - Downstream of the ID Fan

Sampling was performed on the downstream side of the ID fan through two ports 90° to one another on a 15-inch-diameter vertical duct exhausting to atmosphere. The nearest upstream disturbance was the ID fan, which was 51 inches away (3.4 diameters), and the nearest downstream disturbance was a bend in the duct, which was 20 inches away (1.3 diameters). The location is shown in Figure 7. Prior to testing, the flow was checked and no significant swirl was found to be present at greater than 20°.

Table 6. Traverse Point Location in Inches from Duct Wall

Traverse Points	Sampling Locations S13 and S9B (15-Inch Diameter)	Sampling Location S9A (18-Inch Diameter)
1 and 12	0.31	0.38
2 and 11	1.0	1.21
3 and 10	1.77	2.12
4 and 9	2.66	3.19
5 and 8	3.75	4.5
6 and 7	5.34	6.4

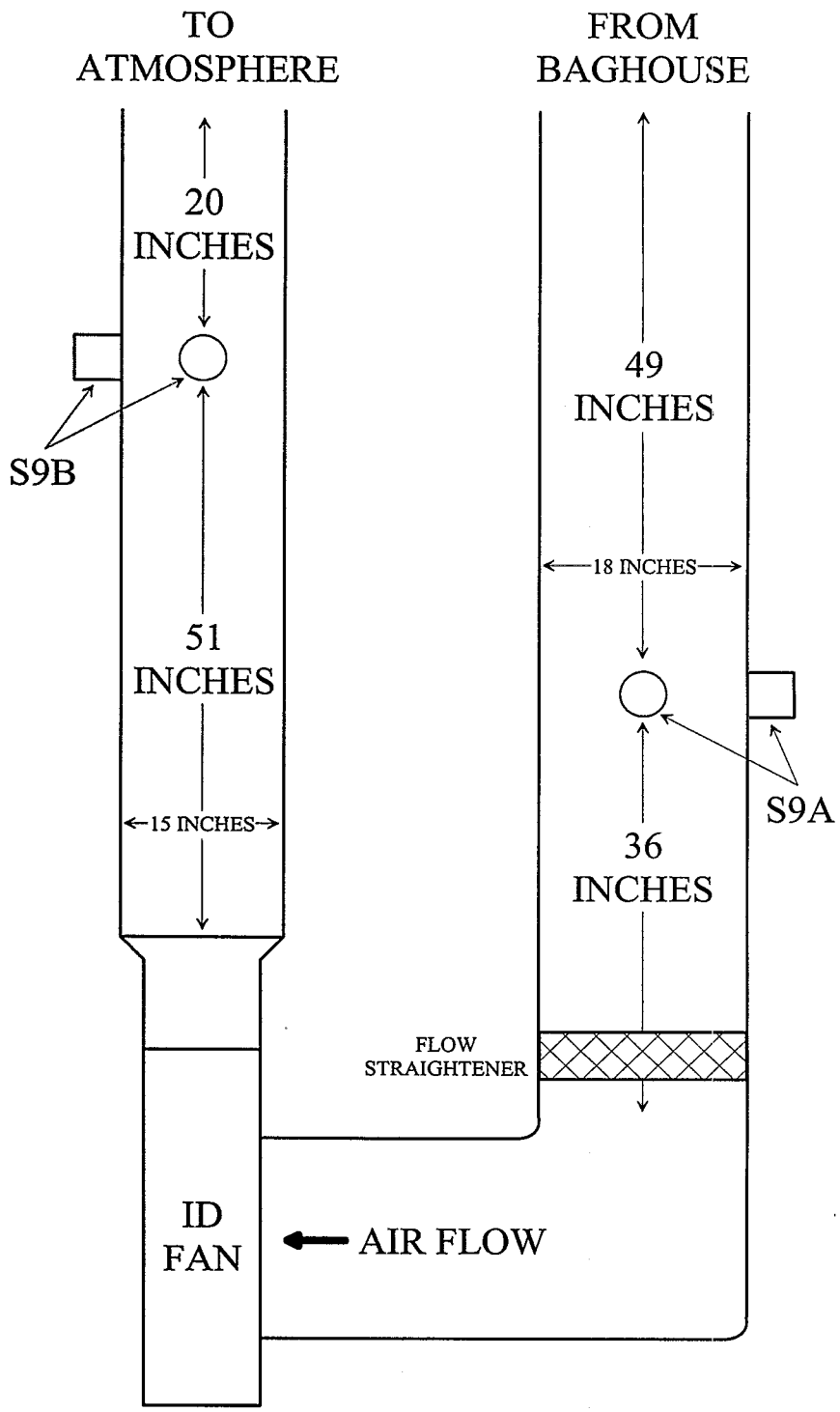


Figure 7. Sampling Locations S9A and S9B in the APCS Outlet

4.3.7 Ferrofurnace Bottoms (Sampling Location S10)

During a test run, a dense vitrified product, referred to as ferrofurnace bottoms, may collect in the bottom of the vitrification furnace. These ferrofurnace bottoms may separate from the vitrified product because of greater density. No ferrofurnace bottoms were produced during the Site 130 demonstration. About 200 pounds of ferrofurnace bottoms were manually removed after the Liberty State Park demonstration. A sample of ferrofurnace bottoms was collected, sized to pass a 0.375-inch sieve, and mixed. The sample was analyzed for chromium and hexavalent chromium. TCLP extraction, followed by chromium analyses of the extracts, was also performed.

4.3.8 Vitrified Product (Sampling Location S11)

During each test run, a vitrified product was produced and tapped from the middle of the vitrification furnace. This vitrified product was placed into insulated molds, where it was allowed to cool slowly, forming solid castings of vitrified product. To obtain representative samples, three complete castings, one each from the beginning, middle, and end of each of the test-run pours, were labeled and transported to NJIT by NJDEP personnel. Because the vitrified product may separate according to density, samples from various locations in each of the castings for each test run were collected and ground to pass a 200-mesh sieve (75 micrometers [μm] [0.0029 in.]). The samples of ground material were shipped to the analytical laboratory for chromium and hexavalent chromium analysis and TCLP extraction, followed by chromium analyses of the extracts.

4.3.9 Sand Added to Vitrification Furnace (Sampling Location S14)

Sand was added to the vitrification furnace before system startup to protect the bottom of the furnace and to help with the entrapment and separation of molten metals that might form from the high concentration of iron in the treatment soil and the reducing conditions of the furnace. One sample of sand was collected from a freshly opened bag using a plastic scoop. This sample was analyzed for chromium and hexavalent chromium.

4.3.10 Mulcoa (Sampling Location S15)

Mulcoa was added to the vitrification furnace before system startup to allow calibration of the heat input to the furnace. Using a plastic scoop, one sample of Mulcoa was collected from a freshly opened bag and analyzed for chromium and hexavalent chromium.

4.3.11 Sample Mass Measurements

The masses of waste and product streams were determined as follows:

Site	Carbon	Sand	Dried Blended Soil Mixture	Vitrification Baghouse Dust	Ferrofurnace Bottoms	Vitrified Product
Site 130	148 lb	1,830 lb	9,298 lb	4.5 lb	--	NR
Liberty State Park	100 lb	1,226 lb	6,226 lb	20 lb	200 lb	NR

Notes:

Ferrofurnace bottoms were not generated during vitrification of Site 130 soil.
lb = Pounds
NR = Not recorded

The sand and Mulcoa were added to the vitrification furnace prior to placing the dried, blended soil mixture in the furnace. The masses of the sand and Mulcoa were not measured and are not included in the above table. Sand was added as thermal insulation to protect the furnace walls. According to Geotech, little or no sand was removed from the furnace when the vitrified soil was tapped. Mulcoa was added to allow the system operators to calibrate the energy input to the furnace. According to Geotech, once the Mulcoa was vitrified, it was completely tapped from the furnace before demonstration testing occurred.

There are some discrepancies in the weight of the dried, blended soil mixtures. Measurements indicated that approximately 6,000 pounds of soil were collected at each site, yet when this soil was crushed, dried, and amended with a very small amount of carbon and 25 percent sand, over 9,000 pounds of material resulted for Site 130 but only 6,000 pounds for Liberty State Park. These masses were

weighed as the dried, blended soil mixtures were readied for shipping to the vitrification facility as a part of the SITE demonstration and are accurate. Clearly there is a discrepancy that the SITE program has not been able to resolve. Possibilities include other material being mixed in with the Site 130 soil, extra sand having been added, or other mistakes. For this reason, along with various operational changes to the Cold Top system, we have concluded that calculation of an accurate mass balance is not possible.

4.4 DEMONSTRATION RESULTS

This section summarizes sampling data collected during the SITE demonstration. Due to the lack of certainty of the mass of the dried, blended soil mixture (see Section 4.3.11); changes to the furnace APCS between the two test runs (see Section 4.4.5.0); and the unexpected system shutdown early in the first test run (see Section 4.4.5.1), all demonstration data are considered to be observational data. Observational data are data that are adequate to make rough comparisons of results but not adequate to meet the high degree of confidence specified in the SITE demonstration project objectives.

4.4.1 RCRA TCLP Chromium Standard

The Cold Top technology vitrified chromium-contaminated soil from the two New Jersey sites, producing a product meeting the RCRA TCLP chromium standard (see Tables 7 and 8). Vitrification of soil from one of the two sites also produced ferrofurnace bottoms, a potentially recyclable metallic product, that also met the RCRA TCLP chromium standard.

4.4.2 Chromium

With the exception of the vitrification-baghouse-dust and the ferrofurnace-bottoms samples, chromium content of the vitrified product did not differ significantly from that of the untreated soil.

The concentrations of chromium in the vitrification-baghouse-dust and ferrofurnace-bottoms samples were about two and five times greater, respectively, than those found in the untreated soils. These data are summarized in Tables 7 and 8.

Table 7. Contaminant Concentrations in Samples from Site 130

Contaminant	Feed Soil		Vitrification Baghouse Dust		Ferrofurnace Bottoms [1]		Vitrified Product	
	Analytical Results	Mean / SD	Analytical Results	Mean / SD	Analytical Results	Mean / SD	Analytical Results	Mean / SD
TCLP	57		23				0.11	
Chromium [2]	58	**58 / 1.1**	24	**24 / 0.58**	–	–	0.15	**0.31 / 0.32**
(mg/L)	59		24				0.68	
Hexavalent	1800						<0.36 [4]	
Chromium	1900	**1800 / 100**	1800 [3]	–	–	–	<0.40 [4]	–
(mg/kg)	2000						<0.41 [4]	
Chromium	5000						5000	
(mg/kg)	5100	**5100 / 100**	11,000 [3]	–	–	–	5700	**5500 / 470**
	5100						5900	

Notes:

[1] Ferrofurnace bottoms were not produced from the vitrification of soil from Site 130.
[2] The RCRA TCLP standard for chromium is 5.0 mg/L.
[3] Only one analysis was performed.
[4] No hexavalent chromium was detected.
mg/kg Milligrams per kilogram
mg/L Milligrams per liter
RCRA Resource Conservation and Recovery Act
SD Standard Deviation
TCLP Toxicity characteristic leaching procedure

Table 8. Contaminant Concentrations in Samples From Liberty State Park

Contaminant	Feed Soil		Vitrification Baghouse Dust		Ferrofurnace Bottoms		Vitrified Product	
	Analytical Results	Mean / SD	Analytical Results	Mean / SD	Analytical Results	Mean / SD	Analytical Results	Mean / SD
TCLP	26		11		1.6		0.33	
Chromium [1]	30	**29 / 3.1**	11	**11 / 0.58**	2.2	**2.4 / 0.92**	0.68	**1.0 / 0.94**
(mg/L)	32		12		3.4		2.1	
Hexavalent	760				<4.0 [3]		<0.39 [3]	
Chromium	950	**900 / 120**	360 [2]	–	<4.0 [3]	–	<0.41 [3]	–
(mg/kg)	980				<4.0 [3]		1.8	
Chromium	6,300				30,300	**35,900 /**	10,000	
(mg/kg)	7,100	**6,900 / 530**	16,000 [2]	–	37,800	**4900**	10,000	**10,300 / 577**
	7,300				39,500		11,100	

Notes:

[1] The RCRA TCLP standard for chromium is 5.0 mg/L.
[2] Only one analysis was performed.
[3] No hexavalent chromium was detected.
mg/kg Milligrams per kilogram
mg/L Milligrams per liter
RCRA Resource Conservation and Recovery Act
SD Standard Deviation
TCLP Toxicity characteristic leaching procedure

4.4.3 Hexavalent Chromium

Hexavalent chromium was not detected in the ferrofurnace-bottoms samples and was only detected in one of six vitrified-product samples (see Tables 7 and 8).

Hexavalent chromium concentrations ranged from one-half to about the same concentration in the vitrification-baghouse dust as in the untreated soil. The baghouse dust was presumed to be mainly fine-sized, untreated soil that was carried over from the dust caused by introducing the dried, blended soil mixture into the vitrification furnace and carried through the APCS.

4.4.4 NJDEP Soil Cleanup Standards

Comparison of metal concentrations in the vitrified product to the NJDEP soil cleanup standards indicated that the vitrified product met the non-residential soils standard for hexavalent chromium, antimony, beryllium, cadmium, nickel, and vanadium, but not for chromium. For residential soils the vitrified product met the NJDEP standard for hexavalent chromium, beryllium, and possibly cadmium, but not for chromium, antimony, nickel, and vanadium. Table 9 presents the metal concentrations found in the vitrified products from each site and the NJDEP soil cleanup standards for non-residential areas.

4.4.5 Stack Emissions

The test program consisted of two separate runs. Sampling for chromium and hexavalent chromium was completed at Sampling Locations S9 and S13 during both runs. Method 23 was completed at Sampling Locations S9A and S13 during Run 1 and at Sampling Location S13 for Run 2. Method 23 sampling was not conducted during Run 2 at Sampling Location S9 because the dioxin and furan results from Run 1 were similar, as expected from their proximity. Method 29 sampling was completed at S9 during both Runs 1 and 2. CEM measurements for oxygen, carbon dioxide, carbon monoxide, nitrogen oxides, and sulfur dioxide were taken during Runs 1 and 2 at Sampling Location S13. Although not a planned measurement, during Run 2 total hydrocarbon (THC) CEM measurements were also taken at Sampling Location S13.

Table 9. New Jersey Soil Cleanup Standards

	Vitrified Product (mg/kg)		New Jersey Soil Cleanup Criteria[1] (mg/kg)	
	Site 130	Liberty State Park	Residential	Non-Residential
Chromium	5500	10,000	500[2]	500[2]
Hexavalent chromium	<0.41	<0.39 to 1.8[3]	10[2]	10[2]
Antimony	61	29	14	340
Beryllium	<0.80	<0.78	1[4]	1[4]
Cadmium	<2.2	<2.1	1	100
Nickel	420	1,600	250	2,400[5,6]
Vanadium	380	440	370	7,100[5]

Notes:

1 State of New Jersey Technical Requirements for Site Remediation (N.J.A.C. 7:23E), Criteria for Residential and Non-Residential Direct Contact Soil Cleanup and Impact to Groundwater, revised July 11, 1996.

2 Currently under revision.

3 Values range from below detection limit (0.39 to 0.41 mg/kg) for five samples to 1.8 mg/kg for one sample.

4 This health-based criteria is lower than analytical limits; the cleanup criteria is based on practical quantitation level.

5 The level of the human health based criterion is such that evaluation for potential environmental impacts on a site-by-site basis is recommended.

6 This criterion is based on the inhalation exposure pathway which yielded a more stringent criterion than the incidental ingestion pathway.

ND Not defined.

4.4.5.1 Field Test Changes

Run 1

A process upset occurred midway through the Run 1 test, and only one of the two required traverses was completed. Because of the incomplete test, the data throughout this report have been qualified as observational due to this sampling deviation.

Post-test calibrations were conducted on two probes with suspect pitot calibrations. A leak in the pitot tubes that was missed during initial calibrations was found prior to sampling. On the sampling run sheet for Method Cr^{+6} (hexavalent chromium) at Sampling Location S13, the pitot tube calibration was 0.876 and the post-test calibration value was 0.848. This latter value was used for all calculations. On the sampling run sheet for Method Cr^{+6} at Sampling Location S9A, the pitot tube calibration was 0.880 and the post-test calibration value was 0.823. This latter value was used for all calculations.

Run 2

Prior to the start of Run 2, a damper in the duct connecting the vitrification furnace hood to the APCS was opened by the technology developer. The sampling team were not aware of this deviation, which allowed much more dilution air to enter the APCS. All results from Run 2, while analytically sound, were not obtained with the system operating under the same conditions as the Run 1 results. The Run 2 results should also be considered observational.

4.4.5.2 Results of Critical Parameters--Fluegas

Tables 10 and 11 present chromium and hexavalent chromium results at Sampling Locations S13 and S9A.

4.4.5.3 Results of Non-Critical Parameters--Fluegas

Tables 12 through 17 present concentrations and emission rate results, as well as measurement parameters, for non-critical parameters, including dioxins and furans, trace metals, particulate, and hydrogen chloride gas (HCl) at Sampling Locations S13 and S9A.

Table 10. Chromium and Hexavalent Chromium Test Results at Sampling Location S13

Parameter	Unit	Site 130	Liberty State Park
Cr^{+6} Concentration, uncorrected	mg/dscm	3.22	0.503
Cr^{+6} Concentration @ 7% O_2	mg/dscm	195	77.7
Cr^{+6} Emission rate	g/hr	6.02	2.17
Chromium concentration, uncorrected	mg/dscm	24.4	7.43
Chromium concentration @ 7% O_2	mg/dscm	1,480	1,150
Chromium emission rate	g/hr	45.7	32.0
Moisture content	%	2.69	1.35
Isokinetic variation	%	102 [1]	97.4
Dry gas volume	dscm	1.05	3.80
Fluegas temperature	°F	137	81.5
Velocity	ft/s	17.7	36.0
Stack gas flow rate	dscm/hr	1,870	4,310
Oxygen content	%V	20.7	20.8
Carbon dioxide content	%V	0.64	0.34

Notes:

[1]	Based on an incomplete test run
Cr^{+6}	Hexavalent chromium
dscm/hr	Dry standard cubic meter per hour
g/hr	Grams per hour
mg/dcsm	Milligrams per dry standard cubic meter
O_2	Oxygen
%V	Percent by volume

Table 11. Chromium and Hexavalent Chromium Test Results at Sampling Location S9A

Parameter	Unit	Site 130	Liberty State Park
Cr^{+6} Concentration, uncorrected	μg/dscm	0.321	-0.322 [1]
Cr^{+6} Concentration @ 7% O_2	μg/dscm	20.3	-56.0 [1]
Cr^{+6} Emission rate	μg/hr	729	-1,410 [1]
Chromium concentration, uncorrected	μg/dscm	2.59	13.7
Chromium concentration @ 7% O_2	μg/dscm	164	2,380
Chromium emission rate	μg/hr	5,900	60100
Moisture content	%	2.86	0.751
Isokinetic variation	%	104 [2]	95.0
Dry gas volume	dscm	1.41	2.61
Fluegas temperature	°F	102	74.1
Velocity	ft/s	14.1	24.9
Stack gas flow rate	dscm/hr	2,270	4,380
Oxygen content	%V	20.7	20.8
Carbon dioxide content	%V	0.61	0.34

Notes:

[1]	Negative numbers due to sample dilution
[2]	Based upon an incomplete test run
Cr^{+6}	Hexavalent chromium
dscm	Dry standard cubic meter
ft/s	Feet per second
O_2	Oxygen
μg/dscm	Microgram per dry standard cubic meter
μg/hr	Microgram per hour
%V	Percent by volume

Table 12. Dioxins and Furans Fluegas Parameters

Parameter	Unit	Sampling Location S13		Sampling Location S9A
		Site 130	Liberty State Park	Site 130
Moisture content	%	4.84	1.31	4.21
Isokinetic variation	%	99.0 [1]	96.5	104 [1]
Dry gas volume	dscm	1.10	2.60	1.07
Fluegas temperature	°F	129	82.7	103
Velocity	ft/s	16.8	38.9	14.4
Stack gas flow rate	dscm/hr	1,760	4,650	2,300
Oxygen content	%V	20.7	20.8	20.7
Carbon dioxide content	%V	0.61	0.34	0.61

Notes:

[1]	Based on an incomplete test run
dscm	Dry standard cubic meter
dscm/hr	Dry standard cubic meter per hour
ft/s	Feet per second
%V	Percent by volume

Table 13. Dioxins and Furans Fluegas Concentration at 7 Percent Oxygen

Parameter	Unit	Sampling Location S13		Sampling Location S9A
		Site 130	Liberty State Park	Site 130
2,3,7,8-TCDF	ng/dscm	58	Q, 7.6	J, 2.2
2,3,7,8-TCDD	ng/dscm	ND, 9.7	ND, 4.6	ND, 2.6
1,2,3,7,8-PeCDF	ng/dscm	28	J, C, 4.0	J, 1.7
2,3,4,7,8-PeCDF	ng/dscm	Q, 31	J, 4.5	J, 1.8
1,2,3,7,8-PeCDD	ng/dscm	Q, 8.0	J, Q, 2.6	ND, 2.2
1,2,3,4,7,8-HxCDF	ng/dscm	J, C, 64	J, Q, 5.9	J, 1.9
1,2,3,6,7,8-HxCDF	ng/dscm	Q, 24	J, Q, 2.8	J, Q, 1.1
2,3,4,6,7,8-HxCDF	ng/dscm	20	J, 3.6	J, 0.82
1,2,3,7,8,9-HxCDF	ng/dscm	J, 4.4	ND, 2.7	ND, 1.0
1,2,3,4,7,8-HxCDD	ng/dscm	J, 6.6	ND, 3.9	ND, 3.1
1,2,3,6,7,8-HxCDD	ng/dscm	J, Q, 8.9	J, 2.1	ND, 3.0
1,2,3,7,8,9-HxCDD	ng/dscm	J, 14	J, 2.1	ND, 2.8
1,2,3,4,6,7,8-HpCDF	ng/dscm	76	J, 8.8	J, 2.6
1,2,3,4,7,8,9-HpCDF	ng/dscm	J, 7.6	ND, 4.4	ND, 2.0
1,2,3,4,6,7,8-HpCDD	ng/dscm	48	J, 10	J, Q, 1.7
1,2,3,4,6,7,8,9-OCDF	ng/dscm	34	J, 7.9	J, Q, 2.0
1,2,3,4,6,7,8,9-OCDD	ng/dscm	J, Q, 290	b, 79	J, Q, 10
Total TCDF	ng/dscm	J, Q, 920	Q, 78	Q, 38
Total PeCDF	ng/dscm	Q, 470	J, Q, 48	J, Q, 13
Total HxCDF	ng/dscm	Q, 250,	J, Q, 28	J, Q, 7.4
Total HpCDF	ng/dscm	Q, 100	J, 10	J, 2.7
Total TCDD	ng/dscm	Q, 57,	Q, 14	J, Q, 2.8
Total PeCDD	ng/dscm	Q, 47	J, Q, 14	J, Q, 1.3
Total HxCDD	ng/dscm	Q, 65	J, Q, 20	J, 2.1
Total HpCDD	ng/dscm	93	J, 21	J, Q, 3.1
Minimum 2,3,7,8-TCDD TEQ (not including ND)	ng/dscm	>39	>5.3	>1.2
Maximum 2,3,7,8-TCDD TEQ (including ND)	ng/dscm	<56	<13	<6.8

Table 13 (Continued). Dioxins and Furans Fluegas Concentration at 7 Percent Oxygen

Notes:

b	Estimated result/result is less than reporting limit
C	Co-eluting isomer
HpCDD	Heptachloro dibenzodioxins
HpCDF	Heptachloro dibenzofuranss
HxCDD	Hexachloro dibenzodioxins
HxCDF	Hexachloro dibenzofurans
J	Detected at less than laboratory reporting limit, result is considered an estimate
ND	Not detected, value reported is the detection limit
ng/dscm	Nanogram per dry standard cubic meter
PeCDD	Pentachloro dibenzodioxins
PeCDF	Pentachloro dibenzofurans
OCDD	Octachloro dibenzodioxins
OCDF	Octachloro dibenzofurans
Q	Estimated maximum possible concentration
TCDD	Tetrachloro dibenzodioxins
TCDF	Tetrachloro dibenzofurans
TEQ	Toxicity equivalency factor

Table 14. Dioxins and Furans Fluegas Mass Emission Rates

Parameter	Unit	Sampling Location S13		Sampling Location S9A
		Site 130	Liberty State Park	Site 130
2,3,7,8-TCDF	μg/hr	1.6	Q, 0.22	J, 0.079
2,3,7,8-TCDD	μg/hr	ND, 0.27	ND, 0.14	ND, 0.093
1,2,3,7,8-PeCDF	μg/hr	0.79	J,C, 0.12	J, 0.062
2,3,4,7,8-PeCDF	μg/hr	Q, 0.85	J, 0.13	J, 0.067
1,2,3,7,8-PeCDD	μg/hr	Q, 0.22	J, Q, 0.08	ND, 0.080
1,2,3,4,7,8-HxCDF	μg/hr	Q, C, 1.8	J, Q, 0.18	J, 0.068
1,2,3,6,7,8-HxCDF	μg/hr	Q, 0.66	J, Q, 0.084	J, Q, 0.039
2,3,4,6,7,8-HxCDF	μg/hr	0.57	J, 0.11	J, 0.030
1,2,3,7,8,9-HxCDF	μg/hr	J, 0.12	ND, 0.08	ND, 0.037
1,2,3,4,7,8-HxCDD	μg/hr	J, 0.18	ND, 0.12	ND, 0.11
1,2,3,6,7,8-HxCDD	μg/hr	J, Q, 0.25	J, 0.060	ND, 0.11
1,2,3,7,8,9-HxCDD	μg/hr	J, 0.39	J, 0.070	ND, 0.10
1,2,3,4,6,7,8-PhCDF	μg/hr	2.1	J, 0.27	J, 0.096
1,2,3,4,7,8,9-HpCDF	μg/hr	J, 0.21	ND, 0.13	ND, 0.073
1,2,3,4,6,7,8-HpCDD	μg/hr	1.3	J, 0.31	J, Q, 0.062
1,2,,3,4,6,7,8,9-OCDF	μg/hr	0.95	J, 0.24	J, Q, 0.073
1,2,3,4,6,7,8,9-OCDD	μg/hr	J, Q, 8.0	b, 2.4	J, Q, 0.37
Total TCDF	μg/hr	J, Q, 26	Q, 2.4	Q, 1.4
Total PeCDF	μg/hr	Q, 13	J, Q, 1.5	J, Q, 0.45
Total HxCDF	μg/hr	Q, 7.0	J, Q, 0.84	J, Q, 0.27
Total HpCDF	μg/hr	Q, 2.9	J, 0.30	J, 0.098
Total TCDD	μg/hr	Q, 1.6	Q, 0.42	J, Q, 0.10
Total PeCDD	μg/hr	Q, 1.3	J, Q, 0.42	J, Q, 0.047
Total HxCDD	μg/hr	Q, 1.8	J, Q, 0.61	J, 0.075
Total HpCDD	μg/hr	2.6	J, 0.63	J, Q, 0.11
Minimum 2,3,7,8-TCDD TEQ (not including ND)	μg/hr	>1.1	>0.16	>0.043
Maximum 2,3,7,8-TCDD TEQ (including ND)	μg/hr	<1.5	<0.39	<0.25

Table 14 (Continued). Dioxins and Furans Fluegas Mass Emission Rates

Notes:

b	Estimated result/result is less than reporting limit
C	Co-eluting isomer
HpCDD	Heptachloro dibenzodioxins
HpCDF	Heptachloro dibenzofurans
HxCDD	Hexachloro dibenzodioxins
HxCDF	Hexachloro dibenzofurans
J	Detected at less than laboratory reporting limit, result is considered an estimate
μg/hr	micrograms per hour
ND	Not detected, value reported is the detection limit
PeCDD	Pentachloro dibenzodioxins
PeCDF	Pentachloro dibenzofurans
OCDD	Octachloro dibenzodioxins
OCDF	Octachloro dibenzofurans
Q	Estimated maximum possible concentration
TCDD	Tetrachloro dibenzodioxins
TCDF	Tetrachloro dibenzofurans
TEQ	Toxicity equivalency factor

Table 15. Trace Metals, Particulate, and Hydrogen Chloride Average Fluegas Values

Parameter	Unit	Sampling Location S9B	Sampling Location S9A
		Site 130	Liberty State Park
Moisture content	%	3.41	1.21
Isokinetic variation	%	107 [1]	96.7
Dry gas volume	dscm	1.06	1.43
Fluegas temperature	°F	98.2	72.6
Velocity	ft/s	19.5	25.8
Stack gas flow rate	dscm/hr	2,250	4,530
Oxygen content	%V	20.7	20.8
Carbon dioxide content	%V	0.61	0.34

Notes:

[1]	Based on an incomplete test run
dscm	Dry standard cubic meter
dscm/hr	Dry standard cubic meter per hour
ft/s	Feet per second
%V	Percent by volume

Table 16. Trace Metals, Particulate, and Hydrogen Chloride Fluegas Concentrations at 7 Percent Oxygen

Parameter	Units	Sampling Location S9B	Sampling Location S9A
		Site 130	Liberty State Park
Antimony	mg/dscm	2.46	1.86
Arsenic	mg/dscm	<10.7	<12.8
Barium	mg/dscm	6.81	7.7
Beryllium	mg/dscm	<0.179	<0.214
Cadmium	mg/dscm	<0.179	0.088B
Chromium	mg/dscm	0.394	0.421
Cobalt	mg/dscm	<1.79	<2.14
Copper	mg/dscm	1.11	0.564
Lead	mg/dscm	15.0	3.97
Manganese	mg/dscm	1.80	<0.64
Mercury	mg/dscm	<0.314	<0.378
Nickel	mg/dscm	1.11	<1.71
Selenium	mg/dscm	<8.96	<10.7
Silver	mg/dscm	<0.358	<0.428
Thallium	mg/dscm	<71.6	<85.7
Vanadium	mg/dscm	1.39	<2.14
Zinc	mg/dscm	23.0	2.97
Particulate	mg/dscm	1,130	425
Hydrogen chloride gas	mg/dscm	<12.3	<5.72

Notes:

B	Blank contamination
mg/dscm	Milligram per dry standard cubic meter
<	Not detected, value reported is detection limit

Table 17. Trace Metals, Particulate, and Hydrogen Chloride Fluegas Mass Emission Rates

Parameter	Units	Sampling Location S9B	Sampling Location S9A
		Site 130	Liberty State Park
Antimony	mg/hr	87.6	48.6
Arsenic	mg/hr	<383	<335
Barium	mg/hr	242	201
Beryllium	mg/hr	<6.38	<5.59
Cadmium	mg/hr	<6.38	2.29B
Chromium	mg/hr	14.0	11.0
Cobalt	mg/hr	<63.8	<55.9
Copper	mg/hr	39.6	14.7
Lead	mg/hr	533	104
Manganese	mg/hr	64.0	<16.6
Mercury	mg/hr	<11.2	<9.87
Nickel	mg/hr	39.6	<44.7
Selenium	mg/hr	<319	<279
Silver	mg/hr	<12.8	<11.2
Thallium	mg/hr	<2550	<2230
Vanadium	mg/hr	49.6	<55.9
Zinc	mg/hr	820	77.5
Particulate	g/hr	40.2	11.1
Hydrogen chloride gas	mg/hr	<438	149

Notes:

B	Blank contamination
g/hr	Grams per hour
mg/hr	Milligrams per hour
<	Not detected, value reported is detection limit

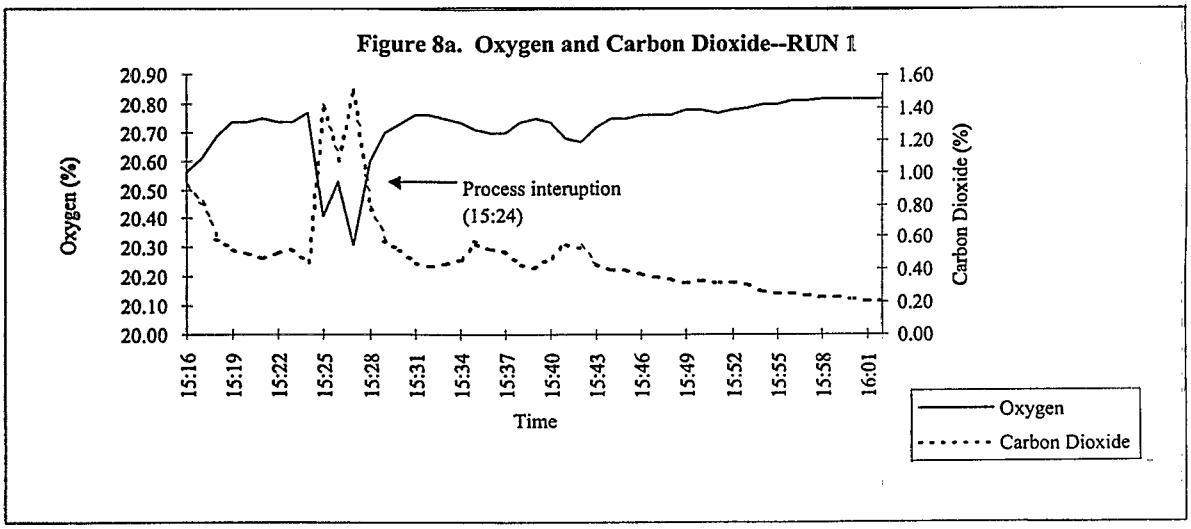
4.4.5.4 Continuous Emissions Monitoring

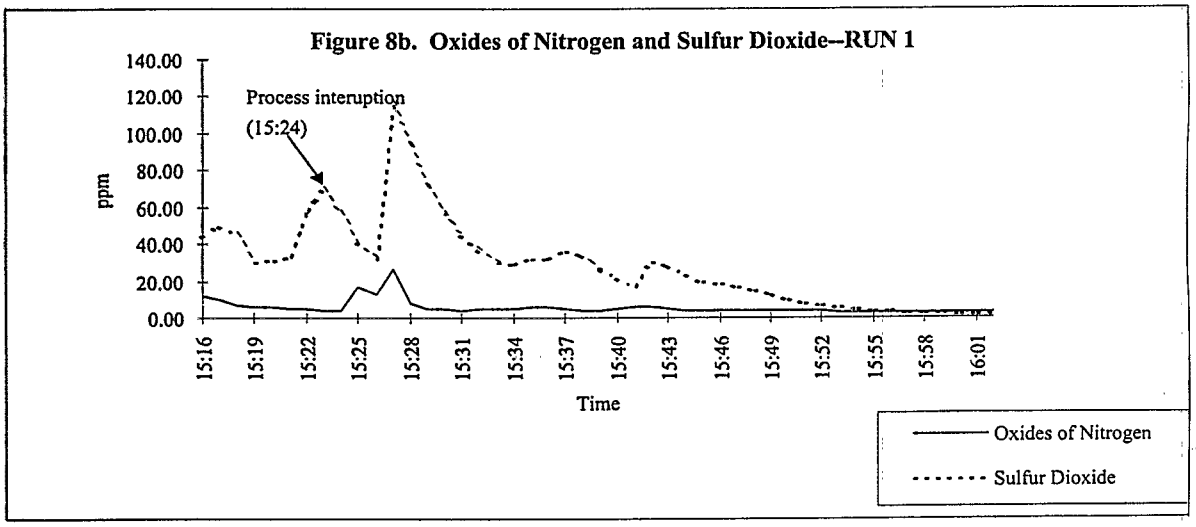
In order to determine the uncontrolled air emissions of carbon monoxide, carbon dioxide, nitrogen oxides, sulfur dioxide, and THC from the vitrification unit, on-line CEMs were used. For both Run 1 and Run 2, the CEMs were extracting uncontrolled exhaust gases at sampling location S13. The gases being analyzed during Run 1 were carbon monoxide, carbon dioxide, nitrogen oxides, oxygen, and sulfur dioxide. Additionally, THC was analyzed during Run 2 to determine if the high carbon monoxide that was encountered during Run 1 was the result of incomplete combustion of any organic compounds in the soil. Table 18 presents the CEM sampling matrix.

Table 18. CEM Sampling Matrix at Location S13

	Run 1	**Run 2**
Nitrogen oxides	X	X
Sulfur dioxide	X	X
Carbon monoxide	X	X
Total hydrocarbons		X
Oxygen	X	X
Carbon dioxide	X	X
Run time	15:16-16:02	10:29-18:00

During Run 1 the CEMs were on-line only during the time that was spent pouring the molds from the vitrification unit. During Run 2 the CEMs were on-line for the entire vitrification process. Figure 8a-c and Figure 9a-c illustrate the results of Run 1 and Run 2 respectively. Table 19 shows the averages of the flue gas concentrations for each gas for Run 1. Table 20 shows the average flue gas concentration for each of the gases with the damper open and closed (see Section 4.4.5.1) during Run 2.





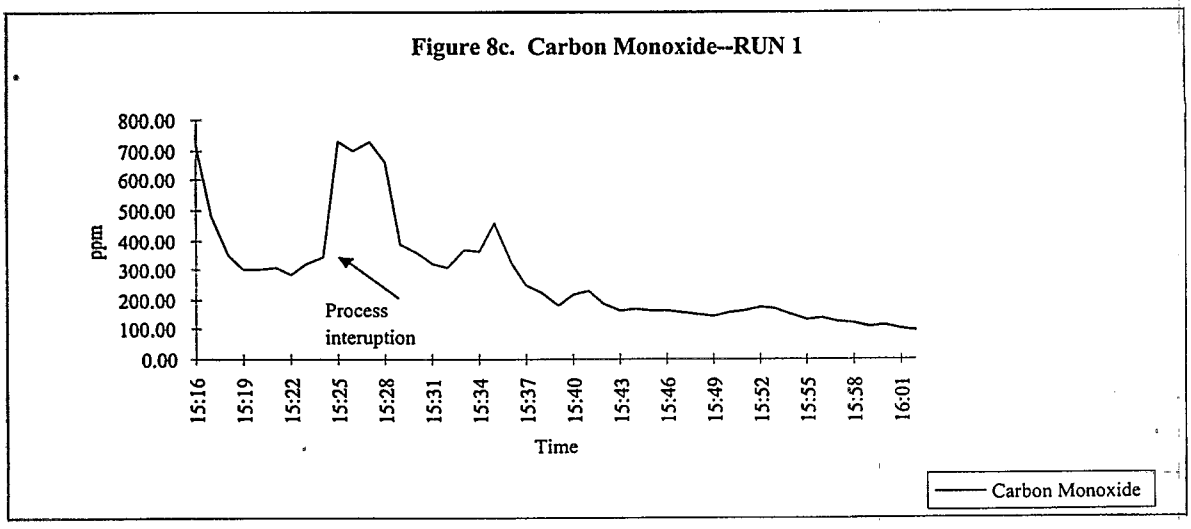


Figure 8. Run 1 Oxygen, Carbon Dioxide, Oxides of Nitrogen, Sulfur Dioxide, THC and Carbon Monoxide CEM Data

Figure 9a. Oxygen and Carbon Dioxide--RUN 2

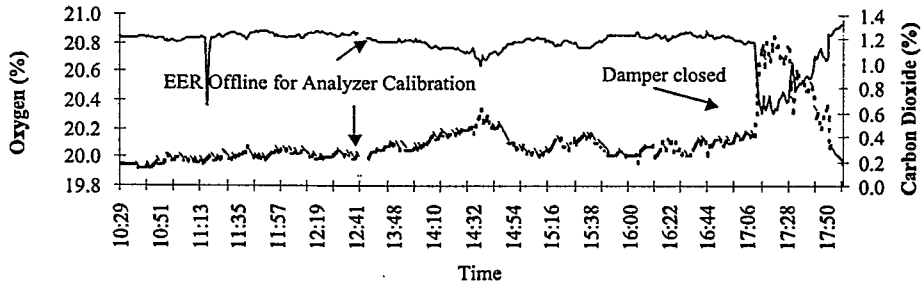


Figure 9b. Oxides of Nitrogen, Sulfur Dioxide and THC --RUN 2

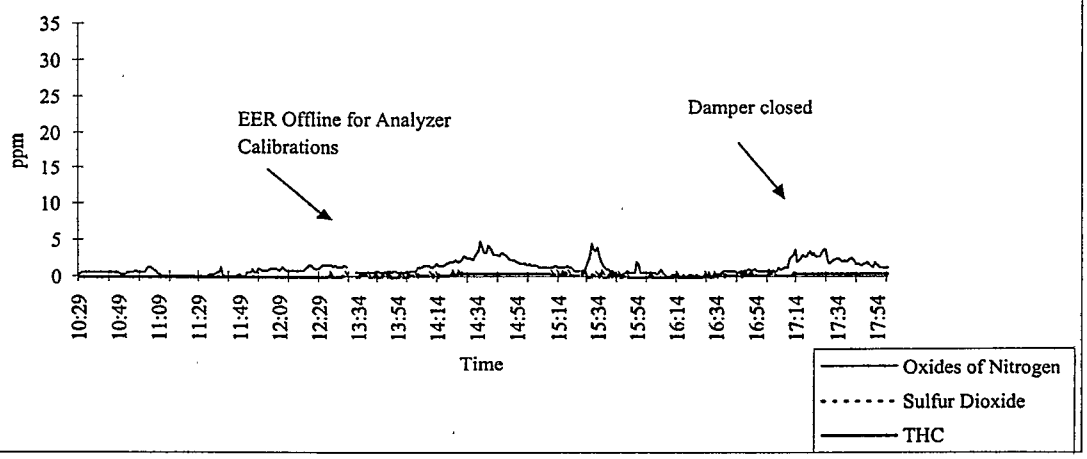


Figure 9c. Carbon Monoxide--RUN 2

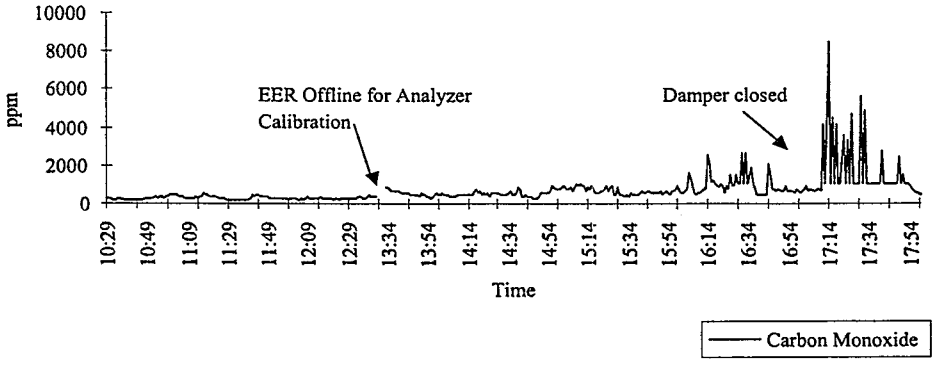


Figure 9. Run 2 Oxygen, Carbon Dioxide, Oxides of Nitrogen, Sulfur Dioxide, THC and Carbon Monoxide CEM Data

Table 19. CEMs--Run 1

	Entire Sampling Time (15:16-16:02)			During Mold Pour Only (15:16-15:40)		
Contaminant	Average	Maximum	Minimum	Average	Maximum	Minimum
Nitrogen oxides	5.51	26.3	2.69	7.11	26.3	3.85
Sulfur dioxide	29.6	116	1.70	46.2	116	21.6
Carbon monoxide	282	725	95.4	398	725	180
Total hydrocarbons	--	--	--	--	--	--
Oxygen	20.7	20.8	20.3	20.7	20.8	20.3
Carbon dioxide	0.49	1.5	0.21	0.63	1.5	0.41

Table 20. CEMs--Run 2

	Damper Open (10:29-17:10)			Damper Closed (17:11-18:00)		
Contaminant	Average	Maximum	Minimum	Average	Maximum	Minimum
Nitrogen oxides	0.96	4.67	0.00	2.32	3.81	1.19
Sulfur dioxide	0.15	0.49	0.00	0.49	0.49	0.33
Carbon monoxide	547	2650	142	1770	8490	469
Total hydrocarbons	5.39	21.3	2.01	18.7	29.0	10.4
Oxygen	20.8	20.9	20.4	20.6	20.9	20.3
Carbon dioxide	0.30	0.62	0.14	0.77	1.2	0.19

The decrease in the flue gas concentrations of the contaminants that is evident from Run 1 to Run 2 was caused by an open damper during the beginning of Run 2. This open damper allowed more dilution air to enter upstream of sampling location S13, thereby reducing the concentration of the contaminants. At the completion of the manual methods sampling this damper was closed as is noted on Figures 9a-c. When

the damper was closed the concentration of each of the gases increased to values similar to Run 1 with the notable exception of carbon monoxide which increased to approximately tenfold the carbon monoxide concentration of Run 1.

4.4.5.5 Compliance with NYSDEC

Flue gas sampling was conducted at Sampling Location S9 to determine adherence to the New York State Department of Environmental Conservation's (NYSDEC) guidelines for air emissions. Trace metals, chromium, and hexavalent chromium were sampled during Runs 1 and 2. Dioxins and furans were sampled at location S9A during Run 1. Dioxin and furan results from Run 1 were much lower than expected, therefore, the more conservative dioxin and furan results from S13 were used during Run 2. Mass emission rates for each of the contaminants tested at Sampling Location S9 are shown in Tables 14 and 17.

New York State employs ambient air guidelines for air emissions based on annual, potential annual, and short-term air quality impacts. The annual impact is based on the annual mass emission rate for a compound. In this case, 12 hours was used to determine the annual emission rate for each of the runs. The potential annual impact is calculated using the hourly mass emission rate for a compound and the maximum hours of operation in 1 year or 8,760 hours. The short-term impact is based on the impact that the mass emission rate of a compound has on the environment in 1 hour. These impacts are calculated using the NYSDEC air guide (NYSDEC 1995).

All compounds were below the NYSDEC annual guideline concentration (AGC) for Runs 1 and 2; however, several compounds apparently failed to meet the potential annual guideline concentration (PGC). Because the results of arsenic analysis were below the detection limit of the laboratory analysis, the actual detection limit was used to determine a conservative mass emission rate. Using this detection limit, arsenic failed to meet the criteria for PGC for Runs 1 and 2. Hexavalent chromium and total tetrachlorinated dibenzofurans failed to meet the PGC during Run 1. The PGC assumes that the vitrification unit emits the same hourly mass emission rate as was tested for 8,760 hours per year. Permit conditions restricting the hours per year of operation would be considered in a commercial setting. Using the arsenic detection limit, short-term guideline concentration (SGC) results show that arsenic also failed

to meet the SGC criteria for Runs 1 and 2. The conservative mass emission rate based upon the laboratory detection limit, coupled with the low SGC for arsenic, would explain this failure to meet the SGC.

4.4.6 Other Analyses

This section discusses the results of additional analyses that were performed on the untreated soil, the vitrified product, or the ferrofurnace-bottoms product.

4.4.6.1 Chloride Analysis

Prior to the demonstration there was concern that chloride present in the untreated soil might, along with the organic compounds present in the soil, lead to the formation of dioxins and furans. To assess whether chloride was present in the untreated soil from Site 130 and Liberty State Park, soil samples from both of these sites were collected and analyzed for chloride. The results are presented in Table 21. The chloride concentrations found in the untreated soil from both sites did not correlate with the dioxins and furans measured the offgas system during the demonstration.

Table 21. Chloride in Dried, Blended Soil Mixture

Site	Chloride (mg/kg)	
	Analytical Results	Mean / SD
Site 130	35 67 93	65 / 29
Liberty State Park	34 42 85	54 / 27

Note:
SD Standard Deviation

4.4.6.2 Metallurgy of Ferrofurnace Bottoms

Ferrofurnace bottoms, a metallic product rich in iron, was formed during the vitrification of the Liberty State Park soil. Samples of this material were sent to a laboratory for analyses. The results of the analyses are presented in Table 22.

4.4.6.3 Synthetic Precipitation Leaching Procedure

After completion of the demonstration an EPA reviewer requested that SW-846 Method 1312, the Synthetic Precipitation Leaching Procedure (SPLP) be performed on the vitrified product as that would be one result that regulators would want to have available. The test was performed and the results are presented in Table 23. No metals were found at concentrations that would cause regulatory concern.

Table 22. Metal Composition of Ferrofurnace Bottoms from Liberty State Park Soil [1]

	Sample #1 (%)	Sample #2 (%)	Sample #3 (%)
Hexavalent chromium	ND	ND	ND
Chromium	3.03	3.78	3.95
Arsenic	0.03	0.04	NA
Iron	53.8	56.3	63.4
Molybdenum[2]	30.1	27.1	18.6
Nickel	0.29	0.31	0.33
Silicon	0.03	0.07	0.07

Notes:

[1] All samples were digested in nitric acid and hydrofluoric acid and analyzed by flame atomic absorption.
[2] Molybdenum was a component of the electrodes used during the demonstration.
ND Not detected
NA Not analyzed

4.4.7 Cost

Cold Top treatment of chromium-contaminated soil, similar to the soils treated during the SITE demonstration, is estimated to cost from $83 to $213 per ton, depending on disposal costs and potential credits for the vitrified product. The three scenarios evaluated included (1) use of the vitrified product as aggregate, (2) backfilling of the aggregate on site, and (3) landfilling of the aggregate. Costs for these three scenarios were $83, $98, and $213 per ton, respectively. Because of the uncertainty of their formation, potential credits for ferrofurnace bottoms were not considered in this economic analysis.

Table 23. Synthetic Precipitation Leaching Procedure Results

SPLP Metal	Site 130 (mg/L)	Liberty State Park (mg/L)
Antimony	<0.050	<0.050
Arsenic	<0.050	<0.050
Barium	0.075	0.11
Beryllium	<0.0010	<0.0010
Cadmium	<0.0046	<0.0046
Chromium	<0.0056	0.016J
Lead	<0.034	<0.034
Nickel	<0.025	<0.025
Selenium	<0.078	<0.078
Silver	<0.0032	<0.0032
Vanadium	<0.0076	<0.0076

Note:

J = Estimated value, below practical quantitation limit.

4.4.8 Summary of Demonstration Results

The following are the observational findings of the Cold Top SITE demonstration at the Geotech facility:

- The Cold Top technology vitrified chromium-contaminated soil from two New Jersey sites, producing a product that met the RCRA TCLP chromium standard. Vitrification of soil from one of the two sites produced, in addition to the vitrified product, a potentially recyclable metallic product meeting the RCRA TCLP chromium standard. Dust collected in the baghouse of the APCS failed to met the RCRA TCLP chromium standard.

- With the exception of the vitrification-baghouse-dust and ferrofurnace-bottoms samples, the chromium content of the vitrified product did not differ significantly from that of the untreated soil. The concentration of chromium in the vitrification-baghouse-dust and ferrofurnace-bottoms sample were about two and five times, respectively, the concentrations found in the untreated soil.

  The hexavalent chromium concentrations in the vitrified-product and ferrofurnace-bottoms samples were either not detected or present at a concentration of 500 times less than that found in the untreated soil. The hexavalent chromium concentrations ranged from one half to approximately the same in the vitrification baghouse dust as in the untreated soil.

- Cold Top treatment of chromium-contaminated soil, similar to the soils treated during the SITE demonstration, is estimated to cost from $83 to $213 per ton, depending on disposal costs and potential credits for the vitrified product.

- Comparison of metal concentrations in the vitrified product to the NJDEP interim standards revealed that antimony, beryllium, cadmium, nickel, vanadium, and hexavalent chromium met the non-residential soil standards while chromium did not.

- Although the Cold Top technology has nothing to do with incineration, stack emissions from the demonstration were compared to Subpart O incinerator regulations, and the results were mixed.

  Data collected during the SITE demonstration were entered into complex modeling calculations for the NYSDEC air emission regulations. The modeling required that site- and waste-specific analyses be performed to assess the environmental impact of Cold Top stack emissions. Modeling results were found to be dependent on the soil, APCS configuration, and detection limits of the various analytes.

- The chloride concentrations found in the untreated soil from both sites did not correlate with the dioxins and furans measured the offgas system during the demonstration. The dioxin and furan results were generally below the laboratory reporting limits.

- Analyses of the ferrofurnace bottoms produced from the Liberty State Park soil indicated that the samples contained 53 to 64 percent iron, 3 to 4 percent chromium, and less than 0.4 percent nickel, as well as molybdenum from the furnace electrodes.

- One sample of vitrified material from each of the soils was extracted and analyzed by the SPLP procedure for 11 metals. Low amounts of barium were found in both samples and a very low amount of chromium (0.0056 mg/L) was found in the sample from Liberty State Park.

4.5 QUALITY ASSURANCE AND QUALITY CONTROL

QC checks and procedures were an integral part of the Geotech SITE demonstration to ensure that QA objectives were met. These checks and procedures focused on (1) the collection of representative samples that were free of external contamination and (2) the analysis of comparable data. Two kinds of QC checks and procedures were conducted during the demonstration: (1) checks controlling field activities, such as sample collection and shipping, and (2) checks controlling laboratory activities, such as extraction and analysis. A detailed discussion of the QA/QC program is provided in the Geotech Technology Evaluation Report (TER) (EPA 1999).

Due to an unexpected system shutdown during Run 1, a change to the vitrification furnace APCS during Run 2, and an unexplainable discrepancy in the mass of untreated soil for Run 1, all data and conclusions from this demonstration are considered to be observational and do not meet the stringent levels of statistical significance established for this project.

4.5.1 Conformance With Quality Assurance Objectives

The overall quality assurance goal for the Cold Top SITE Demonstration, was to produce well-documented data of known quality, as indicated by the data's precision, accuracy, representativeness, comparability, and completeness, and the target reporting limits for the analytical methods. Specific Quality Assurance Objectives (QAOs) were established as benchmarks by which each criterion would be evaluated. These QAOs were presented in the demonstration QAPP and are shown in Table 24. (EPA 1996). This section discusses the quality assurance data for the demonstration.

4.5.1.1 Method Blanks

Method blanks evaluate the representativeness of the data by checking for laboratory-induced contamination. Method blanks were analyzed with each sample batch and consisted of an aliquot of reagent

water carried through all preparation and analysis steps. Ideally, method blanks should not contain analytes at concentrations above the method detection limit (MDL). Should the blank show contamination, corrective actions vary, depending on the specific contaminant, its concentration, and whether the contaminant is also detected in the sample. Chromium was detected in one of three method blank samples at an estimated concentration of 3.9 mg/kg. Samples associated with this blank were the S4 (soil dryer baghouse dust) and S7 (dried, blended soil mixture) samples collected on January 29, 1997.

TCLP chromium was detected in one method blank sample at an estimated concentration of 0.0062 mg/L. The samples associated with this blank were the S11 (vitrified product) samples collected on February 10 and 11, 1997. Chromium was also detected in one TCLP blank at an estimated concentration of 0.0056 mg/L, the same concentration as the MDL; the S7 (dried, blended soil mixture) samples collected on January 27, 1997, were associated with this blank. Barium was detected in only one SPLP blank at a concentration of 0.085 mg/L; the S11 (vitrified product) samples were associated with this blank.

4.5.1.2 Analytical Quality Control Categories

This section discusses the types of analytical QC applied to the data collected during the demonstration. These QC checks determined the data's accuracy, precision, representativeness, completeness, and comparability.

4.5.1.2.1 Accuracy

Accuracy is a measure of the analytical system's achievement of the true value. Accuracy is determined by calculating percent recovery from samples spiked with a known concentration of a selected compound or analyte

All but three recoveries were within QC limits. One sample of dried, blended soil mixture and one sample of vitrification furnace baghouse dust had MS and MSD percent recoveries of 0 for TCLP chromium due to dilution of the extract. Another sample of dried, blended soil mixture had an MS percent recovery of 157.5 for TCLP chromium. Analytical results for these samples are considered to be acceptable without qualification.

Table 24

QA Objectives for Accuracy, Precision, and Completeness

Compound	Matrix	Analytical Method	Accuracy (% Rec)	Precision (% RPD)	TRL	Completeness (%)
Chromium	Solid	SW-846 3052 and 6010A	75 to 125	<25	14 mg/kg	90
Cr^{+6}	Solid	SW-846 3060A and 7196A	70 to 130	<30	0.41mg/kg	90
Chromium (TCLP)[1]	Solid	SW-846 1311, 3010A, and 6010A	75 to 125	<25	0.56 mg/L	90
Chromium	Stack emissions	EPA Method Cr^{+6}/3052/6010A	75 to 125	<20	1.2 ug/ dscm	90
Cr^{+6}	Stack emissions	EPA Method Cr^{+6}	70 to 130	<25	16 ng/dscm	90
Chromium	Vitrified product	SW-846 3052 and 6010A	75 to 125	<25	14 mg/kg	90
Cr^{+6}	Vitrified product	NJIT/XPS[2]	-	-	-	90
Chromium (TCLP)[1]	Vitrified product	SW-846 1311, 3010A, and 6010A	75 to 125	<25	0.56 mg/L	90
Antimony	Vitrified product	SW-846 3051 and 6010A	75 to 125	<25	60 mg/kg	90
Beryllium	Vitrified product	SW-846 3051 and 6010A	75 to 125	<25	20 mg/kg	90
Cadmium	Vitrified product	SW-846 3051 and 6010A	75 to 125	<25	60 mg/kg	90
Nickel	Vitrified product	SW-846 3051 and 6010A	75 to 125	<25	50 mg/kg	90
Vanadium	Vitrified product	SW-846 3051 and 6010A	75 to 125	<25	30 mg/kg	90

Notes:

[1]	A critical parameter
[2]	The New Jersey Institute of Technology (NJIT) performed X-ray photoelectron spectroscopy (XPS).This analysis was not performed as part of the SITE demonstration.
Cr^{+6}	Hexavalent chromium
RPD	Relative percent difference
TCLP	Toxicity characteristic leaching procedure
TRL	Target reporting limit
% REC	Percent recovery
µg; mg	microgram; milligram
ng; kg	nanogram; kilogram
L; dscm	liter; dry standard cubic feet

4.5.1.2.2 Precision

Precision is a measure of the variability associated with the measurement system. Analytical precision is estimated by analyzing samples in pairs, either the unspiked sample and its duplicate or the MS and MSD samples. The degree of variability between a sample and its duplicate is expressed in terms of the relative percent difference (RPD).

One RPD exceeded the 25 percent QC criteria. A sample of dried, blended soil mixture that had MS and MSD percent recoveries of 97.5 and 157.5 had an RPD of 47.

4.5.1.2.3 Completeness

Completeness is an assessment of the amount of valid data obtained from a measurement system compared to the amount of data expected to achieve a particular statistical level of confidence. The percent completeness is calculated by the number of valid points divided by the planned number of measurements and multiplying the result by 100. Completeness was greater than the quality assurance objective of 90 percent for each set of parameters.

4.5.1.2.4 Representativeness

For this demonstration, representativeness involved sample size, sample volume, sampling times, and sampling locations. A sufficient number of samples were collected to analyze all of the parameters required; therefore, the QC objective for representativeness was met.

4.5.1.2.5 Comparability

All parameters were measured using standard methods. Therefore, demonstration data are considered to be comparable to any other performance data generated using standard methods.

4.5.2 Stack Emissions Sampling

Two separate mobilizations were required to complete the two-run project program. Run 1 was not completed because of a process upset; that is, only one of two traverses was completed at each of the sampling locations. Run 2 was completed in full; however, the flow condition was different from Run 1 resulting from a damper on the vitrification hood being open.

4.5.2.1 EPA Method Cr^{+6}

Fluegas concentrations of hexavalent chromium were determined using EPA Method Cr^{+6} (40CFR Part 266, Appendix IX) at both Sampling Locations S13 and S9A.

During Run 1, a 0.1-normal potassium hydroxide absorbing solution was used in accordance with the method. The concentration of sulfur dioxide during Run 1 was detected at levels approaching 50 ppm, much higher than expected. The pH check that is conducted during the train recovery yielded a pH of 9.5 for both the inlet and outlet trains; therefore, the increase in the acidity of the fluegas did not decrease the effectiveness of the absorbing solution. An increase in the normality of the absorbing solution was decided upon for Run 2, because the concentration of sulfur dioxide was expected to be similar to that of Run 1. Using the average value for the concentration of sulfur dioxide during the stack sampling of Run 1, it was calculated that a 5-normal potassium hydroxide absorbing solution should be used. The sulfur dioxide did not reach the expected concentration during Run 2 because a damper in the vitrification hood exhaust was left open. The increase in normality of the potassium hydroxide solution causes interference in the laboratory analysis and because of this, reagent blank values were greater in Run 2 than Run 1, resulting in negative Cr+6 results.

High particulate loading was present at Sampling Location S13, but because the sampling train does not utilize a filter, this did not pose a problem during sampling.

<u>Treatment of Blank Results</u>

Reagent blanks for EPA Method Cr^{+6} were collected during both test runs. A field blank for Sampling Locations S13 and S9A was also collected after Run 2. The following approach for the treatment of results

was used:

- Reagent blank results that were above detection limits were subtracted from the run data, resulting in negative values.
- Reagent blank results that were below detection limits were not used in the correction of the test sample results (for example, results below detection limits were treated as zeros).
- No corrections were made in the test data for field blanks.

4.5.2.2 EPA Method 23

Fluegas concentrations of PCDDs/PCDFs were determined using EPA Method 23: Determination of Polychlorinated-Dibenzo-p-Dioxins and Polychlorinated-Dibenzofurans From Stationary Sources (40CFR Part 60; Appendix A 1994). During Run 1, sampling for PCDD/PCDF was conducted at both Sampling Locations S13 and S9A. During Run 2, sampling for PCDD/PCDF was only conducted at Sampling Location S13.

Treatment of Results Below Detection Limits

Target analytes were present at concentrations both above and below detection limits of Method 23. The following procedures were used to sum the two sample train fractions:

- Both Values Detected. When positive values are detected for both sample fractions, the results for the two fractions are summed. The data are not qualified.
- Both Values Below Detection Limit. When both reported values are below the detection limit, the data are flagged as not detected (ND), and the sum of the detection limits for the analytes are used in all of the calculations.
- Some Values are Detected, and Some are Nondetected. As an approximation of the true value, one-half of the detection limits for the nondetected values, and the actual values for the detected values are used to calculate reported values. In reporting the sums of mixed values, the data are not qualified.

Treatment of Blank Results

Reagent blanks for EPA Method 23 were collected during both test runs and archived. A field blank for Sampling Location S13 was collected after Run 2. No correction to the test data was made for field blanks

or reagent blanks, because these results were below detection limits.

4.5.2.3 EPA Method 29

Fluegas concentrations of trace metals, hydrogen chloride gas, and particulate were determined using modified EPA Method 29: Determination of Metals Emissions from Stationary Sources (40 CFR Part 60, Appendix A 1996) at Sampling Location S9. During Run 1, sampling was conducted at Sampling Location S9B, and during Run 2, sampling was conducted at Sampling Location S9A.

Treatment of Results Below Detection Limits

Target analytes were present at concentrations both above and below detection limits of Method 29. The following procedures were used to sum the two sample train fractions:

- All Values Detected. When positive values are detected for all fractions, the results for the fractions are summed. The data are not qualified.
- All Values Below Detection Limit. When all reported data are below the detection limit, the data are flagged as ND, and sum of the detection limit for the analytes are used in all of the calculations.
- Some Values are Detected, and Some are Nondetected. As an approximation of the true value, one-half of the detection limits for the nondetected values, and the actual values for the detected values are used to calculate reported values. In reporting the sums of mixed values, the data are not qualified.

Treatment of Blank Results

Reagent blanks for EPA Method 29 were collected during both test runs and archived. A field blank for Sampling Location S13 was collected after Run 2. The following approach for treatment of results was used:

- The reagent blank results that were above detection limits were subtracted from the run data as per Method 29. The reagent blank results that were below detection were not used in the correction of the test sample results (i.e. results below detection limits were treated as zeros).
- No correction was made in the run data for field blank results.

SECTION 5
TECHNOLOGY STATUS

The center of the Geotech technology is a water-cooled, double-wall, steel furnace that uses submerged electrode resistance melting. The furnace and associated equipment are capable of a range of melting temperatures up to 5,200 °F. The technology can be used to vitrify chromium-contaminated soil, municipal solid waste incinerator ash, fly ash, asbestos and asbestos-containing materials, ceramic minerals, and a range of other materials, including soils contaminated with heavy metals such as lead and cadmium. The vitrified product can be formed into granular non-porous solids of 3/8 inch or smaller or glassy blocks of up to 300 pounds. These products have potential economic value as shore erosion block, roadbed fill, aggregate for concrete or asphalt, or other uses where a high-density, solid material is needed. The product can also be spun into mineral or ceramic fiber, which may have economic value as insulation, wall board, industrial furnace linings, and ceramic fiber.

Geotech currently operates a 50-ton-per day Cold Top vitrification pilot plant in Niagara Falls, New York. This facility was used for over 34 research and customer demonstrations, including the SITE demonstration. Geotech says this plant is capable of melting any mineral or combination of minerals that is present in a relatively dry condition. The molten stream can be collected in an inert, amorphous, glass-like condition in either large blocks or grit-sized particles or, if the mineralogy is correct, the molten stream can be introduced to a spinner, and fiber can be produced. Materials fused in this plant range from high purity zirconia and magnesite, requiring fusion temperatures in excess of 5,000 °F, to contaminated soils that melt at 1,800 °F.

Geotech has built or assisted with the construction or upgrading of five operating vitrification plants. The first of these is the Sklo Union plant located in Teplice, Czechoslovakia. This plant was built in 1981 to produce alumina silica ceramic fibers from the vitrified material. The plant has also melted and poured basic basalt and coal fly ash to produce mineral-fiber products. The plant mainly produces ceramic fiber, as the commercial value of the ceramic fibers is nearly 20 times that of mineral fiber. The production capacity of this plant ranges from 800 pounds per hour for ceramic fiber to 4,000 pounds per hour for
fly-ash residue. Power consumption ranges from 0.78 kilowatt hour per pound (KWH/lb) for ceramic fiber to 0.23 KWH/lb for fly-ash residue.

Geotech has assisted with the design and construction of another ceramic fiber facility at Fibertek S.P.A. in Atella, Italy, in 1985. The general configuration of this plant was very similar to the Czechoslovakian plant. This plant was also designed with the capability of converting municipal solid waste and fly ash to mineral-wool-grade fiber but, due to the economics, only ceramic fiber has been produced.

In 1983 Geotech supplied molten stream control, high-speed spinning, and fiber-collection equipment to the LaFarge Refractaires facility in Lorete, France. The equipment was used to upgrade the manufacturing efficiency and product quality of the facility.

In 1985 Geotech contracted with Nichias Corporation of Nagano, Japan, to upgrade their melting and fiber-forming process. Geotech furnished a melting furnace, electrical controls, high-speed spinning equipment, and fiber-collection equipment for a plant that produces ceramic fibers.

In 1992 Geotech installed mineral-fusion and fiber-formation equipment in a proprietary plant in Nagoya, Japan. The plant is designed to vitrify a wide variety of solid mineral waste materials, including clam-shell residue, sludge-ash residue, and coal-ash residue.

Geotech plans to build a commercial Cold Top vitrification facility near the northern New Jersey chromium sites. The facility will use electricity to vitrify solid waste including chromium-contaminated wastes. The planned capacity of this facility is 300 tons per day. The facility will be able to receive, prepare, and vitrify waste material, and dispose of the vitrified product from the chromium sites as well as from municipal solid waste incinerators and other producers of hazardous and non-hazardous waste.

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