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**Feasibility Testing of In Situ Vitrification
of Arnold Engineering Development Center
Contaminated Soils**

C. L. Timmerman

March 1989

**Report Prepared by
Pacific Northwest Laboratory
Battelle Boulevard
P. O. Box 999
Richland, Washington 99352
under Project No. 14384**

for

**Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. Department of Energy
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Feasibility Testing of In Situ Vitrification
of a High-Level Waste Development Center
Containing Solids

-C. L. Johnson

March 1988

Report prepared by
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SUMMARY

Process feasibility studies using in situ vitrification (ISV) were successfully performed on two different site soils from the Arnold Engineering Development Center (AEDC) located in the southern portion of middle Tennessee. This effort was directed through the U.S. Department of Energy Hazardous Waste Remedial Action Program (HAZWRAP) Office managed by Martin Marietta Energy Systems. In situ vitrification is a thermal treatment process that converts contaminated soils and wastes into a durable glass and crystalline form. During processing, heavy metals or other inorganic constituents are retained and immobilized in the glass structure; organic constituents are typically destroyed or removed for capture by the off-gas treatment system.

The bench-scale ISV testing results, reported herein, indicate that the two AEDC sites may be successfully processed by ISV. Site 1 is a general landfill area for which ISV processed clean soil to prove that ISV could melt the soil type from that area. The other area, Site 10, is a fire training pit that is contaminated with fuel oils and heavy metals from fire training exercises. Actual site material was processed by ISV to determine its feasible application to those contaminated soils. Initial testing and analyses of the soils determined that a lower melting, electrically conductive, fluxing additive (such as sodium carbonate) is required as an addition to the soil for ISV processing to work effectively. With the additive, ISV processing was successful on both soil types. With the high destruction of organics and high retention of inorganics in the melt, the small percentage of particulate and gaseous releases can be effectively retained by a conventional wet scrubbing and filtering system appropriately designed to meet necessary criteria established for airborne releases.

Analytical efforts for this project were directed towards evaluating the organic destruction and migration effects of ISV processing on the Site 10 contaminated soil. No significant migration of hydrocarbon contaminants was detected in the surrounding soil. Off-gas releases of the hydrocarbons indicated a greater than 98% destruction efficiency by the ISV process. Leach testing using Extraction Procedure (EP) Toxicity and Toxic

Characteristics Leach Procedure (TCLP) showed that all metals of concern were below maximum permissible limits, indicating that the ISV process produces a nonhazardous product. All these favorable results indicate that ISV could be used to treat contaminated soils (specifically Site 10) at the AEDC site. Based on this information, it is recommended to proceed with a pilot-scale test at the AEDC Site 10 fire training pit to verify this performance.

ACKNOWLEDGMENTS

The author gratefully acknowledges Martin Marietta Energy Systems, Inc. and Arnold Engineering Development Center for providing Pacific Northwest Laboratory the opportunity to perform this testing. The author would also like to thank Jim Jeffs for his efforts associated with test preparation, operations, and analyses in support of this program. High-quality analytical staff greatly assisted the interpretation of the data provided in this report--these people included: Mary Ann Reimus, Frank Hara, Rich Hallen, and George Meadows.

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INTRODUCTION

As management of hazardous materials gains increased attention in the United States and throughout the world, new, more effective technologies are being sought to immobilize and/or destroy the materials either in situ for wastes previously disposed of or at the waste generation site. New and proposed environmental regulations are making landfill disposal very costly and are moving toward severely limiting future land disposal. Furthermore, the extended liability associated with future environmental impairment provides a significant incentive to dispose of and delist hazardous chemical wastes within the secured site or waste site boundary.

Pacific Northwest Laboratory (PNL)^(a) is developing a remedial action process for contaminated soils that is significant in its application to these concerns. The process, called in situ vitrification (ISV), was initially developed to demonstrate a potential technology for disposal of soil contaminated with transuranic waste at the Hanford Site in southeastern Washington, although recent tests have shown that many hazardous chemical wastes are also destroyed or immobilized as a result of the treatment. In situ vitrification was originally developed for the Department of Energy by PNL. This report presents evidence that ISV also has applicability to Arnold Engineering Development Center (AEDC) contaminated soils, which are contaminated with fuel oils and heavy metals from fire training exercises.

In situ vitrification is a thermal treatment process that converts contaminated soils into a chemically inert and stable glass and crystalline product. The ISV process could potentially be applied to many contaminated soil sites at AEDC. The processing would be performed in place; high temperature would destroy or remove organic contaminants, and the glass would immobilize any inorganic contaminants. All these functions would be performed in one processing step.

This report presents the results of two bench-scale ISV tests conducted for Martin Marietta Energy Systems. The primary objective of this study was

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to determine the applicability of the ISV process to soils contaminated with fuel oils. To accomplish this objective, initial bench-scale tests--one on Site 1 soils of a landfill and one on Site 10 soils from a fire training pit--were performed. Testing results determined the destruction of organics and the retention of inorganics in the vitrified product. Fractional release of contaminants to the off-gas treatment system and leaching characteristics of the two vitrified materials were also determined.

Given the results of this report on organic-contaminated soils and ISV applications to specific sites, ISV can offer a long-term improvement to remediation of AEDC contaminated soil sites.

CONCLUSIONS

Feasibility testing of the ISV process was successfully performed on two different site soils and contaminants from the AEDC site. Analyses of the data from the two tests provide conclusions regarding the performance of the ISV process to AEDC soils:

- Processing parameters from both tests demonstrated the feasibility of using ISV to process both of these contaminated soil types into a more compact and environmentally stable (immobilized) form with the use of a fluxing additive such as sodium carbonate.
- Organic contaminants were effectively destroyed to >98% level for the fuel oil-contaminated Site 10 soil. The small particulate and gaseous releases can be effectively retained by the appropriate design of a conventional off-gas treatment system, consisting of a wet scrubber and filtering media.
- Leach testing results per the Extraction Procedure (EP) Toxicity and Toxic Characteristics Leach Procedure (TCLP) showed that all metals of concern were below the maximum permissible limit. This indicates that inorganic contaminants are immobilized to a level that should allow the site to be listed as nonhazardous material according to regulatory criteria.
- 5% to 10% sodium carbonate additions are necessary to process AEDC site soils. These fluxing additives can be easily added by soil mixing or injection techniques.

Bench-scale testing indicates the potential for ISV treatment of organic contaminated soils from the fire training pit of the AEDC Site 10. Based on the results of the feasibility tests, it is recommended to perform a pilot-scale test at the AEDC Site 10 fire training pit to verify the efforts presented in this report prior to actual remediation of the site with ISV.

CONCLUSIONS

Feasibility testing of the ISV process was successfully performed on two different site soils and contaminants from the AEDC site. Analysis of the data from the two tests provide conclusions regarding the performance of the ISV process on AEDC soils:

- Processing parameters from both tests demonstrated the feasibility of using ISV to process both of these contaminated soil types from a more compact and environmentally stable (unoxidized) form with the use of a fluxing additive such as sodium carbonate.

- Organic contaminants were effectively destroyed to 99% level for the fuel oil-contaminated Site 10 soil. The total particulate and gaseous releases can be effectively retained by the appropriate design of a conventional off-gas treatment system, consisting of a wet scrubber and filtering media.

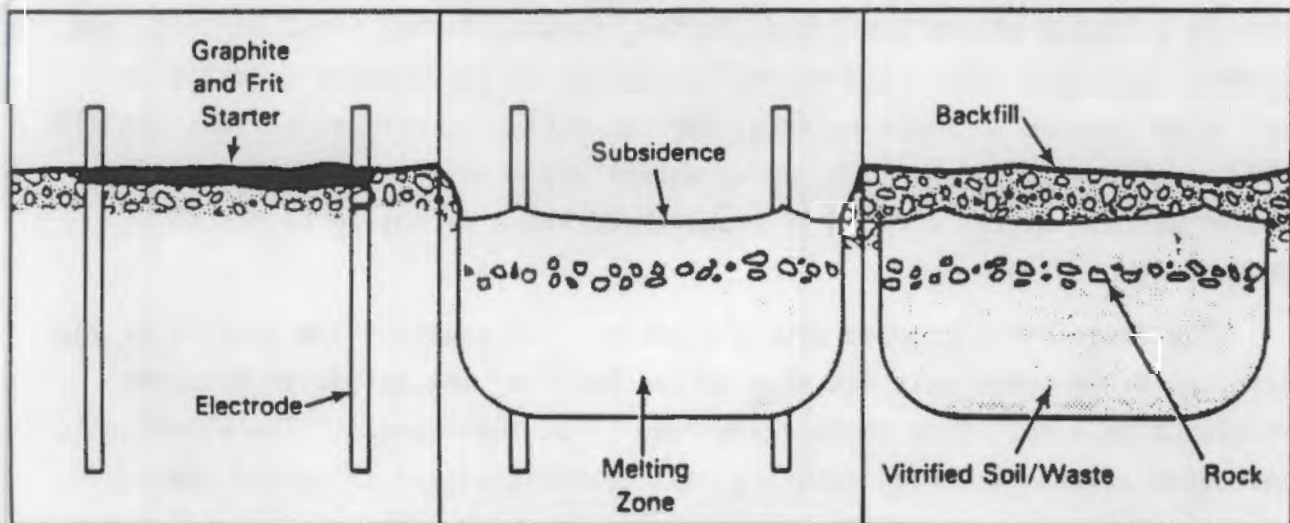
- Leach testing results per the Extraction Procedure (ES) Toxicity and Toxic Characteristic Leach Procedure (TCLP) showed that all metals of concern were below the maximum permissible limit. This indicates that inorganic contaminants are immobilized to a level that should allow the site to be listed as nonhazardous material according to regulatory criteria.

- 5% to 10% sodium carbonate additions are necessary to process AEDC site soils. These fluxing additives can be easily added by soil mixing or injection techniques.

Bench-scale testing indicates the potential for ISV treatment of organic contaminated soils from the fire training pit of the AEDC Site 10. Based on the results of the feasibility tests, it is recommended to perform a pilot scale test at the AEDC Site 10 fire training pit to verify the efforts presented in this report prior to actual remediation of the site with ISV.

PROCESS DESCRIPTION AND STATUS OF DEVELOPMENT

In situ vitrification has been developed as a remedial action process for soils contaminated with hazardous chemical wastes and/or radionuclides. Figure 1 illustrates the operation of the ISV process. A square array of four molybdenum (Mo)/graphite electrodes is inserted into the ground to the desired treatment depth. Because soil is not electrically conductive when its moisture has been driven off, a conductive mixture of flaked graphite and glass frit is placed among the 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. 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°C and 2000°C. As the molten or vitrified zone grows, it incorporates or encapsulates any radionuclides and nonvolatile hazardous elements, such as heavy metals, into the glass structure. The high temperature of the process destroys organic components by pyrolysis. The pyrolyzed byproducts migrate to the surface of the vitrified zone, where they



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FIGURE 1. Process of In Situ Vitrification

combust in the presence of air. A hood placed over the area being vitrified directs the gaseous effluents to an off-gas treatment system.

The process can also accommodate a staging operation alternative. In this processing alternative, outlying materials are placed on the surface of an area to be vitrified to increase the effective vitrification depth. Since ISV is a batch operation, this alternative will increase the amount of material vitrified in each batch setting, thereby improving the efficiency of the operation.

Pacific Northwest Laboratory began developing ISV technology in 1980. Since that time, numerous experimental tests under a variety of site conditions and with a variety of waste types have been conducted (Buel et al. 1987; Timmerman and Oma 1984; Timmerman et al. 1983; Buel and Carter 1986; Carter et al. 1987). Table 1 describes the different scales of testing units that PNL uses in developing and adapting ISV technology. The successful results of 59 bench-, engineering-, pilot-, and large-scale tests have proven the general feasibility and widespread applications of the process. Also, economic studies have indicated that tremendous economies of scale are attainable with the ISV process (Oma et al. 1983). ISV technology has been refined to the point that it is now ready for technology transfer and commercialization for specific hazardous waste types. The ISV process has been broadly patented within the United States, Canada, Japan, Great Britain, and France. Battelle, Pacific Northwest Laboratories (BNW) holds a partially exclusive license to those patents; BNW has exclusive worldwide rights to all ISV technology except for U.S. governmental applications of ISV to radioactive waste. Battelle recently transferred these licensing rights to Geosafe Corporation.

The decision to proceed with the design, fabrication, and testing of the existing large-scale unit was made on the basis of the extensive database developed as a result of engineering- and pilot-scale tests. The pilot-scale unit demonstrated the process using radioactively spiked soils and provided

TABLE 1. Testing Units for Developing In Situ Vitrification Technology

<u>Equipment Size</u>	<u>Electrode Separation, m</u>	<u>Block Size</u>	<u>Tests Completed As of 9/30/88</u>
Bench scale	0.11	1 to 10 kg	12
Engineering scale	0.23 to 0.36	0.05 to 1.0 t	26
Pilot scale	0.9 to 1.5	10 to 50 t	16
Large scale	3.5 to 5.5	400 to 800 t	5

support for the decision to design and fabricate the large-scale system. Subsequent tests have been conducted with the bench-, engineering-, and pilot-scale units to determine processing behavior under various waste conditions and to develop improved operating techniques.

TABLE I. Testing Units for Development in the Vibration Technology

Equipment Size	Electrode Separation	Block Size	Tests Completed As of 9/30/88
bench scale	0.11	1 to 10 g	12
engineering scale	0.25 to 0.38	0.05 to 1.0 g	20
PILOT scale	0.5 to 1.5	10 to 50 g	10
large scale	2.5 to 8.5	400 to 500 g	5

support for the decision to design and fabricate the large-scale system. Subsequent tests have been conducted with the bench, engineering, and pilot-scale units to determine processing behavior under various waste conditions and to develop improved operating techniques.

TEST DESCRIPTION

This section describes the bench- and engineering-scale ISV test equipment and off-gas sampling system, plus the specific test setup and operations used for both the Site 1 and Site 10 AEDC soils. The initial tests performed at the AEDC laboratories were unsuccessful due to the need, later identified, for conductive fluxing soil additives (e.g., sodium carbonate). These onsite tests used the bench-scale system, for which the entire test apparatus, except the electrical power supply and controller, was contained inside a fume hood for each test as shown in Figure 2. Additional testing using fluxing additives was continued at PNL using the engineering-scale system. The engineering-scale system was used instead of the bench-scale system because that power supply better simulates the power density, melt rate, and control of the larger scale operational ISV systems. The specific test equipment used is described in the next section.

SOIL CHARACTERIZATION

This section covers the laboratory testing results with soils from the AEDC Sites 1 and 10 to determine the extent of fluxing additives and their effect on melt behavior. The testing included: melt and fusion temperatures of 10 wt% Na₂O melts of sample AS-10-1 and 2, and AS-1-1 and 8; a 5 wt% Na₂O melt of AS-10-2; viscosity and electrical conductivity measurements of a 10 wt% Na₂O melt of a mixture of Site 10 soil; and a study investigating the melt behavior of a melt with a Na₂CO₃-soil mixture layered on top of a mixture of Site 10 soil. The results of this testing are given below.

<u>Melt Description</u>	<u>Fusion Temperature, °C</u>	<u>Melt Temperature, °C</u>
AS-10-2 ^(a) /5 wt% Na ₂ O	1200	1450
AS-10-1/10 wt% Na ₂ O	1000	1100
AS-10-2/10 wt% Na ₂ O	900	1000
AS-1-1/10 wt% Na ₂ O	1100	1300
AS-1-8/10 wt% Na ₂ O	1000	1300

(a) See Appendix A for sample identification from Sites 1 and 10.

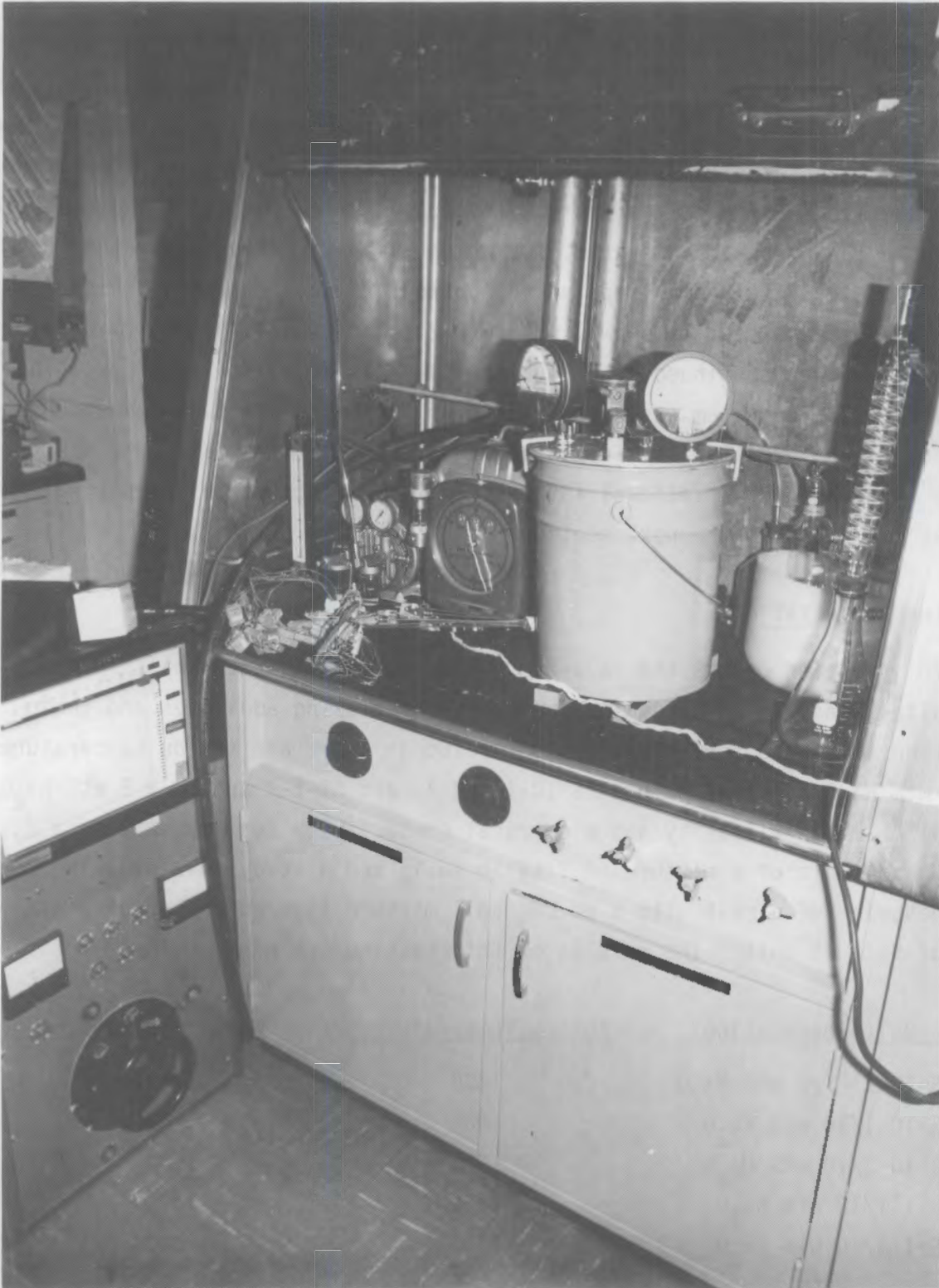


FIGURE 2. ISV Bench-Scale System

Viscosity and Electrical Conductivity

A batch consisting of Site 10 soil and a Na_2CO_3 -soil mix was prepared for viscosity and electrical conductivity measurement of vitrified Site 10 soil. This batch consisted of the identical Site 10 soil mix and Na_2CO_3 -soil mix used in the layered batch melt behavior study discussed later. The T100P of the glass, temperature of the glass when its viscosity is 100 poise, was determined to be 1436°C. The electrical conductivity of the glass was determined to range from 0.159 to 0.071 over the temperature span of 1492°C to 1269°C, respectively. Plots depicting the temperature dependence of viscosity and electrical conductivity are provided in Figures 3 and 4, respectively.

Melt Behavior of Na_2CO_3 -Soil Mix Layering

A layering study gave positive results, indicating that placing a layer of Na_2CO_3 -soil mixture over Site 10 soil aids melting and produces a homogeneous, vitreous product.

The experimental approach to determining the effect of a top layer of a Na_2CO_3 -soil mix on the melt behavior of Site 10 soil was as follows. A specific quantity (i.e., 200 g) of a mixture of Site 10 soil was placed in a fused-silica crucible. Placed in a layer on top of this soil was 95 g of a Na_2CO_3 -soil mixture. This mixture contained 32.5 wt% Na_2O on a dry oxide basis. The vitrified material produced from this mixture and the bottom layer of soil has a Na_2O content of 10 wt%, dry oxide basis. The crucible was then placed in a furnace and held for 1 h at 1000°C. The furnace temperature was then increased to 1500°C at a linear rate of 200°C/h. The crucible was held at 1500°C for 2 h, then at 600°C for 2 h, and then allowed to slowly cool to room temperature. The heat treatment at 600°C anneals the glass and prevents shattering upon cutting. The crucible was then sectioned and the glass examined. Upon examination, the glass was observed to be homogeneous with no traces of devitrification (crystallization), indicating that effective mixing of additive and nonadditive soil had occurred. This method or an injection technique could be employed for applying or mixing the necessary additives with the AEDC soils.

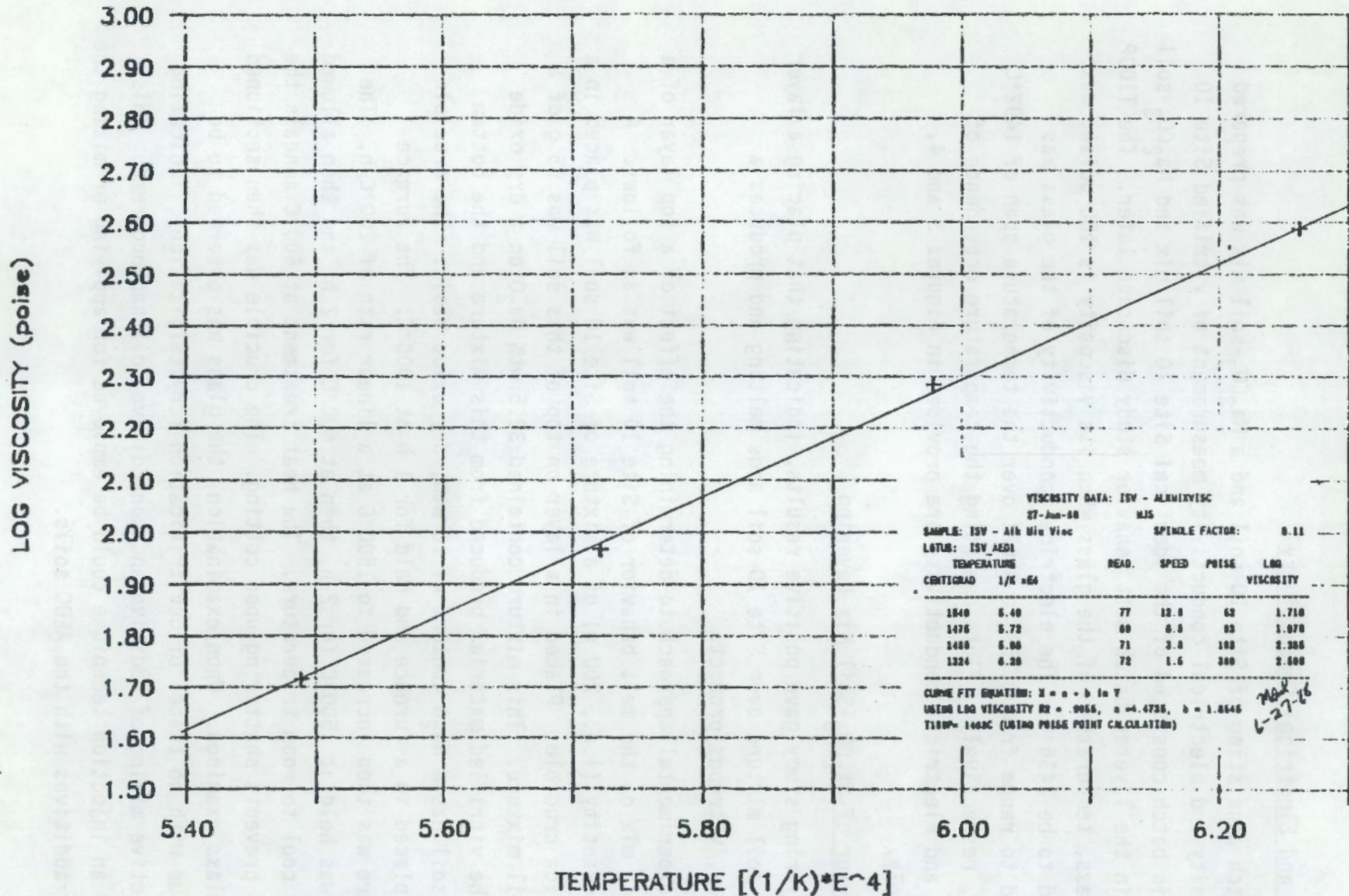


FIGURE 3. AEDC Soil ISV Operating Viscosity for Site 10

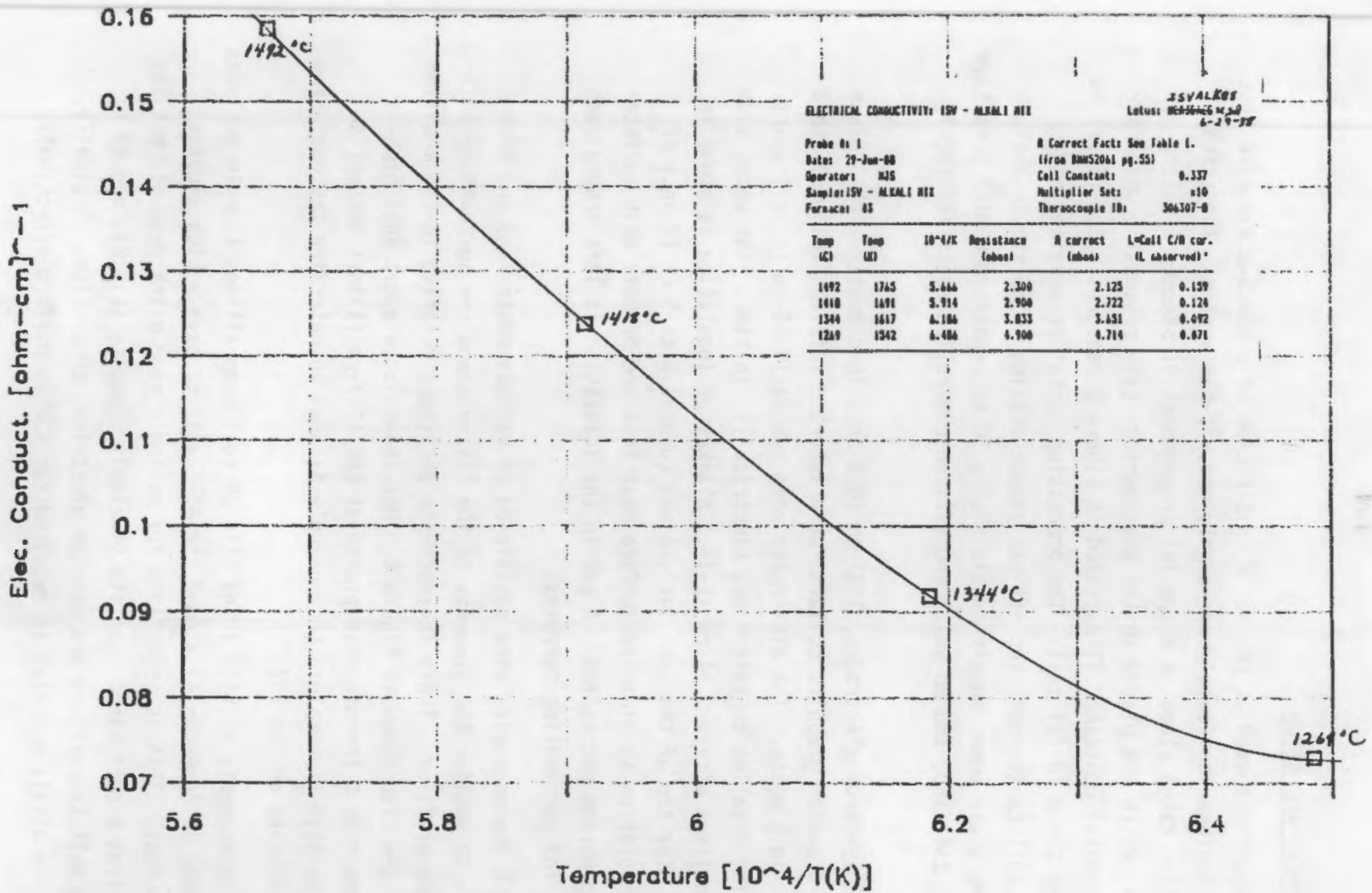


FIGURE 4. AEDC Soil ISV Operating Electrical Conductivity for Site 10

TEST EQUIPMENT AND SETUP

The equipment used at PNL was a combination of a bench-scale size test using the engineering-scale power supply and off-gas system. The actual vitrification takes place in a special arrangement of stacked 5-gallon containers, which are placed in the engineering-scale processing container. The sealed metal container illustrated in Figure 5 measures 1.8 m (6 ft) in diameter by 2.4 m (8 ft) tall. The processing container provides contaminated soil containment and off-gas vacuum sealing. The single-phase engineering-scale power supply consists of a 10-kW transformer with 4 voltage taps (400, 240, 160, and 80 volt) and silicon-controlled rectifier (SCR) control.

Two molybdenum electrodes, 1.27 cm (0.5 in.) in diameter with 3.81-cm (1.5-in.)-diameter graphite collars, were inserted into the test soil to a 17.8-cm (7-in.) depth. The electrodes were spaced 10.16 cm (4 in.) apart. The modified 5-gallon container was electrically isolated. The upper side walls were lined with a 2.54-cm (1-in.) blanket of insulation as shown in Figure 6. The top of the soil surface was covered with 5 cm (2 in.) of blanket insulation to minimize surface heat loss and promote melt surface subsidence during processing. A gap in the insulation is left around each electrode for gas venting purposes.

Type K thermocouples were positioned at various centerline and side increments to monitor the progress of the ISV melt and the surrounding soil temperature profiles. These thermocouple positions relative to the modified container are also shown in Figure 6. Not shown is an additional high-temperature type C thermocouple placed at the 12.7-cm (5-in.) centerline depth. The high-temperature thermocouple is used to determine the operating melt temperature during ISV.

The assessments of Site 1 and Site 10 soil compositions (sample analyses are provided in Appendix A) showed the AEDC soil to have a high alumina/silica content. This is acceptable for making a good glass product, but ISV also requires a sufficient quantity of alkali elements (Li, Na, and K) to lower the melt temperature and provide electrical conduction. Typically, 5 wt% of the alkali material is required for ISV to perform effectively.



FIGURE 5. Engineering-Scale ISV Processing Container (8803779-2CN)

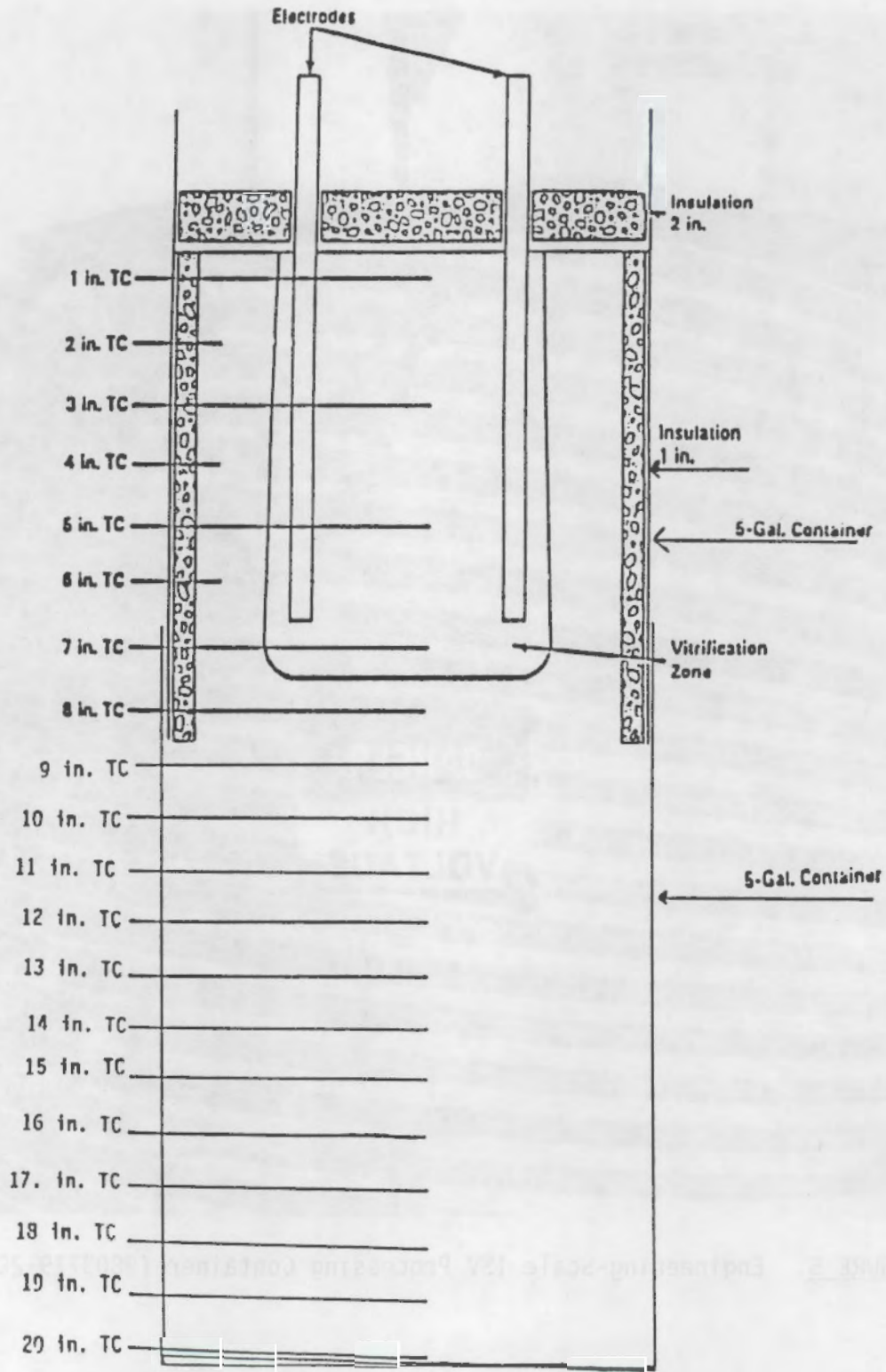


FIGURE 6. Modified Bench-Scale Containers Placed Inside the Engineering-Scale ISV Unit

Arnold soils contain <1 wt% of these materials; therefore, soil fluxing additives were required. Sodium carbonate was added to the 10 wt% oxide-basis-level to ensure ISV processing.

Figure 7 shows the soil configuration for the Site 1 test: 51 cm (20 in.) of Site 1 soil, with the top 17.8 cm (7 in.) mixed with 10 wt% Na_2CO_3 . Shown in Figure 8 is the soil configuration for the Site 10 test: 7.62 cm (3 in.) of cover soil, 10.16 cm (4 in.) of sludge (contaminated soil), and 33 cm (13 in.) of clean soil. Again, 10 wt% Na_2CO_3 is blended with the soil and contaminants in only the upper 17.8 cm (7 in.) of the test. The soil from the 17.8-cm (7-in.) to 51-cm (20-in.) depth in each test will be analyzed to monitor thermal migration effects to the surrounding soil. The contaminated material within the vitrification zone of the upper part of the container will be partially consumed by the ISV melt.

Off gas from the vitrification zone was representatively sampled continuously during each test (Figures 9a and 9b). Train A consisted of a glass fiber prefilter, four 500-mL gas washing bottles with fritted glass ends, a vacuum pump, a flowmeter, and a flow totalizer. Train B consisted of a condenser, two carbon sample tubes, a 500-g carbon reservoir, a vacuum pump, a flowmeter, and a flow totalizer. Train A determines the particulate releases and Train B provides the organic releases and ISV destruction effectiveness.

TEST OPERATIONS

Two bench-scale ISV tests were conducted in late June and early July of 1988 to assess the applicability of the ISV process to contaminated soil sites at AEDC. The first test used Site 1 clean surface soil, while the second test used contaminated soil from the Site 10 fire training pit area.

The upper zone of the Site 1 test (see Figure 4) constituted about 12.2 kg (27 lb) of soil. This 17.8-cm (7-in.)-depth quantity of soil was blended with 2.3 kg (5 lb) of sodium carbonate to achieve a 10 wt% concentration on a sodium oxide basis in the vitrified product. Vitrification processing proceeded to the 20.3-cm (8-in.) depth and produced a 6.8-kg (15-lb) glass block over a 3-hour period. This block was cylindrical at the upper region

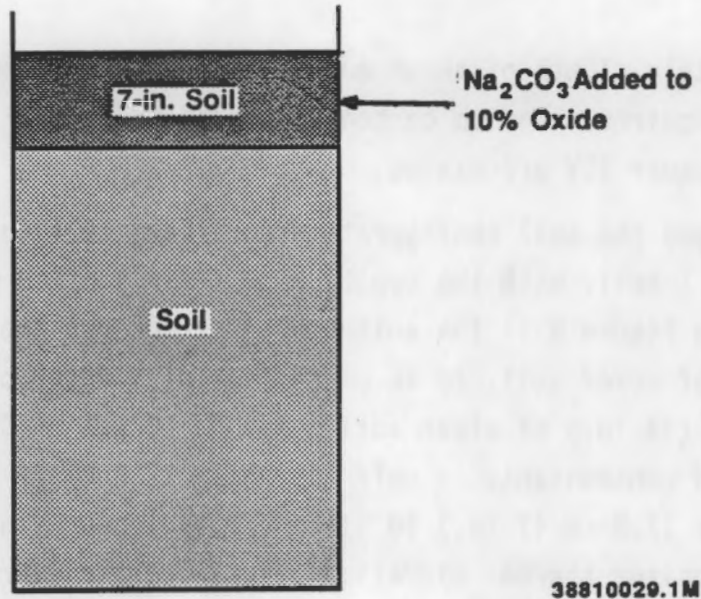


FIGURE 7. Site 1 Soil Configuration

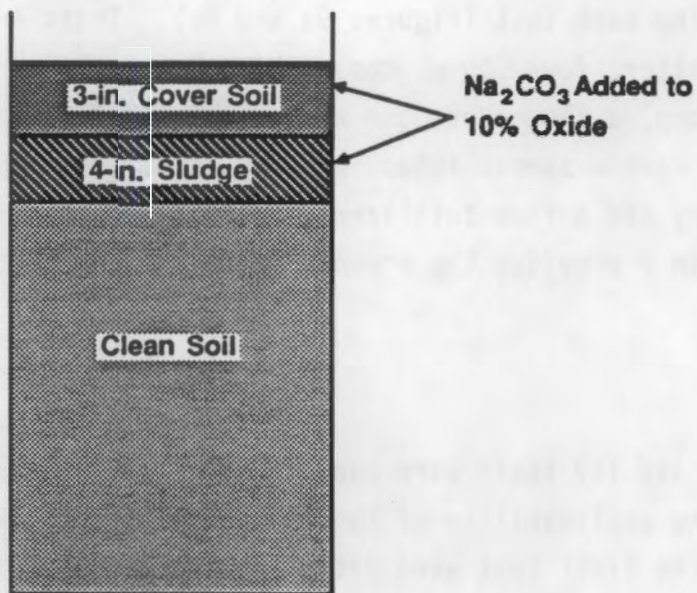


FIGURE 8. Site 10 Soil Configuration

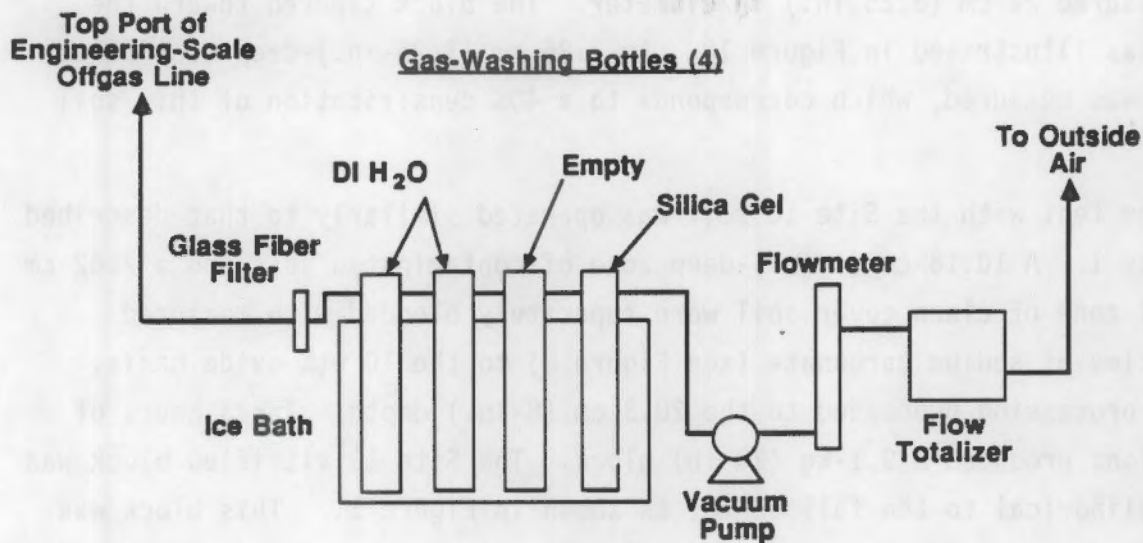
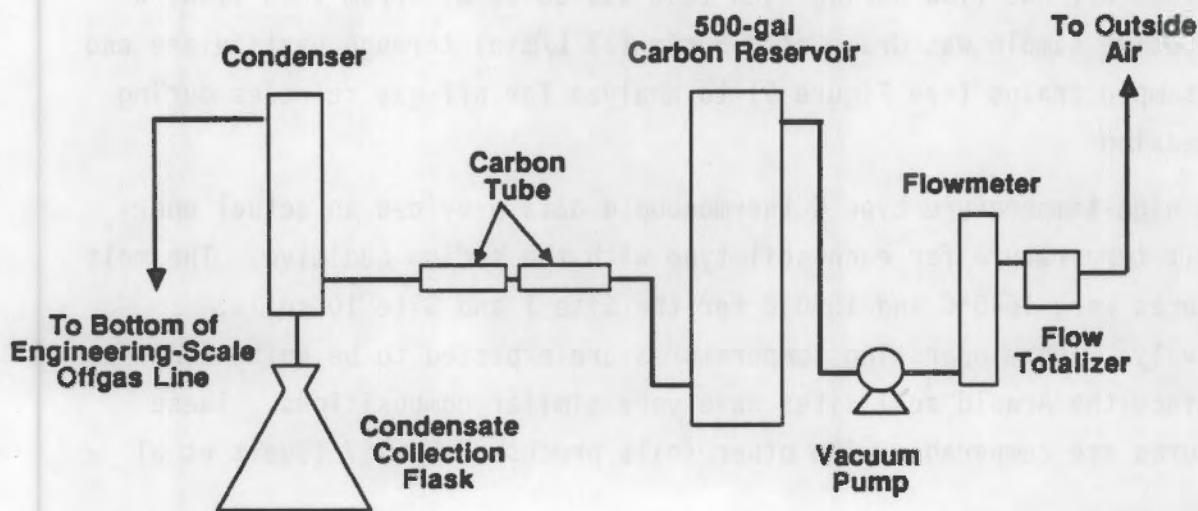


FIGURE 9a. Off-Gas Sample Train A for Particulates



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FIGURE 9b. Off-Gas Sample Train B for Organics

and measured 21 cm (8.25 in.) in diameter. The block tapered toward the bottom as illustrated in Figure 10. An 8.26-cm (3.25-in.)-deep subsidence region was measured, which corresponds to a 40% densification of this soil type.

The test with the Site 10 soil was operated similarly to that described for Site 1. A 10.16-cm (4-in.)-deep zone of contaminated soil and a 7.62-cm (3-in.) zone of clean cover soil were separately blended with measured quantities of sodium carbonate (see Figure 8) to the 10 wt% oxide basis. Again, processing proceeded to the 20.3-cm (8-in.) depth. The 3 hours of operations produced a 9.1-kg (20-lb) block. The Site 10 vitrified block was more cylindrical to the full depth, as shown in Figure 11. This block was 23.5 cm (9.25 in.) in diameter. A uniform subsidence region 4.13-cm (1.625-in.) deep was measured. The subsidence corresponds to a 20% densification for this operation.

Average off-gas flow during each test was 30 scfm. From this flow, a representative sample was drawn at 0.5 cfm (13 L/min) through particulate and organic sample trains (see Figure 9) to analyze for off-gas releases during ISV processing.

The high-temperature type C thermocouple data provided an actual operating melt temperature for each soil type with the sodium additive. The melt temperatures were 1640°C and 1590°C for the Site 1 and Site 10 soils, respectively. These operating temperatures are expected to be quite close as shown, since the Arnold soil sites have very similar compositions. These temperatures are comparable with other soils processed by ISV (Buel et al. 1987).

Electrical power data for the Site 1 and Site 10 ISV tests are plotted in Figures 12 and 13, respectively. The Site 1 plot shows that a slower, more conservative startup was used during that test. The Site 10 test achieved higher power levels earlier into the test. This can be attributed to the experience gained from operating the Site 1 test first. The total energy consumed for the Site 1 test was 6.1 kWh, which provides an energy-to-mass ratio of 0.9 kWh/kg. During the Site 10 test, a total of 9.5 kWh of



FIGURE 10. AEDC Site 1 Vitrified Block (8803810-17CN)

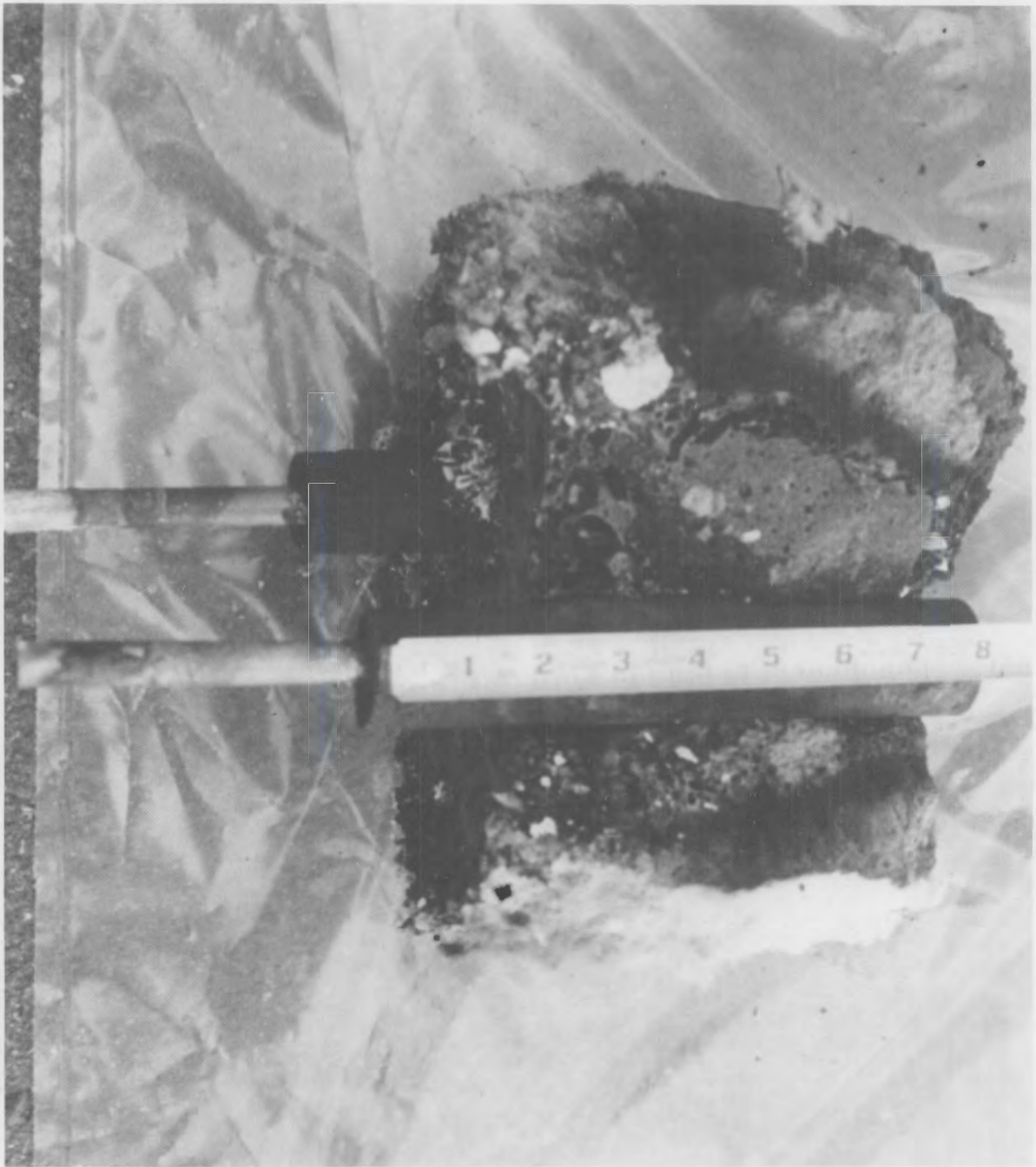


FIGURE 11. AEDC Site 10 Vitrified Block (8803779-22CN)

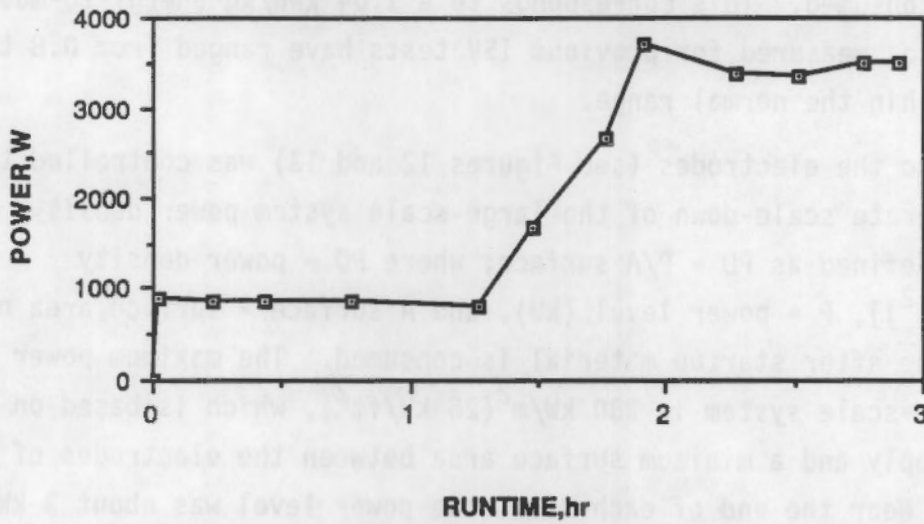


FIGURE 12. Power Performance Plot of the AEDC Site 1 ISV Test

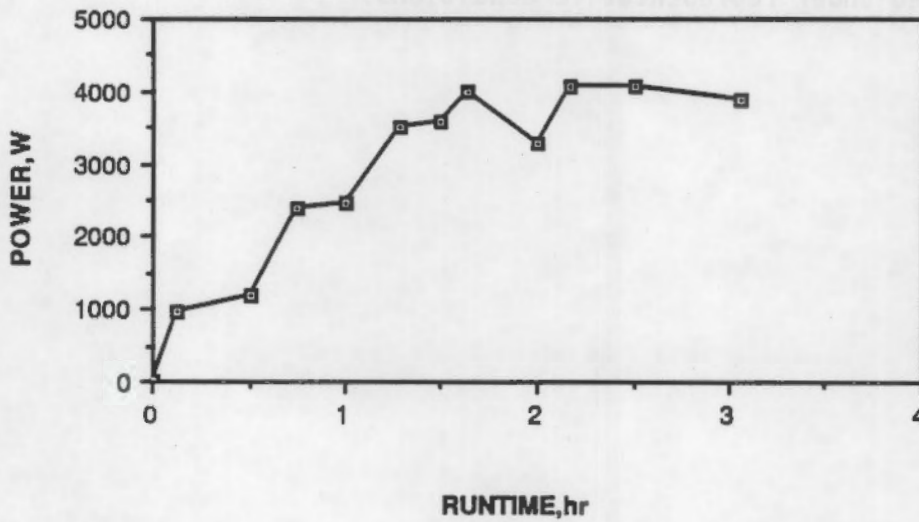


FIGURE 13. Power Performance Plot of the AEDC Site 10 ISV Test

energy was consumed. This corresponds to a 1.04 kWh/kg energy-to-mass ratio. Typical ratios measured for previous ISV tests have ranged from 0.8 to 1.1, which is within the normal range.

Power to the electrodes (see Figures 12 and 13) was controlled to provide an accurate scale-down of the large-scale system power density. Power density is defined as $PD = P/A$ surface; where PD = power density [kW/m^2 (kW/ft^2)], P = power level (kW), and A surface = surface area of vitrification zone after startup material is consumed. The maximum power density of the large-scale system is $280 \text{ kW}/\text{m}^2$ ($26 \text{ kW}/\text{ft}^2$), which is based on a 3750-kW power supply and a minimum surface area between the electrodes of 13.4 m^2 (144 ft^2). Near the end of each test, the power level was about 3 kW and surface area was 103.2 cm^2 (16 in.^2) [10.16-cm (4-in.) wide x 10.16 cm (4 in.) electrode separation] for a power density of $291 \text{ kW}/\text{m}^2$ ($27 \text{ kW}/\text{ft}^2$). This is within acceptable power density limits to confirm that these tests were operated under representative conditions.



FIGURE 13. Power Performance Plot of the ISV Test

TEST RESULTS

Since the Site 1 test was performed on clean surface soil from the Arnold site, most of the test results section concentrates on the determination of ISV processing feasibility for the Site 10 contaminated soil. Each test included analyses of the off-gas emissions for release information, the surrounding soil for migration effects, and the vitrified block for specific inorganic material retention. The processing of the Site 1 soil determined the ability of ISV to process that soil type using a sodium additive. All analytical data from the Site 10 test support the feasibility of processing the organic-contaminated soil with a fluxing addition by ISV in conjunction with a wet scrubbing and filtration off-gas treatment system.

Each bench-scale ISV test was performed over a 3-hour period to achieve a depth of 20.3 cm (8 in.). The Site 1 block weighed 6.8 kg (15 lb); the Site 10 block weighed 9.1 kg (20 lb). Interior views of the Site 1 and Site 10 blocks are shown in Figures 14 and 15, respectively. The increased power levels during Site 10 operations caused the Site 10 block to be larger for the same operating period.

Off-gas sampling (see Figure 9) provides an indication of the amount of inorganic and organic releases during processing. The particulate components released during the tests were entrained on the filters as particulates. The elements that were collected on the filters are provided in Table 2. This table of inorganic releases shows both tests had similar quantitative particulate elemental releases. These releases are in the same range as prior testing with other soils (Buel et al. 1987). The Site 10 data show minor concentrations of copper, nickel, lead, and zinc that were not detected in the Site 1 tests. These heavy metals are indicated as being present at Site 10 in small concentrations by the CH2M Hill data provided in Appendix B. The release quantity is not significant for any of the elements listed in Table 2.



FIGURE 14. Interior View of AEDC Site 1 Vitrified Block (8803779-29CN)



FIGURE 15. Interior View of AEDC Site 10 Vitrified Block (8803779-28CN)

TABLE 2. Particulate Releases from the AEDC Site 1 and Site 10 ISV Tests

<u>Component</u>	<u>Filter Concentration, $\mu\text{g}/\text{cm}^2$</u>	
	<u>Site 1</u>	<u>Site 10</u>
Al	46	26
B	57	80
Ca	123	60
Cu	--	2
Fe	7	6
Li	7	7
Mg	7	7
Mn	1	2
Mo	132	51
Na	288	528
Ni	--	8
P	47	--
Pb	--	36
Si	310	275
Sr	1	1
Ti	5	3
Zn	--	23
Zr	3	2

Primary analyses associated with the Site 10 test were directed toward organic determinations. Total organic carbon (TOC) analyses proved to be indeterminant for organic detection and migration, since the Arnold soils naturally contain 4% to 6% TOC.

The primary contaminant at Site 10 is believed to be fuel oil or hydrocarbons; therefore, the hydrocarbon analyses were used to determine ISV destruction effectiveness and migration to the surrounding soil. Analytical procedures used for the analysis of soil and water samples were similar to

EPA Method 3500. Hydrocarbon contaminants were extracted from the samples with methylene chloride. Quantitation was performed using a gas chromatograph with flame ionization detector (GC/FID). Results for the contaminated soil were between 0.68% to 0.81% hydrocarbon level, while the surrounding clean soil was below detection level (<1 ppm).

The contaminated zone that was vitrified measured 22.9 cm (9 in.) in diameter by 10.16 cm (4 in.) deep. At the 1.6 g/cc density measured for the Site 10 contaminated soil, this corresponds to 6.7 kg of contaminated soil with a 0.68% to 0.81% hydrocarbon content. To determine the extent of organic migration and processing destruction of the hydrocarbons, samples of the surrounding soil and the off gas, respectively, were taken and analyzed. The samples that were taken from the surrounding soil adjacent to the block out to ambient temperature conditions showed below detection limit or low ppm quantities (0-20 ppm) of hydrocarbons. Charcoal adsorption tubes were used to collect organic off-gas samples from the two AEDC ISV tests. The samples were analyzed by GC/FID and gas chromatograph/mass spectrometry (GC/MS). The sample tubes were desorbed using carbon disulfide following the procedure of White et al. (1970). Quantitative analysis was performed by GC/FID using the internal standard method. Characterization of specific organics identified was performed by GC/MS. The results of these analyses are presented in Table 3 for both Site 1 and Site 10.

Table 3 indicates that significantly more hydrocarbons were released during the Site 10 test. This is to be expected since the Site 1 test was with clean soil. The hydrocarbon releases also show much higher quantities of more complex (C12 and higher) hydrocarbons released during the Site 10 test. Again, this is consistent with the fuel oils present in the Site 10 soils. Since little or no migration of the hydrocarbons was detected to the surrounding soil, the off-gas releases can be used to determine the destruction efficiency of the ISV process on the Site 10 organic contaminants. Total hydrocarbon release was 6.24 mg for the off-gas sample tube. The off-gas flow was 60 times the sample flow; therefore, 374 mg of hydrocarbons were released to the off-gas system. Comparing this release to the total hydrocarbons initially present in the contaminated soil indicated that 0.7% to 0.8% of the hydrocarbons were released to the off-gas system and not

TABLE 3. AEDC Site 1 and Site 10 Organic Off-Gas Analyses

Site 1

<u>Organics Identified</u>		<u>Estimated Hydrocarbon Fractions</u>	
benzene	0.271 mg	C6 and less	0.55 mg
toluene	0.047 mg	C7	0.11 mg
xylene	0.021 mg	C8	0.06 mg
total	0.339 mg	C9	0.04 mg
		total	0.76 mg
		hydrocarbons	

SITE 10

<u>Organics Identified</u>		<u>Estimated Hydrocarbon Fractions</u>	
benzene	0.586 mg	C6 and less	1.00 mg
toluene	0.235 mg	C7	0.38 mg
xylene	0.116 mg	C8	0.21 mg
styrene	0.030 mg	C9	0.19 mg
n-C11	0.036 mg	C10	0.54 mg
n-C12	0.084 mg	C11	0.21 mg
n-C13	0.236 mg	C12	0.64 mg
n-C14	0.324 mg	C13	1.24 mg
n-C15	0.190 mg	C14	1.26 mg
n-C16	0.063 mg	C15	0.51 mg
total	1.900 mg	C16 and	0.06 mg
		<u>greater</u>	
		total	6.24 mg
		hydrocarbons	

destroyed. Considering a 20 ppm "worst case" concentration in the surrounding soil, this lowers the ISV process destruction efficiency to 98.1%. The high destruction efficiency illustrates the feasibility of applying ISV to the fire training pit area at the AEDC Site 10.

LEACH TESTING

This section reports the results of the Extraction Procedure (EP) Toxicity and Toxic Characteristics Leach Procedure (TCLP) performed on the Site 1 and Site 10 vitrified materials. Table 4 lists the metals of concern, their maximum concentration limit, and the results of the EP Toxicity and TCLP tests on a per sample and product average basis. The concentrations of all metals listed are below the maximum permissible limits specified; therefore, the vitrified materials from each site passed both leach tests. The leaching information indicates that the residual ISV product would not be listed as a hazardous material after the processing had destroyed the organic content, which should allow release of the site as containing nonhazardous material under regulatory criteria.

Table 4 (faintly visible text):

Table 4 lists the metals of concern, their maximum concentration limit, and the results of the EP Toxicity and TCLP tests on a per sample and product average basis. The concentrations of all metals listed are below the maximum permissible limits specified; therefore, the vitrified materials from each site passed both leach tests. The leaching information indicates that the residual ISV product would not be listed as a hazardous material after the processing had destroyed the organic content, which should allow release of the site as containing nonhazardous material under regulatory criteria.

TABLE 4. EP Toxicity and TCLP Results for the ISV Product

EP Tox. Metals	Max. Conc. ppm	EP Toxicity Results, ppm							
		Site 1				Site 10			
					Ave.				Ave.
As	5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ba	100	0.004	0.005	0.006	0.005	0.037	0.036	0.056	0.043
Cd	1	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Cr	5	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Pb	5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Hg	0.2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Se	1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ag	5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

EP Tox. Metals	Max. Conc. ppm	TCLP Results, ppm					
		Site 1			Site 10		
				Ave.			Ave.
As	5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ba	100	0.026	0.019	0.023	0.067	0.079	0.073
Cd	1	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Cr	5	0.026	0.030	0.028	0.039	0.043	0.041
Pb	5	0.300	<0.1	0.200	<0.1	<0.1	<0.1
Hg	0.2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Se	1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ag	5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tl	(a)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ni	(a)	0.232	0.144	0.188	0.280	0.477	0.379

(a) EPA has not established limits. Tl and Ni are proposed to be added to TCLP list. Good rule of thumb for limit determination is 100X drinking water standards.

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APPENDIX A

AEDC SITE 1 AND SITE 10 SOIL ANALYSIS

TABLE A-1. AEDC Site 1 and Site 10 Sample Identification and Location

<u>Site 1 Samples</u>	
<u>Identification</u>	<u>Location</u>
AS-1-1	Test soil Site 1
AS-1-2	Borrow pit soil - southeast of landfill Site 1
AS-1-3	Surface soil by SL-4 well southwest of landfill site
AS-1-4	South landfill - southeast region surface
AS-1-5	South landfill - southeast region surface
AS-1-6	North landfill - northeast region surface
AS-1-7	North landfill - northwest region surface
AS-1-8	North landfill - central subsurface borings
AS-1-9	Leach pit region - south of landfill Site 1 limestone rock area

<u>Site 10 Samples</u>	
<u>Identification</u>	<u>Location</u>
AS-10-1	Test sludge
AS-10-2	Test clean soil
AS-10-3	Upper burn pit - left wing of mock airplane
AS-10-4	Lower overflow pond - east side
AS-10-5	Lower overflow pond - west side
AS-10-6	Clean soil - surface clay
AS-10-7	Clean soil - subsurface layer
AS-10-8	Run-off area surface soil
AS-10-9	Subsurface soil - east coffer

TABLE A-2. AEDC Site 1 Sample Analyses, wt%

Oxide	AS-1-1	AS-1-2	AS-1-3	AS-1-4	AS-1-5	AS-1-6	AS-1-7	AS-1-8	AS-1-9
Al ₂ O ₃	11.2	10.5	8.19	7.69	6.52	9.72	8.31	6.98	6.24
BaO	0.010	0.011	0.017	0.007	0.013	0.012	0.012	0.013	0.020
CaO	0.22	<0.02	0.28	0.30	2.23	1.52	1.00	3.27	0.91
Fe ₂ O ₃	6.21	5.67	5.08	14.1	3.04	5.45	5.09	3.57	3.24
K ₂ O	(0.29) ^(a)	(0.27) ^(a)	0.54	(0.19) ^(a)	0.56	(0.35) ^(a)	0.36	0.62	0.60
MgO	0.281	0.294	0.273	0.215	0.377	0.341	0.398	1.22	0.46
MnO ₂	--	0.008	--	--	--	--	--	0.008	0.023
Na ₂ O	0.29	0.28	0.39	0.34	0.32	0.24	0.26	0.31	0.38
NiO	0.041	0.055	0.063	0.028	0.032	0.037	0.045	0.037	0.065
SiO ₂	71.5	72.7	75.1	66.8	67.3	73.1	71.3	72.0	78.8
SrO	--	0.006	0.007	--	--	0.008	0.008	0.010	0.008
TiO ₂	1.07	1.12	0.939	0.816	0.636	1.13	1.07	0.733	1.09
ZrO ₂	0.055	0.052	0.057	0.027	0.115	0.059	0.086	0.041	0.085
Total Oxide	90.9	90.7	90.5	90.3	80.7	91.8	87.9	88.4	91.9
Moisture Content	19.3	13.5	14.6	6.36	7.67	10.9	11.0	15.0	16.9

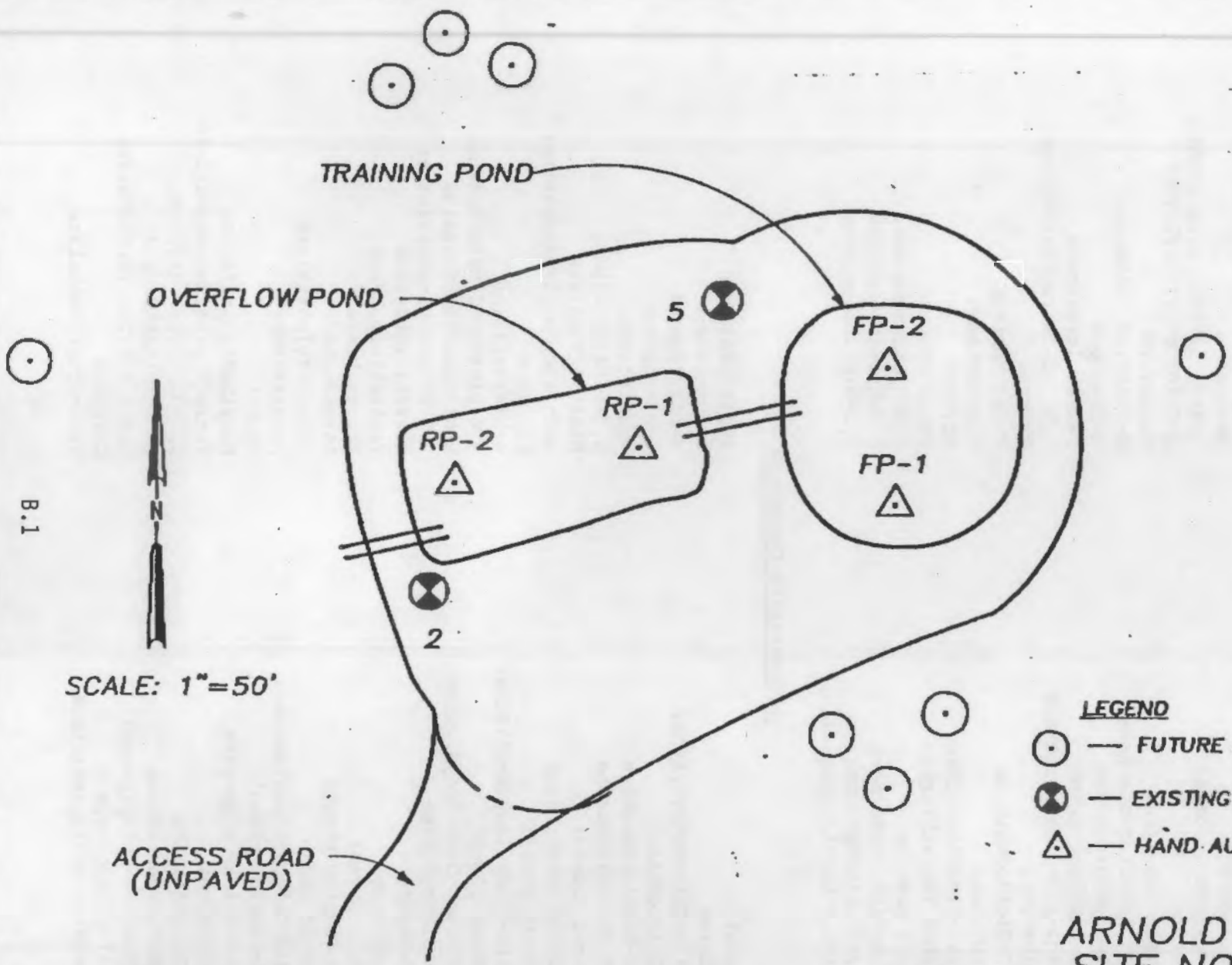
(a) Near detection limit.

TABLE A-2. AEDC Site 10 Sample Analyses, wt%

Oxide	AS-10-1	AS-10-2	AS-10-3	AS-10-4	AS-10-5	AS-10-6	AS-10-7	AS-10-8	AS-10-9
Al ₂ O ₃	6.25	10.4	3.39	5.31	4.80	9.08	11.4	9.51	5.77
BaO	0.022	0.044	0.024	0.012	0.013	0.019	0.059	0.020	0.017
CaO	5.53	5.21	33.5	5.84	23.7	0.92	5.82	2.55	1.08
Cr ₂ O ₃	0.028	0.031	--	--	--	--	0.042	0.033	--
CuO	0.013	0.014	--	--	--	--	0.045	0.014	--
Fe ₂ O ₃	3.78	4.99	2.87	2.75	2.57	4.87	7.11	5.35	2.67
K ₂ O	0.51	1.05	0.46	0.46	0.47	0.47	1.25	0.74	0.40
MgO	0.435	0.534	1.56	0.426	0.855	0.358	0.614	0.508	0.297
MnO ₂	0.016	0.020	0.015	--	0.013	0.012	0.031	0.044	--
Na ₂ O	0.29	0.33	0.24	0.30	0.22	0.26	0.36	0.26	0.28
NiO	0.034	0.041	0.041	0.028	0.033	0.029	0.065	0.047	0.034
SiO ₂	70.7	63.4	28.2	73.3	43.9	72.5	53.2	71.7	77.6
SrO	0.012	0.057	0.036	--	0.023	0.019	0.083	0.015	0.007
TiO ₂	0.984	0.865	0.423	0.941	0.587	1.13	0.739	0.780	1.15
ZrO ₂	0.061	0.046	0.018	0.064	0.022	0.029	0.046	0.087	0.121
Total Oxide	88.7	87.1	70.8	89.4	77.1	89.1	80.8	91.6	87.5
Moisture Content	20.4	16.4	14.3	28.3	24.2	13.8	18.4	15.8	30.4

APPENDIX B

CH2M HILL AEDC SITE 10 DATA



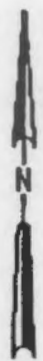
LEGEND

- — FUTURE MONITORING WELL
- ⊗ — EXISTING MONITORING WELL
- △ — HAND AUGER SOIL BORING

ARNOLD AFB
 SITE NO. 10
 FIRE TRAINING AREA NO. 2
 HAND AUGER BORING LAYOUT



SCALE: 1"=50'



B.1

ACCESS ROAD (UNPAVED)

CHEMICAL ANALYSES PERFORMED

Volatile Compounds

Chloromethane	Trichloroethene
Bromomethane	Dibromochloromethane
Vinyl Chloride	1,1,2-Trichloroethane
Chloroethane	Benzene
Methylene Chloride	trans-1,3-Dichloropropene
Acetone	2-Chloroethylvinylether
Carbon Disulfide	Bromoform
Trichlorofluoromethane	4-Methyl-2-Pentanone
1,1-Dichloroethene	2-Hexanone
1,1-Dichloroethane	Tetrachloroethene
Trans-1,2-Dichloroethane	1,1,2,2-Tetrachloroethane
Chloroform	Toluene
1,2-Dichloroethane	Chlorobenzene
2-Butanone	Ethylbenzene
1,1,1-Trichloroethane	Styrene
Carbon Tetrachloride	Total Xylenes
Vinyl Acetate	1,3-Dichlorobenzene
Bromodichloromethane	1,4-Dichlorobenzene
1,2-Dichloropropane	1,2-Dichlorobenzene
cis-1,3-Dichloropropene	

Semivolatile Compounds

Phenol	3-Nitroaniline
Aniline	Acenaphthene
bis(2-Chloroethyl) Ether	4-Nitrophenol
2-Chlorophenol	4-Nitrophenol
1,3-Dichlorobenzene	Dibenzofuran
1,4-Dichlorobenzene	2,4-Dinitrotoluene
Benzyl Alcohol	Diethyl Phtalate
1,2-Dichlorobenzene	4-Chlorophenyl-phenylether
2-Methylphenol	Fluorene
bis(2-Chloroisopropyl) Ether	4-Nitroaniline
4-Methylphenol	4,6-Dinitro-2-Methylphenol
N-Nitroso-Di-n-Propylamine	N-Nitrosodiphenylamine
Hexachloroethane	4-Bromophenyl-phenylether
Nitrobenzene	Hexachlorobenzene
Isophorone	Pentachlorophenol
2-Nitrophenol	Phenanthrene
2,4-Dimethylphenol	Anthracene
Benzoic Acid	Di-n-Butylphthalate
bis(2-Chloroethoxy) Methane	Fluoranthene
2,4-Dichlorophenol	Pyrene
1,2,4-Trichlorobenzene	Butylbenzylphthalate
Naphthalene	Tetrachlorodibenzo-p-dioxin
4-Chloroaniline	3,3-Dichlorobenzidine
Hexachlorobutadiene	Benzo(a)Anthracene
4-Chloro-3-Methylphenol	bis(2-Ethylhexyl) Phthalate
2-Methylnaphthalene	Chrysene
Hexachlorocyclopentadiene	Di-n-Octyl Phthalate

Semivolatile Compounds - (continued)

2,4,6-Trichlorophenol	Benzo(b) Fluoranthene
2,4,5-Trichlorophenol	Benzo(k) Fluoranthene
2-Chloronaphthalene	Benzo(a) Pyrene
2-Nitroaniline	Indeno(1,2,3-cd) Pyrene
Dimethyl Phthalate	Dibenz(a,h) Anthracene
Acenaphthylene	Benzo(g,h,i) Perylene
2,6-Dinitrotoluene	

Pesticide / PCB Compounds

alpha-BHC
 beta-BHC
 delta-BHC
 gamma-BHC (Lindane)
 Heptachlor
 Aldrin
 Heptachlor Epoxide
 Endosulfan I
 Dieldrin
 4,4'-DDE
 Endrin
 Endosulfan II
 4,4'-DDD
 Endosulfan Sulfate
 4,4'-DDT
 Methoxychlor
 Endrin Ketone
 Chlordane
 Toxaphene
 Aroclor-1016
 Aroclor-1221
 Aroclor-1232
 Aroclor-1242
 Aroclor-1248
 Aroclor-1254
 Aroclor-1260

Metals

Silver
 Arsenic
 Beryllium
 Cadmium
 Cyanide, Distilled
 Chromium
 Copper
 Mercury
 Nickel
 Lead
 Antimony
 Selenium
 Thallium
 Zinc

COMPOUND.WR1

ORGANIC
DETECTED COMPOUNDS

LOCATION	DEPTH (ft)	COMPOUND	CONCENTRATION ^{ppb} ug/kg
FP-11	1'	BIS(2-ETHYLHEXYL)PHTHALATE	610
FP-11	1'	AROCLOR-1254	600
FP-13	7'	BIS(2-ETHYLHEXYL)PHTHALATE	2000
FP-13	7'	AROCLOR-1254	50
FP-21	1'	PHENANTHRENE	6100
FP-21	1'	FLUORANTHENE	11000
FP-21	1'	PYRENE	3500
FP-21	1'	BENZO(A)ANTHRACENE	2900
FP-21	1'	BIS(2-ETHYLHEXYL)PHTHALATE	1600
FP-21	1'	CHRYSENE	2800
FP-21	1'	BENZO(B)FLUORANTHENE	2200
FP-21	1'	BENZO(A)PYRENE	1300
FP-21	1'	INDENO(1,2,3-CD)PYRENE	1100
FP-21	1'	BENZO(G,H,I)PERYLENE	1100
FP-21	1'	AROCLOR-1254	4300
FP-22	4'	BIS(2-ETHYLHEXYL)PHTHALATE	910
FP-22	4'	AROCLOR-1254	100
FP-23	7'	AROCLOR-1254	20
RP-12	4'	BIS(2-ETHYLHEXYL)PHTHALATE	1600
RP-23	7'	BIS(2-ETHYLHEXYL)PHTHALATE	230

07/06/88

FOR METAL ANALYSIS, SEE FOLLOWING PAGES



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INORGANIC REPORT OF ANALYSIS

CH2M HILL/ATL
229 PEACHTREE STREET, N.E., SUITE 300
ATLANTA, GEORGIA 30303-1602

Page: 1
Date: 06/30/88

Project Number: SA29491.C

ATTN: MR. N. STRICKLAND/ATL

Laboratory Number: 11226

RE: Sample(s) received by CH2M HILL on 05/18/88.
ARNOLD AIR FORCE BASE

Analysis Description	FP-11	FP-12	FP-13	FP-21	FP-22	FP-23	RP-11
	5/12/88	5/12/88	5/12/88	5/12/88	5/12/88	5/12/88	5/12/88
	1140 COMP	1110 COMP	1200 COMP	1240 COMP	1320 COMP	1350 COMP	1445 COMP
	1 FT.	4 FT.	7 FT.	1 FT.	4 FT.	7 FT.	1 FT.
	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL
Silver (ppb)	<3M	<3M	<3M	<3M	<3M	<3M	<3M
Arsenic (ppb)	9M	6.4M	10.4M	8.1M	7.6M	10M	
Beryllium (ppb)	<0.5M	<0.5M	<0.5M	<0.5M	<0.5M	<0.5M	<0.5M
Cadmium (ppb)	10M	10M	10M	8M	6M	12M	5M
Cyanide, Distilled (ppb)	<0.31M	<0.30M	<0.30M	<0.30M	<0.29M	<0.37M	<0.33M
Chromium (ppb)	30M	39M	49M	20M	27M	60M	25M
Copper (ppb)	8M	5M	8M	103M	6M	9M	19M
Mercury (ppb)	0.3M	0.4M	0.6M	3.7M	1.3M	4.3M	0.4M
Nickel (ppb)	<4M	<4M	<4M	9M	<4M	<4M	<4M
Lead (ppb)	9.8M	5.2M	6.3M	26.9M	6.4M	8.3M	7.3M
Antimony (ppb)	<0.6M	<0.6M	<0.6M	<0.6M	<0.6M	<0.7M	<0.7M
Selenium (ppb)	<0.6M	<0.6M	<0.6M	<0.6M	<0.6M	<0.8M	<0.7M
Thallium (ppb)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.8	<0.8
Zinc (ppb)	15M	16M	44M	94M	21M	22M	42M

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INORGANIC REPORT OF ANALYSIS

CH2M HILL/ATL
229 PEACHTREE STREET, N.E., SUITE 300
ATLANTA, GEORGIA 30303-1602

Page: 2
Date: 06/30/88

Project Number: SA29491.

ATTN: MR. N. STRICKLAND/ATL

Laboratory Number: 11226

RE: Sample(s) received by CH2M HILL on 05/18/88.
ARNOLD AIR FORCE BASE

Analysis Description	RP-12	RP-21	RP-22	RP-22A	RP-23	MS	HSD
	5/12/88 1450 COMP 4 FT.	5/12/88 1545 COMP 1 FT.	5/12/88 1615 COMP 4 FT.	5/12/88 1615 COMP 4 FT.	5/12/88 1645 COMP 7 FT.	MATRIX SPIKE % RECOVERY	MATRIX SPIKE DUPLICATE ANALYSIS RPD
	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL
Silver (ppb)	<3W	<3W	<3W	<3W	<3W	95	3
Arsenic (ppb)	6.2W	6.7W	5.3W	3.7W	7.9W	106	2
Beryllium (ppb)	<0.5W	0.8W	<0.5W	<0.5W	<0.5W	95	0
Cadmium (ppb)	17W	19W	15W	12W	7W	84	0
Cyanide, Distilled (ppm)	<0.35W	<0.30W	<0.33W	<0.34W	<0.33W	102	0
Chromium (ppb)	71W	90W	49W	37W	26W	95	0
Copper (ppb)	9W	6W	5W	4W	12W	100	12
Mercury (ppb)	0.9W	0.8W	0.6W	2.6W	0.6W	101	18
Nickel (ppb)	<4W	<4W	<4W	<4W	<4W	88	21
Lead (ppb)	9.1W	5.1W	6.7W	7.3W	4.0W	89	18
Antimony (ppb)	<0.7W	<0.6W	<0.7W	<0.7W	<0.7W	113	4
Selenium (ppb)	<0.7W	<0.7W	<0.7W	<0.7W	<0.7W	97	4
Thallium (ppb)	<0.8	<0.7	<0.8	<0.8	<0.8	110	6
Zinc (ppb)	33W	21W	14W	21W	19W	97	0

Analysis performed in accordance with methods approved by the USEPA.

COMMENT: W = Results expressed in ppm and reported on a dry weight basis.

Respectfully Submitted,

Mr. James M. Schoen
Inorganic Laboratory Manager

CC. MR. T. GORMAN/ATL

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