IN SITU VITRIFICATION - APPLICATION TO BURIED WASTE

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ABSTRACT

Two in situ vitrification field tests were conducted in June and July 1990 at Idaho National Engineering Laboratory. In situ vitrification is a technology for in-place conversion of contaminated soils into a durable glass and crystalline waste form and is being investigated as a potential remediation technology for buried waste. The overall objective of the two tests was to assess the general suitability of the process to remediate buried waste structures found at Idaho National Engineering Laboratory. In particular, these tests were designed as part of a treatability study to provide essential information on field performance of the process under conditions of significant combustible and metal wastes, and to test a newly developed electrode feed technology. The tests were successfully completed, and the electrode feed technology provided valuable operational control for successfully processing the high metal content waste. The results indicate that in situ vitrification is a feasible technology for application to buried waste.

INTRODUCTION

During June and July 1990 two in situ vitrification (ISV) field tests were conducted at Idaho National Engineering Laboratory (INEL) to investigate the application of ISV to buried waste. The Intermediate Field Tests were a cooperative effort between INEL and Battelle, Pacific Northwest Laboratory (PNL) and used the PNL intermediate-scale processing equipment.

ISV is a thermal treatment that melts contaminated soils and wastes into a chemically inert glass and crystalline substance. The ISV process was developed by PNL during the 1980s, and the successful results of 59 tests conducted under a variety of site conditions and a variety of waste types have proven the general feasibility and widespread applications of the process.(1) The process is initiated by a square array of four graphite electrodes inserted a few inches into the ground. Because soil is not electrically conductive, a mixture of flaked graphite and glass frit is placed among the electrodes to serve as a starter path. Once an electrical potential is applied to the electrodes, an electrical current is started in the starter path that heats up and begins to melt the soil. The graphite starter path is eventually consumed by oxidation, and the current is transferred to the molten soil, which is processed at temperatures between 1450 and 2000°C. As the molten or vitrified zone grows, it incorporates or encapsulates any radionuclides and nonvolatile hazardous elements into the glass structure. The high temperature of the process destroys many organic components by pyrolysis. The pyrolyzed by-products migrate to the surface of the vitrified zone and combust in the presence of air. A hood placed over the area being vitrified directs the gaseous effluent to an off-gas treatment system. After processing, the molten material is allowed to cool, incorporating dissolved waste into the vitrified product.

The intermediate-scale test system used for these tests consists of four graphite electrodes, a power control unit, an off-gas containment hood over the test site, and an off-gas treatment system housed in a portable semi-trailer (see Fig. 1).

The intermediate-scale power system uses a Scott-Tee connection to transform a 3-phase input to a 2-phase secondary load on diagonally opposed electrodes in a square pattern. Electrodes are fed into the melt via a pneumatically controlled feed system. The electrode feed assemblies consist of four independently controlled, air-actuated systems with a feed system for each electrode. The electrode feed system represents an advance in the ISV technology by providing an additional degree of operational control. Previous ISV tests have utilized electrodes that were predrilled into the ground. The use of electrode feeding allows the electrodes to be inserted in shallow holes at the surface and then fed in as the melt progresses. This technique is expected to be particularly useful in buried wastes containing large amounts of metal. Electrode feeding allows the electrodes to be held above any metal pools that may form at the bottom of a melt and avoids potential shorting conditions that might otherwise hamper operation.

The off-gas containment hood is designed to collect off-gases emanating from the melt and direct them to an off-gas treatment system. The hood is operated at a slight vacuum (1 to 2 in. of water), which is created by an induced draft blower, and has a volume of approximately 28.3 m^3 (1000 ft^3) to provide a surge capacity that minimizes vacuum loss during periods of sudden gas release. An air inlet line is provided through which air is drawn into the hood providing oxygen for combustion of pyrolysis gases released from the melt. Off-gases collected in the hood are directed to the off-gas treatment system that consists of a Venturi-Ejector scrubber and separator, a Hydro-Sonic scrubber, a

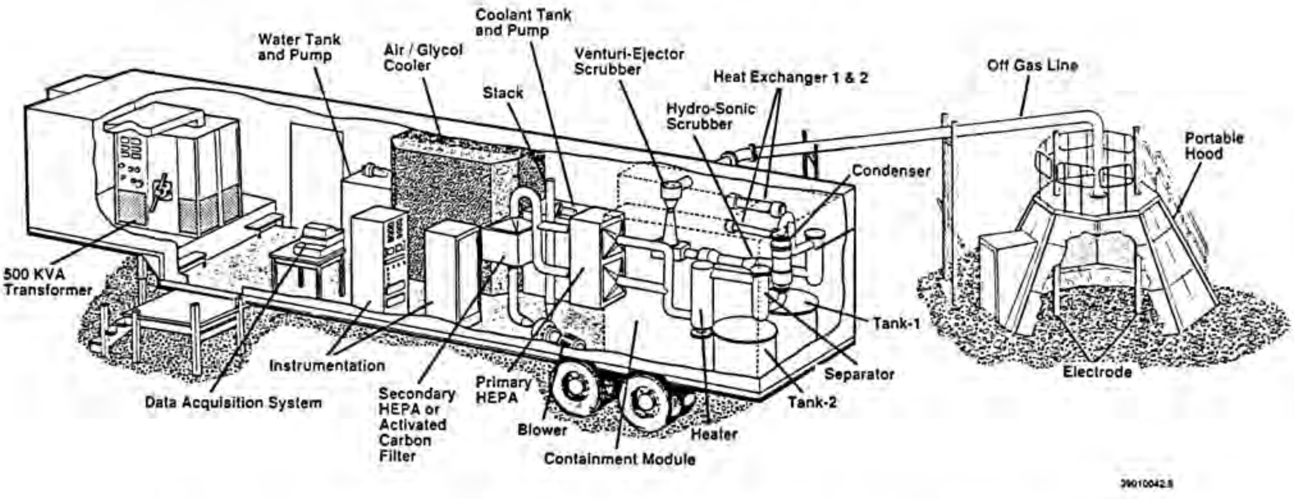

Fig. 1. Cutaway view of the intermediate-scale process trailer and off-gas hood.

separator, a condenser, another separator, a heater, two stages of HEPA filtration, and a blower.* The entire off-gas system has been installed in a 13.7-m long semi-trailer to facilitate transport to a waste site.

TEST OBJECTIVES AND DESIGN BACKGROUND

The overall objective of the two intermediate field tests was to assess the general suitability of the ISV process to remediate waste structures representative of those found at the INEL Radioactive Waste Management Complex (RWMC).

The RWMC encompasses 144 acres in the southwest section of INEL. The Subsurface Disposal Area (SDA) of the RWMC served as a disposal area for radioactive (intermediate- and low-level solid and liquid wastes and transuranic and mixed-fission products) and nonradioactive hazardous wastes. The buried wastes were primarily generated by the Department of Energy (DOE) Rocky Flats Plant and INEL operations.

The solid radioactive waste stored at the SDA is found mixed with nonhazardous waste including broken equipment, lumber, paper, rags, plastic, and other solid debris. In addition, significant amounts of organic wastes generated by Rocky Flats Plant operations are contained in 55-gal drums and buried in several pits.

The INEL ISV field tests were designed to assess feasibility of using ISV to remediate SDA buried waste. The waste materials and containers used in these tests were designed to simulate those found in INEL buried waste. However, because these tests were designed to assess overall process performance, no radioactive or hazardous materials were used. Additionally the waste and containers were scaled versions of SDA waste. It is anticipated that a larger scale system would be used for production remediation of SDA wastes. This full-scale system utilizes greater power applied to electrodes spaced further apart. The anticipated power levels and electrode spacing for full-scale operations are based on achieving sufficient melt depth to process the INEL buried waste. For the intermediate tests, the electrode spacing was reduced in order to provide the same power density to the melt (kW/m^2) as anticipated for full-scale operations. Waste container dimensions were reduced in proportion to the reduced electrode spacing between the two scales (e.g., 55-gal drums were represented by 2.5-gal containers, and 1.22 x 1.22 x 2.44 m boxes were represented by 0.46 x 0.46 x 0.76 m boxes).

The scaling philosophy outlined above resulted in a target depth of 1.8 m for these intermediate-scale tests; this depth corresponds to achievement of approximately 6.3 m at full-scale.

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*References herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof.

INTERMEDIATE FIELD TEST 1

Test Pit 1 was primarily designed to test the ISV process in an area of randomly disposed waste representative of conditions expected to exist at the SDA. Due to the nonhomogeneous character of the SDA waste and the uncertainties regarding characterization of the waste, it was possible to represent SDA waste only in an overall sense. However, several key aspects of SDA buried waste were represented in order to collect applicable data for ISV processing performance, namely, buried combustible material and buried scrap metal in containers.

From bottom to top, Test Pit 1 consisted of 0.6 m of soil underburden, 1.8 m of a randomly-disposed box and can layer mixed with fill dirt, and 0.6 m of soil overburden. Fig. 2 is a schematic of the completed Test Pit 1 with the hood in place. Materials placed in the 2.5-gal cans were paper, cloth, wood, metal, simulated sludge, and concrete/glass. Materials placed in the boxes were metal and concrete/glass. Table I shows summary amounts of waste materials contained in the pit.

TEST 1 RESULTS

Test 1 started on June 14, 1990. The power levels fluctuated during the test but generally averaged around 300 kW for the total test duration of approximately 18 hours and at the approximate total of 5400 kWh. The overall rate of downward melt growth averaged 4.6 cm/h.

The achieved melt depth was approximately 1.9 m. Subsidence was measured at 1.5 m, leaving a 0.4 m layer of glass in the bottom of the vitrified area.

Generally, operations conducted on the random disposal orientation of Test 1 resulted in a very dynamic process that was extremely uncharacteristic of processing contaminated soil sites. Significant temperature and pressure spikes were observed in the hood throughout the test and appeared to be associated with each encounter of a buried can or box. Significant imbalances in the power supply routinely created electrical instabilities.

Figure 3 is a combined plot of hood vacuum and hood plenum temperature and shows the correlated pressure and temperature spikes. The first transient event occurred at 5.9 hours into the test, as shown in the figure. This event

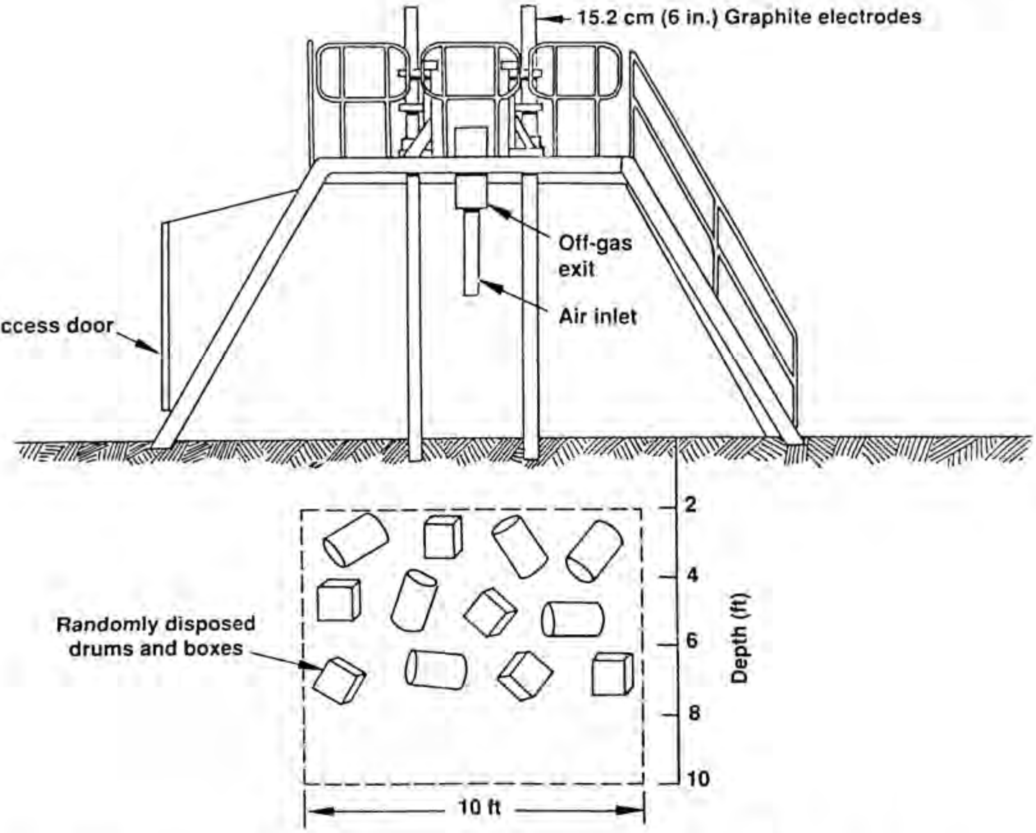

Fig. 2. Schematic of completed Test Pit 1 with hood assembly covering the test site.

TABLE I

Contents of Test Pit 1

Material	No. Cans	No. Boxes	Kg Per Can or Box	Total
Combustible				
Paper/Cloth	104		1.88	196
Wood	4		2.21	9
Cardboard (box)		20	3.63	73
Wood Pallet (on boxes)		4	6.12	24
Sludge				
Water	62		3.50	217
Floor-Dri			0.32	20
Micro cell E			1.05	65
Metals (stainless and carbon steel)				
Inside Cans	17		3.74	64
Can-Metal	208		0.79	165
Inside boxes		16	55.82	893
Concrete/Glass				
Concrete Inside Cans	21		5.01	105
Glass Inside Cans			2.91	61
Concrete Inside Boxes		4	72.01	288
Glass Inside Boxes			39.75	159
Soil				
(estimated, excluding underburden)				24,780

resulted in the most dramatic pressure and temperature spikes for the test. (The temperature spike shown on the figure at 5.9 hours is biased high due to molten glass splattering from the melt and contacting the thermocouple.) The spikes resulted from pyrolysis gases being released from the melt and combusting in the hood. These gases were generated from the combustible materials buried in 2.5-gal cans; approximately 2 kg of material were placed in those cans containing combustibles. Combustion was evidenced by gas monitors in the off-gas line, which measured an increase in carbon monoxide and a decrease in oxygen concentrations during most spike events. The pressure spikes of the first and subsequent events were not characteristic of detonations; most pressure spikes occurred over a 10 to 30-second duration.

The dynamic behavior of buried waste processing posed a variety of operational instabilities relative to the electrical power supply. As the melt encountered the buried containers, many of the sudden gas releases that affected the hood environment also affected the transformer. The primary cause for these disruptions was the minimal glass volume associated with the test. Inherent with any ISV process, the treated soil region is densified as water, soil, gases, and other decomposition products that are driven off. This densification, or subsidence, typically ranges from 30 to 50% for a contaminated soil site; however, subsidence was significantly greater for this test (75%) involving a simulated buried waste site.

A minimal amount of glass available to the melt, coupled with the dynamic melt behavior, created electrical instabilities. For this test, only 0.6 m of soil overburden was available to provide a approximate 30 cm layer of glass before encountering the buried waste. As each waste container was encountered, glass flowed into the container, temporarily resulting in a net loss of glass between the electrodes available to conduct current. When containers near the edge of the melt were encountered, the glass flowed into the containers and froze, thereafter being unavailable to the melt and resulting in a continual net loss of glass. With only a minimal level of glass to conduct the electrical current, the transformer was very susceptible to imbalances. (The intermediate-scale power transformer used in these scaled tests is not as flexibly-designed to handle electrical imbalances as is the full-scale transformer.)

The electrical instabilities ultimately resulted in terminating the test shortly after the 1.8 m depth objective for the test was achieved. A particular electrical problem was related to the coating used to minimize oxidation of the graphite electrodes. The electrodes were painted with a silicon-based coating to help reduce oxidation of the graphite electrodes at the air/melt interface. The oxidation can lead to electrode failure if the electrodes are held in a static position for several hours. The use of the coating is a compromise in that, while the coating helps prevent oxidation, it tends to cause the electrodes to stick to the glass. This sticking can become particularly problematic when a "cold cap" has formed on the melt surface; a cold cap is formed when the top surface cools enough to partially solidify. During the test, the coated electrodes froze into the cold cap and could not be moved (inserted or retracted) to compensate for electrical imbalances. The electrodes would become free from the cold cap whenever a container was encountered that disrupted or melted the cold cap with combustion or other sudden gas release and would free fall

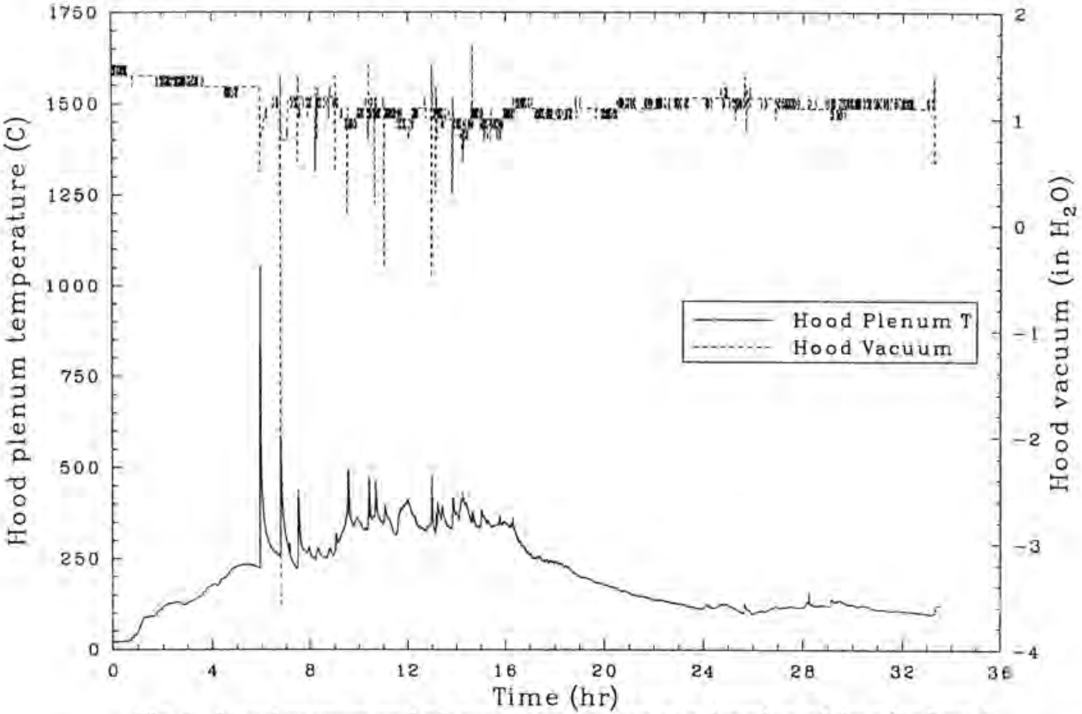

Fig. 3. Hood vacuum and plenum temperature as a function of time for Test 1.

for typically 15 cm until they rested on the bottom of the melt. Ultimately, the test was terminated when the molten glass melted away from the frozen electrodes during a period of time when no containers were encountered.

Test 1 results indicated that ISV processing of buried waste produces dynamic and transient events within the melt resulting both from gas release from combustible waste and from glass flow into void areas. Additionally the reduced amount of soil for buried waste (relative to previous ISV applications) tends to magnify the effect of melt behavior on the power system.

INTERMEDIATE FIELD TEST 2

Test 2 was designed to test the ISV process under two conditions: stacked waste and high-metal content waste. Stacked waste presents a potential challenge for the ISV process in that such a region may contain a reduced amount of soil relative to the waste fraction. Additionally, a stacked waste region could challenge the capability of the off-gas processing system if several containers were breached at about the same time.

High-metal content waste may result in a challenge to the process because ISV is based on resistance heating, and metal shorting can interfere with this process. Previous testing indicated limitations on allowable metal content; however, this testing was conducted with fixed electrodes. The use of the electrode feed system provides a potential method to process high-metal waste because the electrode can be inserted or retracted from the melt based on changing melt electrical characteristics.

From bottom to top, Test Pit 2 consisted of approximately 0.9 m of soil underburden, 0.9 m of a stacked box region, 0.6 m of a three-layered stacked can region, and 1.2 m of soil overburden. Test Pit 2 was originally constructed with 0.6 m of overburden; additional overburden was added after completion of Test 1. A single instrumented can was placed in the soil overburden at an approximate 0.6 m depth. Fig. 4 shows a schematic of the contents of Test Pit 2 with the hood in place. Materials placed in the 2.5-gal cans were paper, cloth, wood, metal, simulated sludge, and concrete/glass. Materials placed in the boxes were metal and fill dirt. Table II provides summary information on pit waste material contents.

During pit construction, two arrays of thermocouples were placed, a vertical array and a horizontal array. These were placed in order to monitor melt growth during the test.

Following an evaluation of Test 1, several equipment and operational changes were implemented for Test 2. As indicated above, an extra 0.6 m of soil overburden was placed on top of Test Pit 2. The additional overburden was placed in order to evaluate the effectiveness of overburden in reducing or buffering the effects of transient gas releases related to vacuum fluctuations in the hood. During the placement of the additional overburden, a single can containing approximately 1.8 kg of paper was placed in order to gain data on hood plenum responses for gas release from a single can. Prior to starting Test 2, the electrodes were

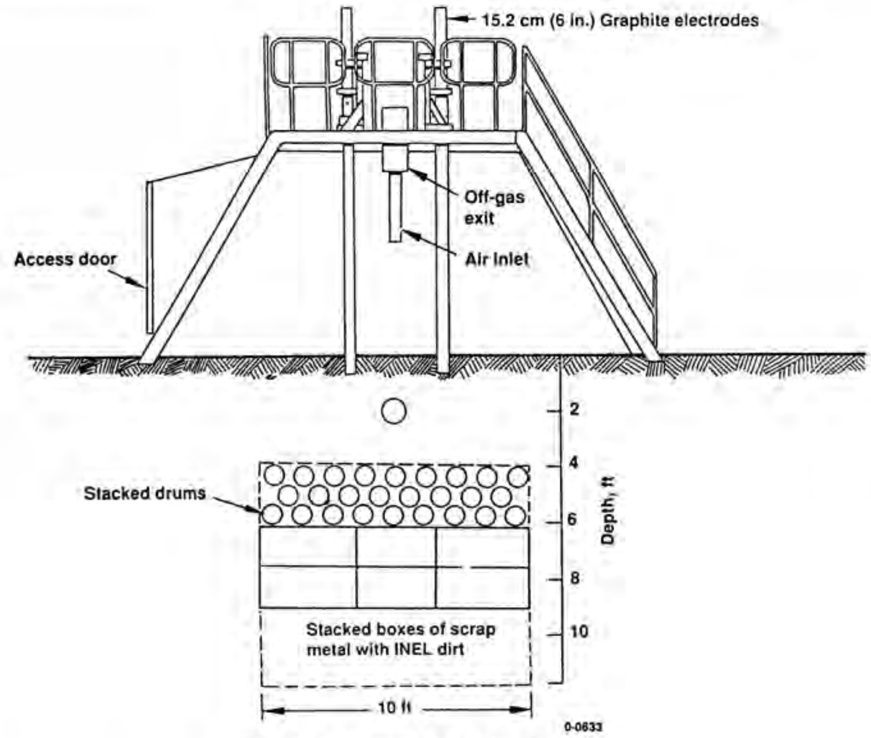

Fig. 4. Schematic of Test Pit 2.

not coated with the silica-based coating used in Test 1. This change was based on the assumption the electrode coating was the cause of the sticking and allowed determination of the rate of graphite oxidation without such a coating. A final change was made regarding operational control of the electrodes. Whereas the electrodes in Test 1 were primarily allowed to feed via gravity as the melt progressed, for Test 2 they were primarily gripped and manually fed as the melt progressed. This allowed greater control over electrical imbalances. (Experimentation during the test indicated best electrical performance when electrodes were held a few centimeters above the bottom of the melt.)

TEST 2 RESULTS

Test 2 started on July 11, 1990 and lasted 70.5 hours. The total power applied to the melt was 21,300 kWh. The achieved melt depth was 3.9 m. The average melt rate was 4.6 cm/h. Test 2 was much less dynamic than Test 1; there were fewer transient conditions in the hood. Electrical imbalances did occur when melting through the stacked can region; however, an improved understanding of this phenomenon combined with uncoated electrodes resulted in smoother electrical operations.

At approximately 8 hours, the melt started to thermally influence the instrumented can placed at the 0.6 m depth. The resulting temperature spike occurred at 10.9 hours and was the most significant thermal event for the entire test. The plenum temperature spiked from 360 to 630°C. The carbon monoxide concentrations indicated combustion occurred in the hood.

As the melt front approached the stacked can region, the downward melting rate decreased. The can region appeared to act as a heat sink causing the downward melt progression to slow dramatically, as shown in Fig. 5. For approximately 14 hours, the melt front remained at the same depth until all thermocouples in the stacked can region indicated a temperature of at least 100°C. The melt depth, as measured by the depth of the electrode inserted into the melt, did not progress into the can region until the entire can region reached 100°C. A positive consequence of this situation is that most, if not all, of the water in the sludge cans vaporized and escaped from the cans into the surrounding soil well ahead of the approaching melt front. Additionally, the cans released pressure generated by the simple heat expansion of air well ahead of the approaching melt front. These factors, combined with the additional 0.6 m of soil overburden, effectively prevented the dramatic pressure spikes that were characteristic of Test 1.

The stacked box region, consisting of high metal content waste intermixed with soil, resulted in different operational behavior compared to the stacked can region. During the processing of the stacked box region, power levels averaged 300 to 350 kW. The high metal content of this region combined with the molten metal from the stacked can region did not hamper electrical operations of the transformer. The reasons for the smooth electrical operations

TABLE II
Contents of Test Pit 2

Material	No. Cans	No. Boxes	kg per can or box	Total (kg)
Combustible				
Paper/Cloth	202		1.80	363
Wood	7		1.42	10
Box Cardboard		48	3.63	174
Pallets (4 @ 79 lb/pallet)				143
Sludge				
Water	134		3.50	469
Floor-Dri			0.32	43
Micro cell E			1.05	140
Concrete/Glass	50			
Concrete Inside Cans			5.44	272
Glass Inside Cans			2.15	107
Metals (stainless and carbon steel)				
Inside Cans	40		2.98	119
Can-Metal	433		0.79	344
Inside boxes		48	54.21	2602
Soil				
Inside Boxes (measured)		48	110.69	5313
other, excluding underburden (estimated)				17350

relative to Test 1 include: (a) the electrodes were continually gripped and held above the molten metal at the bottom of the melt with the insertion depths adjusted as needed and (b) the mass of the melt was increased relative to Test 1 due to increased overburden. No significant fluctuations in resistance were observed, and resistance averaged less than 1 ohm for both phases. From 48 hours through the remainder of the test, voltage consistently averaged 220 Vac for both electrical phases.

At approximately 68 hours, power to the electrodes was deenergized and the electrodes allowed to rest on the bottom surface of the melt to confirm the depth of the melt. Melt depth was confirmed at an average electrode depth of 3.1 m.

PRODUCT EXCAVATION AND DESCRIPTION

Upon completion of the tests, the two ISV blocks were allowed to cool and then excavated. The general shape of Test Pit 1 after ISV processing was a square-sided hole with walls 8 to 10 cm thick. At the bottom of the hole was a glass oval monolith with approximate dimensions of 1.5 x 1.8 m and with a thickness of approximately 0.55 to 0.61 m. The depth from ground surface to the bottom of the melt was approximately 2 m. The total amount of processed waste recovered from Test Pit 1 was 8267 kg.

An interesting feature noted during excavation of the vitrified product was the presence of a number of glass molds of cardboard boxes at the edges of the vitrified area. The original shape of the cardboard box was preserved. It is likely that the molds were formed as glass flowed into the boxes and rapidly cooled.

The vitrified product in Test Pit 2 was much more massive than the Test Pit 1 product. The subsidence hole to the top of the melt ranged from about 2.2 to about 2.3 m, with the monolith being about 0.98 m in thickness. Total depth from ground surface to the bottom of the melt was approximately 3.2 to 3.9 m. The glass walls on the sides of the subsidence hole ranged in thickness from 10 cm to 60

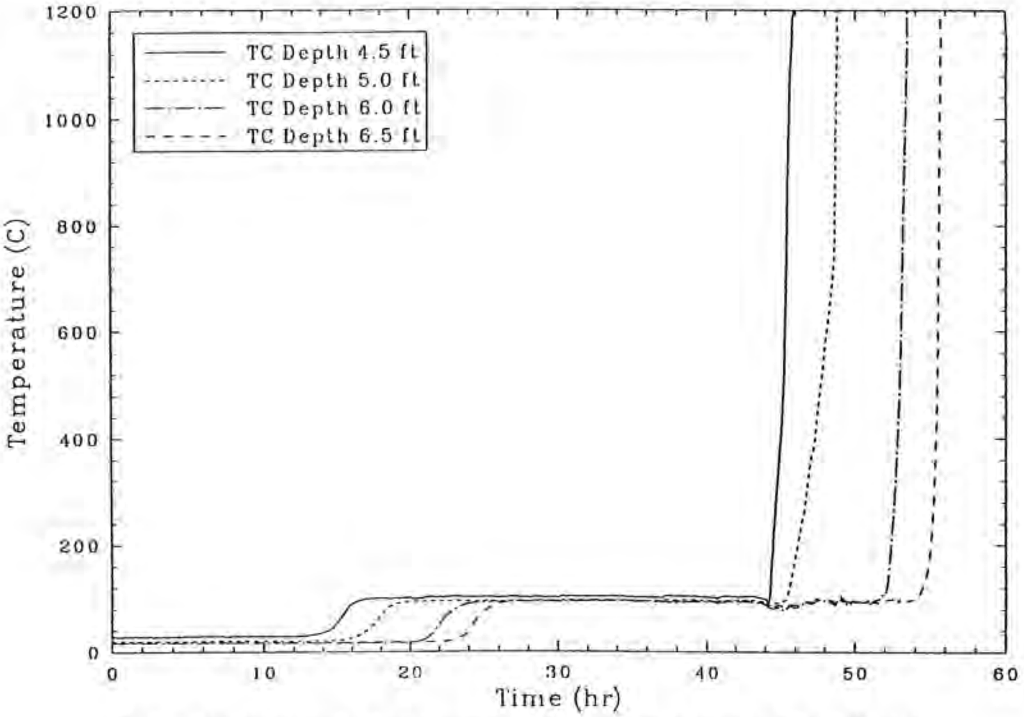

Fig. 5. Thermocouple temperatures in the stacked can region for Test 2.

cm. The weight of the monolith was 13,109 kg, and the total amount of product recovered from Test Pit 2 was 17,430 kg. The product from Test Pit 2 contained both a glass phase and a crystalline phase. (Only the glass phase was observed in the Test Pit 1 product). The Test Pit 2 monolith consisted of an outermost zone of black glass about 5.1 cm thick followed by a fine-grained white to beige zone and a faint lavender porcelaneous region 5.1 to 10.2 cm thick that graded into a more coarsely grained material. This more coarsely grained material constituted the bulk of the monolith.

An interesting feature observed during excavation of both ISV blocks was the apparent steep thermal gradient at the edge of the melt front. Alteration effects of waste in proximity to the melt front were restricted to short distances. For example, molten steel sheet metal was observed within about 5 cm of unaltered cardboard. Carbonized paper and cloth were often observed in direct contact with the glass. The extent of alteration, and therefore the thermal gradient, is probably a function of both the temperature and mass of the nearby melt and is highly variable from point to point around the pits. The above observations indicate the probability of underground fires is very low provided that there are no oxygen sources.

CONCLUSIONS

Based on analyses of test data to date, the following points can be made relative to the application of ISV to buried waste.

The ISV process appears to be a feasible technology for application to buried wastes. For both tests, the target depth of 1.8 m was achieved. The process fully incorporated and dissolved simulated waste containers into the melt to produce a glass and crystalline product. Evaluation of product durability is currently ongoing.

The electrode feed technology was successful in processing the high metal content waste. Electrode feeding represents a significant advancement in ISV technology by allowing greater operational control and response to melt electrical characteristics.

The temperature and pressure spikes will require further analyses. It is expected that a robust processing system will be required to effectively contain the off-gases inside the hood. The hood must be designed to accommodate the pressure spikes created by gas releases from containers, combustion, and thermal expansion of gas. The pressure spikes experienced in Tests 1 and 2 were not characteristic of detonations that produce rapid pressure spikes. The hood must be capable of withstanding contact from splatter of molten glass and must be capable of accommodating short-lived gas temperatures in excess of 700°C.

Relative to previous ISV applications to contaminated soils, ISV processing of buried waste produces a significant reduction in the volume of the waste being processed. The resulting subsidence of the vitrified area from grade level may result in uncovering adjacent waste, thus increasing the hazards of post test activities. Consequently, it appears desirable to incorporate into the equipment design the ability to add glass-forming materials during processing to prevent adjacent waste forms from being uncovered. The presence of additional molten glass during processing would also serve to limit electrical instabilities by reducing the impact of events such as glass flow into adjacent containers. Additional glass may also serve to reduce the severity of transient temperature and pressure spikes in the hood. Evidence from Test 1 indicates that waste forms buried at greater depths produced less severe transients.

Additional information regarding the INEL intermediate field tests is presented in (2). Additional analysis of test results is currently ongoing; this analysis includes analytical modeling of hood transients, determination of migration of nonradioactive tracers placed in the pit to simulate plutonium, and characterization studies of the vitrified product.

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