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RECENT ADVANCES IN IN SITU VITRIFICATION

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INTRODUCTION

In Situ Vitrification (ISV) is an innovative mobile remediation technology for soils and other underground contamination. Developed by the U.S. Department of Energy's Pacific Northwest Laboratory[1] (PNL), ISV has advanced during the past decade from a laboratory concept to a remediation technology commercially available for contaminated soils.

ISV technology is currently being developed for remediation of DOE waste sites at Hanford, Oak Ridge National Laboratory (ORNL), Idaho National Laboratory (INEL), and other sites. Technical staff at each of these sites are actively preparing for application of the technology to contaminated soils and are considering future application to other types of wastes.

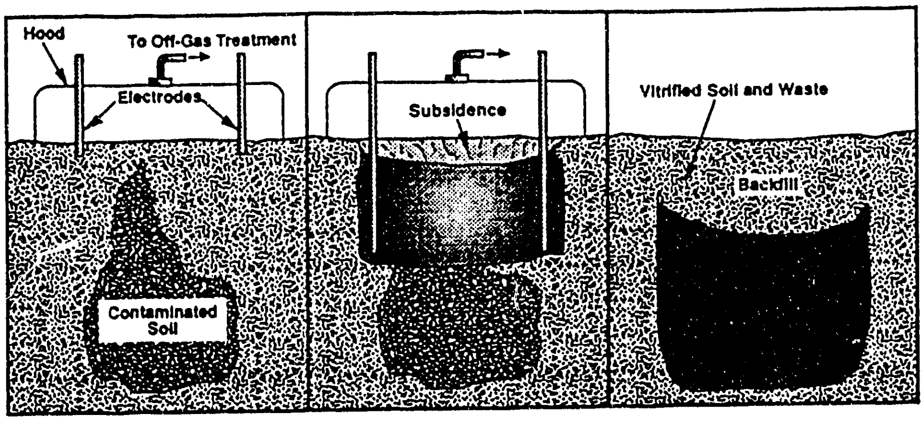
The incentives for application of ISV are large. ISV can convert contaminated sites to a solid, highly durable block similar to naturally occurring obsidian. The ISV product has been shown capable of passing U.S. Environmental Protection Agency (EPA) tests such as the Toxic Characteristic Leach Procedure (TCLP). Retrieval, handling and transport of untreated hazardous material would normally not be required after application of ISV. Therefore, costs, exposure to personnel, risk of releases to the environment, and generation of secondary wastes are greatly reduced compared with remove-and-treat technologies.

PROCESS DESCRIPTION

The ISV process melts contaminated soils in situ. Figure 1 illustrates the progressive stages of ISV treatment. An array of vertical electrodes, typically four, is set a few inches into the soil. A conductive mixture of graphite and glass frit is placed on the surface between the electrodes to serve as an initial conductive (starter) path. As electric potential is applied between the electrodes, current flows through the starter path, heating it and the adjacent soil to the melting point. Upon melting, typical soils become electrically conductive and the molten mass becomes the primary electrical conductor and heat transfer medium. Most soils melt in the range of 1600 to 2000 °C. As melting proceeds, the electrodes are moved correspondingly lower into the soil until the desired depth is reached, at which time the power is discontinued. The molten mass cools to a durable, multi-tonne block. Volume reductions of 25-45% are typically observed.

An off-gas collection hood maintained under a slight negative pressure gathers gases that evolve from the treatment zone. During melting, water vapor from the soil and organic pyrolysis products evolve and are collected in the hood and then passed through the off-gas treatment system.

Figure 1. ISV Operating Sequence



ISV INTEGRATED PROGRAM

The U.S. Department of Energy (DOE) is continuing to pursue application of ISV technology. In 1991 the DOE Office of Technology Development established the ISV Integrated Program to ensure that ISV technology development is focused and closely coordinated among the several DOE sites preparing to use ISV. The current program focus is to 1) transfer the technology for use on contaminated soils, 2) resolve issues necessary to allow ISV application to soils beyond the current limits, and 3) resolve issues common to soils as well as to advanced applications.

To complete these objectives, the program is concentrating on resolution of near-term issues, including:

- Fate of volatile organics during processing
- Vapor release from wet soils and compressible wastes
- Depth and melt shape control
- Waste minimization for sites with high Cs concentrations.

REGULATORY STATUS

The capabilities of ISV to permanently treat a site and to be performed in situ are considered to be highly advantageous by the regulatory community. Although ISV has not yet been used for remediation of a commercial site, strong regulatory support has developed for the technology.

Commercial ISV remediation services, as offered by Geosafe Corporation, have been selected as a preferred remedy at 10 private, EPA Superfund, and DOD sites within the U.S. These sites are located in the states of Colorado, Illinois, Michigan, Tennessee, Texas, Utah and Washington. The sites contain a broad range of organic (e.g., VOCs, SVOCs, herbicides, pesticides, dioxin, and PCBs) and heavy metal (e.g., As, Hg, and Pb) contaminants. Most include mixtures of organics and heavy metals. Remediation contracts now exist for two of these sites. Several are contingent selections, depending upon results from treatability testing and evaluation of alternatives by the principally responsible parties.

TECHNICAL STATUS

In the decade of ISV development, over 150 ISV tests have been conducted, each test treating from a few kilograms to over 800 tonnes of soil. Although several limitations have been identified, experience shows that most soils and contaminants are processable by ISV.

Recent Technology Demonstrations

Testing of ISV on multi-tonne quantities of contaminated soil is necessary to understand actual operating characteristics of the technology. To date, nine large-scale tests have been conducted in which 300 to 800 tonnes of soil were melted in each test. Pilot-scale tests, each melting tens of tonnes, have been conducted at ORNL, INEL, Arnold Air Force Base and Hanford. A few of the most recent of these tests are described below.

ORNL Trench A collaborative effort between ORNL and PNL has resulted in successful completion of a radioactive demonstration of ISV technology at ORNL. During the successful May 1991 5-day test, a target depth of 2.6 m (8.5 ft) was achieved and approximately 13 tonnes of a simulated ORNL waste disposal trench were vitrified with the PNL pilot-scale ISV unit.

Over 97.3% of the 10 mCi of ^{137}Cs was incorporated into the melt, and the remainder was captured in a HEPA prefilter assembly. The differences between the 1987 ISV test at ORNL and other tests in which over 99.8% of the Cs was retained are being examined. Retention of all other species in the block was well over 99%, as is normal for ISV.

The simulated trench was highly instrumented with over 110 buried thermocouples, pyrometers, pressure transducers, heat flux monitors and fugacity probes. Three geophysical surveys were performed during the melting process. The instrumentation, coupled with the surveys, provides significant real-time data on the ISV process.

Hanford Mixed Waste The roughly 800-tonne block produced during the April 1990 CERCLA Treatability Test[2] on a mixed waste crib at Hanford has recently been core-drilled and analyzed. This was the first large-scale test of mixed waste containing transuranic materials, fission products and hazardous chemicals, including chromium and lead. Characterization of the site confirmed the presence of wood timbers used to construct the crib.

The test required a total of 288 hours to reach the bottom of the wooden crib, producing a block 11-12 m diameter and over 4 m deep. Although pyrolysis products were observed in the off gas while melting through the area where the creosote-impregnated timbers were present, little impact on operating parameters was observed. Analysis of the glass and crystalline product shows high durability and a high degree of homogeneity throughout the block. For example, the TCLP leachate concentrations for both Chromium and Lead are each less than 0.05 mg/liter, which is two orders of magnitude lower than the permissible leachate concentration.

INEL Buried Waste Since 1988 PNL, INEL, Geosafe Corporation, other private firms, and universities have pursued a collaborative effort adapting ISV technology for application to buried waste. Until recently, efforts have focused on evaluating the ISV technology for application to TRU and mixed, contaminated buried waste in the Subsurface Disposal Area (SDA) at the INEL. Continued developmental efforts for this, and other, advanced applications of the ISV technology are currently on hold pending resolution of issues described herein concerning the implementation of ISV for contaminated soil.

In June and July 1990, two intermediate-scale ISV field tests were conducted by PNL and EG&G Idaho staff at the INEL.[3] The overall objective of the two settings was to assess the general suitability of the ISV process to remediate waste structures representative of buried waste found at INEL. In particular, these treatability tests were designed to provide essential information on field ISV performance while processing buried waste containing significant combustible and metal content.

Two test pits were constructed containing scaled-down (2-gallon buckets for 55 gallon drums) simulated waste but nc radioactive nor otherwise hazardous material. Test Pit 1 was designed to simulate a waste region of randomly disposed drums and boxes intermixed with soil. Test Pit 2 was designed to simulate a region of stacked drums and stacked boxes containing high metal content. Although Test Pit 2 is not believed to be a representative arrangement for most of the buried waste at the INEL, it was designed to represent a reasonable "worst case" bounding condition for the ISV technology. The material contained in the drums and boxes was similar to waste types contained within the INEL buried waste.

Tens of tons of soil and buried waste in the two test pits were successfully vitrified by the mobile ISV unit. An electrode feed system was demonstrated which allows processing of sites with unusually high metal content. Up to 75% volume reduction was achieved. Waste form durability tests using the MCC-1 leach procedure show the durability of the vitrified soil was comparable to that of naturally occurring obsidian and granite. Intrinsic rate constant measurements show the dissolution rates to be from 0.01 to 0.06 $g/(m^2d)$ at 90 °C. Over 90% of the iron is present in the ferrus form indicating the melt to be chemically reducing.

Compared to previous ISV tests in contaminated soils at other DOE sites, however, vitrification of buried waste is significantly more dynamic. This dynamic behavior is illustrated in Figure 2, which shows a 6-minute segment of the off-gas hood vacuum and the off-gas hood plenum temperature during melting of Test Pit 1, the random dump configuration. The pressure and temperature surges indicate that containment of off gases within the hood may require a more sophisticated off-gas containment system than was in use at the time. An improved design may also be required for other ISV applications potentially capable of rapid gas generation, such as underground tanks.

Underground Tanks Although the ISV program is currently concentrating on application of ISV to contaminated soils, vitrifying underground tanks in situ can in the future potentially provide substantial cost savings to DOE compared to retrieve-and-treat technologies. An ISV test vitrifying a 6000-gallon tank was conducted in July 1991.[4] This was the first opportunity to test the new large-scale moving electrode system with 30-cm-dia electrodes. The test proceeded well with the electrode feeding system functioning properly, and low-density materials were observed to be effective for enhancing melt depth. At a depth of 4 m, however, a sudden unexpected hood pressurization occurred, and a decision was made to cease operation to better understand the cause of the pressure buildup.

Further specific technology development for vitrification of underground tanks is delayed until the technology is implemented on contaminated soils and a better understanding of the causes of pressure buildup is obtained. However, despite the hood pressurization event, the large-scale electrode feed system was successfully tested and is ready for transfer and use on contaminated soil applications.

Off-Gas Containment System

PNL and INEL have jointly pursued tasks to determine the fundamental mechanism behind the dynamic behavior observed in the off-gas hood during the processing of buried waste. Possible mechanisms leading to dynamic events in the off-gas hood may be simplified to one, or a combination, of the following:

- Net energy increase of gases in the off-gas hood
  - Addition of hot gases from the ISV melt
  - Combustion of pyrolysis gases in the off-gas hood
  - Increased radiant and convective heating of gases in the off-gas due to changes at the melt surface
- Net increase in number of moles of gases in the off-gas hood.

In addition to this effort to develop an understanding of the fundamental mechanism for transient off-gas events, PNL also evaluated suppression systems designed to buffer and/or mitigate these transient events. This work led PNL to a water spray suppression system which is believed capable of combating dynamic events in the off-gas hood irrespective of the underlying mechanism. Calculations show that a water spray suppression system designed to remove energy from the gases in the off-gas hood has great potential for mitigating the pressure increases associated with transient gas releases from the ISV melt. The premise for this concept is as follows: during a transient event (caused by energy and/or material addition to the off-gas hood), a fine water spray can be rapidly injected into the off-gas hood. Heat from the hot gas vaporizes the water, and the latent heat of vaporization causes a rapid overall temperature decrease in the off-gas hood plenum. Although gas is generated by evaporation of the injected water, the reduction in gas volume due to the temperature decrease (per the ideal gas law relationship) is much more significant. The pressure within the hood therefore rapidly decreases.

During the operational acceptance test for the upgraded PNL engineering-scale ISV unit, proof-of-principle testing of the water spray suppression system was performed.[5] Figure 3 illustrates the pressure and temperature response in the off-gas hood after two separate 10-sec trials of the water spray suppression system. For both water spray trials, initiation of the water spray system (indicated by the asterisks in Figure 3) resulted in a dramatic decrease in the off-gas hood pressure (an increase in hood vacuum) within less than a second. The change in temperature resulting from the onset of the water spray occurs in less than a second. The apparent delayed decrease in the recorded off-gas temperature is due to the slower response time of the thermocouple.

Further research is needed to gain a fundamental understanding of transient off-gas behavior resulting from rapid gas releases during application of ISV to buried waste. This understanding will allow development of ISV predictive tools and design of off-gas containment systems suitable for application to buried waste. However, as the proof-of-principle testing of the water spray suppression system illustrates, engineered solutions to ensure containment of off gases during processing need not be complex.

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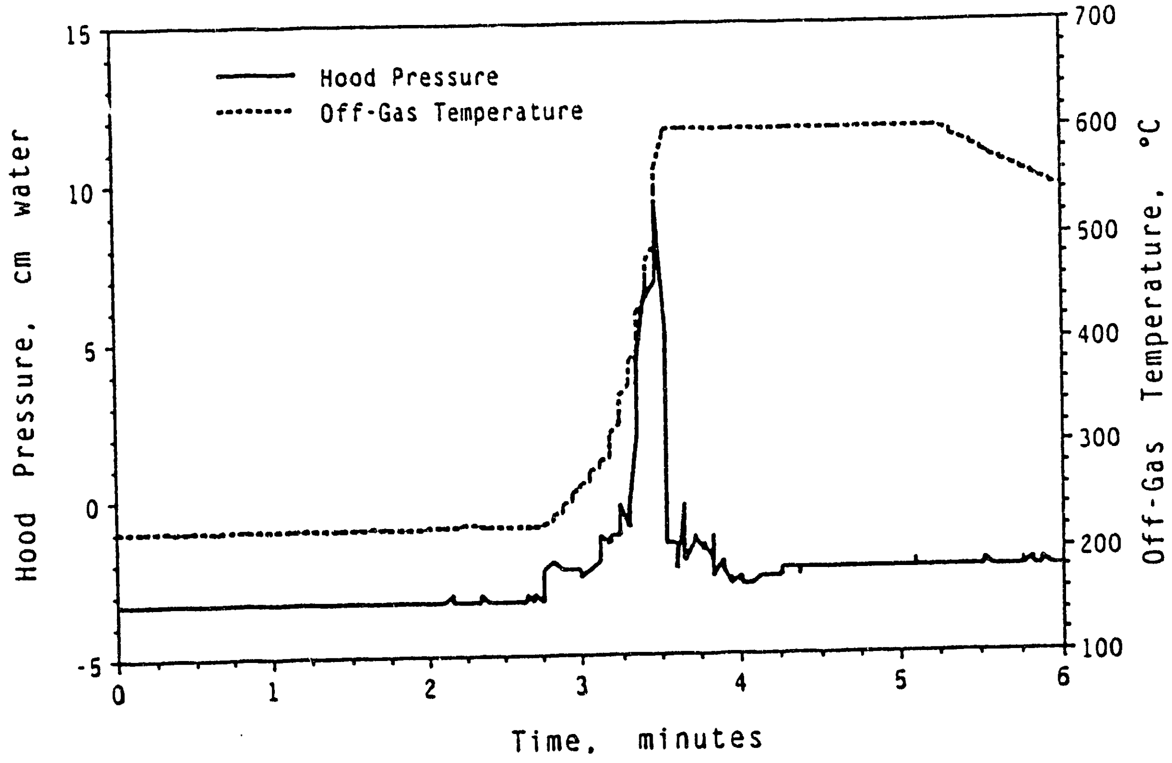
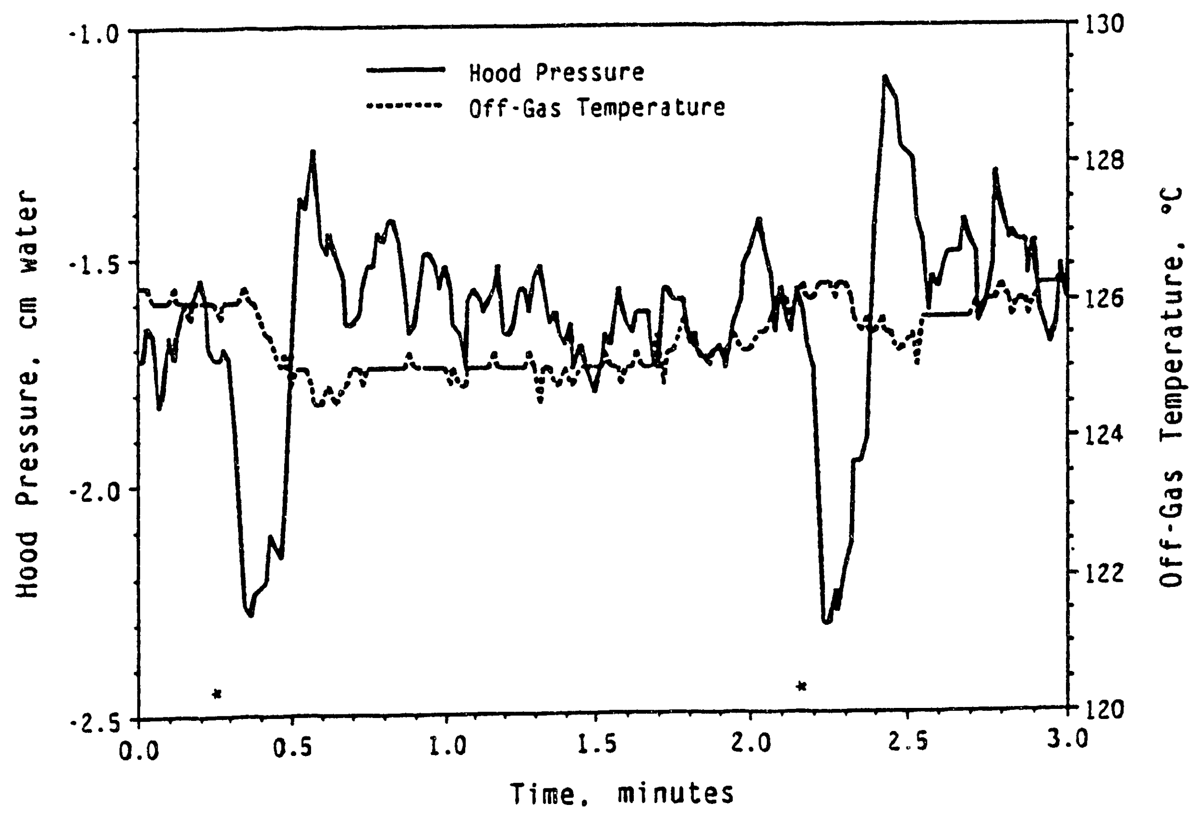


<u>Figure 2</u>. Off-Gas Hood Conditions During Buried Waste Vitrification



<u>Figure 3</u>. ISV Hood Vacuum Enhancement by Water Spray

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