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IN SITU VITRIFICATION: DEMONSTRATED CAPABILITIES AND POTENTIAL APPLICATIONS

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Richland, Washington 99352

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IN SITU VITRIFICATION:

DEMONSTRATED CAPABILITIES AND POTENTIAL APPLICATIONS

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ABSTRACT

A large-scale demonstration of the in situ vitrification (ISV) process was performed in April 1990 on the 116-B-6A Crib in the 100 Area of the Hanford Site in southeastern Washington. The 116-B-6A Crib is a radioactive mixed waste site and was selected to demonstrate the applicability of ISV to soils contaminated with mixed wastes common to many U.S. Department of Energy (DOE) sites. Results from the demonstration show that the ISV process is a viable remediation technology for contaminated soils.

The demonstration of the ISV process on an actual contaminated soil site followed research and development efforts by the Pacific Northwest Laboratory (PNL) over the last 10 years. PNL's research has led to the development of the ISV process as a viable remediation technology for contaminated soils and the creation of a commercial supplier of ISV services, Geosafe Corporation. Development efforts for ISV applications other than treatment of contaminated soils, by PNL and in collaboration with Oak Ridge National Laboratory (ORNL) and Idaho National Engineering Laboratory (INEL), show the ISV process has potential applicability for remediating buried waste sites, remediating underground storage tanks, and enabling the placement of subsurface vitrified barriers and engineered structures.

This paper discusses the results from the April 1990 large-scale demonstration and provides a general overview of the current capabilities of the ISV process for contaminated soils. In addition, this paper outlines some of the technical issues associated with other ISV applications and provides a qualitative discussion of the level of effort needed to resolve these technical issues.

ISV PROCESS DESCRIPTION

In situ vitrification is a patented thermal treatment process developed by researchers at PNL for the in-place destruction and immobilization of hazardous chemicals and/or radionuclides in soil.[1,2] Figure 1 illustrates the ISV process. An array of graphite electrodes is inserted a few centimeters into the ground. Because soil is not electrically conductive when its moisture has been driven off, a conductive mixture of graphite and glass frit is placed between each electrodes to serve as a starter path. An electrical potential is applied to the electrodes to establish an electrical current in the starter path. The flow of current heats the starter path and surrounding soil to well above the initial soil-melting temperatures of 1100°C to 1400°C. Once the soil becomes molten, it becomes electrically conductive, and the molten region grows outward and downward. Nonvolatile radionuclides and inorganics become incorporated into the molten soil, which is processed at temperatures between 1450°C and 2000°C. Organic components in the soil are destroyed by pyrolysis. The pyrolyzed byproducts migrate to the surface, where they combust in the presence of air. A hood placed over the area being vitrified directs the gaseous effluents to an

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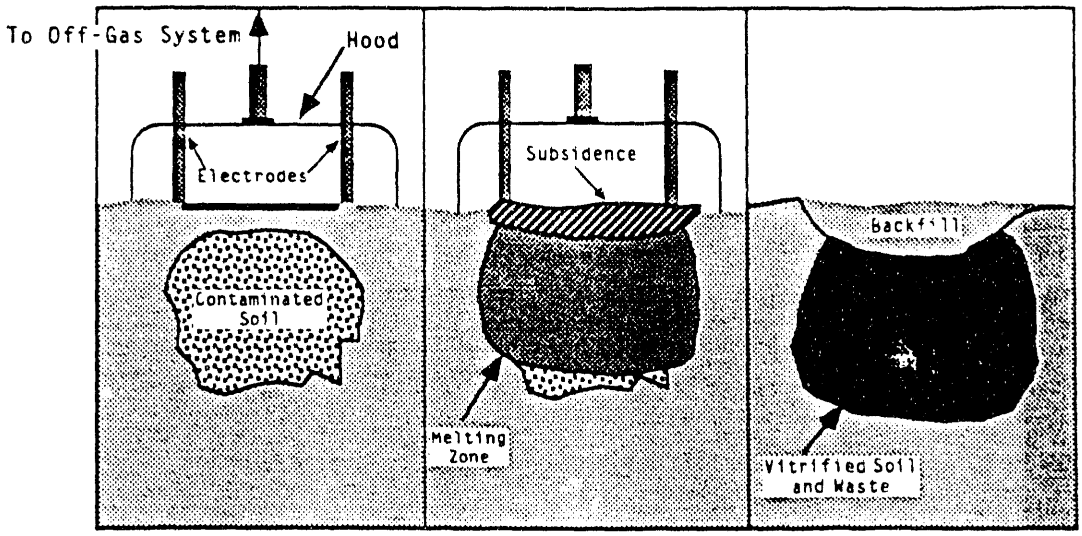

Figure 1. In Situ Vitrification Operating Sequence.

off-gas treatment system, where they are scrubbed and filtered before being released to the atmosphere. Upon cooling, the solidified glass and crystalline monolith is highly resistant to leaching and is estimated to be stable for geologic periods. For expansive contaminated areas, adjacent settings of the process result in the formation of a single, contiguous monolith.

LARGE-SCALE ISV DEMONSTRATION AT THE 116-B-6A CRIB

The April 1990 large-scale demonstration on the 116-B-6A Crib extended the ISV technology by demonstrating the ISV process on a site with heavy metal- and radionuclide-contaminated soil that also contained combustible wooden timbers.[3] The 116-B-6A Crib was an inactive, mixed waste site that historically received liquid radioactive waste from the decontamination of equipment and fuel element spacers. The crib structure itself was 3.7-m square by 2.4-m high, and was buried 1.8-m underground. Site characterization activities confirmed the crib as being a radioactive mixed waste site. Site characterization also confirmed the presence of wooden timbers and a sandy gravel fill material. The soil in the crib contained approximately 900 mCi of Sr-90, 150 mCi of Cs-137, and a mixture of hazardous chemicals including chromium and lead. A single setting of the large-scale ISV equipment vitrified the entire crib.

The ISV demonstration on the 116-B-6A Crib was completed after 288 hours of operation. The demonstration consumed 550 MWh of electrical energy and resulted in a vitrified product of approximately 775 metric tons. Significant results from the 1990 large-scale demonstration include the following:

- Retention of chromium and lead in the vitrified product was greater than 99.99%
- Retention of Cs-137 in the vitrified product was greater than 99.98%

- The off-gas treatment system performed within design criteria and successfully handled the high-combustible loadings (the wooden crib timbers) of the contaminated soil site
- Analysis of core samples from the vitrified product showed a homogeneous distribution of elements within the monolith and a product quality similar to previous ISV products
- The presence of a cobble layer at the bottom of the crib prevented the process from reaching the target depth; however, the entire crib was processed and a mechanism for depth limitation was verified.

The results from this large-scale demonstration on an actual site, along with the results from tests on simulated sites, provide the basis for identification of the capabilities and limitations of the ISV process for contaminated soil applications discussed in the next section.

ISV PROCESS FOR CONTAMINATED SOIL - CURRENT CAPABILITIES

As the result of over 150 ISV tests and a variety of computational analyses, operational capabilities for application of the ISV technology to contaminated soils have been established.[4] The capabilities listed below represent the state of the technology based on the current understanding of the process and the capabilities of existing process equipment. As technological advances are realized, the operating envelope will be revised accordingly.

Soil Type

ISV is currently applicable to contaminated soils and sludges regardless of whether they are [illegible], silt, or clay. Even rocky soils are melted by the process. However, special monitoring and/or analyses must be performed when processing silty soils or nonswelling clays. These materials generally have lower permeabilities (i.e., less than 10^{-3} cm/s) even after being dried out.[5] Sandy soils and clays that shrink and crack when dried are relatively permeable. They easily allow the release of water vapor from the soil in advance of the melt front, thus precluding the potential for buildup of vapor pressure beneath the ISV melt zone in excess of the static head pressure of the molten glass.

Soil Moisture

ISV is generally applicable for soils regardless of soil moisture content. Soils and sludge ranging from 4 wt% moisture to 50 wt%[6] have been successfully vitrified. The process, however, is not applicable for soils that lie within a permeable aquifer (i.e., greater than 10^{-4} cm/s permeability[7]), unless combined with a groundwater diversion or pumping technique during processing to limit the rate of water recharge to the molten soil zone.

Soil Composition

Because soils and sludges are naturally composed of glass-forming materials such as silica, they generally can be processed by ISV without modification. However, a minimal alkali content (i.e., combined Na_2O and K_2O content) of 1.4 wt% is necessary. Alkaline oxides are responsible for carrying the electrical current among electrodes in the molten soil pool. Weathered soils with less than 1.4 wt% alkaline oxides require the addition and mixing of alkaline materials to lower the melting temperature and raise electrical conductivity.[8]

Depth of Treatment

The ISV process has been demonstrated to depths up to 5.75 m in relatively homogenous soils. The achievable depth, however, can be limited under certain conditions, such as the presence of a rock or gravel layer where heat transfer is less efficient, or of a soil layer with significantly higher melting temperature than the overlying material. In addition, the relative density of the soils to be processed influences the achievable melt depth. Higher density soils require more time and energy to be processed, and thus influence the achievable treatment depth. The current demonstrated depth capability of 5 to 5.75 m is sufficient for many commercial and DOE contaminated soil sites; however, to be extensively applied to contaminated soils on DOE sites, a target depth of 10 m should be demonstrated.

Hazardous Inorganic Chemicals

ISV is extremely effective in immobilizing heavy metals and other inorganic contaminants. The majority (70 to 99.99 wt%) of heavy metals such as As, Pb, Cd, Ba, and Cr are retained and immobilized in the vitrified product. The remainder are collected by the off-gas system and either can be returned to the melt or disposed of separately. Nitrates are decomposed by the process and mercury is removed and collected by the off-gas system for recovery or disposal.

Hazardous Organic Chemicals

The high processing temperature of ISV destroys hazardous organic chemicals by pyrolysis. Organic concentrations up to 7 wt% in the soil canbe processed by ISV. The small percentage of organic contaminants not destroyed by the process (between 0.01 and 1 wt%) are removed from the soil during processing and collected by the off-gas treatment system. Further research is necessary before applying ISV to reactive or explosive materials.

POTENTIAL APPLICATIONS FOR THE ISV PROCESS

During the development of the ISV process for contaminated soils it was recognized that many of the benefits of the ISV process (e.g., in situ treatment, in situ stabilization, volume reduction, lower costs relative to many ex situ remedial options, and a durable, long-lasting final product) might be realized for other ISV applications. Potential applications for which the ISV process may be suitable are discussed below along, with the technical issues that must be resolved prior to full implementation of the ISV process for a given application.

Application to Buried Waste

A collaborative effort between PNL and INEL demonstrated the feasibility of using the ISV process for the remediation of buried waste.[9] Pilot-scale field tests (1/4 of large-scale) on simulated buried waste were successfully completed in June and July 1990 on the INEL site. Results from these tests showed the ability of the process to handle buried waste sites containing minimal soil, high metal content, and a large void space fraction. Analyses of the final product showed the product to have a durability and leach resistance comparable to previous ISV products. In addition to these positive results showing the feasibility of the ISV process for treating buried waste, results from the 1990 pilot-scale field tests also illustrated technical issues that must be resolved before full implementation of the ISV technology.[10]

The application of the ISV process to buried waste is not limited to DOE applications. Buried materials such as those found in landfills are also amenable to the ISV treatment process. Application of the process to such sites will result in volume reduction, site stabilization, creation of a durable product, creation of a product with excellent leach resistance properties, and creation of a final product that may have commercial uses. For DOE applications, cost studies have shown the ISV process to be competitive with many ex situ treatment processes, including development and implementation costs.[11] These cost benefits are also expected for application of the process to landfills.

The primary technical issue that must be resolved for this application is the ability of the ISV technology to process buried, sealed containers. Experience at pilot- and large-scale shows that the presence of sealed containers can lead to pressurization of the off-gas hood and/or the displacement of molten soil from the vitrification area. Resolution of this technical issue requires a fundamental understanding of the mechanisms causing transient gas release events. This understanding will allow the design of new equipment, a change in the operating procedure, the development of a technique(s) to compromise the integrity of these sealed containers prior to processing, or a combination of each of these options.

Application to Underground Storage Tanks

Underground storage tanks containing sludges and salt cakes composed of radioactive and/or hazardous wastes represent a significant environmental concern and a major technological cleanup challenge at many DOE sites. The ISV technology has potential as a closure technique for tank carcasses with residuals and surrounding contaminated soil. To date, four ISV tests have been conducted on simulated underground storage tanks--two engineering-scale, one pilot-scale, and one large-scale.[12] The use of ISV for this advanced application depends on the resolution of significant technical and institutional issues related to containing or controlling transient gas releases, increasing ISV processing depth, confirming the capability of ISV for processing salt cake-based tank wastes, and implementing regulations that are conducive to waste tank remediation. Resolution of the issues would provide an in situ treatment technology option for the remediation of this significant environmental concern.

Placement of Subsurface Vitrified Barriers

Underground barriers are a proposed means of providing long-term isolation and containment of waste sites. The ISV process produces a final product that would be ideal for containing the migration and fluid transport of wastes as well as isolating the waste from contact with animals, plants and people. This barrier concept using the ISV process has been successfully demonstrated at engineering-scale in which a vitrified floor and walls were created.[13] The results from this test demonstrate the feasibility of placing subsurface vitrified barriers beside, beneath, and/or around a waste site. Future work for this application needs to concentrate on analysis and computer modelling of the potential integrity of the vitrified barrier and an economic analysis of field-scale testing, demonstration, and application.

Engineered Structures

Early in the development process for ISV, it was recognized that the process may have civil ...eering, or structural, applications.[4] The primary application area is soil solidification (e.g., erosion barriers, slope stabilization, simulated building materials, etc.), especially in remote or cold weather regions where aggregate, cement, and conventional building materials are very costly. Development of the ISV process for this application has been limited since the primary emphasis for the ISV process is the remediation of contaminated sites. Implementation of the ISV process for this application requires adapting the equipment and/or operating parameters to meet civil engineering needs.

CONCLUSION

The ISV process is a remediation technology that is ready for implementation on contaminated soil sites less than 5.75-m deep. This depth is sufficient for most commercial applications and many DOE applications, but should be extended to 10 m for extensive application on DOE sites. The ISV process has great potential for applications other than contaminated soils such as remediation of buried waste sites, remediation of underground storage tanks, and placement of underground barriers and engineered structures. Costs for the resolution of technical issues for each of these potential ISV applications vary and would have to be evaluated on an application-specific basis. However, if cost studies for buried waste are an indication, the development costs for ISV are small relative to development costs for ex situ technologies, and the cost savings from the implementation of the ISV process are significant.

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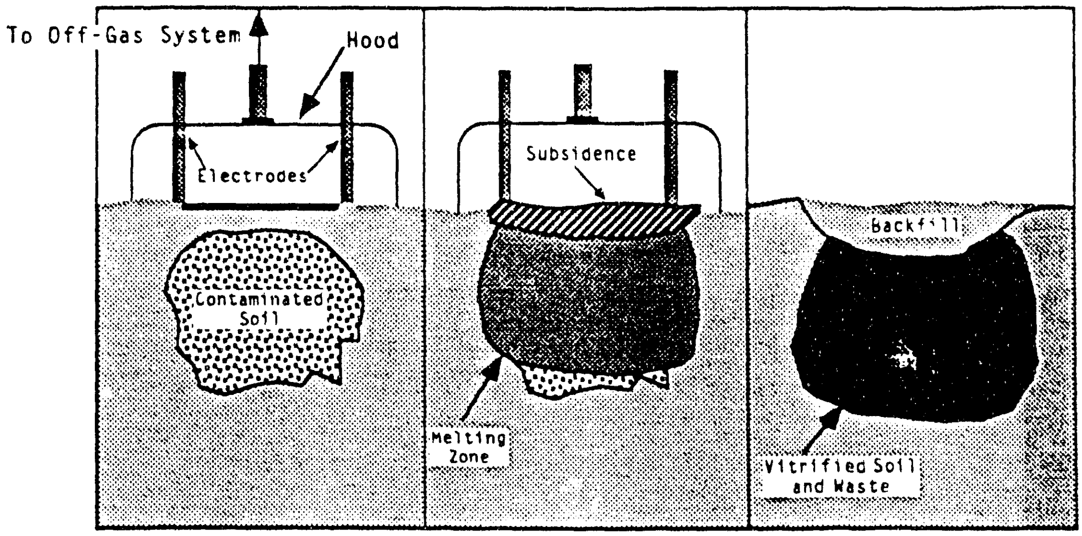

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- The off-gas treatment system performed within design criteria and successfully handled the high-combustible loadings (the wooden crib timbers) of the contaminated soil site
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POTENTIAL APPLICATIONS FOR THE ISV PROCESS

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Placement of Subsurface Vitrified Barriers

Underground barriers are a proposed means of providing long-term isolation and containment of waste sites. The ISV process produces a final product that would be ideal for containing the migration and fluid transport of wastes as well as isolating the waste from contact with animals, plants and people. This barrier concept using the ISV process has been successfully demonstrated at engineering-scale in which a vitrified floor and walls were created.[13] The results from this test demonstrate the feasibility of placing subsurface vitrified barriers beside, beneath, and/or around a waste site. Future work for this application needs to concentrate on analysis and computer modelling of the potential integrity of the vitrified barrier and an economic analysis of field-scale testing, demonstration, and application.

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CONCLUSION

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