Case Study Abstract

In Situ Vitrification, U.S. Department of Energy, Hanford Site, Richland, Washington; Oak Ridge National Laboratory WAG 7, Oak Ridge, Tennessee; and Various Commercial Sites

Site Name:
1. U.S. Department of Energy (DOE), Hanford Site
2. Oak Ridge National Laboratory WAG 7
   Various commercial sites (e.g., Parsons, Wasatch)

Contaminants:
Parsons: pesticides (chlordane, dieldrin, 4,4-DDT), metals (As, Pb, Hg)
ORNL: Radioactive elements (Ce^{137})
Wasatch: dioxin/furan, pentachlorophenol, pesticides, VOCs, SVOCs
Private Superfund site: PCBs

Period of Operation:
Information not provided

Location:
1. Richland, Washington
2. Oak Ridge, Tennessee
Commercial sites - various

Cleanup Type:
Full-scale remediation (Parsons, Wasatch)
Field demonstration (e.g., ORNL)

Technical Information:
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Technology:
In Situ Vitrification (ISV)
- Patented process that destroys organics and some inorganics by pyrolysis
- Uses electricity as energy source
- Remaining contaminants (heavy metals and radionuclides) are incorporated into product; product has significantly reduced leachability
- Vitrified material has 20-50% less volume than original material
- Hood used to contain and collect off-gasses from melt

Cleanup Authority:
- Information not provided about authorities for specific remediations and demonstrations
- Detailed regulatory analysis of ISV provided by CERCLA criteria

SIC Code:
9711 (National Security)
Commercial sites - Information not provided
Others - Information not provided

Points of Contact:
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B. Spalding, ORNL, (423) 574-7265

Waste Source:
Wasatch - Other (concrete evaporation pond)
Others - Information not provided

Type/Quantity of Media Treated:
Soil, Sludge, and Debris
- Parsons: 4800 tons
- Wasatch: 5600 tons
- Private Superfund site: 3100 tons

Purpose/Significance of Application:
Full-scale and field demonstrations of ISV for variety of media types and variety of contaminants

Regulatory Requirements/Cleanup Goals:
- Parsons: regulatory limits for Hg, chlordane, dieldrin, and 4,4-DDT
- Others - information not provided

In Situ Vitrification, U.S. Department of Energy, Hanford Site, Richland, Washington; Oak Ridge National Laboratory WAG 7, Oak Ridge, Tennessee; and Various Commercial Sites (Continued)

Results:
- Parsons: contamination reduced to below detection limits (ND) for most constituents
- Wasatch: molten product dip samples and surrounding berm post-ISV samples mostly ND
- ORNL treatability test had a "melt expulsion event (MEE)" where excess water vapor generation upset the melt and caused overheating of the off-gas collection hood
- Superfund site in Washington State showed DRE for PCBs of greater than 99.9999%

Cost Factors:
- Vitrification operations $375-425/ton
- Ancillary costs: treatability/pilot testing - $50-150K; mobilization - $150-200K; and demobilization - $150-200K
- No information is provided on the capital or operating costs for other full-scale or demonstration projects

Description:
In situ vitrification (ISV) has been used in three large-scale commercial remediations in the United States and in several demonstrations. The commercial remediations were conducted at the Parsons Chemical Superfund site (see separate report on Parsons); a Superfund site in Washington State; and at the Wasatch Chemical site. A demonstration of ISV was conducted at ORNL WAG 7 on Cs^{137}-contaminated material, where a melt expulsion event occurred .

ISV simultaneously treats mixtures of waste types, contaminated with organic and inorganic compounds. ISV has been demonstrated at sites contaminated with hazardous and mixed wastes, and achieves volume reductions ranging from 20-50%. Metals and radioactive elements are bound tightly within the vitrified product. Full-scale remediation at Parsons met the regulatory limits for chlordane, dieldrin, 4,4-DDT, and mercury. Full-scale remediation at Wasatch achieved ND for 12 constituents in the molten product dip samples. A TSCA demonstration at a Superfund site in Washington State showed destruction and removal efficiency (DRE) for PCBs of greater than 99.9999%. At the ORNL WAG 7 demonstration, a need was identified to take additional precautions when dealing with sites containing large amounts of free water.

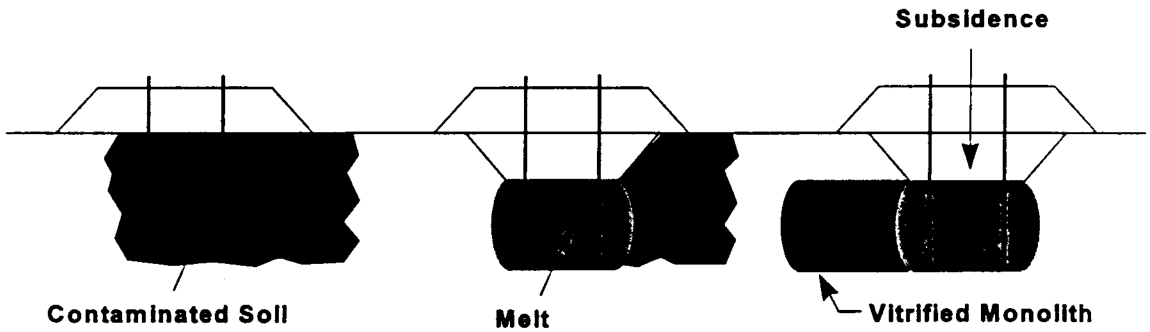
Site requirements for ISV, as identified by the vendor, are a function of: (1) the size and layout for equipment used in the process; (2) the staging area requirements for treatment cell construction; and (3) the area needed for maneuvering and operating equipment, excavating soils, and preparing treatment cells. In addition, the properties for fusion, melt temperature, and viscosity are determined by the overall oxide composition of the soil.

SECTION I

SUMMARY

Technology Description

In situ vitrification (ISV) is a thermal process for remediation of contaminated soil, sediment, sludge, mill tailings, and other earthen materials containing hazardous and radioactive contaminants (mixed waste). ISV is one of the few technologies that can simultaneously treat wastes with high concentrations of both organic and inorganic contaminants (e.g., heavy metals, radionuclides) (Figure 1).



- **1600-2000°C (soils)**
- **3-5 ton/hr melt rate**
- **5-20 ft depth (single melt)**
- **500-1000 ton melts (typ)**
- **Limitations exist for organic content, water recharge rate, large voids, size and quantity of debris, and sealed containers**

Figure 1. Overview of the in situ vitrification process.

Contaminants are either destroyed, immobilized, and/or removed during ISV treatment. Gases generated by the ISV process are collected in a hood and treated by an off-gas treatment system before discharge. Most metals, radionuclides, and other inert materials are retained in the melt (Figure 2). When cooled, the melt becomes a monolithic structure resembling obsidian or other forms of natural volcanic rock.

ISV also has a high tolerance for debris and other waste materials that might be in the treatment area (e.g., wood, scrap metal, concrete, boulders, asphalt, plastics, tires, or vegetation). Underground structures such as storage tanks, piping, and cribs may be able to be vitrified in place.

Technology Status

The ISV process was conceived in 1980 by Battelle Pacific Northwest Laboratory (PNL) for the U.S. Department of Energy (DOE). Since then, more than 200 development tests, demonstrations, and commercial operations of the technology have been conducted, ranging from bench-scale to full-scale commercial melts at various sites. The Idaho National Engineering and Environmental Laboratory participated in the ISV technology development activities, conducting bench- and pilot-scale testing.

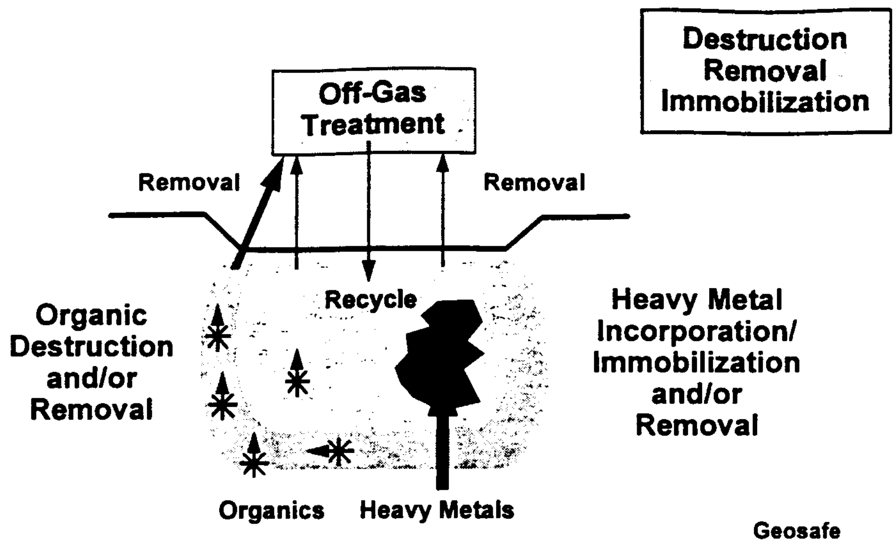


Figure 2. Contaminant disposition.

Geosafe Corporation licensed the ISV technology from PNL to apply ISV commercially to known contaminated soils for environmental restoration and waste treatment needs. Geosafe has successfully performed three large-scale commercial remediations in the United States and numerous test projects.

- The first commercial project was performed at the Parsons Chemical Superfund site and was included in the U.S. Environmental Protection Agency (EPA) SITE program. This first remediation involved soils contaminated by pesticides and metals.
- The second commercial remediation was a Toxic Substances Control Act (TSCA) demonstration for soils contaminated with polychlorinated biphenyls (PCBs). This second remediation resulted in the issuance of a national TSCA Operating Permit for PCBs.
- The third remediation project was performed on a Superfund site heavily contaminated with volatile, semivolatile, and nonvolatile organics, including dioxin, herbicides, and pesticides.

In the three U.S. remediations, the process was evaluated in detail for off-gas emissions, surrounding adjacent soils, and product quality.

Full-scale ISV operations have been successfully conducted on sites containing significant quantities of combustibles such as wooden timbers, automobile tires, personal protective equipment, and plastic sheeting. The process has also been tested in Japan and Australia, where Geosafe subsidiaries have been licensed to apply the ISV process.

Key Results

- ISV simultaneously processes mixtures of waste types, including both organic and inorganic contaminants.
- Treatment is effective in terms of reduction of toxicity/mobility, speed, and permanence.
- Substantial (20% to 50% for soils) volume reductions are achieved.
- ISV produces a superior residual product in terms of physical, chemical, and weathering properties and volume reduction.

- ISV is cost-effective on difficult sites.
- ISV is effective in achieving on-site and in situ safety and cost benefits.
- ISV can treat mixed waste (hazardous and radioactive) directly by thermally destroying organic and some inorganic components and immobilizing inorganic and most radioactive components in a vitrified product with outstanding life expectancy.
- ISV technology is applicable to earthen materials such as soil, sludge, sediments, mill tailings, and incinerator ash and has a high tolerance for debris.
- Multiple melts are required to treat large areas. When melt settings overlap previous melts, the melts fuse together into a large vitrified block.

The technology is still under refinement for applications involving liquid-bearing sealed containers or subsurface conditions where large amounts of water may move through the subsurface to the treatment zone rapidly. Such conditions may result in an excessive water vapor generation rate, which in turn can upset the melt and result in melt displacement and overheating of the off-gas collection hood.

Such a melt expulsion event occurred during a recent large-scale treatability test at the Oak Ridge National Laboratory (ORNL) WAG 7 site; however, project personnel performing tasks at the site at the time were not injured or contaminated during the incident, and air samples that were taken from the hood perimeter did not show any airborne contamination.

This event has indicated the need for additional precautions related to personnel and equipment safety when dealing with sites containing large amounts of free water. The means to avoid such occurrences include dewatering of sites containing large amounts of free water and other methods of preventing rapid recharge to the treatment zone. The event also confirmed that the high retention of ^{137}Cs and other radionuclides within the vitrified material minimizes the risk of any radiological release during such events.

All issues related to the ORNL WAG 7 event are being resolved, and remediation using ISV is expected to resume at WAG 7 in September 1996.

Contacts

Technical

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TECHNOLOGY DESCRIPTION

Process Schematic

ISV is a patented process that destroys most organic and some inorganic compounds by thermally induced decomposition (pyrolysis) in an oxygen-depleted environment in and around the melt zone. Pyrolyzed compounds are typically broken down to their elemental components. Volatile components travel to the surface of the melt where they are collected in a hood. Residence time within the hood allows the components to be oxidized. The remaining volatile components and carryover particulates are captured and treated by an off-gas treatment system (Figure 3).

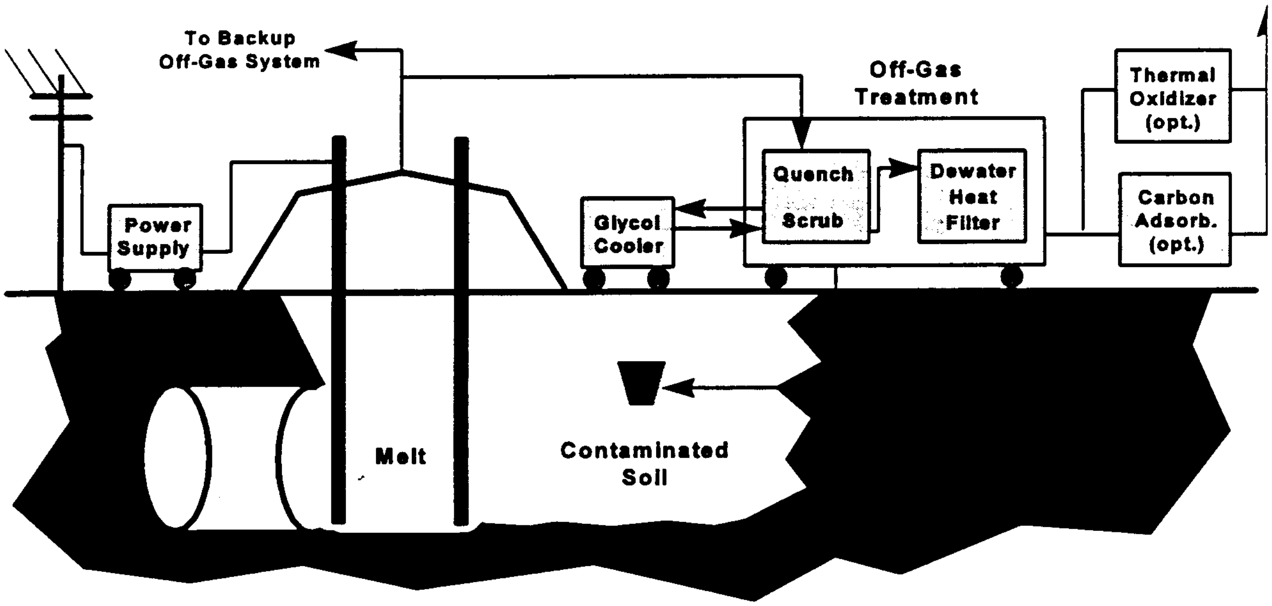

Figure 3. Overall in situ vitrification process system.

The volatile contaminants present on the site affect the off-gas treatment system more dramatically than they affect the rest of the ISV system. For that reason, the off-gas treatment system is modular in configuration, thus allowing treatment of the off-gas to be site specific. Contaminants that remain in the molten soil (heavy metals and radionuclides) are incorporated into the vitrified product. The vitrified product is a chemically stable, leach-resistant, glass and crystalline material similar to obsidian or basalt rock. As a result of densification, volume reductions of 20% to 50% are typical.

To initiate the melt, electric potential is applied to graphite electrodes.

- Current initially flows through a starter path of highly conductive graphite and glass frit.
- As the starter path heats up, it melts the surrounding soil.
- The process produces temperatures of about 1600° to 2000°C. Once the soil is molten, it becomes electrically conductive.

- Continued application of electricity results in Joule heating within the molten soil between the electrodes.
- After the melt is established, the melt zone grows steadily downward and outward through the contaminated soil. Gases generated are collected and treated before discharge.

The rate of melting and other operating parameters are dependent on soil type, moisture content, and contaminant loading. A 60-ft-diam hood is placed over the vitrification zone to contain and collect gases emanating from the melt and adjacent soil. The off-gas treatment system keeps the hood under slightly negative pressure.

During ISV processing, water vapor and other vapors form in and move through the dry zone adjacent to the melt toward the ground surface under the hood. The normal pathway for vapor movement is within the dry zone; however, if relatively high vapor generation rates are experienced, it is possible for vapors to intrude and move through the melt to the surface. Under extreme conditions of vapor generation, movement of vapors through the melt can cause undesirable melt disturbances, including partial melt displacement. Such extreme conditions can occur during the treatment of liquid-bearing sealed steel containers or when melting below the water table in geologic conditions that may allow rapid intrusion of water to the treatment zone. Such conditions can be avoided by pretreating liquid-bearing sealed steel containers so as to violate their seals. Similarly, some means (e.g., pumping, dewatering, or intercept trenches) may be required to limit or prevent recharge of water to the treatment zone when treating below the water table.

Ancillary Equipment/Systems

The electric power requirements on site for the ISV process are 4 MW of 3-phase, 60-cycle, ac power at 12.7 or 13.5 kV, from either a utility grid or a diesel generator. The power is converted to 2-phase and transformed to a variable level in the range of 400 to 4000 V, depending on melt size and conductivity. The maximum power delivered to the electrodes is 3.5 MW, which results in a maximum melting rate of about 5 ton/hr. The process requires 700 to 900 kWh/ton of soil treated, including the amount of water in the soil.

The off-gas treatment train is normally configured as follows: quencher, scrubber, demister, reheater, high-efficiency particulate air filters, and activated carbon adsorption and/or thermal oxidizer. Scrubbing system water may require treatment before discharge. Secondary effluents, contaminated equipment, and contaminated materials produced in the ISV process could possibly be collected and recycled to subsequent melts, thus minimizing secondary wastes.

SECTION 3

PERFORMANCE

Demonstration Overview

ISV technology has been demonstrated and transferred to the Geosafe Corporation. Geosafe has had three commercial remediations and numerous test melts. The first remediation project involved an EPA SITE program addressing pesticides and metals. The second project was a TSCA demonstration focusing on PCBs at a private Superfund site. The third demonstration addressed dioxins/furans, pesticides, herbicides, and considerable debris. The ISV technology performed as expected in these three applications. Typical performance parameters for ISV applications are summarized as follows:

- organic destruction and removal efficiency (DRE): 99.99% to >99.999999%;
- metals retention: 98% to > 99.9999% (Pu, U, Ra, Sr, and Cs);
- volume reduction: 20% to 50% (soils);
- permanence: geologic life expectancy;
- leachability: far surpasses Toxicity Characteristic Leaching Procedure (TCLP) and product consistency test (PCT); and
- maximum overall treatment effectiveness (reduction of toxicity, mobility, and volume).

Performance

The Parsons Chemical Superfund Site remediation project treated 4800 tons of clay soils contaminated with a variety of pesticides (DDT, dieldrin, and chlordane) and heavy metals (mercury, lead, and arsenic). The remediation site was independently monitored by EPA's SITE program and evaluated in an EPA technical report (EPA 1994). As indicated in Table 1, the level of contamination was reduced to below detection limits in most cases and below the state regulatory limits for all of the contaminants of concern.

Table 1. Pre- and post-in situ vitrification (ISV) soil contaminant concentrations (ppb)

Contaminant	Pre-ISV	Post-ISV	Regulatory limit
Mercury	24,160	33	12,000
Chlordane	2,010	<80	1,000
Dieldrin	11,630	<16	80
4,4-DDT	72,100	<16	80

Note: Data are from the Parsons site.

A TSCA demonstration project was performed at a private Superfund site in Washington state. The TSCA demonstration fulfilled the requirements to receive a national TSCA Operating Permit for the application of ISV to PCB-contaminated soils and debris. Five melts were performed to treat 3100 tons of contaminated soil and materials. The melts were staged to contain one or more of the following materials: concrete, asphalt, ruptured drums, and spiked soil up to 17,860 ppm PCBs. Soil adjacent to the treatment zone was analyzed before and after treatment. The results indicated a decrease in PCB concentration in the adjacent soil 60 to 90 cm from the melt boundary and no impact in the more distant soils. Soil, vitrified product, and off-gas emission testing indicated that a typical DRE of more than 99.9999% was achieved for PCBs.

The Wasatch Chemical Site project involved remediating a concrete evaporation pond containing 5600 tons of contaminated sludge, soil, and debris. Debris consisted of wooden timbers, clay pipe, sample containers, scrap metal, smashed 55-gal drums, plastic sheeting, protective clothing, miscellaneous contaminated site soils, and a sludge heel from an evaporation process. Other contaminants included dioxins/furans, pentachlorophenol, pesticides, volatile organic compounds, and semivolatile organic compounds. Thirty-seven contiguous melts were performed to treat the complete volume of contaminated soil and debris. Off-gas analytical results confirmed the complete absence (nondetection) of dioxins/furans in the off-gasses. Sampling of soil surrounding the berm before and after ISV treatment indicated that no contamination migrated outside the melt. In addition, dip samples of the glass taken during the processing of three melts confirmed that no detectable organic contamination remained in the treated soil. The results of the pre-ISV melt, dip sampling of the vitrified product, and pre- and post-ISV surrounding soil sampling are presented in Table 2.

Table 2. Wasatch Chemical soil and glass sampling results (ppb)

Contaminant	Pre-ISV levels	Molten product dip samples	Surrounding berm pre-ISV	Surrounding berm post-ISV
Dioxin/Furan	12,400	ND	0.005	0.004
Pentachlorophenol	272,918	ND	NA	1.2
Tetrachloroethene	<100	ND	700	ND
Trichloroethene	36,875	ND	850	ND
2,4-D	34,793	ND	2.8	ND
2,4,5-T	1,137	ND	7.36	ND
4,4'-DDD	27	ND	ND	ND
4,4'-DDE	3,600	ND	ND	2.4
4,4'-DDT	5,305	ND	ND	ND
Total chlordane	2,368	ND	0.5	83.4
Heptachlor	137.5	ND	ND	ND
Hexachlorobenzene	17,000	ND	ND	ND

Abbreviations: ISV = in situ vitrification; NA = not analyzed; ND = not detectable.

Typical residual product properties are summarized as follows:

- composition: analogous to natural volcanic rock;
- strength: ten times unreinforced concrete;
- volume reduction: 20% to 50%;
- toxicity reduction: organics are removed/destroyed, and inorganic-bearing residual had acceptable biotoxicity (EPA);
- mobility reduction: surpasses TCLP, and PCT;
- wet/dry cycling: unaffected;
- freeze/thaw cycling: unaffected; and
- life expectancy: geologic time period.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

Technology Applicability

ISV is a stand-alone technology that can treat a wide variety of media, including contaminated soils, sediments, sludges, rocks, sand, silt, and clay that may contain radionuclides, transuranics, fission products, organic chemicals, metals, and other inorganic chemicals. Site characteristics should be favorable for ISV or be able to be modified to make the site suitable.

ISV is a mobile system mounted on three trailers. The hood and remaining equipment are transported on two additional trailers.

The basic ISV technology can be applied in a number of alternative configurations:

- in situ;
- staged in situ, where contaminated media and waste have been placed (staged) for treatment, either above, below, or above and below grade; and
- stationary/batch or continuous modes.

Figures 4 and 5 illustrate the possible configuration alternatives.

Because of this flexibility, ISV may be applied to a broad range of contaminated media situations:

- contaminated soils;
- buried wastes;
- contaminated below-grade structures (e.g., tanks, pipes, cribs, and vaults);
- construction and decommissioning debris (e.g., concrete, asphalt, and structural and scrap metal); and
- mixed waste (e.g., low-level radioactive and transuranic).

In some of these cases, pretreatment (e.g., dynamic disruption) of the contaminated media may be necessary before ISV processing.

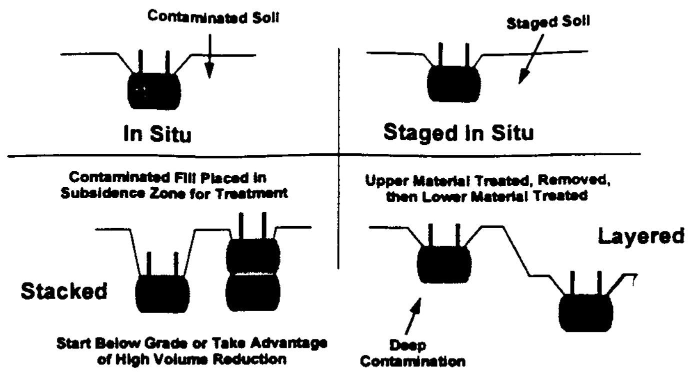

Figure 4. In situ vitrification treatment alternatives-1.

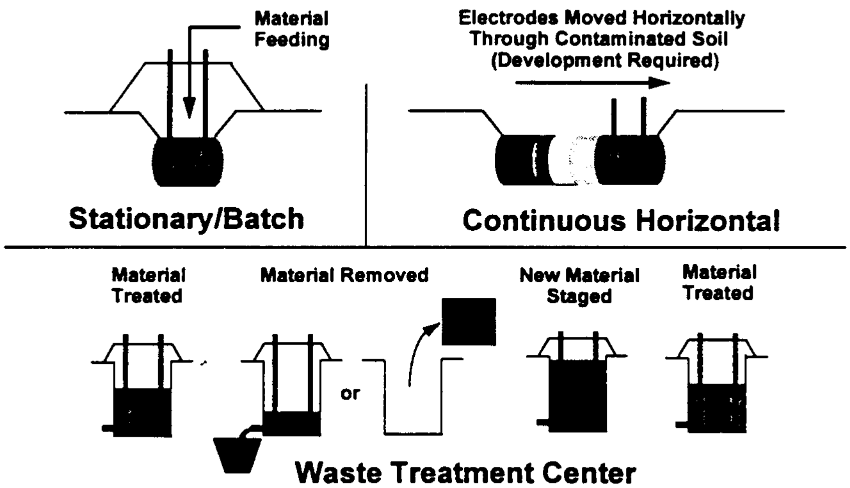

Figure 5. In situ vitrification treatment alternatives-2.

Alternative Technologies

- In situ grouting with monitoring.
- Retrieving, grouting, and reburial on site with monitoring.
- Exhumation and reburial of pit contents in an engineered landfill with monitoring.
- In situ barriers for the side walls and floor with monitoring.
- Retrieval and thermal desorption with off-gas treatment.
- Retrieval and incineration with off-gas treatment. (This alternative is most similar to ISV; consequently, this method was selected for the cost comparison.)

SECTION 5

COST

Introduction

The cost estimates used in this report are based on data in the EPA SITE technology report on the Parsons Chemical Superfund site (EPA 1994).

The primary cost elements include utilities (largely the local price of electricity), consumables, labor, mobilization and startup, facilities modifications, maintenance, equipment used and remaining on site, and amortization of transportable equipment. Typical elements of project cost follow. (Note: items that have a dollar amount assigned to them are items that are typically provided by Geosafe. The other items are activities that are usually provided by support contractors under contract to the client or under subcontract to Geosafe.)

- Treatability/pilot testing ($50K to 150K).
- Remedial design.
- Site preparation (power; staging; preconditioning, if any).
- Mobilization ($150K to 200K).
- Vitrification operations ($375 to 425/ton).
- Demobilization ($150K to 200K).
- Site restoration.
- Long-term monitoring (operations and maintenance).

Power requirements are as follows:

- 4 MW maximum at 12.7 or 13.5 kV;
- 3-phase, 60-cycle ac;
- Utility grid or diesel generation; and
- 700 to 900 kWh/ton treated.

ISV consumes 50% to 70% less thermal energy than incineration and 20% less energy than simple trucking of soil to a landfill.

The cost estimates for treatment using Geosafe technology were based on the following assumptions.

- The contaminated soil is staged into treatment cells by an independent contractor before Geosafe's arrival on-site. Cell preparation and construction are site specific and may be different for each site; however, it is assumed that each site is prepared in a similar manner to the Parsons site.
- The depth of treatment is assumed to exceed the depth of contamination by at least 1 ft to ensure that the melt incorporates the floor of the cell and beyond.
- Treatment takes place 24 hrs/day, 7 days/week, 52 weeks/year. An on-line efficiency factor of 80% has been incorporated to account for downtime for scheduled and unscheduled maintenance and other unforeseen events.
- Operations for a typical shift require one shift engineer and one operator. In addition, one site manager and one project control specialist are present on-site during the day shift. Three shifts of workers are assumed to work 8 hrs/day, 7 days/week for 3 weeks. At the end of 3 weeks, a shift of

workers are assumed to work 8 hrs/day, 7 days/week for 3 weeks. At the end of 3 weeks, a shift of workers is rotated out and a new set of workers replaces them.

- The costs presented (in dollars per cubic yard) are calculated based on the number of cubic yards of contaminated soil treated. Because clean fill and surrounding uncontaminated soil are treated as part of the melt, the total number of cubic yards of soil treated is higher than the number of cubic yards of contaminated soil treated. Costs per cubic yard based on total soil treated would, therefore, be lower than the costs presented in this estimate.

If Geosafe scales its process differently than assumed in this analysis, then the cost of remediation per cubic yard of contaminated soil will change.

These cost estimates are representative of charges typically assessed to the client by the vendor and do not include profit. The developer claims these costs were unusually high and expects the treatment costs for future sites to be less than the treatment costs for the Parsons site.

Table 3 presents a general order of magnitude estimate for the cost of remediating a site. The estimate represents capital and operating costs based on treating about 3200 yd^3 or about 5700 tons of contaminated soil at the Parsons site.

Table 3. In situ vitrification cost estimates (based on Parsons site experience)

Volume (yd^3)	Cost ($\$/yd^3$)	Cost ($/ton)
970	1500	833
3200	780	433
4400	670	372

Note: The Parsons site had unusually high soil density.

Geosafe notes that the cost estimates prepared by the SITE program are significantly higher than its own commercial experience. For reference purposes, Geosafe's prices typically fall in the range of $375 to $425/ton for vitrification operations. Mobilization and demobilization of the 100 ton/day system can cost in the range of $300K to 400K (combined total). Preconditioning of the site may cost additional. Geosafe finds that the bottom line cost per ton for most sites falls in the range of $400 to $600/ton, depending on size, location, and site preparation needs.

Cost Comparison

The cost comparisons used in this report are based on data reported by Showalter et al. (1992). The mobile rotary kiln incinerator was chosen for the baseline because of its flexibility and low capital cost combined with the minimal decontamination and decommissioning cost at the end of its useful life. The site developed for this comparison is similar to mixed waste trenches and pits that are found on DOE property. The site in this comparison is 30-m wide × 90-m long × 5-m deep. The soil is homogeneous and contaminated with low-level radioactive mixed waste. The soil moisture content is 5%.

The site is considered to be in a flat, readily accessible area and will require only minimum clearing and leveling before remediation. The perimeter fencing will be 10-ft high with four-strand razor wire topping.

Factors

- Capital equipment costs are similar for the two technologies. ISV costs slightly more because of the decision to generate power on site. (When electric power in sufficient quantities is not available from an electric utility, a generator must be purchased for on-site.) Purchasing power from a local utility would eliminate the need to purchase a generator.

- Mobilization of the ISV system is much more labor intensive than it is for incineration.
- The ISV system includes extensive sampling of the vitrified area to verify that the final waste form is acceptable. Both estimates include extensive stack sampling and analysis. Incineration incurs more than twice the cost of ISV in this category because of much larger air flow through the incinerator.
- Although incineration operates for a shorter time, it has a higher labor cost during operation. One reason for this is the increased worker protection requirements for incineration over ISV.
- ISV is more expensive in the consumables category.
- The cost of secondary disposal is the most expensive component of the cost of incineration. ISV creates a vitrified mass that may be left in place, while incineration requires that the residual be moved to monitored storage.
- Where secondary disposal is eliminated, the total cost of incineration will be similar to the total cost of ISV. If only a hazardous organic component had to be destroyed, there would be little or no waste to be disposed of under incineration. Allowing a minimal cost for secondary waste in each case and reducing the cost risk factor accordingly results in incineration being roughly $500/m^3, slightly less than ISV, which costs about $600/m^3.

Costs Considered

Examination of the specific cost categories listed in Table 4 highlights the differences in cost. Several costs have been left out of the analysis, but only after deciding that they would be similar between the two processes. Costs included in this analysis are capital (equipment); site preparation; mobilization and demobilization (mobilize/demobilize, crew relocation, site administration, ISV melt analysis, backfill and grade, and decommission and dispose); operations (stack sampling, labor, consumables, subcontractors, and oversight engineer); secondary waste disposal; miscellaneous (includes environmental impairment insurance); labor and material; performance bonds; and escalation.

Table 4. Cost comparison of in situ vitrification (ISV) and incineration for a 30-m-wide × 90-m-long × 5-m-deep mixed waste site

Cost category	ISV: total scenario cost ($)	ISV: cost per cubic meter ($)	Incineration: total scenario cost ($)	Incineration: cost per cubic meter ($)
Capital	1,038,654	76.94	775,557	57.45
Site preparation, mobilization, and demobilization	1,681,702	124.57	1,074,212	79.58
Operations	3,694,430	273.65	3,016,930	223.48
Secondary waste disposal	1,038,310	76.91	17,877,816	1,324.28
Miscellaneous	307,468	22.78	270,000	20.00
Labor, material, and performance bonds	100,954	7.48	345,218	25.57
Escalation	156,147	11.57	366,367	24.92
Total	8,017,665	593.90	23,726,100	1,755.28

Cost Summary

Based on this scenario, ISV is significantly less expensive than incineration. ISV costs about $600/m^3 versus roughly $1755/m^3 for incineration. Table 4 shows the comparison of the major cost categories.

SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

Table 5 presents a regulatory analysis of ISV technology using Comprehensive Environmental Response, Compensation, and Liability Act (1980) criteria.

Safety, Risks, Benefits, and Community Reaction

The EPA Technology Innovation Office is encouraging the inclusion of ISV technology in remedial investigations, feasibility studies, records of decision, and remedial design. State regulatory agencies have accepted the ISV process where demonstrations and remediations have been proposed.

Site preparation or pretreatment steps that include water removal by pumping or diversion and barrier systems to avoid recharge to the zone to be vitrified may be necessary to reduce the risk of a melt expulsion event (MEE) at some sites. In an MEE, a buildup of vapor pressure occurs and results in a sudden intrusion of vapor into and through the ISV melt. Detailed site characterization and quantitative modeling may be required to evaluate the nature and extent of necessary pretreatment.

Benefits Summary

Safety, regulatory, and other benefits are summarized in Figure 6.

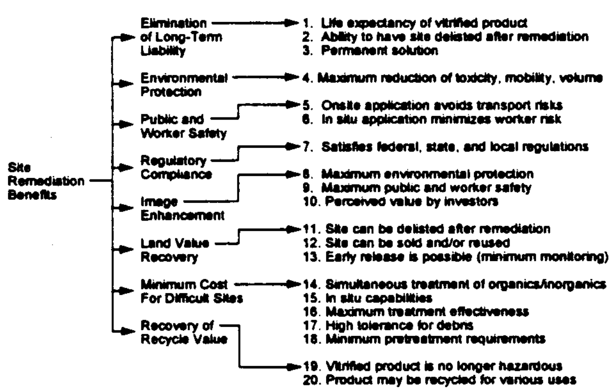

Figure 6. Remediation benefits related to technology features.

Community Reaction

Some stakeholders, primarily those living near sites, have expressed concerns about public and worker safety. The effectiveness of the ISV process has also been questioned. Close communication and coordination with local stakeholders early in the planning stage should help identify and address their concerns.

Table 5. Regulatory analysis of the Geosafe in situ vitrification (ISV) technology using Comprehensive Environmental Response, Compensation, and Liability Act criteria

Overall protection of human health and the environment	Compliance with ARARs	Long-term effectiveness	Short-term effectiveness	Reduction of toxicity, mobility, or volume through treatment	Implementability	Cost
Provides both short- and long-term protection by destroying organic contaminants and immobilizing inorganic material.	Requires compliance with RCRA treatment, storage, and land disposal regulations (for a hazardous waste). Successfully treated solid waste may be delisted or handled as nonhazardous waste.	Effectively destroys organic contamination and immobilizes inorganic material.	Effectively destroys organic contamination and immobilizes inorganic material.	Significantly reduces toxicity and mobility of soil contaminants through treatment.	A suitable source of electric power is required to use this technology.	The estimated cost for treatment when the soil is staged into nine 15-ft-deep cells is about $780/yd^3$ ($430/ton). This cost is based on data gathered from the Parsons site. Costs are highly site-specific and will vary with on-site conditions.
Remediation can be performed in situ, thereby reducing the need for excavation.	Operation of on-site treatment unit may require compliance with location-specific ARARs.	Reduces the likelihood of contaminants leaching from treated soil. ISV glass is thought to have a stability similar to volcanic obsidian. The vitrified product is conservatively estimated to remain physically and chemically stable for about 1000 years.	Vitrification of a single 15-ft-deep treatment setting may be accomplished in about 10 days. Treatment times will vary with actual treatment depth and site-specific conditions.	Volume reductions of 20% to 50% are typical after treatment.	Equipment is transportable and can be brought to a site using conventional shipping methods. Weight restrictions on tractors/trailers may vary from state to state.	Treatment is most economical when treating large sites to maximum depths.
Technology can simultaneously treat a mixture of waste types (e.g., organic and inorganic wastes).	Emission controls may be needed to ensure compliance with air quality standards depending on local ARARs and test soil components.	May allow reuse of property after remediation.	Presents potential short-term exposure risks to workers operating process equipment. Temperature and electric hazards exist.	Some inorganic contaminants, especially volatile metals, may escape the vitrification process and require subsequent treatment by the off-gas treatment system.	Necessary support equipment includes earth-moving equipment for staging treatment areas with clean soil. A crane is required for off-gas hood placement and movement.	Electric power is a major element of costs associated with ISV processing. Other important factors (in order of significance) include labor costs, startup and fixed costs, equipment costs, and facility modifications and maintenance costs.

Table 5. (Continued)

Overall protection of human health and the environment	Compliance with ARARs	Long-term effectiveness	Short-term effectiveness	Reduction of toxicity, mobility, or volume through treatment	Implementability	Cost
	Scrubber water will likely require secondary treatment before discharge to POT or surface bodies. Disposal requires compliance with Clean Water Act regulations.		Some short-term risks associated with air emissions are dependent upon test material composition and off-gas treatment system design.	Some treatment residues (e.g., filters and personal protective equipment) may themselves be treated during subsequent vitrification settings. Residues from the final setting, including expended or contaminated processing equipment, may require special disposal requirements.	The staging of treatment areas is recommended for areas where the contamination is limited to shallow (less than 8 ft) depths.	Moisture content of the media being treated directly influences the cost of treatment as electric energy must be used to vaporize water before soil melting occurs.
			Staging, if required, involves excavation and construction of treatment areas. A potential for fugitive emissions and exposure exists during excavation and construction.	Volume of scrubber water generated is highly dependent upon soil moisture content, ambient air humidity, and soil particulate levels in the off-gas.	The soil oxide composition must provide sufficient electrical conductivity in the molten state and adequate quantities of glass formers to produce a vitrified product. Oxides can be added to soil to correct for deficiencies.	Sites that require staging and extensive site preparation will have high overall costs.
					Ground water should be diverted away from treatment areas to improve economic viability.	

Abbreviations used: ARAR = applicable or relevant and appropriate requirements; RCRA = Resource Conservation and Recovery Act of 1976, and POT = publicly owned treatment works.

Source: EPA 1994.

SECTION 7

LESSONS LEARNED

Implementation Considerations

- A suitable source of electric power is required for this technology.
- Equipment is transportable and can be brought to a site using conventional shipping methods.
- Necessary support equipment includes a crane for placing and removing the off-gas hood, and earth-moving equipment may be needed.
- The staging of treatment areas is recommended for areas where contamination is limited to less than 8 ft to attain economic processing rates.
- The overall oxide composition of the soil determines the properties such as fusion and melt temperature and viscosity. Other constituents needed for acceptable glass formation must be present in the soil or be added.

Site Requirements

Site requirements for the Geosafe ISV technology are a function of (1) the size and layout for equipment used in the process; (2) the staging area requirements for the construction of treatment cells (if needed); and (3) the room required to maneuver equipment for excavating contaminated soils, preparing treatment cells, and placing and relocating equipment.

Technology Limitations/Needs for Future Development

- The maximum acceptable treatment depth with current equipment is 20 ft below ground surface.
- Water in the soil is removed by evaporation in advance of the melt. The process may be used in supersaturated media (e.g., 70 wt % water); however, the removal of water consumes energy and increases cost. Therefore, it is desirable to maintain the treatment zone at low water levels.
- Water vapor generated below grade passes to the surface through the dry zone adjacent to the melt. If vapor generation rates are very high, some vapor may pass through the melt itself. Excessive amounts of vapor passing through the melt may cause melt disruption (bubbling) and possible melt displacement (splattering). Therefore, it is necessary during the remedial design phase of a project to consider process conditions that will result in acceptable water vapor generation and removal rates.
- Buried steel drums that still have structural and sealing integrity and contain liquids hold the potential for introducing vapors through the melt disruptively. Site characterization should be sufficient to assess whether such liquid-bearing drums exist within a site. If they do, then they can be pretreated by dynamic disruption and/or compaction technologies so that they can be safely processed by ISV without melt disturbance.
- The overall oxide composition of the media being treated determines the melt properties (e.g., fusion and melt temperature and viscosity). It is essential that the media contain sufficient monovalent alkali earth oxides to provide the amount of electrical conductivity required of the melt. The amount of glass-forming oxides (e.g., silica and alumina) present is a primary determinant of the vitrified product physical, chemical leaching, and weathering properties. Typical soils throughout the world possess adequate properties to allow ISV processing and produce a high-quality vitrified product. In rare cases, additives may be necessary to obtain the electrical conductivity or vitrified product properties desired.

- The heat-removal limitations of the current equipment dictate that the organic content of the treatment media be less than 10 wt % if operating at full power level. Higher organic loading can be accommodated by operating at correspondingly lower power levels. Waste containing up to 25 wt % organics has been treated using existing equipment. Some chemical reduction of ferrous metal oxides may occur during ISV, resulting in pooling of iron at the bottom of the melt. Geosafe has performed melts containing up to 37 wt % scrap metal with no difficulty. Similarly, the process is highly tolerant of debris and rubble, and Geosafe has successfully treated soil containing more than 50 wt % of such materials.
- Upon completion of melting, clean backfill soil is placed in the subsidence volume that exists above the melt (because of volume reduction). The melt surfaces cool sufficiently quickly that heavy equipment may be operated above backfilled melts in less than 1 day. Sufficient cooling of the vitrified monolith to enable revegetation can take several months.

Three technology limitation areas warrant further development to increase the potential value of the technology for DOE needs. These limitations fall into the areas of (1) maximum attainable depth, (2) applicability to higher organic concentrations, and (3) processibility of liquid-bearing sealed containers.

- Relative to increased depth potential, Geosafe is exploring ways either to melt more deeply from the surface downward or to initiate melting at deeper depths with completion melting either upward or downward from the initiation depth. These areas of exploration hold the potential to increase significantly the depth capability of the technology.
- Relative to higher organic concentrations, Geosafe notes that this limitation is equipment related and is not an inherent limitation of the technology. Higher organic concentrations may be treated by using off-gas treatment equipment with greater flow and heat-removal capacity. Such equipment would have to be designed and built for specific site needs.
- Relative to the liquid-bearing sealed container issue, Geosafe has explored a number of pretreatment alternatives that may be used to remove this limitation. In addition, DOE and Geosafe are pursuing an alternative avenue of investigation. That alternative is designing off-gas collection hood and treatment equipment that is capable of withstanding the intermittent vapor pressure and volume surges and elevated temperatures associated with treatment of sealed containers containing liquids. Note that not all containers of liquids are subject to this limitation; only containers that are tightly sealed, that contain liquids, and that are capable of withstanding very high temperatures (e.g., steel containers) are subject to this limitation.

Field Observations

Approximately 60 large-scale ISV melts have been conducted successfully in the United States and abroad. During these melts, only four MEEs were observed. No worker exposure nor injuries have been reported. Environmental contamination was insignificant, largely because of containment within the glass melt itself and capture by the off-gas filter media. However, DOE considers worker safety and protection of the environment to be paramount and has conducted an ISV Workshop to examine the root cause(s) of MEEs and to provide recommendations to reduce or eliminate the potential for an MEE occurrence.

The ISV Workshop attendees concluded that the two necessary conditions for an MEE are as follows:

- a source of vapor (either pore water, water structurally bound in materials, CO_2 bound in materials, soil organic matter, or other volatiles such as organic contaminants), and
- a confining structure or zone of low hydraulic conductivity that prevents routine dissipation of pressure.

Because both conditions are believed to be necessary for an MEE occurrence, the elimination or reduction of either or both conditions would reduced or eliminate the probability of an MEE.

The ISV Workshop attendees have adopted the following recommendations.

- DOE should continue to pursue applications of ISV for contaminated soil remediation.
- Site characterization and site-specific planning, including projections of ISV performance (modeling), should be a part of every application. The degree of planning and prediction will vary according to site and contaminant conditions, but may include the following factors:
  - mineralogic makeup of the soils,
  - chemical composition of the waste and waste forms present,
  - porosity and effective porosity,
  - moisture content/saturation,
  - relative permeability for gases and liquids,
  - permeability as a function of temperature and pressure,
  - subsurface geological structure, and
  - engineered structures or barriers.
- Engineering measures to modify a site in preparation for ISV (e.g., dewatering or mechanical disruption) should be considered where an analysis of characterization data indicates the possibility of an MEE.
- Monitoring tools for use during ISV need to be developed, adapted, and improved.
- Engineering measures to control the impacts of MEEs were not considered during the workshop but merit further evaluation.

APPENDIX A

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