START

0035061

DOE/RL-93-45
Draft A

100 Area ISV Pilot-Scale Treatability Study for Retrieved Burial Ground Waste

Date Published
August 1993

9413221.785

United States
Department of Energy
P.O. Box 550
Richland, Washington 99352

SEP 1993
RECEIVED
EDMC

BEST AVAILABLE COPY

Approved for Public Release

THIS PAGE INTENTIONALLY
LEFT BLANK

SUMMARY

This treatability study test plan will be used by Pacific Northwest Laboratory (PNL) to direct pilot-scale testing of the in situ vitrification (ISV) technology. This treatability study will use the pilot-scale ISV unit to demonstrate the ISV process as a physical stabilization technique for retrieved buried waste. An engineered test site containing nonhazardous and nonradioactive material representative of waste to be retrieved from the 100 Area of the Hanford Site at Richland, Washington, will be used for this demonstration. Because elements of the dynamics associated with the ISV processing of sealed containers are currently unknown, sealed containers will not be included in the simulated waste matrix. In addition to demonstrating the ISV technology as a physical stabilization technique, the pilot-scale demonstration will allow researchers to collect field data that will assist in identifying the operating limits for this application, provide the basis for modifying the full-scale equipment for this application, and provide processing information for estimating full-scale operating costs.

This test plan describes the procedures to be used to test the ISV process on the engineered test site, including a complete description of the engineered test site, the ISV process, the test objectives, and the experimental design. It also includes procedures for sampling and analysis, data management, analysis and interpretation, health and safety, waste management, reporting, scheduling, and test specific procedures. The Engineering Analysis, Sampling and Analysis Plan, and Quality Assurance Project Plan for this treatability study are attached as appendixes.

This treatability study is part of the overall remedial investigation and feasibility study being performed for the 100 Area of the Hanford Site (DOE 1992). This treatability study is one of many that is being performed as part of the "Development and Screening of Alternatives" phase of the feasibility study (EPA 1988). Results from this treatability test will be used to evaluate the ISV technology as a physical stabilization technique based on its effectiveness, implementability, and cost. If the ISV technology is selected as a physical stabilization technique based on these evaluation criteria, the next phase of the study would be to analyze the feasibility of integrating the ISV technology into an overall remedial strategy for the 100 Area. Because this treatability test

does not contain hazardous or radioactive materials, further treatability studies containing such materials will be needed to obtain the necessary data for this detailed analysis phase. The inclusion of hazardous and radioactive materials are not necessary for this pilot-scale test since its purpose is to evaluate the ISV technology only as a physical stabilization technique.

9413221.1787

CONTENTS

SUMMARY iii
1.0 PROJECT DESCRIPTION 1.1
1.1 TREATABILITY STUDY. 1.1
1.2 BACKGROUND 1.1
2.0 REMEDIAL TECHNOLOGY DESCRIPTION 2.1
3.0 TEST OBJECTIVES 3.1
4.0 EXPERIMENTAL DESIGN AND PROCEDURES 4.1
4.1 TEST PARAMETERS 4.1
4.2 MODEL/CALCULATIONS 4.2
4.2.1 Results from the ISV Computer Model 4.2
4.2.2 Results from the TOUGH2 Model 4.4
4.3 PILOT-SCALE ISV TEST SYSTEM. 4.4
4.3.1 Power System Design 4.4
4.3.2 Electrodes and Electrode Feed System 4.6
4.3.3 Off-Gas Containment Hood 4.6
4.3.4 Off-Gas Treatment System 4.7
4.3.5 Data Acquisition Systems 4.7
4.4 SAFE OPERATING PROCEDURES 4.7
4.5 ENGINEERING ANALYSIS 4.8
5.0 SITE LAYOUT 5.1
5.1 WASTE COMPOSITION 5.1
5.2 TEST CONFIGURATION 5.2
5.2.1 Trench Configuration 5.2
5.2.2 Waste Configuration 5.2
5.3 INSTRUMENTATION 5.4
6.0 SAMPLING AND ANALYSIS 6.1
7.0 DATA MANAGEMENT 7.1
7.1 QUALITY ASSURANCE. 7.1
7.2 LABORATORY RECORD BOOKS 7.1

9413221.1788

7.3 DATA SHEETS 7.2
7.4 COMPUTER GENERATED DATA 7.2
7.5 ARCHIVE RECORDS MANAGEMENT 7.2
8.0 DATA ANALYSIS AND INTERPRETATION 8.1
8.1 OBJECTIVE ONE: DEMONSTRATE ISV AS A STABILIZATION TECHNIQUE FOR RETRIEVED BURIED WASTE 8.1
8.2 OBJECTIVE TWO: DETERMINATION OF THE ISV OPERATING ENVELOPE FOR APPLICATION TO COMBUSTIBLE AND COMPACTABLE WASTE 8.2
8.3 OBJECTIVE THREE : DEMONSTRATE ISV ON A SITE THAT CONTAINS SIGNIFICANT QUANTITIES OF COMBUSTIBLE MATERIAL 8.3
8.4 DESIGN FOR FULL-SCALE ISV OPERATIONS 8.3
9.0 HEALTH AND SAFETY 9.1
10.0 WASTE MANAGEMENT 10.1
11.0 COMMUNITY RELATIONS 11.1
12.0 REPORTS 12.1
13.0 SCHEDULE 13.1
13.1 WORK BREAKDOWN STRUCTURE 13.1
13.2 SCHEDULE/MILESTONES 13.1
14.0 MANAGEMENT AND STAFFING 14.1
14.1 KEY PERSONNEL 14.1
14.2 TRAINING REQUIREMENTS 14.1
15.0 TEST-SPECIFIC PROCEDURES 15.1
15.1 WASTE SIMULATION 15.1
15.2 POWER REQUIREMENTS 15.1
15.3 WATER SPRAY 15.2
15.4 PASSIVE VENT 15.6
15.5 VOID SPACE MINIMIZATION 15.7
16.0 REFERENCES 16.1

9413221.1789

APPENDIX A - Engineering Analysis
APPENDIX B - Sampling and Analysis Plan
APPENDIX C - Quality Assurance Project Plan
APPENDIX D - Data Sheets

9413227.1390

FIGURES

2.1 Sequence of the ISV Process 2.2
4.1 Test Parameters of Interest 4.3
4.2 Cutaway View of Pilot-Scale ISV Process Trailer and Hood 4.5
5.1 Waste Configuration for the 100 Area Pilot-Scale Demonstration . . . 5.3
5.2 Electrode Positions for the 100 Area Pilot-Scale Demonstration . . . 5.4
5.3 Soil Pressure Arrays - Plan View 5.8
5.4 Soil Pressure Arrays - View Along 90° - 270° Axes 5.9
5.5 Soil Thermocouple Arrays - Plan View 5.10
5.6 Soil Thermocouple Arrays - View Along 90° - 270° Axes 5.11
13.1 Work Breakdown Structure 13.2
13.2 Schedule Timeline 13.3
14.1 PNL Organization Chart for ISV Demonstration with WHC and DOE Interface . 14.3
15.1 Schematic of the Off-Gas Hood with Water Spray Nozzles 15.4
15.2 Flow and Control Schematic for the Water Spray System. 15.5
15.3 Schematic of the Passive Vent System 15.7

9413221.1791

TABLES

1.1	Estimated 100 Area Solid Waste Disposal Site Contents	1.3
5.1	Physical Description of Selected 100 Area Burial Ground Materials	5.1
5.2	Test Parameter Measurements	5.5
5.3	Off-Gas Data Collected	5.6
12.1	Suggested Organization of Treatability Study Report	12.1
13.1	Schedule for WBS Elements	13.1
14.1	Responsibilities of Key Personnel	14.2
14.2	Training Classes	14.4
15.1	Water Spray Operating Criteria	15.6

9413221.1792

THIS PAGE INTENTIONALLY
LEFT BLANK

1.0 PROJECT DESCRIPTION

1.1 TREATABILITY STUDY

In situ vitrification (ISV) is proposed as a physical stabilization technique for burial ground waste retrieved from the 100 Area. Originally developed for contaminated soils, ISV is a thermal treatment technology that converts contaminated soils to a glass and crystalline product. The ISV product has been shown to have a compressive and splitting tensile strength approximately ten times that of unreinforced concrete and has very good leach resistance properties (Buelt et al. 1987). In addition to these desirable product qualities, the ISV process is versatile in nature relative to the waste site parameters that it can process (e.g., soil type, soil moisture, and soil inclusions) (Buelt and Thompson 1992).

This treatability study will utilize the pilot-scale ISV equipment to demonstrate the ISV process as a physical stabilization technique for compressible waste. An engineered site containing nonregulated, nonhazardous, and nonradioactive material representative of waste to be retrieved from the 100 Area will be used for this demonstration. Due to a current lack of understanding of the dynamics associated with the ISV processing of sealed containers, sealed containers will not be included in the simulated waste matrix. In addition to demonstrating the ISV technology as a stabilization technique, the pilot-scale demonstration will collect field data that will assist in identifying the operating envelope for this application, provide the basis for modification of full-scale equipment for this application, and provide processing information necessary to estimate full-scale operating costs.

1.2 BACKGROUND

This ISV demonstration is one of many treatability studies identified for the 100 Area of the Hanford Site (DOE 1992). Treatability studies provide necessary site-specific data necessary to support remedial actions. These treatability studies serve two primary purposes:

- to aid in the selection of a remedy
- to aid in the implementation of the remedy.

The ISV treatability study will provide data necessary to evaluate the ISV technology as a physical stabilization technique for retrieved burial ground waste from the 100 Area.

In the 100 Area of the Hanford Site, direct land burial was used to dispose of solid, low-level radioactive wastes associated with reactor operations (Miller and Wahlen 1987). From 1944 through 1973, the waste was buried in 28 locations which have been identified as burial grounds. Table 1.1 provides information on the estimated solid waste disposal contents in the 100 Area. As shown in Table 1.1, there is a significant inventory of metallic (aluminum and lead) and other waste (soft waste, desiccant, miscellaneous material). The nonmetallic wastes, and some of the metallic waste, are expected to be compressible. This compressibility represents a potential mechanism for future subsidence once the material is disposed of in a central landfill. In addition, long term degradation of material may also contribute to future subsidence. Subsidence is of concern because it has the potential to compromise the long-term integrity of a barrier placed over a landfill. Stabilization of the waste form disposed of in a central landfill and/or construction of a barrier resistant to long-term subsidence are methods to ensure the long-term integrity of the protective barrier.

9413122.1794

TABLE 1.1. Estimated 100 Area Solid Waste Disposal Site Contents. Adapted from Miller and Wahlen (1987)

Metallic and Other Waste (tons)

Burial Site	Lead	Aluminum[1]	Pb/Cd	Boron[2]	Mercury	Graphite	Other[3]
118-B-1	30.0	135.2	201.2/8.4	1.4	1.0	0.08	527
118-B-2[4]	-	-	-	-	-	-	-
118-B-3[4]	-	-	-	-	-	-	-
118-B-4[4]	-	-	-	-	-	-	-
118-B-5[4]	-	-	-	-	-	-	-
118-B-6	18.0	25.0	-	-	0.05	-	23
118-B-7[4]	-	-	-	-	-	-	-
118-C-1	23.8	94.8	105.9/4.4	1.2	-	0.56	211
118-C-2[5]	-	-	-	-	-	-	-
118-D-1[6]	-	-	-	-	-	-	-
118-D-2	109.8	134.4	222.4/9.4	1.4	-	0.08	280
118-D-3	23.8	97.0	137.7/5.7	1.0	-	0.06	181
118-D-4[6]	-	-	-	-	-	-	-
118-D-5[6]	-	-	-	-	-	-	-
118-DR-1[6]	-	-	-	-	-	-	-
118-F-1	23.8	127.8	222.4/9.4	1.3	-	0.07	247
118-F-2[7]	-	-	-	-	-	-	-
118-F-3[7]	-	-	-	-	-	-	-
118-F-4[7]	-	-	-	-	-	-	0.30
118-F-5[8]	-	-	-	-	-	-	-
118-F-6[9]	-	-	-	-	-	-	-
118-F-7[7]	-	-	148.3/6.2	-	-	-	-
118-H-1	23.8	109.9	154.4/6.4	1.0	-	0.05	200
118-H-2	-	-	-	-	-	-	0.30
118-H-3[10]	-	-	-	-	-	-	-
118-H-4	-	-	-	-	-	-	-
118-H-5[10]	-	-	-	-	-	-	-
118-K-1	30.0	208.1	21.1/0.9	3.2	-	0.20	368
TOTALS	283.00	932.2	1059.0/44.0[11]	10.5[2]	1.05	1.1	2047

[1]Includes aluminum cans on Pb/Cd pieces, spacers, and aluminum contained in splines.
[2]Includes boron from splines, VSRs, and HCRs at 1.5% x total weight buried.
[3]Includes soft waste, desiccant, and miscellaneous materials.
[4]Included in 118-B-1 totals.
[5]Hot balls from ball sorting in 105-C.
[6]Divided between 118-D-2 and 118-D-3 totals.
[7]Included in 118-F-1 totals.
[8]Contained 3×10^5 ft^3 of contaminated sawdust and other solids removed from dog kennels and animal pens.
[9]Contained 1×10^5 ft^3 of contaminated solid waste such as animal carcasses.
[10]Included in 118-H-1 totals.
[11]Included sheet cadmium.

9413221.1796

2.0 REMEDIAL TECHNOLOGY DESCRIPTION

The ISV technology has been under development since 1980 at Pacific Northwest Laboratory (PNL)[a] (Buelt et al. 1987; Oma et al. 1989a). Initial effort was directed to contaminated soil applications, and the technology has been transferred to a licensee, Geosafe Corporation, for commercial applications. Development efforts for ISV applications other than treatment of contaminated soils, by PNL and in collaboration with Oak Ridge National Laboratory (ORNL) and Idaho National Engineering Laboratory (INEL), show the ISV process has potential applicability for remediating buried waste sites (Callow et al. 1991), remediating underground storage tanks (Tixier et al. 1992), and enabling the placement of subsurface vitrified barriers and engineered structures (Tixier et al. 1991).

In addition to processing a variety of waste forms, buried inclusions, and soil types, the ISV technology has been tested on a wide variety of contaminants. Organic contaminants for which the ISV process has been applied include polychlorinated biphenyls (PCBs), dioxins, methyl ethyl ketone, glycol, toluene, and benzene (Mitchell 1987; Buelt and Bonner 1988; Oma et al. 1989b; Timmerman 1989; Shade et al. 1991). The destruction efficiency for these contaminants was found to be greater than 99% without including the off-gas treatment system. Including the treatment system increases the overall efficiency for a wide range of organics to greater than 99.99%.

Inorganic contaminants for which the ISV process has been applied includes plutonium and plutonium simulants, uranium, cesium, americium, strontium, lead, arsenic, and various other heavy metals (Buelt 1989; Buelt and Westsik 1988; Hansen 1991; Luey et al. 1992a; Spaulding et al. 1993). These tests have shown either excellent retention of the inorganic material in the final glass and crystalline product or excellent collection of the material in the combined final product and off-gas treatment system.

The ISV process utilizes joule heating to melt contaminated solid media (e.g., soil, sediment, sludge, and mill tailings). The process, which is performed in situ or in a prepared location where the contaminated material may be staged for treatment, is very effective in

---

[a] Operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

removing, destroying, and/or immobilizing hazardous chemicals, radioactive materials, and mixed contaminants. The ISV process produces a high-quality glass-and-crystalline waste form that is highly resistant to corrosion and leaching and is capable of long-term environmental exposure without significant degradation. The melting process also results in a significant volume reduction (20% to 45% for most soils and up to 75% for buried waste).

Figure 2.1 illustrates the stages of the ISV process. The melting process is accomplished through joule heating between an array of electrodes. A starter path of graphite and glass frit is placed between the electrodes to allow initiation of the process in typically nonconductive soil. Once the soil surface becomes molten (1200 to 1400°C), it becomes electrically conductive. Joule heating now occurs in the molten soil as electricity flows through it, resulting in molten soil temperatures ranging from 1600 to 2000°C. Heat is conducted from the melt to the surrounding, adjacent soil, causing growth of the melt in both the downward and outward directions.

9413221.1798

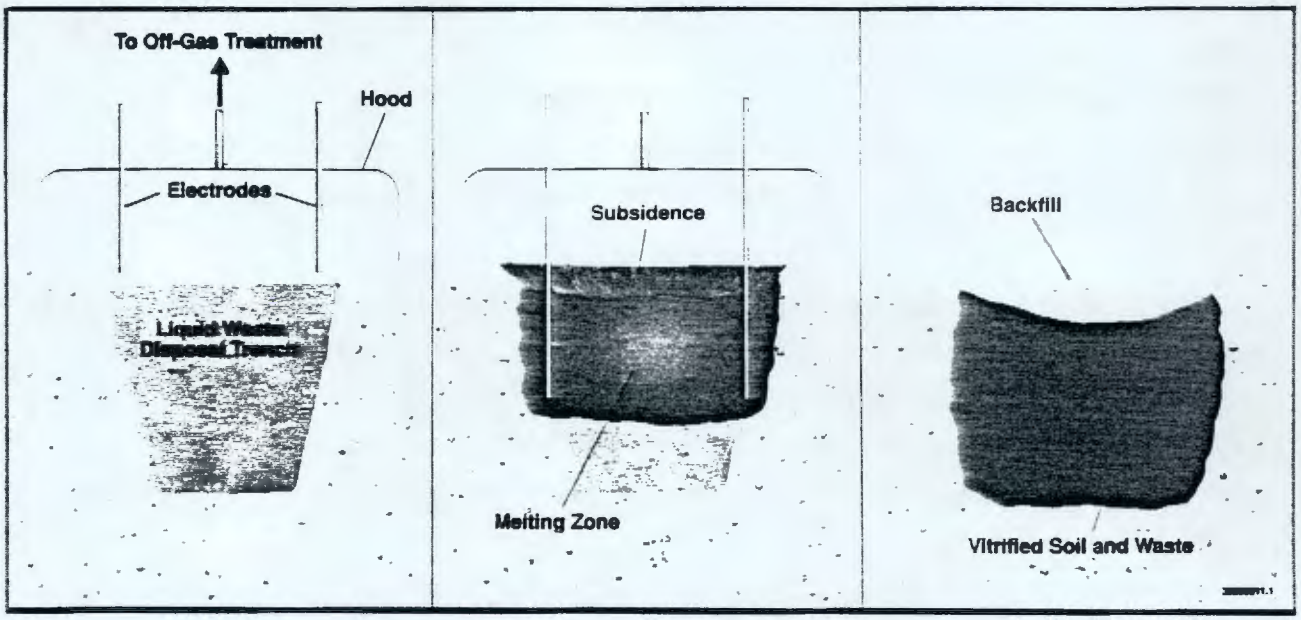


FIGURE 2.1. Sequence of the ISV Process

The ISV technology has been developed through bench-, engineering-, pilot-, and large-scale applications. The size of a single ISV melt ranges from 50 kg at bench-scale to 1000 metric tons at large-scale. The large-scale equipment is capable of processing at the rate of 4 to 6 metric tons/h. It employs 1) a 3,750-kVA multiple-tap transformer supplying electrical power to the electrodes; 2) an off-gas collection hood and an electrode feed system; 3) an off-gas treatment system employing quenching, scrubbing, dewatering, filtering, and adsorption-unit processes; 4) a distributed microprocessor control system; 5) an emergency backup off-gas treatment system; and 6) an emergency backup generator to supply power to the off-gas treatment and process control trailers in the event of a site power outage.

The pilot-scale system is capable of processing up to 50 metric tons of soil in a single melt at the rate of 0.4 to 0.6 metric tons/h. The pilot-scale equipment differs from the large-scale unit in that it is operated manually and does not use a distributed microprocessor control system. Section 4.0 provides more detail, including schematics, of the pilot-scale setup.

More than 150 individual tests of the ISV technology at various scales have demonstrated the efficacy of the technology to treat a broad range of contaminants and solid media types. The technology has been shown effective for destroying organic contaminants by pyrolysis, as well as for removal and/or immobilization of heavy metal contaminants or radionuclides within the vitrified residual product (Buelt et al. 1987; Luey et al. 1992a). The current capabilities of the ISV technology are summarized by Buelt and Thompson (1992). Although the 150 tests of the ISV system represent a significant database, this particular demonstration will be the first application of ISV to waste that contains aluminum and a high combustible loading.

9413221.1800

3.0 TEST OBJECTIVES

A pilot-scale ISV treatability test will be performed using the existing pilot-scale ISV equipment at the 300W Site (46°22'21" north by 119°10'55" west) located near the 300 Area of the Hanford Site, Richland, Washington. The treatability test will be performed on a staged site containing nonhazardous, nonradioactive, and nonregulated material to simulate waste retrieved from the 100 Area. The objectives of this test are the following:

9413221.1801

- **Demonstrate ISV as a stabilization technique for retrieved buried waste.** Performance will be determined by the ability of the ISV process to eliminate potential mechanisms for future subsidence. Mechanisms for future subsidence involve the consolidation of the waste material through the elimination of void spaces created during filling of the waste disposal trench, pre-existing in the waste material, or created as the result of decomposition and degradation of the waste material. The ISV process eliminates these future subsidence mechanisms through densification and by forming a stable, durable product. Analyses to qualify and/or quantify the elimination of these future subsidence mechanisms, thus demonstrating ISV as a stabilization technique, include post-test examination of the ISV product to determine fraction void space and amount of subsidence and strength and durability tests on core samples from the ISV product.

- **Define the ISV operating envelope for application to combustible and compactable waste.** Performance will be determined by the ability to establish the ISV operating envelope for this application via computations and verifying the computational prediction(s) with field data collected on a staged site within the identified envelope. In addition, performance will be measured through the completeness of field data collected to identify design modifications full-scale equipment and the identification of full-scale operating procedures. The identification of design modifications to the full-scale ISV unit and the identification of full-scale operating procedures are necessary to estimate the fixed and operating costs for this ISV application.

- **Demonstrate ISV on a site that contains significant quantities of combustible material.** Performance will be determined by the ability of the ISV process to treat a site that contains significant quantities of combustible material without a molten soil displacement event (see Roberts et al. 1993 for description). Successful completion of the pilot-scale demonstration without a molten soil displacement event, combined with verification of computational predictions, will serve as the primary measure of success for this objective. A secondary measure of success for this objective will be the completeness of data collected to evaluate the anticipated secondary effects of processing a high combustible-loaded site (e.g., higher heat loads, higher operating temperatures, higher carbon monoxide and dioxide levels).

9413221.1802

4.0 EXPERIMENTAL DESIGN AND PARAMETERS

4.1 TEST PARAMETERS

Several test parameters for the pilot-scale ISV treatability test have been identified. These parameters are those needed to either assist in the verification of computational modeling or to characterize the ISV process so that design criteria for full-scale equipment modifications for this application can be identified. The specified test parameters will help identify or characterize the following elements of the ISV process: the combustion air inlet, the off-gas exit, the electrode seal air bleed, the graphite electrodes, the off-gas hood, and the process zone. Following is a brief description of these elements.

- Combustion Air Inlet - The combustion air inlet provides a continuous source of oxygen in the off-gas hood to support the combustion of volatilized organic material. Since the off-gas containment hood is kept at a slight negative pressure relative to ambient, the normal flow of gases is into the off-gas hood. If the pressure becomes positive, the air inlet line provides a filtered release point. Combustion air inlet temperature and flowrate, as well as ambient pressure and gas composition (e.g., oxygen, carbon monoxide, and carbon dioxide), are necessary data points for a material and energy balance on the off-gas hood.
- Off-Gas Exhaust - The off-gas exhaust refers to either the exit from the off-gas hood or the exit through the stack of the off-gas treatment system. Flow from the off-gas hood is provided by the blower in the off-gas treatment system. This flow provides the slightly negative pressure in the off-gas hood. Characterization of the off-gas exhaust in terms of temperature (from hood and stack), flowrate (from stack), and composition (from stack) is necessary for a complete material and energy balance on the off-gas hood. Since the pilot-scale demonstration will not contain any regulated, hazardous, or radioactive material, the primary off-gas components of interest are oxygen, carbon monoxide, and carbon dioxide.
- Electrode Seal Air Bleed - The electrode seal air bleed provides air to the positive pressure seals that fit onto the graphite electrodes. These seals prevent potential uncontrolled releases of gases from around the insertion points for the electrodes into the off-gas hood. Temperature, pressure, and flowrate are necessary data points for a complete material and energy balance on the off-gas hood.
- Graphite Electrodes - The graphite electrodes conduct electrical current to the advancing ISV melt. The amount of power input into the ISV melt is controlled by adjusting the amount of current or voltage added. Measurement of these parameters, as well as the calculation of the electrical resistance of the zone being processed, is necessary to determine full-scale power requirements.
- Off-Gas Hood - This term refers to both the off-gas hood skin and the volume contained by the off-gas hood. The off-gas hood confines gases and particulate evolved from the ISV process into the off-gas treatment system for processing. Important parameters to evaluate

the performance of the off-gas hood include the temperature of the off-gas hood (skin and plenum), pressure within the off-gas hood, and the flux of energy from the off-gas hood. These parameters are necessary for the design of full-scale equipment.

- Process Zone (ISV Melt, Surrounding Soil, and Simulated Waste) - The process zone is the zone that will be affected by the ISV process. Characterization of this zone is needed to verify computational model predictions and to provide operating information needed for full-scale equipment design. Parameters of interest are the temperature and pressure in the simulated waste site and the surrounding soil. The temperature data provides information on the shape of the progressing melt, the sphere of influence for the ISV process, and also is used to estimate the rate of melting.

Figure 4.1 illustrates the elements of the ISV process (described above) from which data will be collected during the demonstration. The instrumentation used for measuring the data collected from each of these elements is discussed in section 5.3 of this test plan.

4.2 MODEL/CALCULATIONS

Two computational models were used to estimate test parameters of interest for this ISV demonstration. The ISV 3.01 PC model was used to estimate the melt shape for the 100 Area demonstration while the TOUGH2 computer code was used to investigate the transient hydrothermal phenomena occurring in the soil below an advancing ISV melt. A description of these models and the model results are provide in Appendix A. A short summary of the modeling results is provided in the remainder of this section.

4.2.1 Results from ISV Computer Model

The ISV model estimates that the melt width upon completion of the demonstration would be about 3.2 m. This is narrower than the base of the ISV pilot-scale hood which is about 4.3 m. It is not anticipated that the ISV melt for the 100 Area demonstration, which will contain a high metal and combustible loading, will grow to be any wider than the estimated 3.2 m. The reasons for this prediction are 1) prior experience with buried waste at INEL showed the melt to progress as if in an "elevator shaft" (Callow et al. 1991) and 2) the metal loading of the simulated waste site is believed to enhance downward melt growth.

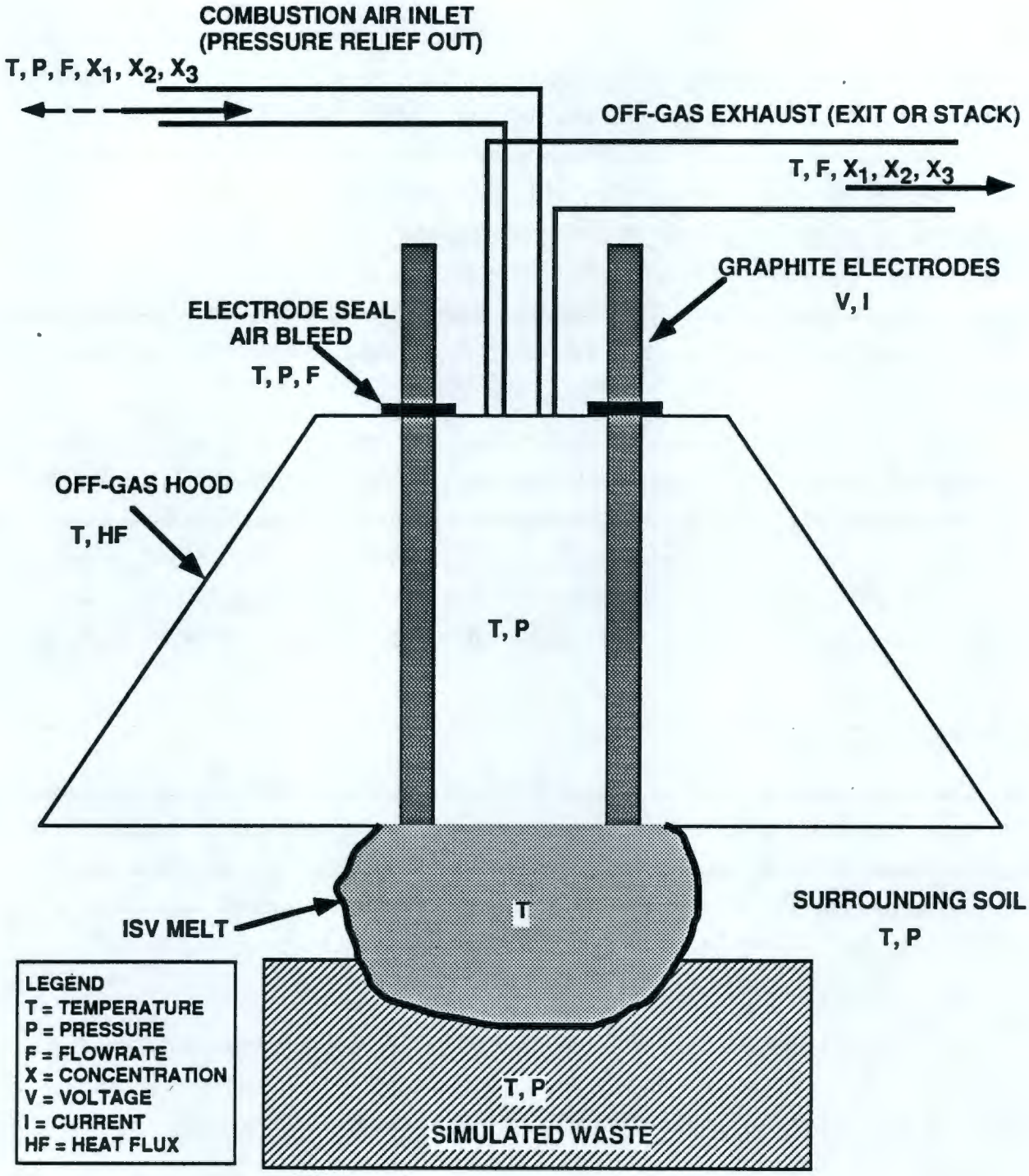


FIGURE 4.1. Test Parameters of Interest

4.2.2 Results from the TOUGH2 Model

Simulations were run using two statistical distributions of waste. One happened to have metal sections well dispersed (random distribution #1) so that they did not form long impermeable barriers that prevented fluid flow and increased pressure. The other distribution had many such barrier zones (random distribution #2). The distribution of metal sections and the assumptions used in modeling them had a dramatic effect on the calculated results. From these runs, it is apparent that the pyrolyzing gases do affect the pressure beneath the melt, but not strongly. The two methods used for modeling the pyrolysis process gave similar results, with the worst-case model predicting a higher pressure. The restrictions caused by metal loadings may have as great an impact as the pyrolyzing waste, especially if they form impermeable containment to pyrolyzing material.

It is important to note that these simulations assumed a constant melt progression rate of 2.5 cm per hour based on past pilot-scale ISV experience. It is possible that the high loading of combustible material for this project would increase the melt progression rate, leading to an increased rate of pyrolysis gas generation. This modeling work is preliminary and is only intended to suggest the effects of different loading conditions. It is hoped that data will be collected during the demonstration that can be used to adjust and partially validate the model for further predictions.

9413221.1806

4.3 PILOT-SCALE ISV TEST SYSTEM

The pilot-scale test equipment consists of a power supply and control system, an off-gas treatment system housed in a portable semi-trailer, and an off-gas containment hood over the test site. A schematic of the apparatus is shown in Figure 4.2. This section will briefly discuss each of the elements of the pilot-scale test system. For more detailed discussions on the test system, see the Safe Operating Procedure for the pilot-scale ISV equipment and Spaulding et al. (1992).

4.3.1 Power System Design

The pilot-scale electrode power system uses a 500-KVA Scott connected transformer producing a variable voltage output through a range of four operator-selectable voltage taps. Power output is controlled at the primary side of the transformer with SCR (silicon control rectifier) technology using a single potentiometer selectable for either voltage or current control.

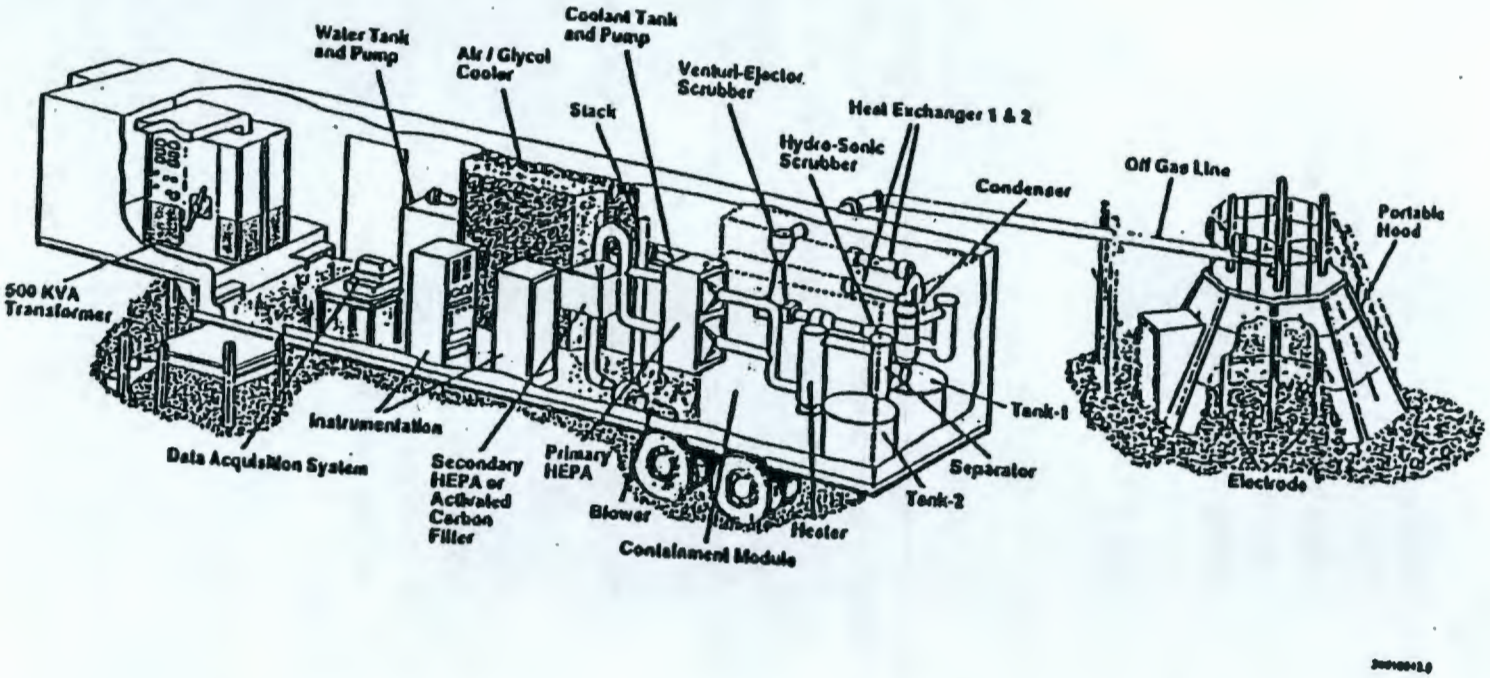


FIGURE 4.2. Cutaway View of Pilot-Scale ISV Process Trailer and Hood

The Scott connected transformer is a phase conversion system converting 3-phase power (three-wire primary) to 4-phase power (four-wire secondary).

The entire pilot-scale system (vitrification power, off-gas processing equipment, etc.), requires 750 kW of power at 480 VAC, 800 amps, 3 phase, and 60 Hz. A backup diesel generator is utilized to provide energy for the operation of all essential equipment for personnel and environmental safety in the event utility line power is interrupted. These include the off-gas system, data acquisition system, environmental and system monitoring equipment, HVAC, lights and system lighting. The diesel generator provides 93 kVA of power at 480 VAC, 3 phase, and 60 Hz. Activation of the generator is automatic upon loss of utility line power, thus providing interrupted power to essential process equipment.

9413221.1808

4.3.2 Electrodes and Electrode Feed System

The electrodes used to conduct current to the molten soil are 15.2-cm-diameter by approximately 185-cm-long sections of graphite. Each electrode section is machined at both ends with female threads to allow connection of successive lengths via male threaded graphite connecting pins. The electrodes are initially buried to depths of one to two electrode diameters and the starter-path, consisting of graphite and glass frit, is laid around and between the electrodes. For this test, the electrodes will be arranged in a square array with a center-to-center separation of 1.0 meter per side of the square.

The electrode feed system consists of four independently controlled, pneumatically powered units, one feed unit for each electrode, and a control unit with manually operated valves for each feed unit. Normally, operations are conducted with the electrodes in a gravity fed, non-gripped mode (electrode feed system clamps not engaged), allowing the electrodes to rest on the bottom of the advancing melt front. As metallic objects, molten metal pools, or other electrically disruptive situations are encountered, the feed system is utilized to retract the effected electrode(s) until a stable electrical balance is achieved. Typically, retraction of only 2 to 3 cm is needed to restore balance.

4.3.3 Off-Gas Containment Hood

The off-gas hood consists of a steel shell and a superstructure for supporting the shell as well as the electrode feed units. 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 that is created by an induced draft blower. With a flow of between 10 and 15 cubic meters per minute, gases in the hood have a residence time of approximately 2 minutes.

4.3.4 Off-Gas Treatment System

The off-gas treatment system passes off-gases from the ISV process through a Venturi-Ejector scrubber and a separator, a Hydro-Sonic® scrubber, a separator, a condenser, another separator, a heater, two stages of HEPA filtration, and a blower before exiting back to the atmosphere. Liquid to the two wet scrubbers is supplied by two independent liquid recirculation tanks, each equipped with a pump and heat exchanger. The entire off-gas treatment system, along with the ISV power supply, has been installed in a 13.7-m long semi-trailer to facilitate transport to sites.

4.3.5 Data Acquisition Systems

The data acquisition system (DAS) and associated instrumentation provide extensive process monitoring capabilities for ISV testing. For monitoring the off-gas treatment process, inputs from process instruments are routed through a Hewlett Packard model 3497A data acquisition and control unit linked to a Macintosh II cx computer operating LabView 2.0 software. Data inputs from instruments characterizing the ISV process (e.g., soil temperature and pressure, off-gas flowrates, and heat flux in the vitrification zone and from the off-gas hood) are routed through a multiplexed system and then linked to the Macintosh computer. The DAS scans, records, displays, and files process-control informational data and characterization data at a nominal rate of two samples per minute for each channel. Process control data include numerous off-gas equipment temperature and flow measurements, differential pressures of scrubbing components, vitrification electrical power volts/amps, off-gas hood plenum temperatures and pressure, etc.

4.4 SAFE OPERATING PROCEDURES

The specific steps to be followed when operating the existing DOE pilot-scale ISV equipment are described in the supporting document, Safe Operating Procedure (SOP No. 49, Revision 9) (Powell 1993b). This SOP includes startup, operating, and shutdown instructions as well as potential system failures, consequences, and required operator actions. The SOP is written

for the general operation of the pilot-scale equipment. Specific procedures required for this treatability study can be found in Section 15.0 of this test plan.

4.5 ENGINEERING ANALYSIS

An engineering analysis of the 100 Area ISV Pilot-Scale Demonstration was written as a supporting document for this treatability test and is included here as Appendix A. This engineering analysis describes test-specific potential events (different from those described in the SOP) that may occur during this demonstration and how they can be prevented or controlled. The possibility exists for these events to occur because the ISV setting for this demonstration differs from an ISV setting with only soil. An evaluation to determine or quantify the probability of any specific event was not part of the engineering analysis; however, the probability of such events at full-scale will be evaluated using data from the pilot-scale treatability test.

The test-specific potential events include the following: high heat load in the off-gas hood, electrical shorting in the melt, loss of the off-gas hood vacuum, high CO/CO_2 emissions, outward growth of the melt, underground fires, molten soil displacement, and an inability to sustain the melt. Mitigating systems and/or procedures that will be used during the 100 Area demonstration include establishment of a control zone, reduction of applied power, water spray system, electrode feed system, passive hood vent, monitoring of off-gas composition, monitoring of melt progression, random placement of waste, computational modeling, addition of a soil berm inside the off-gas hood, use of a camera to monitor conditions inside the off-gas hood, bench-scale testing, engineering calculations, and soil pressure measurements. Each event, the various mitigating systems to be used, and the implementation of these mitigating systems are described in greater detail in Appendix A.

5.0 SITE LAYOUT

5.1 WASTE COMPOSITION

The site for this demonstration will be an engineered site containing nonhazardous and nonradioactive material representative of waste to be retrieved from the 100 Area. Table 5.1 provides a physical description of some of the major constituents in the 100 Area burial grounds (Miller and Wahlen 1987). Using Tables 5.1 and 1.1 as guidelines, the 100 Area ISV demonstration will use simulated waste material that is both compositionally and geometrically similar to that to be retrieved from the 100 Area. Due to the wide variability anticipated for both composition and geometry of the waste during retrieval operations, it is not possible to stage a completely representative site for this ISV demonstration. However, it is possible to stage a site that will fall within the expected envelope. Successful completion of this demonstration (which is defined by meeting the three test objectives) will 1) demonstrate ISV as a physical stabilization

TABLE 5.1. Physical Description of Selected 100 Area Burial Ground Materials. Adapted from Miller and Wahlen (1987)

Material	Description
Aluminum Spacers	The spacers were 20.3 cm long with an outside diameter of 3.6 cm and a 0.6-cm wall thickness. Cylindrical in shape, the spacers had a number of perforations along the axis.
Lead-Cadmium Poison Pieces	The lead-cadmium alloy used as reactor poison was in the form of a solid rod ≈3.6 cm in diameter and 15.2 cm long.
Boron Splines	The majority of splines were about 1.3 cm wide, 0.2 cm thick, and 0.9 m long. The splines were made of a combination of 12% boron and 88% aluminum.
Process Tubes	The process tubes, fabricated out of an aluminum alloy, were about 1.2 m long with an inside diameter of 4.4 cm and a wall thickness of about 0.3 cm.
Reactor Gunbarrel	The reactor gunbarrels are similar to a Schedule 40 carbon steel pipe and measure about 4.5 cm in diameter and .2 m in length.
Soft Waste	Soft waste consists of contaminated plastic, paper, and clothing packaged in cardboard cartons. Comprises more than 75% of the waste volume in the 100 Area burial trenches.

technique for solid waste, 2) result in the necessary data for identifying full-scale equipment requirements, and 3) result in the necessary data to identify the operating envelope for this application (e.g., waste composition and acceptable waste forms).

The target simulated waste composition for the 100 Area demonstration will be 63 wt% Hanford soil, 12 wt% combustibles, and 25 wt% metal. These weight percents were determined based on the estimated solid waste disposal site contents in the 100 Area (see Table 1.1), computational modeling, and engineering calculations (see Appendix A). The combustible waste will be composed of rags, clothing, paper, and other soft material; the metal will be composed of aluminum and steel (mixture of stainless and carbon). When possible, simulated waste will be obtained from an existing waste stream to minimize secondary waste generated from this treatability test.

9413221.1812

5.2 TEST CONFIGURATION

5.2.1 Trench Configuration

Stabilization of solid waste in the 100 Area may be performed either in the 100 Area or at the central disposal facility, depending upon economics and site staging. For stabilization in the 100 Area, the waste would likely be staged and processed in the disposal trenches from which it originated. For large-scale stabilization of solid waste at a central disposal facility, a square trench configuration is the most economical and practical for central landfill trenches. Such a square configuration minimizes the perimeter relative to the surface area, which is important for a protective barrier, and maximizes the amount of waste processed per ISV setting, which minimizes ISV operating cost.

5.2.2 Waste Configuration

The pilot-scale ISV treatability test will simulate an ISV setting performed within a square trench configuration. A rectangular simulated waste form will be used with the electrodes positioned in a postulated worst-case scenario in which waste surrounds the ISV setting on three sides. This is considered worst-case since the permeability of the heterogeneous waste is likely to be less than that of Hanford soil because of the presence of impermeable regions such as metal objects. Figures 5.1 and 5.2 show the waste configuration and the electrode positions, respectively.

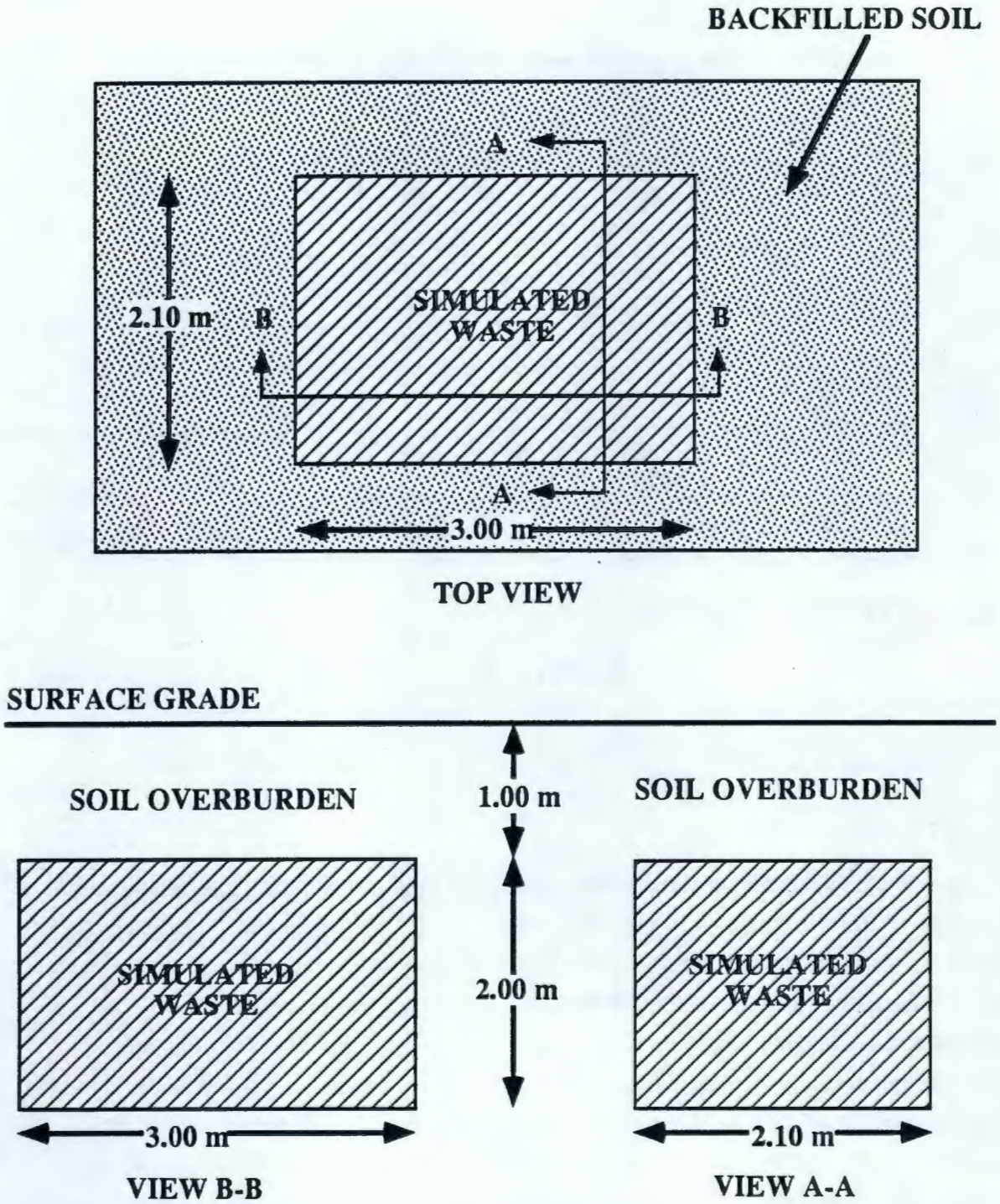


FIGURE 5.1. Waste Configuration for 100 Area Pilot-Scale Demonstration

9413221.1813

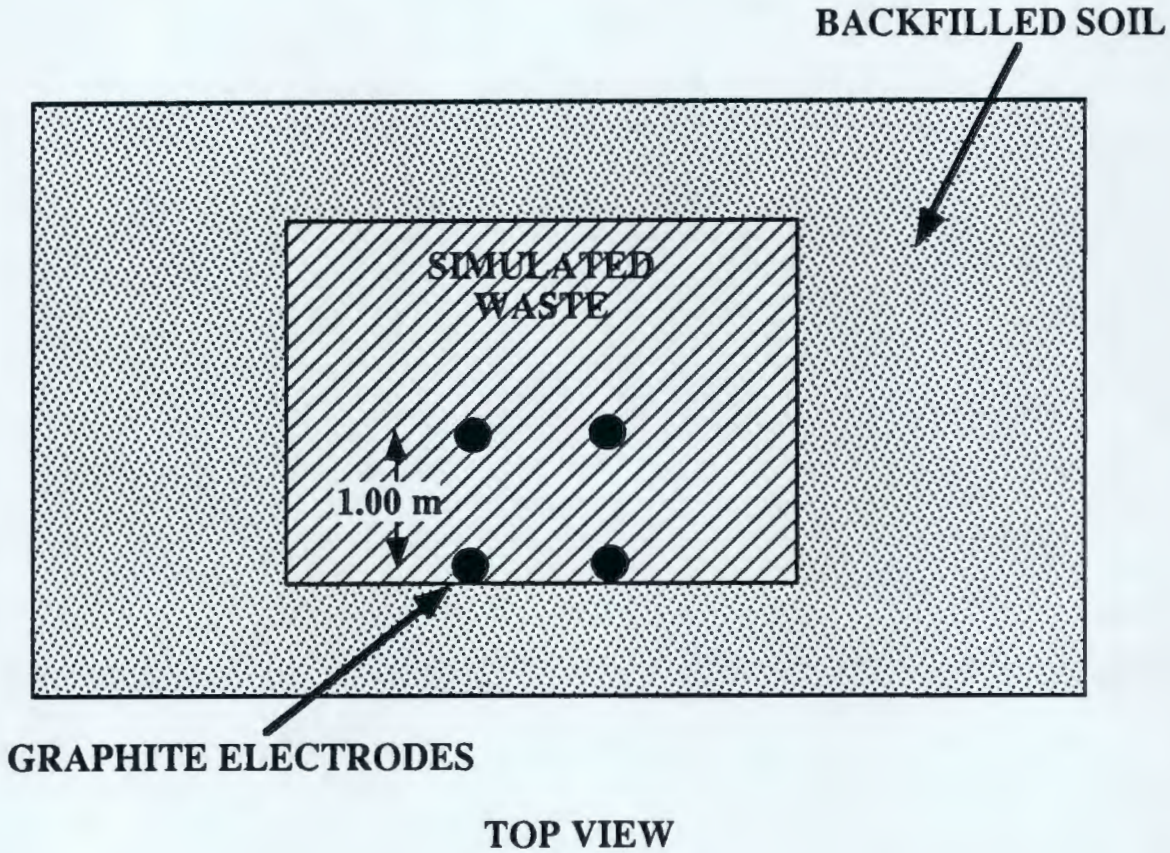


FIGURE 5.2. Electrode Positions for the 100 Area Pilot-Scale Demonstration

5.3 INSTRUMENTATION

Figure 4.1 illustrated the test parameters of interest for this treatability test. The instrument types, location of the instruments, sampling frequency, and the required accuracy for each of the identified test parameters can be found in Table 5.2. Note that the test parameters listed in Table 5.2 are those that can be measured. Parameters such as inleakge into the off-gas hood, melt rate, power consumption, and melt shape are either directly calculated from other measurements, estimated from material and energy balances, or inferred based on data trends. In addition to the test parameters in Table 5.2, data are routinely collected on the off-gas treatment system to characterize its performance. Table 5.3 illustrates the instrumentation, sampling frequency, and required accuracy for the data collected on the off-gas treatment system. The Material and Test Equipment (M&TE) list for the instrumentation is included as a data sheet in Appendix D.

9413221.1814

TABLE 5.2. Test Parameter Measurements

Test Parameter	Measurement Instrument	Sampling Frequency	Range Eng. Units	Required Accuracy
Air Inlet Temperature (T)	Type T Thermocouple	60 s	0-1200°C	± 5°C
(ambient)	Type K Thermocouple	60 s	0-1200°C	± 20°C
Air Inlet Pressure (P)	Barograph	1 hr	AP* in. Hg	±.075" Hg
Air Inlet Flowrate (F)	Pitot Tubes	60 s	0-15 m^3/min.	± 2%
Off-Gas Temperature (T)				
Exit Line	Type K Thermocouple	60 s	0-1200°C	± 20°C
Off-Gas Treatment Stack	Type T Thermocouple	60 s	0-1200°C	± 5°C
Off-Gas Flowrate (F)				
Off-Gas Treatment Stack	Pitot Tube	60 s	0-15 m^3/min.	± 2%
Off-Gas Concentration (X)				
Ambient O_2 Concentration	Electrochemical	5 min	0-25%	± 4% Full Scale
Stack O_2 Concentration	Electrochemical	60 s	0-25%	± 4% Full Scale
Ambient CO Concentration	Infrared	5 min	0-1900 ppm	± 5% Full Scale
Stack CO Concentration	Infrared	60 s	0-1900 ppm	± 5% Full Scale
Ambient CO_2 Concentration	Infrared	5 min	0-15%	± 2% Full Scale
Stack CO_2 Concentration	Infrared	60 s	0-15%	± 2% Full Scale
Electrode Seal Air Temperature (T)	Type T Thermocouple	10 min	0-1200°C	± 5°C
Electrode Seal Air Pressure (P)	Pressure Regulator	30 min	0-40 kPag	± 1.0 kPa
Electrode Seal Air Flowrate (F)	Float Tube	30 min	0-100 L/min	± 50 L/min
Graphite Electrode Voltage (V)	Digital Volt Meter	60 s	0-1000 VAC	±0.5% or 5 Volts
Graphite Electrode Current (I)	Digital Volt Meter	60 s	0-1000 Amps AC	±0.1% or 5
Off-Gas Hood Temperature (T)				
Plenum	Type K Thermocouple	60 s	0-1200°C	± 20°C
Off-Gas Hood Skin	Type K Thermocouple	5 min	0-1200°C	± 20°C
Off-Gas Hood Pressure (P)	Differential Pressure Gauges	60 s	0-17 kPag	± 0.05 kPa
Off-Gas Hood Heat Flux (HF)	HT-50 (Heat Flux Sensor)	5 min	0-1000 BTU/hr	± 10% Full-scale
ISV Melt Temperature (T)	Type C Thermocouple	30 min	0-2300°C	± 20°C
Surrounding Soil Temperature (T)	Type K Thermocouple	5 min	0-1200°C	± 20°C
Surrounding Soil Pressure (P)	Pressure Xducer	60 s	3-35 kPag	± 1 kPa
Simulated Waste Temperature (T)	Type K Thermocouple	5 min	0-2300°C	± 20°C
Simulated Waste Pressure (P)	Pressure Xducer	60 s	0-35 kPag	± 1 kPa

9413221.1815

TABLE 5.3. Off-Gas Data Collected

Test Parameter	Measurement Instrument	Sampling Frequency	Eng. Units Range	Required Accuracy
Off-Gas Treatment System				
Gas Differential Pressure @ Venturi	Diff. Pressure Xdcer	10 min	0-30 in. wc	± 2%
Gas Differential Pressure @ Hydrosonic	Diff. Pressure Xdcer	10 min	0-90 in. wc	± 2%
Gas Differential Pressure @ Condenser	Diff. Pressure Xdcer	10 min	0-30 in. wc	± 2%
Gas Differential Pressure @ HEPA	Diff. Pressure Xdcer	10 min	0-3 in. wc	± 2%
Pump 1 Outlet Pressure	Pressure Transducer	10 min	0-125 psi	± 2%
Pump 2 Outlet Pressure	Pressure Transducer	10 min	0-50 psi	± 2%
Pump 1 Flow	Electronic Flowmeter	10 min	0-50 gpm	± 5%
Pump 2 Flow	Electronic Flowmeter	10 min	0-30 gpm	± 5%
Glycol Coolant Flowrate	Electronic Flowmeter	10 min	0-100 gpm	± 5%
Glycol Coolant Temperature	Type K Thermocouple	10 min	0-1200°C	± 20°C
Pressure @ Blower	Diff. Pressure Xdcer	10 min	0-140 wc	± 2%
Tank 1 Liquid Level	Diff. Pressure Xdcer	10 min	0-350 L	± 2%
Tank 2 Liquid Level	Diff. Pressure Xdcer	10 min	0-350 L	± 2%
Off-Gas Temperature @ Venturi	Type K Thermocouple	10 min	0-1200°C	± 20°C
Off-Gas Temperature @ Stack	Type K Thermocouple	10 min	0-1200°C	± 20°C
Tank 1 Liquid Temperature	Type K Thermocouple	10 min	0-1200°C	± 20°C
Tank 2 Liquid Temperature	Type K Thermocouple	10 min	0-1200°C	± 20°C

Of the test parameters illustrated in Table 5.2, the soil temperature and pressure data, as well as the simulated waste temperature and pressure data, require the most extensive instrumentation placement. The data to be collected will characterize the conditions in front of the advancing ISV melt front and be used to verify computational modelling predictions. In addition, the pressure and temperature data will be used to develop guidelines for full-scale ISV application to solid waste.

9413221.1816

Figure 5.3 illustrates the plan view of the soil pressure arrays. These arrays include type K thermocouple measurements and pressure sampling points in both Hanford soil and the simulated waste zone. A total of six soil pressure arrays will be used (each consisting of five pairs of temperature/pressure sampling points)- one along the centerline, one along the 90° axis, two along the 0° axis, and two along the 180° axis. Each of the soil pressure arrays will be oriented horizontally except for the centerline array, which will be oriented vertically. The lateral array along the 90° axis will be placed at a depth of 1.5 m. The arrays along the 0° and 180° axes will be at depths of 1.5 m and 2.5 m. Figure 5.4 illustrates the side view of the soil pressure arrays looking along the 90° - 270° axis. Also shown in Figures 5.3 and 5.4 are type thermocouples along the vertical centerline array. These thermocouples have a higher temperature range than the type K thermocouples and will be used to measure the ISV melt temperature at different depths. A measure of the melt temperature will provide information on whether the incorporation of different materials into the molten soil zone, which results in a change in the melt composition, affects the melt temperature.

9413221.1817

Figure 5.5 and 5.6 illustrate the plan view and side view of the thermocouple arrays, respectively. These thermocouple arrays consist of type K thermocouples and will be used to track the advancing melt front in regions containing only Hanford soil and regions containing soil and simulated waste. Six tiers of thermocouples will be placed along the 0°, 45°, 90°, 125°, and 180° axes. Each array will consist of five thermocouples spaced 0.3 m apart and be placed at depths of 1.00 m, 1.25 m, 1.75 m, 2.00 m, 2.25 m, and 3.00 m. The thermocouples from the soil pressure arrays will be used to fill in missing data locations (i.e., centerline, and intermediate depths).

Due to the large number of instruments and sampling points that are to be placed into the soil, a standardized numbering system will be used that will allow an operator to quickly identify the location of a given instrument. This system is based on a cylindrical coordinate system and denotes the instrument type, depth from grade, angular position relative to a selected zero position, and radial distance from the center line. An example label is "TCK090270810." The first three letters denote that the instrument is a type K thermocouple (TCK), the next three numbers indicate a depth from grade of 90 cm (090), the following three numbers indicate a position 270° relative to north (270), and the final three numbers indicate a radial position 810 cm from the center line (810). The instrument labels will be placed on both ends of a signal cable so that instruments are not connected to the data acquisition system improperly.

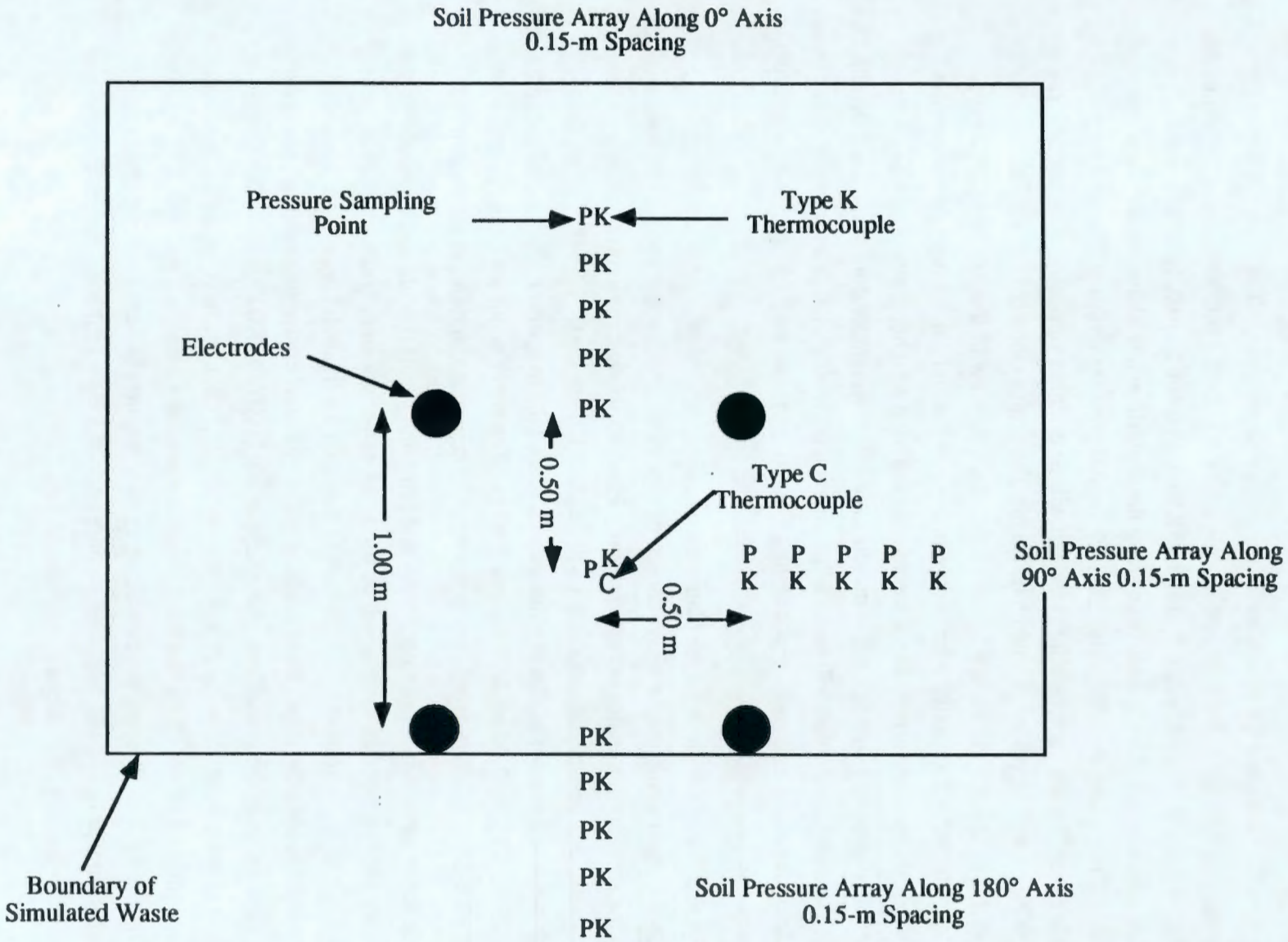


FIGURE 5.3. Soil Pressure Arrays - Plan View

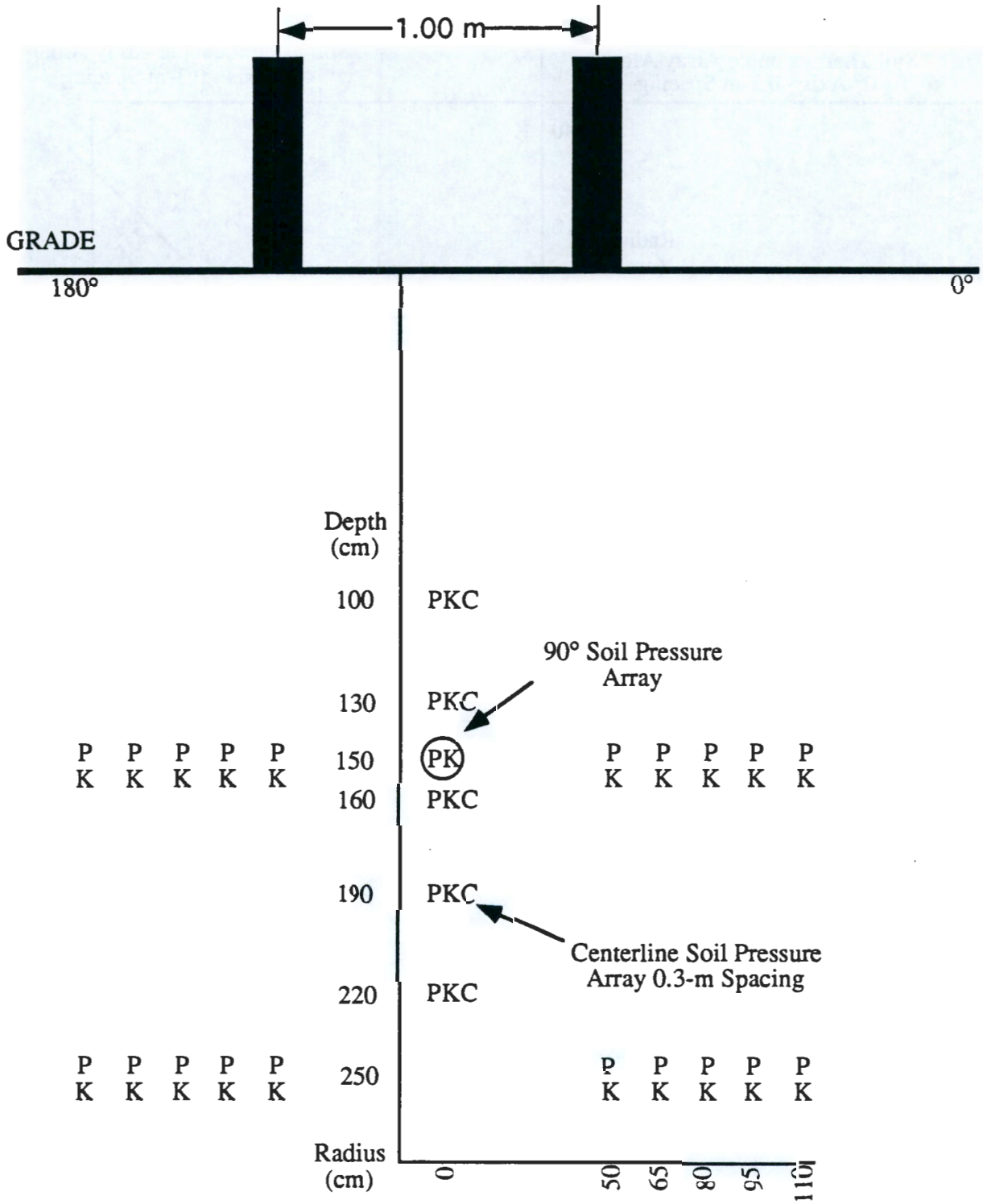


FIGURE 5.4. Soil Pressure Arrays - View Along 90°-270° Axes

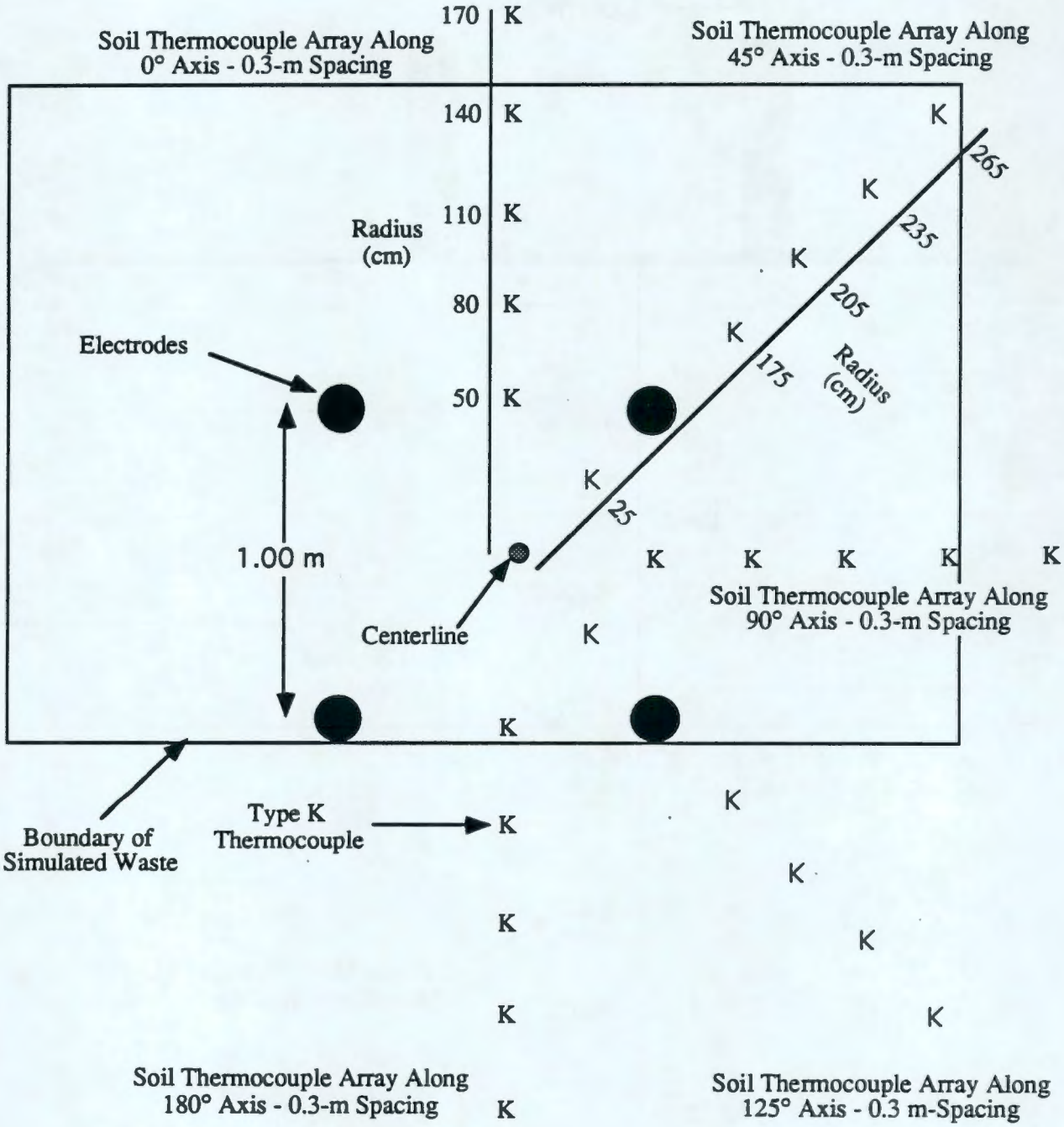


FIGURE 5.5. Soil Thermocouple Arrays - Plan View

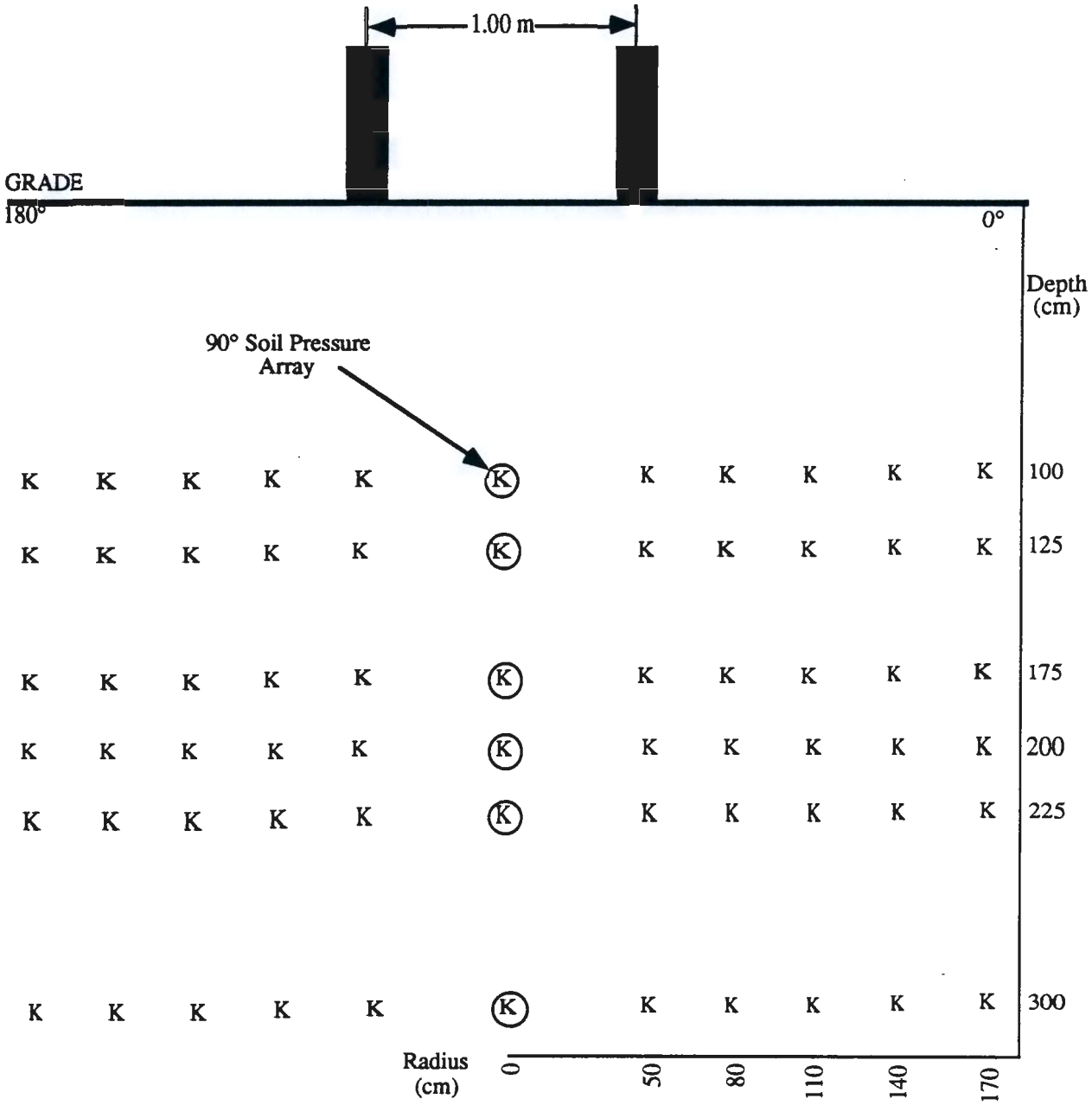


FIGURE 5.6. Soil Thermocouple Arrays - View Along 90°-270° Axes. The 45° and 125° thermocouple arrays are not shown.

9413221.1822

6.0 SAMPLING AND ANALYSIS

The Sampling and Analysis Plan (SAP) for this treatability test is included as Appendix B. The purpose of this supporting document is to ensure that the samples obtained for characterization and testing are representative and that the quality of the analytical data generated is known. The SAP addresses collection, identification, and analysis of samples obtained from the test site, before, during, and after the ISV demonstration. The types of samples to be collected include all of the electronic data discussed in Section 5.0 and core samples of the final vitrified product. Section 8.0 of this test plan describes how the analyses will be used to achieve the objectives (Section 3.0) for this demonstration.

9413221.1823

9413221.1824

7.0 DATA MANAGEMENT

7.1 QUALITY ASSURANCE

This treatability test will be conducted in accordance with the requirements outlined in this test plan and its supporting documents, Safe Operating Procedures (SOP) and the Quality Assurance Project Plan (QAPjP) (Appendix C). The QAPjP was developed in accordance with PNL's *Quality Assurance Manual*, PNL-MA-70, which was developed to address the U.S. Environmental Protection Agency (EPA) document QAMS-005/80, *Interim Guidelines for Preparing Quality Assurance Project Plans*. A Quality Assurance (QA) engineer provides independent oversight of project activities and will monitor activities to ensure compliance with established requirements during test preparations, testing, and subsequent sampling.

9413221.1825

Unplanned deviations from the procedural requirements must be documented by completing a Deficiency Report (DR) in accordance with PNL-MA-70 Administrative Procedure PAP-70-1502, Controlling Deviations from QA Requirements and Established Procedures. The DR must identify the requirement deviated from, the causes of the deviations, whether any results were effected, and corrective action needed to remedy the immediate problem and prevent recurrence.

Planned deviations, documented on the test plan, test procedure, SOP, and/or in the laboratory record book (LRB) (including justification) and approved by the project manager or task leader in advance, do not constitute a deficiency as defined in PAP-70-1502 and do not require development of a DR. Where appropriate, approval by Westinghouse Hanford Company (WHC), Laboratory Safety, and/or Quality Assurance must also be obtained in addition to the approval by the project manager or task leader.

7.2 LABORATORY RECORD BOOKS

The LRB is the primary method of recording day-to-day project activities. The LRB is intended to provide information with sufficient thoroughness to permit an independent person of equivalent technical background to understand the work and evaluate the technical soundness of the work, continue unfinished work, and/or be able to replicate the work. All pertinent data and observations will be recorded in designated LRBs or in data sheets referenced by the LRBs with all

entries signed and dated. All assumptions, calculations, and analyses will be documented in the LRB or filed in the project file. Currently, LRB BNW-54883 has been assigned to this treatability project. Any other required LRBs will be assigned as they become necessary.

7.3 DATA SHEETS

Pertinent data gathered before, during, and after processing will be entered on data sheets. These data sheets will be referenced in the appropriate LRB and signed and dated. The following data sheets are attached as Appendix D:

- M&TE Control Listing (from PAP-70-1201)
- Soil Temperature Array
- Soil Pressure Array
- General Process Status Sheet
- Off-Gas Treatment System Data
- Power Readings
- Electrode Depth.

9413221.1826

7.4 COMPUTER-GENERATED DATA

Much of the process data and off-gas treatment system data from the ISV test will be stored in the form of magnetic disks. The pilot-scale ISV system provides automatic data logging at intervals specified by the operator. The computerized data include process conditions (temperature, flowrates, pressures, etc.) and environmental monitoring output, such as from the carbon dioxide and carbon monoxide monitors. The accuracy of the data is dependent on the calibrations of the instruments used to obtain the data. Calibration and maintenance procedures are detailed in the SAP (Appendix B) and the QAPjP (Appendix C).

7.5 ARCHIVE RECORDS MANAGEMENT

The identification, maintenance, storage, and final disposition of records are governed by the Quality Assurance Project Plan. Section 17.0, Records, of the QAPjP (Appendix C) details the requirements for records management.

8.0 DATA ANALYSIS AND INTERPRETATION

The criteria for determining the success of this pilot-scale demonstration, and how the results of the demonstration will be measured against the criteria, are discussed in this section. The test objectives for the 100 Area ISV Pilot-Scale Demonstration were described in Section 3.0. Performance criteria for each of these three objectives are presented in this section. The SAP (Appendix B) contains additional detail.

9413221.1827

8.1 OBJECTIVE ONE: DEMONSTRATE ISV AS A STABILIZATION TECHNIQUE FOR RETRIEVED BURIED WASTE

To meet this objective, the ability of the ISV process to eliminate potential mechanisms for future subsidence must be determined. Mechanisms for future subsidence involve the consolidation of the waste material through the elimination of void spaces created during filling of the waste disposal trench, pre-existing in the waste material, or created as the result of decomposition and degradation of the waste material. The ISV process eliminates these future subsidence mechanisms through densification and the creation of a stable, durable product. Analyses to qualify and/or quantify the elimination of these subsidence mechanisms, thus demonstrating ISV as a stabilization technique, include post-test examination of the ISV product to determine fraction void space, strength tests on core samples from the ISV product, and durability testing of the ISV product.

Core samples of the cooled glass monolith will be collected using a rotary coring device and then wrapped in plastic and labeled upon removal from the core bit. The samples will be analyzed for chemical composition, strength, and durability. Vitrified product composition will be determined by preparing the samples for analysis using either a $NaHO_2$ fusion or a KOH fusion, and then analyzing the resulting sample solutions using the EPA Method 6010 (inductively coupled plasma) to determine total inorganic composition.

Vitrified product strength will be determined by analyzing the core samples for axial compression strength (ASTM D2938) and splitting tensile strength (ASTM D3967). The dimensional, shape, and surface tolerances of the core specimens as defined in ASTM D4543 are important for determining structural properties of intact specimens.

Vitrified product chemical durability will be determined by analyzing the core samples using the Product Consistency Test (PCT) (Jantzen et al. 1991). In order to fully achieve this objective, the above analyses will need to prove that the core samples are stable, strong, and durable.

8.2 OBJECTIVE TWO: DETERMINATION OF THE ISV OPERATING ENVELOPE FOR APPLICATION TO COMBUSTIBLE AND COMPACTABLE WASTE

This objective will be achieved via engineering calculations and verifying the computational prediction(s) with field data collected on a staged site within the identified envelope. In addition, performance will be measured through the completeness of field data collected to support design of full-scale equipment and the identification of full-scale operating procedures.

The ISV 3.01 PC model and the TOUGH2 model (both described in Appendix A) were used to determine the operating envelope for this demonstration. This predicted operating envelope will be verified with the field data collected during this demonstration. Field data will include data on the performance of the ISV processing equipment. The pilot-scale ISV system is equipped with electronic measuring devices to provide process monitoring and performance data. These data can later be used to evaluate the performance of individual system components and help provide an accurate evaluation of the process application. Process data are recorded both on a computer data acquisition system and manually by process operators at a frequency specified on the individual data sheet.

In addition to the data collected on the ISV processing equipment during operation, data will also be collected from instruments placed in the soil and simulated waste. Type K and C thermocouples will be used to track advancing melt front throughout the vitrification process and pressure transducers will be used to monitor pressure gradients in the adjacent soil and simulated waste.

In order to fully achieve this objective, the electronic field data collected must be sufficient to support material and energy balance calculations on various systems, verify the computational prediction(s) from the two models, support the design of full-scale equipment, and support the identification of full-scale operating procedures. To ensure success, "extra" instrumentation is to be used for critical test parameters (e.g., use of two analyzers to measure off-gas composition, extensive soil thermocouple arrays, redundant flow measurements).

8.3 OBJECTIVE THREE : DEMONSTRATE ISV ON A SITE THAT CONTAINS SIGNIFICANT QUANTITIES OF COMBUSTIBLE MATERIAL

To achieve this objective, the ISV process must treat a site that contains significant quantities of combustible materials without a molten soil displacement event (see Appendix A for description of a molten soil displacement event). Experience with sealed containers and other situations that constrain the flow of vapor from underneath the advancing ISV melt have illustrated the potential for a molten soil displacement event. Successful completion of the pilot-scale demonstration without such an event, combined with verification of computational prediction(s), will serve as the primary measure of success for this objective.

The TOUGH2 computer program was used to evaluate the possibility of a molten soil displacement event during this demonstration (see Appendix A). According to the model, it does not appear that one will occur. This prediction will be verified during the demonstration. In addition, pressure transducers will be used to monitor pressure gradients in the adjacent soil and simulated waste. This will alert operators if a molten soil event is likely to occur so they can take the appropriate action to prevent it.

9413221.1829

8.4 DESIGN FOR FULL-SCALE ISV OPERATIONS

The data obtained from the pilot-scale treatability test will be analyzed used to provide a basis for a conceptual design for full-scale application of ISV as a stabilization technique for retrieved burial ground waste. This conceptual design will include:

- Staging requirements for this application
- Identification of the waste form and composition operating envelope
- Identification of equipment needed for this application
- Description of the operation

Based on this conceptual design, costs for using ISV for this application will be estimated. These costs will be determined for each of the stages of the full-scale operation. These stages can be generalized into the following areas:

- Site preparation
- Process equipment
- Mobilization and demobilization of ISV system
- ISV operations
- Secondary waste disposal
- Decontamination and decommisioning of equipment.

Costs associated for each of these stages may include elements such as labor, consumable supplies (e.g., electrodes, HEPA filters, caustic solution, and starter path material), electricity, temporary facilities (e.g., sanitation units, communications, and office trailers), and analytical services. Assumptions used for this cost estimate will be clearly defined and included in this analysis.

9413221.1830

9.0 HEALTH AND SAFETY

It is the goal of this project to take every practical precaution to protect the health and safety of employees, subcontractors, and visitors from any adverse effect that might result from activities conducted during this pilot-scale ISV demonstration test. Adherence to the guidance contained in this test plan and the Health and Safety Plan (Powell 1993b) will ensure the attainment of this goal. The Health and Safety Plan describes potential hazards, control measures for the potential hazards, and the work safety plan.

9413122.1831

9413221.1832

10.0 WASTE MANAGEMENT

The pilot-scale ISV demonstration will be performed on a staged site containing simulants of solid waste from the Hanford 100 Area. Simulants used for testing will be nonhazardous and nonradioactive. Where possible, simulants will be from an existing waste stream so that additional waste is not generated as the result of this pilot-scale test. Although simulants used for testing will be nonhazardous and nonradioactive, there exists the potential that secondary waste from the off-gas treatment system would be hazardous or radioactive. This is because the pilot-scale ISV system has been used previously for radioactive tests and may have residual material in the system, the most likely location being in the scrub solution tanks. In addition, small amounts of material naturally present in the soil (e.g., lead and arsenic) may be volatilized and subsequently collected and concentrated in the scrub solution tanks of the off-gas treatment system. Therefore, secondary waste from the scrub solution tanks will be managed as hazardous waste and treated as such until analytical results of the secondary waste provides the basis for a different designation.

The majority of solid waste material generated during testing will be in the form of vitrified (glass and crystalline) product as the result of the ISV process. The vitrified product and all other solid waste generated as a result of this ISV demonstration will be managed in accordance with applicable state and federal regulations and guidelines.

Liquid waste generation or release is not expected during normal operations. Water used for scrubbing and cooling of off-gases from the ISV process will be recirculated within a self-contained off-gas treatment system. Within the off-gas treatment system, process water containing material scrubbed from the off-gas stream (e.g., particulate and water soluble chemicals) is collected in scrub solution tanks. During the latter stages of the test and after testing is complete, the off-gas treatment system is operated to evaporate the process water in the scrub solution tanks, leaving a solid residue. The solid waste will be managed in accordance with applicable state and federal regulations and guidelines once analyzed. If evaporation is not complete, and/or flushing of the off-gas treatment system is required, then the resulting liquid will be analyzed and managed in accordance with applicable state and federal regulations.

9413221.1833

9413271.1834

11.0 COMMUNITY RELATIONS

Community relations shall be performed in accordance with the Tri-Party Agreement, Section 10. It is expected that information regarding this study will be disseminated during the quarterly public information meetings.

9413221.1835

9413221.1836

12.0 REPORTS

Upon completion of this treatability test and after reduction of all analytical and process data, a final report will be presented to WHC by December 14, 1994. The final report will include information such as a background discussion, a description of the test objectives, an overview of the demonstration performed which outlines any off-normal events that may have occurred, a summary of the analyses performed on the collected data, a results section, conclusions, and recommendations. The organization of this final report will be based on that recommended by the EPA for treatability studies performed under CERCLA. This suggested organization is presented in Table 12.1.

9413227.1837

TABLE 12.1. Suggested Organization of Treatability Study Report. Adapted from EPA (1989)

1. Introduction
   - 1.1 Site Description
   - 1.2 Waste Stream Description
   - 1.3 Remedial Technology Description
2. Conclusions and Recommendations
   - 2.1 Conclusions
   - 2.2 Recommendations
3. Treatability Study Approach
   - 3.1 Test Objectives and Rationale
   - 3.2 Experimental Design and Procedures
   - 3.3 Equipment and Materials
   - 3.4 Sampling and Analysis
   - 3.5 Data Management
   - 3.6 Deviations from Test Plan
4. Results and Discussions
   - 4.1 Data Analysis and Interpretation
   - 4.2 Quality Assurance/Quality Control
   - 4.3 Costs/Schedule for Performing the Treatability Study
   - 4.4 Key Contacts

References
Appendices

9413221.1838

13.0 SCHEDULE

13.1 WORK BREAKDOWN STRUCTURE

All work for the 100 Area ISV Pilot-Scale Demonstration is guided by the Work Breakdown Structure (WBS), which is divided into logical, manageable elements of work. The seven major elements of the WBS define the entire 100 Area ISV Demonstration life-cycle and are shown in Figure 13.1, along with sub-elements. Project Management (WBS 1.0) includes all administrative activities for the life of the project, while the other elements are fiscal year planned activities. Test Documentation (WBS 2.0) activities are currently planned to be completed by the end of fiscal year 1993; the remaining five tasks are planned for fiscal years 1994 and 1995.

9413221.1839

13.2 SCHEDULE/MILESTONES

Milestones are planned at the lowest WBS elements and provide a measure of progress. Figure 13.2 is a timeline showing the desired start and finish dates for the various milestones within each WBS element and how all the various tasks interface with each other. Table 13.1 below shows the anticipated starting and ending dates for each WBS element.

TABLE 13.1. Schedule for WBS Elements

WBS Element	Start Date	Finish Date
1.0 Project Management	11/09/92	12/14/94
2.0 Test Documentation	11/09/92	10/07/93
3.0 Site and Equipment Prep.	10/01/93	01/07/94
4.0 Operations	01/03/94	01/24/94
5.0 Return to Standby	01/25/94	09/30/94
6.0 Sample and Analysis	01/25/94	07/29/94
7.0 Reporting	01/25/94	12/14/94

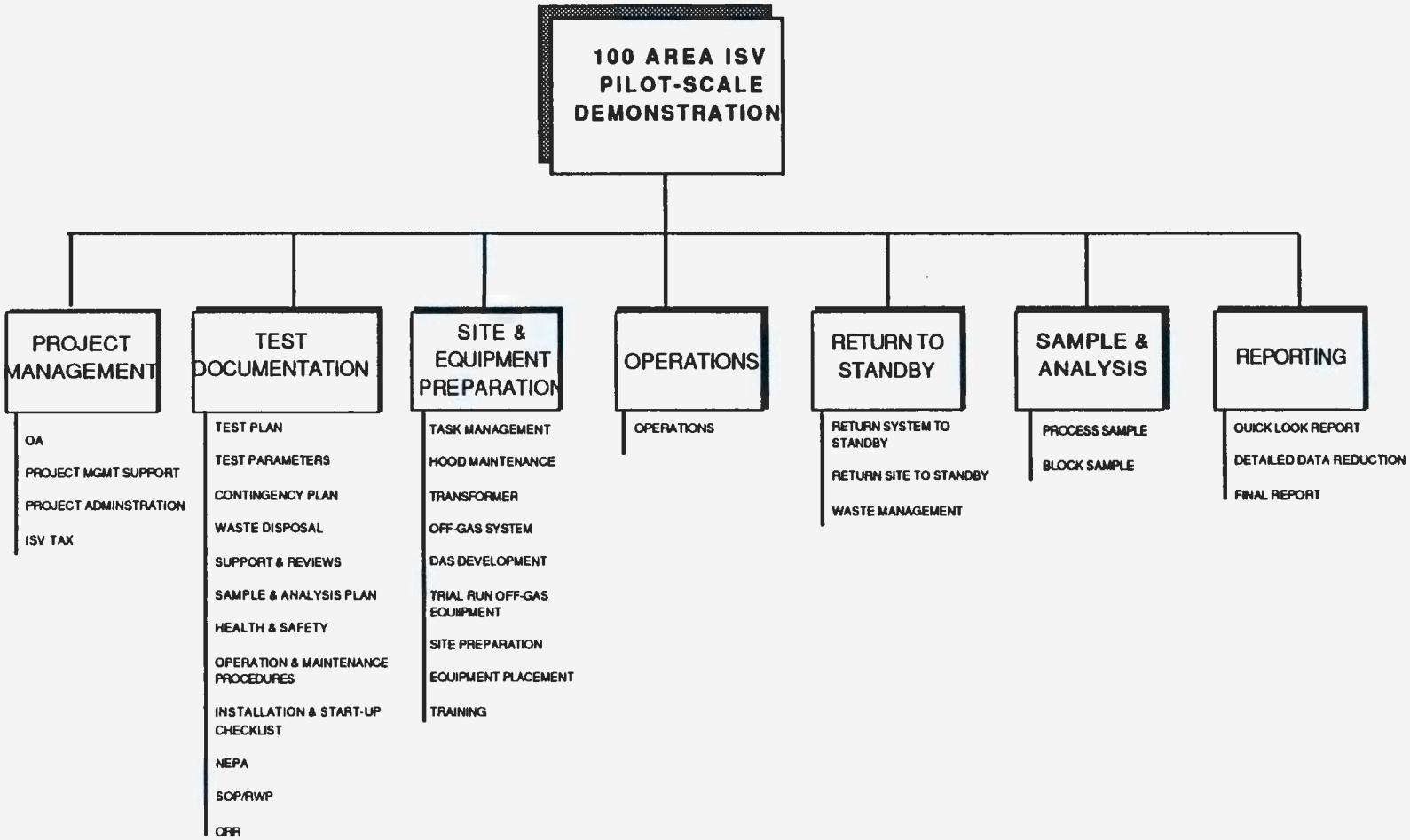


FIGURE 13.1. Work Breakdown Structure

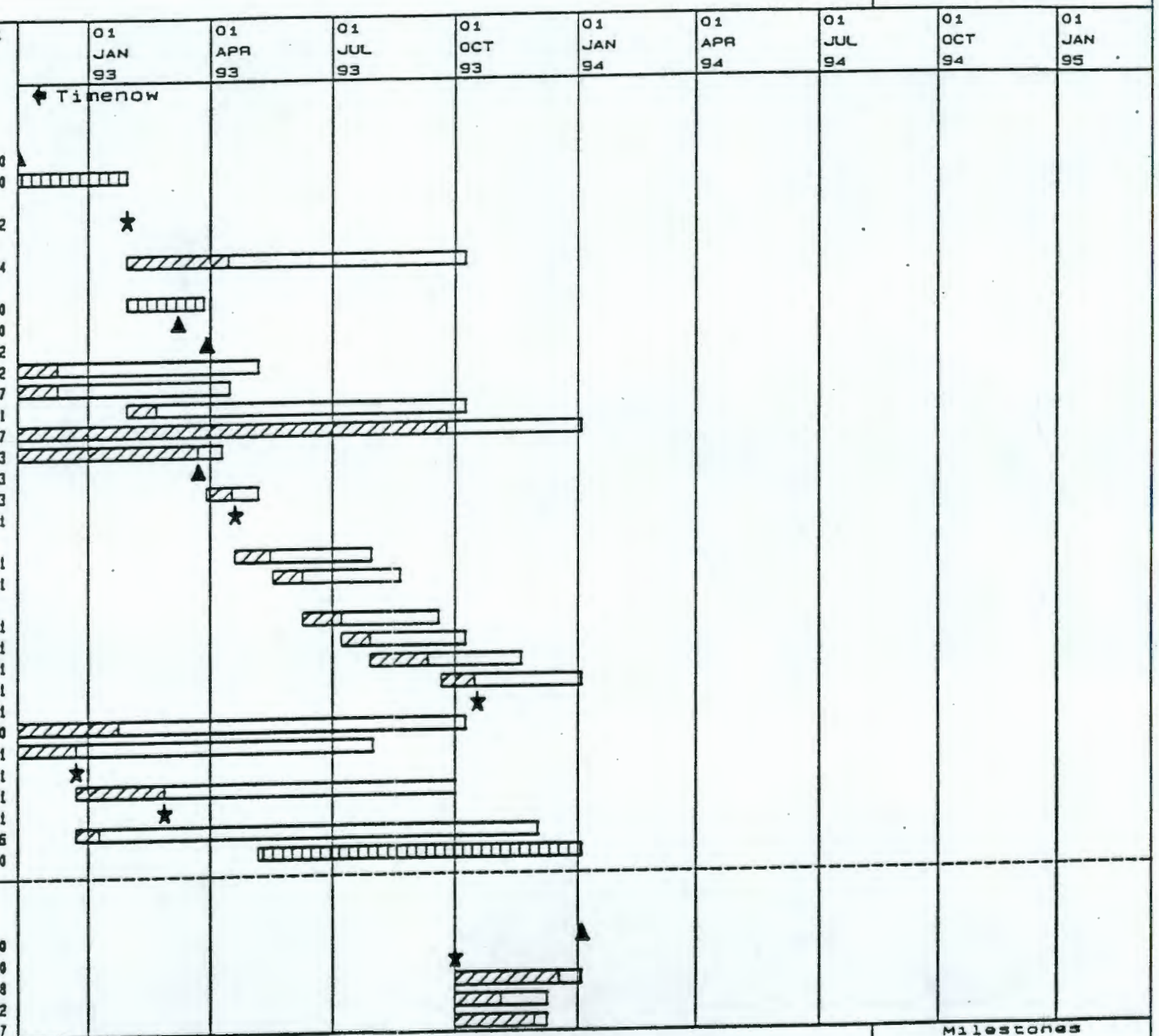
9413221.1841

OPEN PLAN (A)
Report: BCOES1
Project: BCR1BASE
Time Now: 09-NOV-92
Date: 05-AUG-93
Time: 11:40:23
Page:

100 Area ISV Demonstration Baseline

Pacific Northwest Laboratory

Activity	Description	Start	Finish	Dur	Float
WBS: 2.0 — Test Documentation					
20000	BEGIN TEST DOCUMENTATION	09-NOV-92	06-NOV-92	0	0
20101A	BEGIN TEST PARAMETERS & WASTE CONFIGURATION	09-NOV-92	28-JAN-93	54	0
20101B	IDENTIFY TEST PARAMATERS & WASTE CONFIG.	29-JAN-93	28-JAN-93	0	472
20101C	COMPLETE TEST PARAMETERS & WASTE CONFIG.	29-JAN-93	13-APR-93	52	124
20102	CONTINGENCY PLAN	29-JAN-93	26-MAR-93	40	0
20102A	COMPLETE 1ST DRAFT - CONTINGENCY PLAN	08-MAR-93	05-MAR-93	0	0
20102B	FINALYZE CONTINGENCY PLAN	29-MAR-93	26-MAR-93	0	432
20105	SAMPLING AND ANALYSIS PLAN	09-NOV-92	08-DEC-92	20	102
20107	HEALTH & SAFETY PLAN	09-NOV-92	08-DEC-92	20	87
20109	INSTALLATION & STARTUP CHECKLIST	29-JAN-93	19-FEB-93	15	161
20110	TECHNICAL SUPPORT & REVIEWS	EMPTY (A)	23-SEP-93	235	67
20200A	PREPARE DRAFT TEST PLAN	09-NOV-92	22-MAR-93	90	13
20200B	COMPLETE 1ST DRAFT - TEST PLAN	23-MAR-93	22-MAR-93	0	13
20200C	COMPLETE DRAFT TEST PLAN	29-MAR-93	16-APR-93	15	13
20200M	COMPLET TEST PLAN DRAFT - SUMBIT TO WHC	19-APR-93	16-APR-93	0	51
20201	WHC REVIEW OF DRAFT TEST PLAN	19-APR-93	14-MAY-93	20	51
20202	INCORPORATE WHC COMMENTS INTO TEST PLAN	17-MAY-93	07-JUN-93	15	51
20203	DOE-RL REVIEW OF DRAFT TEST PLAN	08-JUN-93	07-JUL-93	20	51
20204	COMPLETE FINAL TEST PLAN DRAFT	08-JUL-93	28-JUL-93	15	51
20205	REGULATORY REVIEW OF TEST PLAN	29-JUL-93	09-SEP-93	30	51
20206	FINALYZE TEST PLAN	20-SEP-93	15-OCT-93	20	51
20206M	COMPLETE FINALYZED TEST PLAN	18-OCT-93	15-OCT-93	0	291
20300	NEPA	09-NOV-92	22-JAN-93	50	180
20401	MODIFY SOP	09-NOV-92	22-DEC-92	30	151
20401A	SUBMIT PROCEDURES TO WHC FOR REVIEW	23-DEC-92	22-DEC-92	0	151
20401B	WHC REVIEW PROCEDURES	23-DEC-92	25-FEB-93	43	151
20401C	PROCEDURES APPROVED BY WHC	26-FEB-93	25-FEB-93	0	151
20402	MODIFY RMP	23-DEC-92	08-JAN-93	10	226
30910	OPERATIONAL READINESS REVIEW	06-MAY-93	03-JAN-94	164	0
WBS:	— Site & Equipment Preparation				
20501	COMPLETE ORR PROCESS	04-JAN-94	03-JAN-94	0	240
30000	BEGIN EQUIPMENT & SITE PREPARATION	01-OCT-93	30-SEP-93	0	0
30100	TASK MANAGEMENT	01-OCT-93	17-DEC-93	54	8
30200	HOOD MAINTENANCE	01-OCT-93	04-NOV-93	25	22
30200	TRANSFORMER & ELECTRICAL PREPARATION	01-OCT-93	29-NOV-93	40	7



Legend
- In progress
- Planned
- Float
- Critical

Bar Chart Key: Early Dates

Milestones
- ★ Client (WHC)
- ▲ Internal (PNL)

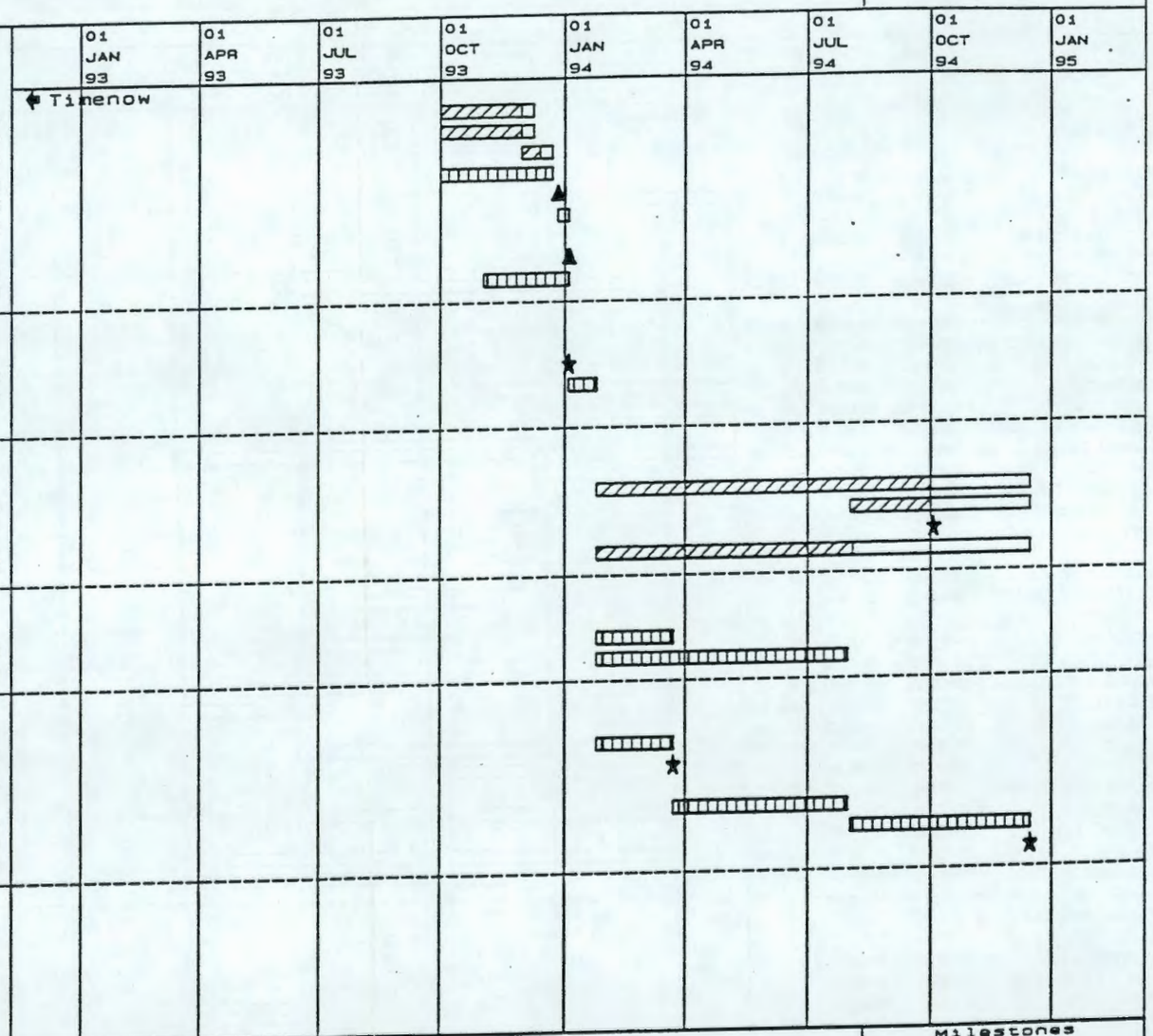
FIGURE 13.2. Schedule Timeline

OPEN PLAN (A)
Report: BCOES1
Project: BCA1BASE
Time Now: 09-NOV-92
Date: 05-AUG-93
Time: 11:40:23
Page: 2

100 Area ISV Demonstration Baseline

Pacific Northwest Laboratory

Activity	Description	Start	Finish	Dur	Float
30400	OFF-GAS TREATMENT-SYSTEM PREPARATION	01-OCT-93	29-NOV-93	40	7
30500	PROCESS GAS CONFIGURATION	01-OCT-93	29-NOV-93	40	7
30600	TRIAL RUN OFF-GAS SYSTEM	30-NOV-93	13-DEC-93	10	7
30700	SITE PREPARATION	01-OCT-93	22-DEC-93	57	0
30700A	COMPLETE TEST SITE PREPARATION	27-DEC-93	22-DEC-93	0	245
30800	PLACE PROCESS EQUIPMENT ONTO TEST LOCATION	27-DEC-93	03-JAN-94	5	0
30800A	PROCESS EQUIPMENT READY FOR OPERATION	04-JAN-94	03-JAN-94	0	240
30900	OPERATIONAL TRAINING	02-NOV-93	03-JAN-94	40	0
WBS:	— Operations				
40000	BEGIN 100 AREA ISV DEMONSTRATION	04-JAN-94	03-JAN-94	0	0
40100	OPERATIONS FOR PILOT SCALE DEMONSTRATION	04-JAN-94	24-JAN-94	15	0
WBS: 5.0	— Return to Standby				
50100	RETURN SYSTEM TO STANDBY	25-JAN-94	30-SEP-94	174	51
50200	RETURN SITE TO STANDBY	01-AUG-94	30-SEP-94	44	51
50200M	COMPLETE PRODUCT AND DATA ANALYSIS	03-OCT-94	30-SEP-94	0	51
50300	WASTE MANAGEMENT	25-JAN-94	02-AUG-94	132	93
WBS: 6.0	— Sample & Analysis				
60100	PROCESS SAMPLING & ANALYSIS	25-JAN-94	22-MAR-94	40	0
60200	BLOCK SAMPLE & ANALYSIS	25-JAN-94	29-JUL-94	130	0
WBS: 7.0	— Reporting				
70101	PREPARE QUICK LOOK REPORT	25-JAN-94	22-MAR-94	40	0
70102	SUBMIT QUICK LOOK REPORT TO WHC & REG. CON.	23-MAR-94	22-MAR-94	0	0
70200	DETAILED DATA REDUCTION	23-MAR-94	29-JUL-94	90	0
70301	PREPARE FINAL REPORT	01-AUG-94	14-DEC-94	95	0
70302	SUBMIT FINAL REPORT TO WHC	15-DEC-94	14-DEC-94	0	0



Legend
- In progress
- Planned
- Float
- Critical

Bar Chart Key: Early Dates

Milestones
- ★ Client (WHC)
- △ Internal (PNL)

FIGURE 13.2 Continued. Schedule Timeline

9413221.1842

14.0 MANAGEMENT AND STAFFING

14.1 KEY PERSONNEL

Table 14.1 identifies the key PNL management and technical positions and defines the project roles and responsibilities associated with each position. Not shown are support organizations such as Laboratory Safety and Project Management Support. These support organizations provide key oversight of the project in specific areas and help ensure the project's success. Figure 14.1 is an organization chart that portrays the line of authority for the 100 Area ISV pilot-scale demonstration. This demonstration is being performed by PNL for WHC. WHC has overall responsibility for management of treatability tests, of which this demonstration is one.

9413221.1843

14.2 TRAINING REQUIREMENTS

ISV operating personnel receive job-specific training at both the laboratory and center levels. In addition to this training, each operating staff member will receive on-the-job training and be required to know and understand the material contained in the this test plan, the SOP, the Engineering Analysis (Appendix A), the Health and Safety Plan, the Radiation Work Procedure (RWP), and all other documents and procedures required as training for specific tasks. All relevant documents will be posted in the process trailer at the test site during operation.

Training documentation is maintained by the training coordinator for the Waste Technology Center with training documentation required for the 100 Area ISV Demonstration located in the project files. Retraining on non-ISV operation subjects is automatically scheduled through the center training coordinator. The ISV site equipment supervisor will conduct a review with all operating personnel to ensure familiarity and understanding of operational equipment and procedures. Due to the infrequency of ISV operations, on-the-job training and operator process qualifications are conducted before each test or demonstration using the ISV equipment.

Table 14.2 gives a brief description of the various training classes required of operating personnel. Not all of the training listed is required, depending on the responsibilities of the individual.

TABLE 14.1. Responsibilities of Key PNL Personnel

Position	Responsibilities
Group Leader	Provides management review of the project. Ensures appropriate and qualified staff are available.
Project Manager	Interfaces with WHC project lead and provides bimonthly reports of activities. Provides overall PNL direction of the project and day-to-day activities necessary to accomplish all project objectives. Has direct contact with the PNL quality engineer. Coordinates all quality control (QC) activities including scheduling, preparation, and submittal of QC samples to PNL, and evaluates the results. Transmits documents and records to WHC at project completion. In addition to these QA responsibilities, the project manager is responsible for the overall technical direction, managing and leading the project team, budget/schedule management, and information exchange.
Quality Engineer	Provides the project manager with QA requirements, interpretation, and implementation assistance. Provides for QA training as necessary. Provides for independent quality assurance reviews, surveillances, and data quality and traceability audits. Is responsible for reviewing and has sign-off authority for QA project plans.
Technical Specialist	Pepares the operating equipment and test site. Coordinates crafts and other services necessary to accomplish these tasks. Prepares site and test specific operating procedures and supports the preparation of the test plan, SAP, Radiation Work Permit, and the Health and Safety Plan.
Research Engineer	Performs computational modeling and engineering calculations for the test to identify potential safety concerns and to identify critical parameters that need to be measured in the field. Assists in the development and identification of the test configuration, simulated waste material, and location of field instrumentation. Aids in the interpretation and analysis of generated data and in the preparation of a technical report in collaboration with the project manager.
Site Equipment Supervisor	Is responsible for the overall operation of the pilot-scale system. This person is on call 24 h/day.
Shift Engineer	Is responsible for the operation of the pilot-scale system during an assigned period of time.
Operator	Provides technical support during system operation.
Operating Personnel	Includes site equipment supervisor, shift engineer, and operators.

9413221.1844

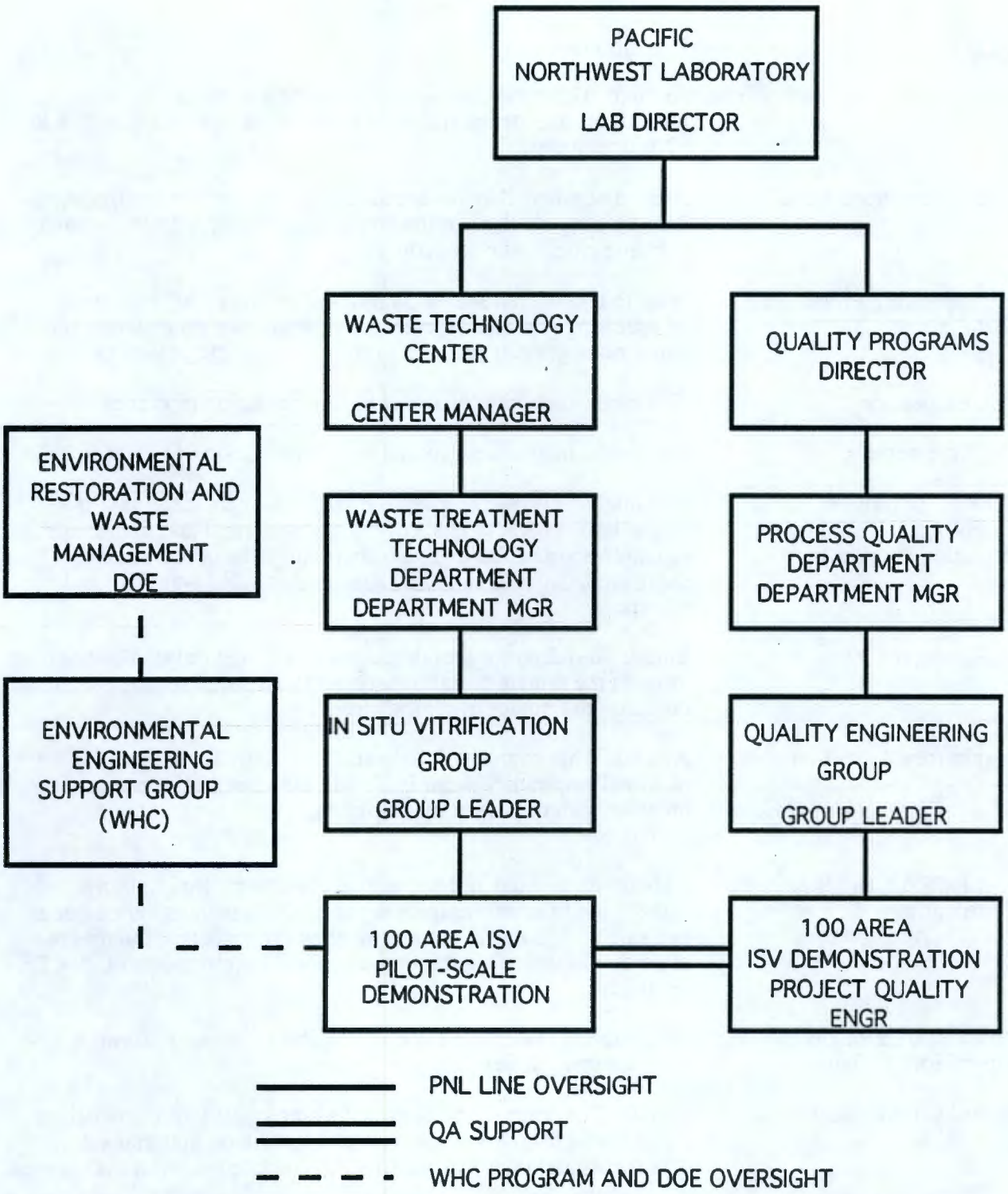


FIGURE 14.1. PNL Organization Chart for ISV Demonstration with WHC and DOE Interface

TABLE 14.2. Training Classes

Class	Description
Hazardous Waste Management	Annual: This training covers hazardous and mixed waste procedures and issues and regulatory requirements applicable to PNL operations.
Emergency Procedures	Annual or when changes are made, whichever is more frequent: This training shall make the employee familiar with the written building emergency procedures.
ISV Operating Procedures/ Test Plans	Prior to test operations: This training informs staff members of operating procedures, emergency shutdown procedures, and waste management procedures for each specific project or test.
Crane Operator	Triennial: Instructs personnel in safe operation of cranes.
Forklift Operator	Triennial: Instructs personnel in safe operation of forklifts.
General Employee Radiological Training/ Radiation Worker II	Biannual: This course gives the staff members information on the basic characteristics of radiation: natural and man-made radiation sources, biological effects and risks of radiation exposure, ALARA, contamination control, and warnings and alarms.
NCRP Report 39	Initial: Required for female radiation workers only! The briefing informs the female radiation worker about the potential hazards of radiation to females of reproductive age.
Respiratory Protection	Annual: This course will help staff members to recognize potential respiratory hazards. It will also familiarize the staff member with the use of air-purifying respirators and their limitations.
40-h RCRA/CERCLA Certification	At least 40-h initial and 8-h annual refresher: This training is designed to enable employees to perform their assigned duties in a safe and healthful manner so as to not endanger themselves or other employees. This training meets the requirements of 29 CFR 1910.120.
8-h RCRA/CERCLA Supervisors Training	This training is designed to enable supervisors to perform their assigned duties.
Hazard Communication	Initial: This course familiarizes the employee with his/her rights under the right-to-know status. Information on material safety data sheets and their availability and on standard industrial hygiene terms is also covered.

9413221.1846

15.0 TEST-SPECIFIC PROCEDURES

The SOP (Powell 1993b) details the general operation of the existing pilot-scale ISV system. This section includes specific operating procedures for this treatability test. These specific procedures include the waste simulation, the power requirements for the operation of the pilot-scale system, the use of the water spray system to help control the off-gas hood temperature and pressure, and the use of a passive vent to control the off-gas hood pressure.

9413221.1847

15.1 WASTE SIMULATION

The pilot-scale ISV demonstration will be performed on a staged site containing simulants of solid waste from the Hanford 100 Area. Simulants used for testing will be nonhazardous and nonradioactive. Where possible, simulants will be from an existing waste stream so that additional waste is not generated as the result of this pilot-scale test.

The three types of solid waste simulants will be combustibles (e.g., wood, paper, personnel protective clothing), metal (e.g., stainless and carbon steel, aluminum), and soil. The target simulated waste composition is

soil: 63 wt% combustible: 12 wt% metal: 25 wt%.

Of the metal fraction, as much as 50% may be aluminum. This aluminum loading represents a potential scenario for full-scale application of ISV to solid waste from the 100 Area.

As material is collected, the type, weight, and estimated volume will be recorded in the LRB. Material will be stored at the 300W site before placement. Placement of the material into the staged site will be performed in a random manner and done after instrumentation has been placed into the site to be vitrified. Photographs will be taken periodically to document the placement of waste into the site. In addition, visual observations will be recorded in the LRB (e.g., location of pockets of similar material, type of material surrounding instrumentation).

15.2 POWER REQUIREMENTS

The startup activities outlined in the SOP will be followed to power up the pilot-scale ISV equipment. The desired power level (~ 250 kW) must be able to maintain a melt rate of 2.5 cm/h

and maintain the soil pressure below the static head of the melt. During the demonstration, if one of the above stipulations is not maintained, the power level will be adjusted as necessary. For example, if the melt rate is greater than 2.5 cm/h, and/or if the soil pressure becomes greater than the static head of the melt, the power level will be decreased.

The melt rate will be measured by tracking soil/waste temperatures with type K and C thermocouples and noting the position of the electrodes (with the electrode feed system, an estimate of melt depth at the electrodes is possible by noting the amount of electrode that has been fed into the melt zone). Once a type K thermocouple reaches 1200°C, it is estimated that the melt front is within centimeters of the thermocouple. Temperature readings beyond 1200°C are not reliable due to the limitations of the isolation devices typically used. Type C thermocouples have a maximum operating temperature of greater than 2000°C. This is considerably higher than the temperature maintained in typical Hanford soil melts (1400°C to 1600°C). Based on the position of the thermocouples, the melt rate can be estimated by noting the time for the melt front to reach adjacent thermocouples.

The surrounding soil pressure will be measured with an array of pressure sensors. These sensors will be housed above ground and connected to sampling points via tubing because 1) the pressure sensors are not of sufficient durability to be buried in the soil, and 2) if buried, the expected soil temperatures place the sensors outside their operating range. The surrounding soil pressure will be compared to the static head of the advancing ISV melt. The static head of the melt can be calculated using the following equation:

static head = (molten soil depth)(melt density)(gravity)

Molten soil depth will be based on the process depth (as indicated by the electrodes and soil thermocouples) minus the estimated amount of subsidence (as observed visually with via the camera or viewport). Appropriate unit conversions will be used to convert the static head to the same units as the pressure sensors.

15.3 WATER SPRAY

A water spray system is to be used as the primary mitigator for combating high heat loads in the off-gas containment hood and as a secondary system to combat positive pressures in the off-gas containment hood. The water spray system was designed to remove energy from the gases in

9413221.1848

the off-gas hood by evaporative cooling, thus mitigating the pressure and temperature increases associated with transient gas releases from the ISV melt (Luey et al. 1992b). In addition, the water spray system can be used in a semi-continuous or continuous mode to combat elevated steady-state heat loads in the off-gas hood. This latter use of the water spray system will be employed for the 100 Area ISV demonstration.

The premise for the water spray concept is based on the ideal gas law in which pressure is proportional to temperature for a given volume and number of moles. During a transient event, water is sprayed into the off-gas hood to remove energy from the gases in the hood. Energy transferred from gases within the hood is used to vaporize the added water. This energy transfer leads to an overall temperature decrease in the hood plenum. As a result of the temperature decrease, the pressure within the off-gas hood also decreases.

9413221.1849

The water spray system employed during this demonstration will include three conical spray nozzles equally spaced from each other around the perimeter of the off-gas hood. The nozzles are connected to the water supply line via solenoid valves. The water supply line is connected to a water pump in a recirculating mode. This configuration will maintain adequate pressure in the water supply line and ensure that there will not be a significant lag phase upon start-up of the water spray system. Figure 15.1 is a schematic of the off-gas hood with spray nozzles.

The water spray system will be set up so that the nozzles can be triggered automatically when an off-gas hood temperature setpoint has been reached, or manually if needed (e.g., the water spray system would be triggered manually to combat pressurization of the off-gas hood). Figure 15.2 is a schematic of the flow and control setup for the automatic operation of the water spray system. Water from a 57-L tank will circulate through a 38-L/min, 220-kPag pump until the hood skin temperature reaches the setpoint value of 425 °C. This setpoint temperature is lower than the 470 °C continuous operating temperature design limit of the off-gas hood. Once the set-point temperature has been reached, a signal will be sent to a three-way switch that will trigger a timer and open the valves on the nozzles so that water can be sprayed onto the off-gas hood for the duration set on the timer. Initially,the timer will be set to allow for a 5-s water spray pulse. If this proves insufficient to combat the heat load in the off-gas hood, then the cycle will repeat. Frequent actuation of the water spray system may indicate that the timer duration is too short. If the system is triggered three times in one hour, then the timer setpoint will be increased in increments of 5 s.

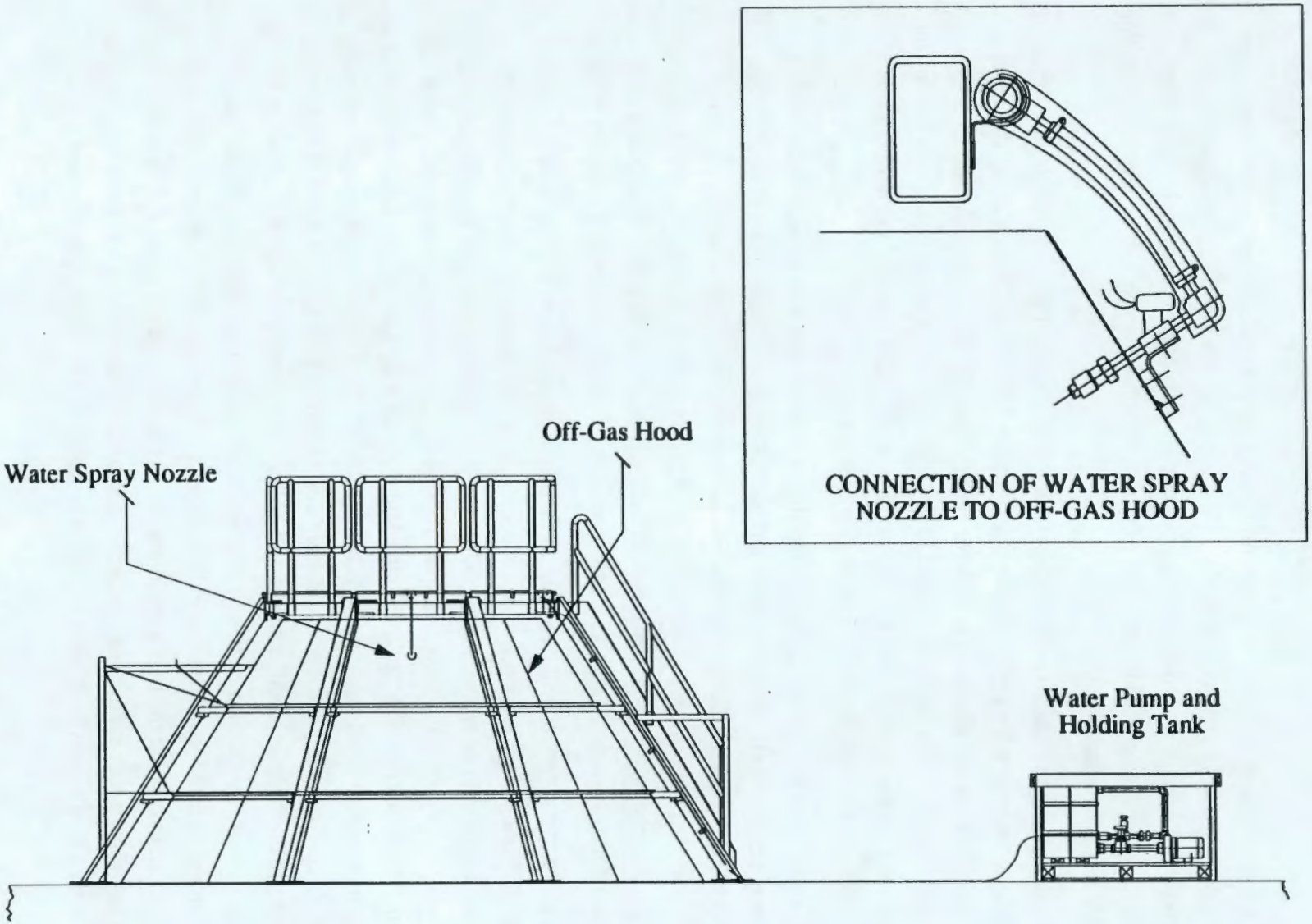


FIGURE 15.1. Schematic of the Off-Gas Hood with Water Spray Nozzles

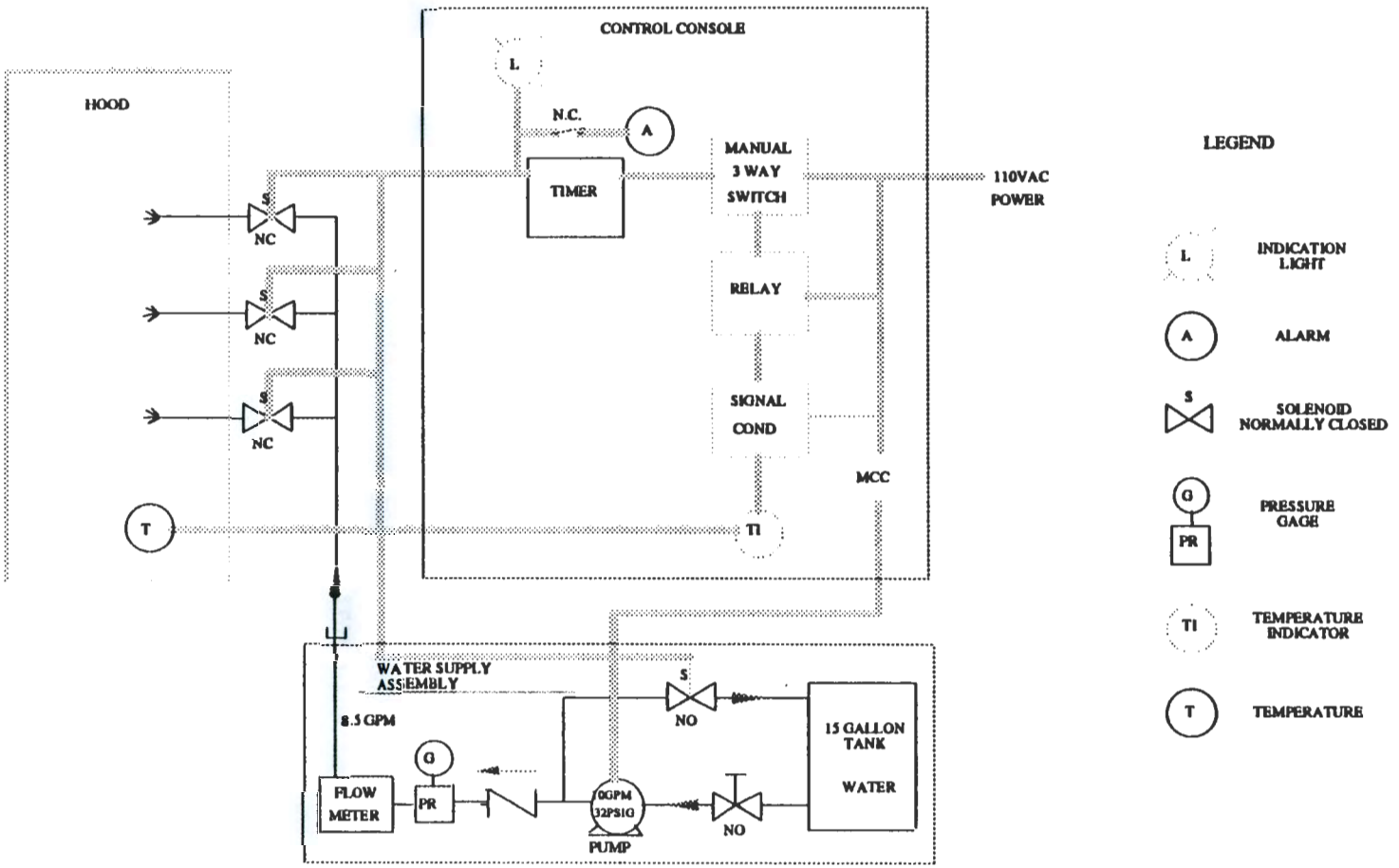


FIGURE 15.2. Flow and Control Schematic for the Water Spray System

The automatic release of water for timed periods may be insufficient to combat high heat loads in the off-gas hood. If the automatic water spray system begins to continuously cycle, or if the scrub tank liquid temperatures become excessive (greater than 60 °C), the automatic system will be shut down and the water spray valves operated manually to maintain the desired temperatures in the off-gas hood and off-gas treatment system. Table 15.1 shows the operating criteria for the water spray system.

15.4 PASSIVE VENT

A passive vent is to be used as the primary mitigator for combating pressurization of the off-gas containment hood. This passive system consists of a 30-cm diameter pressure relief line, HEPA filter and housing, and one-way flow damper. Figure 15.3 illustrates the components of the passive vent system. The one-way flow damper will ensure that flow through the pressure relief line is out of the off-gas hood only. The HEPA filter will provide a means for capturing particulate that may be entrained in the exhausting gas stream. An exhaust point for the passive vent will be placed approximately 3 m above grade to ensure that personnel are not exposed to potentially hot gases venting from the off-gas hood.

9413221.1852

TABLE 15.1. Water Spray Operating Criteria

1. Setpoints (Automatic Control)
   - Hood skin temperature = 425 °C
   - Timer = 5 s (initial)
   - Water flowrate = 4.6 L/min (total)

2. Criteria for Changing Timer Set-Point
   - Increase timer duration if water spray is triggered three times in one hour

3. Criteria for Switching to Manual Control
   - Scrub solution temperature ≥ 60 °C
   - Water spray actuation is continuously cycling.

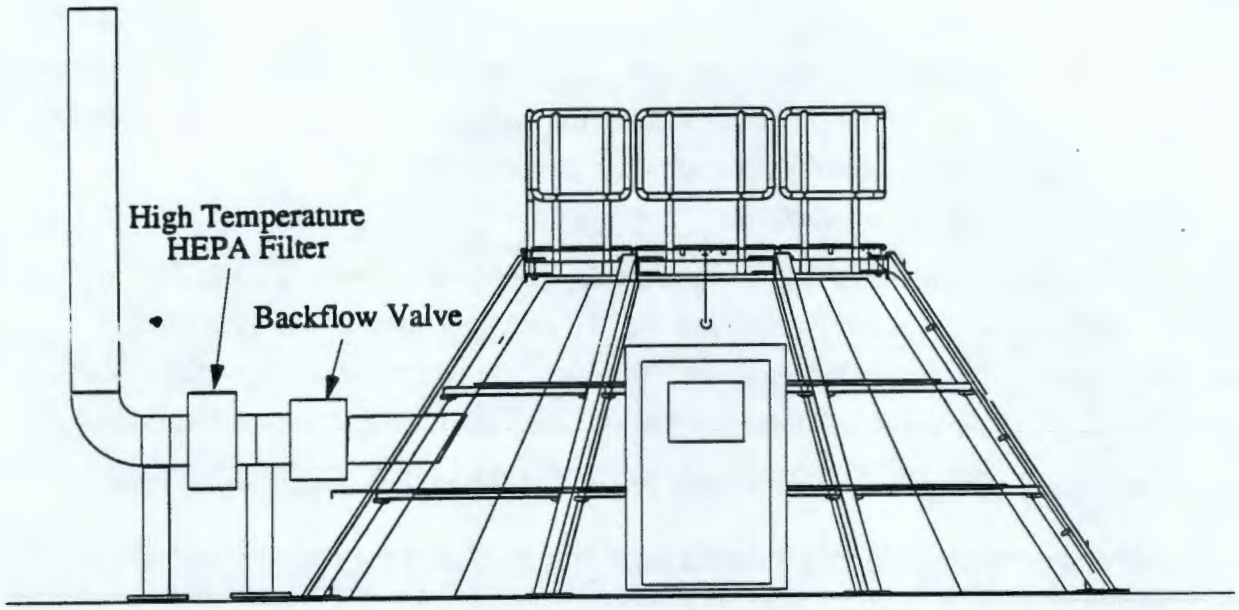


FIGURE 15.3. Schematic of the Passive Vent System

15.5 VOID SPACE MINIMIZATION

A key test objective for the 100 Area ISV demonstration is to demonstrate ISV as a physical stabilization technique for retrieved buried waste. Performance will be determined by the ability of the ISV process to eliminate potential mechanisms for future subsidence. Mechanisms for future subsidence involve the consolidation of the waste material through the elimination of void spaces created during filling of the waste disposal trench, pre-existing in the waste material, or created as the result of decomposition and degradation of the waste material. The ISV process eliminates these future subsidence mechanisms through densification and the creation of a stable, durable product.

Due to the high loading of gas-generating material (i.e., combustibles) in the demonstration test site, there exists the possibility that the final ISV product may contain a higher void fraction than desired. The ideal final product should contain zero void spaces, thus eliminating a potential

mechanism for future subsidence. Gases generated during ISV processing may create voids in the final product by becoming trapped in the glass during processing or during product cooling. The likely area for void space formation is the cold cap region. This region is at the surface of the ISV melt and is often cooler than other parts of the melt due to heat loss to the off-gas hood. Since the region is cooler, the viscosity (and surface tension) of the material is higher than other portions of the ISV melt. This increased viscosity does not allow gases to readily pass through it, thus trapping gases in the final ISV product.

To minimize the amount of void space in the final ISV product, the electrodes will be gradually withdrawn (with applied power) from the ISV melt upon meeting the three test objectives. Power will be reduced to a total of 100 kW and the electrodes withdrawn at a steady rate of 30 cm/h. This procedure will minimize the amount of void space in the final product by

- allowing the gases generated during ISV processing greater time to exit the molten soil zone, and
- heating the upper regions of the molten zone, thus decreasing the viscosity and surface tension of the material in the upper regions. This will, in turn, better allow gases to escape this region of the molten zone.

The rate of electrode withdrawal will not be greater than 30 cm/h but may be slower. The basis for slowing the rate of electrode withdrawal will be either temperature readings from key components of the off-gas hood (e.g., temperature of the off-gas skin near the electrode feed point, the temperature of the material composing the electrode seals) or resistance produced from the viscocity of the ISV melt.

9413221.1854

16.0 REFERENCES

Buelt, J.L., and L.E. Thompson. 1992. The In Situ Vitrification Integrated Program: Focusing an Innovative Solution on Environmental Restoration Needs. PNL-SA-20853, Pacific Northwest Laboratory, Richland, Washington.

Buelt, J.L. 1989. In Situ Vitrification Treatability Test of Arsenic-Contaminated Soils from the Crystal Chemical Site. Pacific Northwest Laboratory, Richland, Washington.

Buelt, J.L. and W.F. Bonner. 1988. Application of In Situ Vitrification for Organic-Contaminated Soils and Sludges. PNWD-1264, Pacific Northwest Laboratory, Richland, Washington.

Buelt, J.L. and J.H. Westsik. 1988. In Situ Vitrification - Preliminary Results from the First Large-Scale Radioactive Test. PNL-SA-15277, Pacific Northwest Laboratory, Richland, Washington.

Buelt, J.L., C.L. Timmerman, K.H. Oma, V.F. FitzPatrick, and J.G. Carter. 1987. In Situ Vitrification of Transuranic Waste: An Updated Systems Evaluation and Applications Assessment. PNL-4800 Suppl.1, Pacific Northwest Laboratory, Richland, Washington.

Callow, R.A., L.E. Thompson, J.R. Weidner, C.A. Loehr, B.P. McGrail, and S.O. Bates. 1991. In Situ Vitrification Application to Buried Waste: Final Report of Intermediate Field Tests at Idaho National Engineering Laboratory. EGG-WTD-9807, Idaho National Engineering Laboratory, Idaho Falls, Idaho.

Hansen, J.E. 1991. Treatment of Heavy Metal Contaminated Soils by In Situ Vitrification. Geosafe Corporation, Richland, Washington.

Jantzen, C.M., N.E. Bibler, D.C. Beam, W.G. Ramsey, B.J. Waters. 1991. Standard Test Method Relative to Durability of Nuclear Waste Glasses: The Product Consistency Test (PCT). Westinghouse Savannah River Co., Savannah, Georgia.

Luey, J., S.S. Koegler, W.L. Kuhn, P.S. Lowery, and R.G. Winkelman. 1992a. In Situ Vitrification of a Mixed-Waste Contaminated Soil Site: The 116-B-6A Crib at Hanford. PNL-8281, Pacific Northwest Laboratory, Richland, Washington.

Luey, J., T.D. Powell, W.O. Heath, and R.L. Richardson. 1992b. Evaluation of New Concepts for In Situ Vitrification: Power System, Melt Insulation, and Off-Gas Containment. PNL-8231, Pacific Northwest Laboratory, Richland, Washington.

Mitchell, S.J. 1987. In Situ Vitrification of Dioxin-Contaminated Soils. PNWD-1055. Pacific Northwest Laboratory, Richland, Washington.

Miller, R.L., and R.K. Wahlen. 1987. Estimates of Solid Waste Buried in the 100 Area Burial Grounds. WHC-EP-0087, Westinghouse Hanford Company, Richland, Washington.

9413221.1855

Oma, K. H., M. A. H. Reimus, and C. L. Timmerman. 1989a. Support for the In Situ Vitrification Treatability Study at the Idaho National Engineering Laboratory: FY 1988 Summary. PNL-6787, Pacific Northwest Laboratory, Richland, Washington.

Oma, K.H., C.L. Timmerman, and J.L. Buelt. 1989b. Pilot-Scale Test of In Situ Vitrification of PCB-Contaminated Soil. PNL-6788. Pacific Northwest Laboratory, Richland, Washington.

Powell, T.D. 1993a. Health and Safety Plan: 100 Area ISV Pilot-Scale Treatability Study for Retrieved Solid Waste. PNL-8701, Pacific Northwest Laboratory, Richland, Washington.

Powell, T.D., 1993b. In Situ Vitrification Pilot-Scale Test System: Safe Operating Procedure #49. PNL-8729, Pacific Northwest Laboratory, Richland, Washington.

Roberts, J.S., C.W. Strachan, and J. Luey. 1993. Investigation of Potential for Occurrence of Molten Soil Displacement Events During In Situ Vitrification of Combustible Wastes. PNL-SA-21870, Pacific Northwest Laboratory, Richland, Washington.

Shade, J.W., R.K. Farnsworth, J.S. Tixier, and B.L. Charboneau. 1991. Engineering-Scale Test 4: In Situ Vitrification of Toxic Metals and Volatile Organics Buried in INEL Soils. PNL-7611, Pacific Northwest Laboratory, Richland, Washington.

Spaulding, B.P., G.K. Jacobs, N.W. Dunbar, M.T. Naney, J.S. Tixier, and T.D. Powell. 1992. Tracer-Level Radioactive Pilot-Scale Test of In Situ Vitrification for the Stabilization of Contaminated Soil Sites at ORNL. ORNL/TM-12201, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Timmerman, C.L. 1989. Feasibility Testing of In Situ Vitrification of PCB-Contaminated Soil from a Spokane, WA Site. PNWD-1355, Pacific Northwest Laboratory, Richland, Washington.

Tixier, J.S., L.A. Corathers, and L.D. Anderson. 1992. "Vitrification of Underground Storage Tanks: Technology Development, Regulatory Issues, and Cost Analysis". In Waste Management '92, Vol 2, ed. R. G. Post, pp. 1521-1528. March 1-5, 1992, Tucson, Arizona.

Tixier, J.S., J.A. Stottlemyre, and M.T. Murphy. 1991. "Vitrified Underground Barriers". In Waste Management '91, Vol 1, ed. R. G. Post, pp. 603-611. February 24-28, 1991, Tucson, Arizona.

U.S. Department of Energy (DOE). 1992. Treatability Study Program Plan. DOE/RL-92-48, U.S. Department of Energy Richland Field Office, Richland, Washington.

U.S. Environmental Protection Agency (EPA). 1989. Guide for Conducting Treatability Studies Under CERCLA. EPA/540/1-89/058, Cincinnati, Ohio.

9413221.1856

DOE/RL-93-45
Draft A

APPENDIX A

Engineering Analysis

9413221.1857

DOE/RL-93-45
Draft A

ENGINEERING ANALYSIS:
100 AREA ISV PILOT-SCALE DEMONSTRATION

Revision 0

Project No. 20082

9413221.1858

Approvals:

J. Luey, Project Manager — 5/28/93 Date

J.S. Tixier, Senior Engineer — 5/28/93 Date

L.E. Thompson, Group Leader
In Situ Vitrification Group — 5/28/93 Date

S.E. Walker, Quality Assurance — 6/1/93 Date

G.R. Hoenes, Laboratory Safety — 6/1/93 Date

CONTENTS

1.0 INTRODUCTION 1.1
2.0 NORMAL OPERATING PROCEDURES 2.1
3.0 POTENTIAL TEST SPECIFIC EVENTS 3.1
3.1 HIGH HEAT LOAD 3.2
3.2 ELECTRICAL SHORTING IN MELT 3.3
3.3 LOSS OF HOOD VACUUM 3.3
3.4 HIGH CO/CO_2 EMISSIONS 3.4
3.5 OUTWARD GROWTH OF MELT 3.4
3.6 UNDERGROUND FIRES 3.5
3.7 MOLTEN SOIL DISPLACEMENT. 3.6
3.8 INABILITY TO SUSTAIN THE MELT 3.7
4.0 MITIGATING SYSTEMS/PROCEDURES 4.1
4.1 CONTROL ZONE. 4.2
4.2 REDUCTION OF POWER 4.2
4.3 WATER SPRAY 4.2
4.4 ELECTRODE FEED SYSTEM 4.3
4.5 PASSIVE HOOD VENT 4.3
4.6 MONITOR IN CONTROL TRAILER AND AT STACK 4.3
4.7 MONITOR MOLTEN ZONE 4.4
4.8 RANDOM PLACEMENT OF WASTE 4.4
4.9 MODELING 4.4
4.9.1 ISV Computer Model 4.4
4.9.1.1 Model Overview. 4.4
4.9.1.2 Results from ISV Computer Model 4.6
4.9.2 TOUGH2 Model 4.6
4.9.2.1 Model Overview. 4.8
4.9.2.2 Input Parameters 4.8
4.9.2.3 Pyrolysis Model 4.9
4.9.2.4 Results from the TOUGH2 Model 4.14
4.10 ADDITION OF A SOIL BERM INSIDE THE HOOD 4.17
4.11 CAMERA 4.17
4.12 BENCH-SCALE-TEST 4.17

9413221.1859

4.13 ENGINEERING CALCULATIONS 4.18
4.13.1 High Heat Load and Loss of Hood Vacuum 4.18
4.13.2 Aluminum Oxidation 4.20
4.13.3 High CO Levels 4.21
4.13.4 Formation of H_2 . . . . . 4.21
4.14 SIZE OF HOOD MUCH LARGER THAN SIZE OF TRENCH. . . 4.22
4.15 SOIL PRESSURE MEASUREMENTS 4.22
5.0 IMPLEMENTATION 5.1
5.1 HIGH HEAT LOAD 5.1
5.2 ELECTRICAL SHORTING IN MELT 5.1
5.3 LOSS OF HOOD VACUUM 5.1
5.4 HIGH CO/CO_2 EMISSIONS 5.2
5.5 OUTWARD GROWTH OF MELT 5.2
5.6 UNDERGROUND FIRES 5.2
5.7 MOLTEN SOIL DISPLACEMENT. 5.2
6.0 REFERENCES 6.1
ATTACHMENT A - Engineering Calculations

9413221.1860

FIGURES

4.1 Projected Pilot-Scale Melt Depth and Width Profile 4.7
4.2 ISV Model - Projected Melt Shape 4.7
4.3 Typical Temperature Profile in Soil Surrounding ISV Melt 4.11
4.4 Pressure History Beneath the ISV Melt with Random Waste Distribution #1 . . 4.15
4.5 Pressure History Beneath the ISV Melt with Random Waste Distribution #2 . . 4.16
4.6 Flow Diagram of the ISV Melt 4.19
4.7 Projected Melt Shape Relative to Pilot-Scale Off-Gas Hood 4.23

9413221.1861

TABLES

3.1 Test Specific Potential Events 3.1
4.1 Potential Mitigators 4.1
4.2 ACGIH Regulatory Limits for CO 4.4
4.3 ISV Site Soil Properties 4.9
4.4 Typical Pyrolysis Products 4.10
4.5 Properties of Pyrolysis Products as a Function of Temperature 4.12

1.0 INTRODUCTION

The purpose of this Engineering Analysis of the 100 Area ISV Pilot-Scale Demonstration is to address any potential test specific events that may occur during this treatability test that are not already covered in existing operating procedures. Although more than 150 individual tests of the ISV technology at various scale have evaluated the efficacy of the technology to treat a broad range of contaminants and solid media types, this particular demonstration will be the first application of ISV to waste that contains aluminum and a high combustible loading.

The target simulated waste composition for the 100 Area demonstration will be 63 wt% Hanford soil, 12 wt% combustibles, and 25 wt% metal. These target weight percentages were determined based on the estimated 100 Area solid waste disposal site contents, computational modelling, and engineering calculations. The combustible waste will be composed of rags, clothing, paper, and other soft material while the metal will be composed of aluminum and steel (mixture of stainless and carbon). Whenever possible, solid materials selected for the 100 Area pilot-scale demonstration will not only be representative of the materials buried in the 100 Area but also be representative of the expected geometries of the solid waste. Hazardous and radioactive materials will be excluded from this pilot-scale demonstration.

9413221.1862

2.0 NORMAL OPERATING PROCEDURES

The specific steps to be followed when operating the existing DOE pilot-scale ISV equipment are described in the supporting document, Safe Operating Procedure (SOP) (Powell 1993). The SOP includes start-up, operating, and shutdown instructions as well as a description of potential system failures, consequences, and required operator actions. These potential system failures, while not standard, are anticipated in advance of their possible occurrence during the ISV process. These anticipated system failures include such things as: electrode failure, loss of power, fire, process blower or wet scrubber pump malfunction, area evacuation, discontinuity of process control instrument feedback signal loop, loss of heat exchanger cooling, high transformer temperature, failure of the process off-gas heater, off-gas hood pressurization, low and high scrub tank volumes, process piping leaks, HEPA filter system high pressure drop, equipment restart, excessive hood temperatures, and loss of instrument(s). Since these events have been evaluated and accounted for in the SOP for the pilot-scale ISV equipment, no further discussion is included in this Engineering Analysis.

9413221.1863

3.0 TEST SPECIFIC POTENTIAL EVENTS

The high combustible and metal loading that will be present in the simulated waste for the 100 Area ISV pilot-scale demonstration represents a different setting relative to processing only soil. Therefore, several test specific potential events were considered based on these differences. Table 3.1 shows each of these possible events, their causes, and any primary and secondary consequences. The remainder of this section provides a brief discussion about each event.

9413221.1864

TABLE 3.1. Test Specific Potential Events

Potential Events	Causes	Primary Consequences	Secondary Consequences
High Heat Load	• High Combustible Loading • High Aluminum Loading	Exceed Design Limits for the Off-Gas Hood	• Exceed Design Limits for External Devices • Cesium Volatility
Electrical Shorting in Melt	High Metal Loading Causes Separate Phase in Melt	Exceed Design Limits for the Transformer	Compromised Safety
Loss of Hood Vacuum	High Combustible Loading	Exceed Design Limits for the Off-Gas Hood	None Identified
High CO/CO_2 Levels	High Combustible Loading	Compromised Safety	None Identified
Outward Growth of Melt	High Combustible Loading	Reduction in Hood Vacuum	Compromised Safety
Underground Fires	High Combustible Loading	Escape of Untreated Off-Gases	Compromised Safety
Molten Soil Displacement	• High Combustible Loading • Excessive Melt Rate	• Exceed Design Limits for Equipment • Compromised Safety	Hood Pressurization
Inability to Sustain the Melt	Aluminum Oxidation Resulting from High Metal (Aluminum) Loading	Unable to Complete Demonstration	•Thermite Reaction •Hotter Off-Gas and Plenum • Exceed Design Limits for the Off-Gas Hood •Compromised Safety

3.1 HIGH HEAT LOAD

The maximum steady-state operating temperature limit for the pilot-scale off-gas hood skin is 470 °C. Previous pilot-scale ISV melts done at Idaho National Engineering Laboratory (INEL) on waste containing combustible material (1-3 wt%) resulted in short durations (< 5 minutes) of off-gas hood plenum temperatures in excess of 700 °C (Callow et al. 1991). One source for these temperature spikes could be when combustible material was encountered by the melt front. The combustible wastes pyrolyze, move to the melt surface, and burn during the ISV process which causes an increase in gas volume and heat load to the off-gas system. Another source for the temperature spikes could be transient gas releases from sealed containers. The 100 Area pilot-scale demonstration will not use sealed containers; however, the simulated waste will contain a much higher combustible loading (12 wt%) than the INEL tests. This increased plenum temperature may increase the temperature of the off-gas hood skin and approach the steady-state design limit.

Another possible cause of a high heat load in the pilot-scale off-gas hood is an increased melt temperature. This possibility exists for this treatability test because of the high aluminum loading (up to 10 wt%) in the simulated waste. The aluminum has the potential to oxidize to alumina (see section 3.8 of the this Engineering Analysis), which would result in a higher viscosity glass. An increase in viscosity results in somewhat higher melt temperatures and longer melt times required to accomplish melting. This increased melt temperature would cause a higher heat load to the off-gas hood through convective and radiative heat transfer.

The primary consequence from a high heat load scenario would be exceeding the design limits of the off-gas hood, thereby possibly compromising its integrity. Once compromised, untreated off-gases may enter the environment if the off-gas hood is pressurized to a pressure above that of the ambient environment. For this pilot-scale demonstration, a release of untreated off-gases pose a minimal safety threat because all the simulated waste will be non-regulated, non-hazardous, and non-radioactive (major safety threat would be exposure to hot gases escaping from the off-gas hood).

Secondary consequence of a high heat load in the off-gas hood would be exceeding the design limits of the external devices located near the hood (i.e., electrical cables, pneumatic hoses, fibergrate platform and steps). Non-smearable trace levels (0.04 μCi) of cesium-137 exist on the off-gas hood and off-gas outlet piping from previous tests. In the unlikely event that all of the cesium-137 was volatilized and released to the environment, this trace amount would be less than

the reportable release quantity of 1 Ci. Such a release of any material has a very low probability for it requires the following to occur: 1) the entire inventory of Cs-137 would become volatilized, 2) the off-gas hood would become positively pressurized, and 3) all of the controlled release points for gases (off-gas treatment line, passive vent, and backup blower) fail. The key to this sequence, the volatilization of the entire Cs-137 inventory, is very unlikely since this would require the off-gas hood skin and/or piping to reach a temperature of at least 670°C. Control measures, discussed in Section 4.0, are implemented to maintain the temperature of the off-gas hood skin at 425°C or lower.

3.2 ELECTRICAL SHORTING IN MELT

The high metal loading (≈ 25 wt%) in the simulated waste for this demonstration may lead to electrical shorting in the melt. Metal, which has a much higher electrical conductivity then molten soil, can decrease electrode voltage when present during ISV, and in extreme cases it can result in a short circuit. As the melt grows and proceeds downward through a metal object, the metal will melt and settle at the bottom, resolidifying if the temperature is below the metal's melting point. As the metal pool grows and the fraction of electrode spacing occupied by metal increases, the power and voltage decline gradually until a short circuit occurs.

The primary consequence of this electrical shorting would be to exceed the design limits of the transformer. This could result in blown fuses and tripped breakers requiring increased access to the transformer cabinet. This increased access to the transformer cabinet brings about a secondary consequence of compromised personnel safety because parts of the cabinet are energized.

3.3 LOSS OF HOOD VACUUM

The off-gas hood is maintained at a vacuum (3.8-cm wc average) in order to route off gases through the off-gas treatment system. Previous ISV melts performed at INEL on waste containing combustible material (1 - 3 wt%) resulted in relatively slow developing pressure spikes (Callow et al. 1991). The mechanisms by which the off-gas hood may become positively pressurized are as follows: 1) a net energy increase of gases in the hood caused by either an addition of hot gases from the ISV melt, combustion or pyrolysis gases in the hood, or increased radiant and convective heating of gases in the hood due to changes at the melt surface, 2) a net increase in the number of moles of gases in the hood, and 3) a net increase in both the energy and the number of moles of gases. The simulated waste used in this

100 Area demonstration will contain a much higher combustible loading (12 wt%) than the INEL tests, so the potential for pressurization of the off-gas hood exists.

As with the high heat load, the primary consequence of a positive pressure event would be exceeding the design limits of the off-gas hood, thereby possibly compromising its integrity. A temporary pressurization the off-gas hood to a pressure above that of the ambient environment could potentially allow untreated off-gases to enter the environment . This is referred to as a transient event. As previously stated, only the release of trace levels of Cs-137 (found on the off-gas hood and off-gas piping) may be of concern since all of the simulated waste material used for the demonstration is non-regulated, non-hazardous, and non-radioactive. However, as previously discussed, a number of events need to occur in order for any Cs-137 to be released.

3.4 HIGH CO/CO_2 EMISSIONS

During ISV of a waste site, any solid combustible inclusions within the soil are pyrolyzed into gases by the high ISV melt temperature. The pyrolysis gases move upward either around or through the molten zone. Combustion occurs when the pyrolyzed gases contact air at the surface of the molten soil (since the environment under an ISV melt is reducing in nature, very little combustion occurs beneath an ISV melt). Since the simulated waste for this demonstration contains a high loading of combustibles (12 wt%), there is a possibility that the CO/CO_2 emissions from the off-gas hood may be excessive. The possibility of high CO concentrations /emissions could result in localized CO concentration gradients in the processing area around the trailer and possibly exceeding the lower explosion limit (LEL) of CO (12.5% at standard temperature and pressure). During operation, levels should be maintained below 10% of the LEL. The primary consequence of this event would be a compromise of personnel safety.

During the full-scale application of this demonstration, a negative consequence of high CO levels could be exceeding the 40 CFR limit of 100 tons per stack per year. If during the pilot-scale demonstration the CO emissions turn out to be high, mitigating factors will need to be addressed in order to control this during the full-scale application.

3.5 OUTWARD GROWTH OF MELT

During the ISV process, the ISV melt propagates both vertically and laterally via heat transfer from the ISV melt to the surrounding media. For the initial phases of the ISV process, the surface area at the bottom of an ISV melt is greater than the surface area of the sides; therefore, the

rate of melt growth downward is greater than the rate of growth outward. As the process progresses, the ratio between the surface area of the bottom of the ISV melt and the surface area of the sides of the ISV melt decreases, resulting in a more uniform downward and outward growth rate. For ISV melts with just soil, the heat transfer mechanism results in an ISV melt that is hemispherical in shape.

Two factors that influence melt shape and melt growth are the composition of the material that is being processed and the heterogeneity of the waste site. Since the ISV process relies on heat transfer to the surrounding media to propagate, the presence of voids and materials that melt easily would increase the melt growth into regions containing such influences. If the materials are not uniformly distributed throughout the waste site, then preferential melt paths may be established.

For the 100 Area ISV demonstration, the waste will be staged in a rectangular shaped trench that will be completely covered by the ISV off-gas hood. Metal and combustible material to be used for the demonstration will be processed more easily than Hanford soil and may create a preferential path for melt growth along the axis of the simulated waste trench. If the growth along these paths is excessive (i.e., approaches the boundaries of the ISV off-gas hood), then the primary consequence may be a reduction in the seal of soil around the base on the off-gas hood and a reduction of the off-gas hood vacuum. A secondary consequence would be to compromise the safety of personnel who may be walking near the off-gas hood.

3.6 UNDERGROUND FIRES

Underground fires is a technical issue identified for buried waste applications such as those predicted at the INEL (Nickelson, Luey, and Callow 1992). The issue is the potential for an underground fire to be initiated by the high temperature of the ISV process and then self-propagated. If the underground fire propagates beyond the boundaries of the ISV off-gas containment hood, then there exists the possibility that off-gases created by the fire may enter the atmosphere untreated. Previous tests with combustible material have not shown that this phenomena occurs. However, the high combustible loading for the 100 Area ISV demonstration may create conditions conducive for underground fires that did not exist for previous tests.

The primary consequence of this event, if it propagates beyond the boundaries of the ISV off-gas hood, would be the potential for off-gases to be released to the environment untreated. A secondary consequence would be the compromised safety of personnel working around the ISV hood. The former consequence is not an issue for the pilot-scale test since nonregulated,

9413221.1868

nonhazardous, and nonradioactive materials will be used for testing. The latter, however, may be of concern since the products from combustion (CO and CO_2) pose a risk to personnel if the exposure levels are high enough.

3.7 MOLTEN SOIL DISPLACEMENT

During the ISV process, the water present in the pores of the soil near the melt is heated to boiling and combustibles are combusted or pyrolyzed (depending on the availability of oxygen). Both of these processes produce significant quantities of gas beneath the ISV melt. If the permeability of the soil is low due to its tight structure, or the presence of solid regions (e.g., metal drum, concrete wall, etc.), the gas generated can cause a significant increase in pressure below the melt. When this pressure becomes greater than the static head of the melt, there is the possibility it can rupture the sintered soil layer surrounding the melt and send one or more bubbles of gas into the melt. As the bubbles rise through the melt, their volume increases due to both decreasing pressure and increasing temperature as the bubbles are heated up. The bubbles break when they reach the surface.

The presence of bubbling during the ISV process in itself is not an issue. However, problems can arise if the bubble becomes large (>2 meters in diameter). This large bubble volume displaces an equal volume of melt, causing the molten soil to overflow its boundaries (termed a "molten soil displacement event") and causing a temporary pressurization of the containment hood (Roberts et al. 1992). When the bubble reaches the melt surface, it bursts, and may result in the expulsion of molten soil onto the off-gas hood. It should be noted that the only true molten soil displacement events that have occurred to date involved large-scale tests on settings with large, high integrity steel containers. One test involved 55-gallon drums (Roberts et al. 1992; Geosafe Corporation 1993) and the other a 3.0-m-diameter tank (Tixier, Corathers, and Anderson 1992).

The primary consequences of such a scenario is to compromise personnel safety and exceed the design limits of the off-gas hood. In addition, a secondary consequence of a molten soil displacement is the potential for an uncontrolled release of contaminants into the atmosphere as the off-gas hood is pressurized. As previously stated, the latter consequence is minimal for this test since the simulated waste does not contain any regulated, hazardous, or radioactive material.

3.8 INABILITY TO SUSTAIN THE MELT

The 100 Area trenches contain a significant quantity of aluminum (≈ 15 wt% of the waste inventory, exclusive of soil). Questions about the influence of the aluminum on the ISV process arose because no previous ISV melts have been attempted on waste containing aluminum. To estimate the fate of aluminum during ISV processing and the effect of the aluminum on the melting process, calculations were performed using the experience of joule-heated melters as a basis (100AREA-93-05). Based on this analysis there is the potential that the aluminum will oxidize during the melt and therefore change the properties of the ISV melt. The primary consequence from this aluminum oxidation would be the inability to complete the demonstration due to a change in properties that lead to an inability to sustain the melt.

One secondary consequence of the oxidation of aluminum in the waste is the possibility of a thermite reaction. A thermite reaction refers to the exothermic chemical reduction of a metal oxide by metal powders of another more reactive metal. Such reactions do not require any external source of O_2 since it is supplied by the metal oxide. In the combustion of aluminum to form alumina, the heat of formation of the latter so far exceeds the heat absorbed in the decomposition of the oxides of many metals, that both the liberated metal and the alumina produced in the reaction reach a sufficient temperature to melt them and possibly cause an explosion. If a thermite reaction were to occur during the ISV melt, it could cause a hotter off-gas plenum, possibly exceed the design limits of the off-gas hood, and potentially compromise personnel safety.

Another secondary consequence would be the formation of a final product that did not meet test objectives. If the aluminum becomes an oxide at the expense of oxides already present in an ISV melt, there is the potential that the final melt composition would not be conducive to a durable glass and may not form a glass at all. The final product strength may also be compromised.

9413221.1870

4.0 MITIGATING SYSTEMS/PROCEDURES

Once the potential test specific events from Section 3.0 were identified, potential mitigators for these events were addressed. This section defines and identifies all the mitigating systems/procedures that will be used to help prevent and/or control the potential events defined in section 3.0. Table 4.1 shows which potential events will be mitigated (prevented or controlled) by each system/procedure.

TABLE 4.1. Potential Mitigators

Potential Events	Potential Mitigators
High Heat Load	Control Zone Reduction of Power Water Spray Engineering Calculations
Electrical Shorting in Melt	Reduction of Power Electrode Feed System
Loss of Hood Vacuum	Control Zone Reduction of Power Water Spray Passive Hood Vent Engineering Calculations
High CO/CO_2 Levels	Reduction of Power Monitor in Control Trailer and at Stack Engineering Calculations
Outward Growth of Melt	Control Zone Reduction of Power Monitor Melt Path Random Placement of Waste Video Camera Size of Hood >> Size of Trench
Underground Fires	Control Zone Reduction of Power Monitor Melt Path Size of Hood >> Size of Trench
Molten Soil Displacement	Control Zone Reduction of Power Modeling Add Soil Berm Inside Hood Video Camera Soil Pressure Measurements
Inability to Sustain the Melt	Bench-Scale Test Engineering Calculations

4.1 CONTROL ZONE

A Control Zone will be set up around the pilot-scale hood at the ISV site in order to protect site personnel from any injuries during a high heat load and/or loss of vacuum in the off-gas hood, any outward growth of the melt, underground fires, or a molten soil displacement event. During operation, visitors will be excluded from the control zone. A visitor is defined as an individual who has not received all of the test specific training (e.g., Test Plan, SOP, Radiation Work Perimt (RWP), etc.).

4.2 REDUCTION OF POWER

The melt rate will be slowed down by either reducing or suspending power in order to mitigate any one or more of the following: a high heat load or a loss of vacuum in the off-gas hood, high CO/CO_2 levels in the off-gas treatment system stack, an outward growth of the molten zone, underground fires, and/or a molten soil displacement event.

4.3 WATER SPRAY

In order to mitigate transient events in the off-gas hood that are the result of net energy and/or material increases within the off-gas hood, a water spray system will be used. The water spray system is designed to remove energy from the gases in the off-gas hood by evaporative cooling, thus mitigating the pressure and temperature increases associated with transient gas releases from the ISV melt (Luey et al. 1992a). The water spray system can also be used in a semi-continuous or continuous mode to combat steady-state heat loads in the off-gas hood.

The premise for the water spray concept is based on the ideal gas law in which pressure is proportional to temperature for a given volume and number of moles. During a transient event, water is sprayed into the off-gas hood to remove energy from the gases in the hood. This energy transfer leads to an overall temperature decrease in the hood plenum. As a result of the temperature decrease, the pressure within the off-gas hood also decreases. The addition of liquid water, which vaporizes, does not increase the hood pressure as may be expected because the decrease in off-gas temperature resulting from the energy transfer is sufficient to compensate for the expanding volume of the vaporized water.

It is possible that the addition of water will convert some of the CO produced from combustion to CO_2 and H_2 gas as per the "water gas shift reaction":

$$CO(g) + H_2O(g) \text{ -------> } CO_2(g) + H_2(g) \quad (T = 250^\circ C, \text{ iron oxide catalyst})$$

9413221.1872

Engineering calculations to estimate the levels of hydrogen that may be produced are discussed in Section 4.13.4.

4.4 ELECTRODE FEED SYSTEM

The electrode feed system provides a means of controlling the vertical position of the electrodes in the ISV melt and is described in greater detail in the SOP for the pilot-scale ISV equipment. If conditions in the melt change (e.g. electrodes establish contact with the molten metal pool at the melt bottom, causing a direct short), the electrodes can be gripped and retracted out of the shorting condition without process delays or lost time.

4.5 PASSIVE HOOD VENT

A passive hood vent will be included in the design of the off-gas hood to prevent untreated off-gases from entering the environment when a positive pressure event occurs. The vent will consist of a flapper valve and HEPA filter housing. The flapper valve will allow flow out of the hood only, while the HEPA filter will remove particulate. Allowing increased flow out of the off-gas hood will reduce the positive pressure attained during an event.

In addition to this passive hood vent, there is also an existing seal pot assembly system on the off-gas hood. This system allows for controlled air in-leakage and hood vacuum control. The seal pot assembly will be checked every hour and if the water level is low it will be adjusted as necessary.

4.6 MONITOR IN CONTROL TRAILER AND AT STACK

CO and CO_2 emissions from the off-gas will be monitored at the stack. In addition, CO concentrations will be monitored in the process control trailer. Because of the high combustible loading in the simulated waste for this demonstration, there is the possibility that the CO concentrations could exceed safety limits. Table 4.2 shows the regulating limits that DOE must follow for CO. These are listed in the "Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices" as published by ACGIH.

Gathering good data on the CO and CO_2 emissions during this pilot-scale demonstration is very important because this data will be needed when scaling up for the full-scale application. A complete regulatory analysis must be done for the full-scale application.

9413271.1873

TABLE 4.2. ACGIH Regulatory Limits for CO

PEL, [a]	CL, [b]	IDLH, [c]
29 mg/m^3	229 mg/m^3	1740 mg/m^3
25 ppm	200 ppm	1500 ppm

a) PEL (Permissible Exposure Limit) = The time weighted average concentrations that must not be exceeded during any 8-hr work shift of a 40-hr work week.
b) CL (Ceiling Limit) = The limit that should not be exceeded during any part of the workday
c) IDLH (Immediately Dangerous to Life and Health) = The maximum concentration from which, in the event of a respirator failure, one could escape within 30 minutes without a respirator and without experiencing any irreversible health effects.

4.7 MONITOR MOLTEN ZONE

Type C and type K thermocouples will be used to monitor the molten zone. The monitoring frequency will range between 1 - 30 minutes. These monitored temperatures will be able to detect any significant outward growth of the molten zone or any significant underground fires.

4.8 RANDOM PLACEMENT OF WASTE

The simulated waste will be randomly placed in the trench so that there is not a large concentration of combustibles in one area. This will minimize outward growth of the melt by avoiding the creation of preferential melt paths. This placement of waste is also more representative of full-scale, in which earth moving equipment would be used to stage sites.

4.9 MODELING

Two computational models were used to estimate parameters for the 100 Area pilot-scale demonstration. The ISV computer model estimates melts shape for homogenous soils while the TOUGH2 code is used to estimate gas profiles (specifically pressure) surrounding an advancing ISV melt. This section discusses the use of these two models and the results.

4.9.1 ISV Computer Model

4.9.1.1 Model Overview

The ISV 3.01 PC model was used to estimate the melt shape for the pilot-scale 100 Area demonstration. Predictions for melt rate, shape, and power consumptions are estimations only due to the assumptions within the PC model (e.g., the model does not take into account heterogeneous

settings). During operation of the program, the ISV melt zone depth grows downward in equally spaced increments. The rate of melt growth is based on the heat flux at the edge of the melt. Power input is dependent on power transformer size, voltage tap selection, and melt zone resistance. The equations used to calculate power are:

$$P = V^2/R$$

and

$$P = I^2R$$

where P = power, V = voltage, R = resistance and I = current.

The resistance is calculated between edge electrodes (R_e) and diagonal electrodes (R_d) as described by the following two equations:

$$R_e = p\frac{\ln(2S_e/D)}{\pi D_g}$$

$$R_d = p\frac{\ln(S_d/D)}{\pi D_g}$$

where:

p = average electrical resistivity of the glass
S_e = electrode separation along the edge
S_d = diagonal electrode separation
D = electrode diameter
D_g = molten glass depth.

The overall melt zone resistance is then calculated by:

$$R = \frac{R_dR_e}{R_d + R_e}$$

The mathematical model calculates heat losses through the exposed upper surface and into the surrounding soil. Heat losses into the soil are calculated using a constant heat flux value

applied to the molten zone side and bottom surface area in contact with soil. The surface heat losses are determined in a similar fashion using the area defined by the four corner electrodes for data. Using an average soil thermal conductivity of 0.20 W/m•K, the heat flux from molten glass to surrounding soil ranged from 2.3 to 3.2 kW/m^2. The maximum value, 3.2 kW/m^2, was conservatively selected as the heat flux term for heat losses into the surrounding soil. Based on a measured nominal surface temperature of 570°C, the heat flux through the upper surface was 32 kW/m^2. This value agrees with actual pilot-scale test data and was selected as the surface heat flux term for the model.

The model assumes that glass temperature was constant and thermal conduction of the electrodes had no effect. While glass temperature does change during an actual operation due to changing power density, the average temperature used by the model agrees well with actual pilot-scale data.

4.9.1.2 Results from ISV Computer Model

The ISV model estimates that the melt width upon completion of the demonstration would be about 3.2 m. This is narrower than the base of the ISV pilot-scale hood which is about 4.3 m. It is not anticipated that the ISV melt for the 100 Area demonstration, which will contain a high metal and combustible loading, will grow to be any wider than the estimated 3.2 m. The reasons for this prediction are 1) prior experience with buried waste at Idaho National Engineering Laboratory (INEL) showed the melt to progress as if in an "elevator shaft" (Callow et al. 1991) and 2) the metal loading of the simulated waste site is believed to enhance downward melt growth. Figure 4.1 shows the projected melt depth and width as a function of time and Figure 4.2 shows the projected melt shape after 60 hours of run time. It should be noted that the model assumes a homogeneous soil; therefore, the shape and melt rate for the demonstration will likely be different.

4.9.2 TOUGH2 Model

Computer simulations were used to investigate the application of ISV for processing contaminated soil containing high loadings of solid, compressible and metal waste materials typical of the 100-B/C trench at Hanford. These simulations investigated the transient hydrothermal phenomena occurring in the soil below an ISV melt using TOUGH2 computer code. This work will help researchers understand what conditions are likely to cause pressurization of the soil surrounding the melt in order to prevent gas flow from this region through the melt - a potentially hazardous condition.

9413722.1876

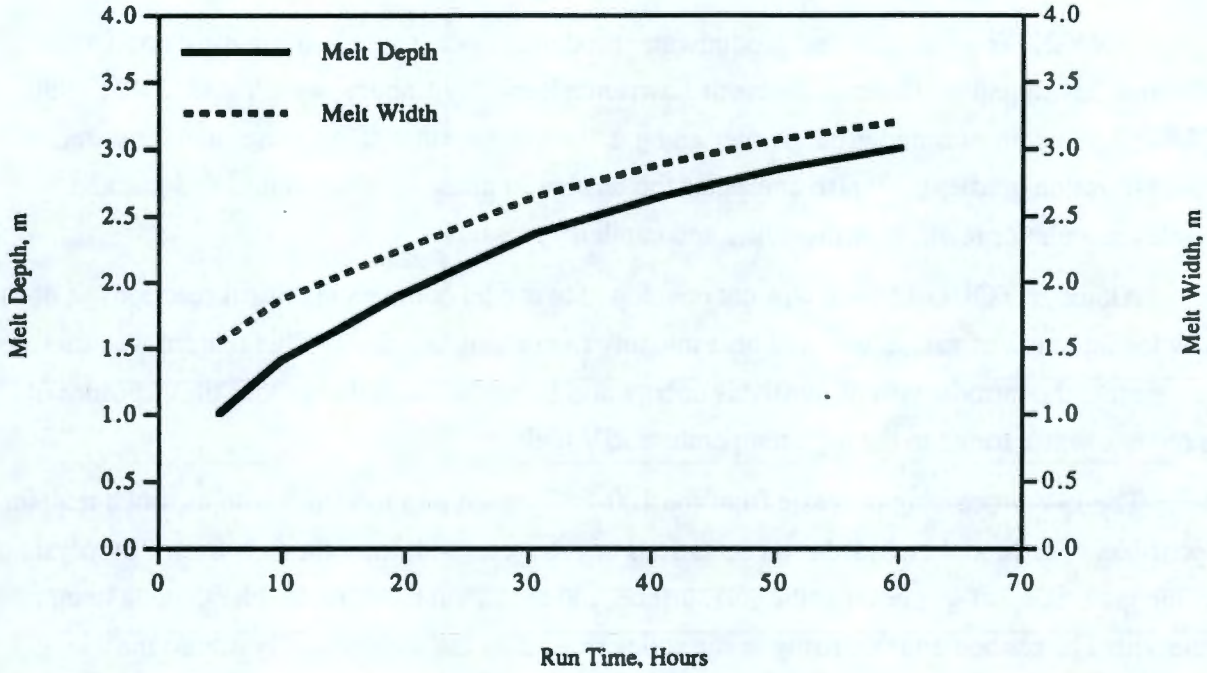


FIGURE 4.1. Projected Pilot-Scale Melt Depth and Width Profile

FIGURE 4.2. ISV Model - Projected Melt Shape

9413221.1878

4.9.2.1 Model Overview

TOUGH2 is an unsaturated groundwater modeling code, capable of treating non-isothermal problems, developed by Karsten Pruess at Lawrence Berkeley Laboratory (Pruess, 1987, 1990). TOUGH2 treats unsaturated groundwater and gas flow in response to pressure, temperature, and liquid saturation gradients. It also computes the change in phase between liquid and gas and includes models for relative permeability and capillary pressure.

Although TOUGH2 code was not developed to model complex chemical reactions, it does allow for injection of gas, liquid, and heat into any number of locations. This feature was used to approximate the introduction of pyrolysis energy and byproducts resulting from the exposure of the organic waste forms to the high temperature ISV melt.

The ISV processing of waste from the 100-B/C trench was modeled with as much realism as possible. The model included representations of the melt (with moving melt front), pyrolysis of organic materials, off-gas hood at the soil surface, and the thermal-hydraulic phenomena occurring in the soil. The phenomena occurring in the soil surrounding the melt typically mimic the approximately hemispherical shape of the melt, and there is little variation around the perimeter of the melt. To take advantage of this symmetry, the simulations used a two-dimensional wedge from a spherical coordinate system. Several simulations where run using this 2-D model.

4.9.2.2 Input Parameters

Properties from soil typical of the ISV site in the 300 Area of the Hanford reservation were used for these models. Experimentally measured hydraulic properties and approximations for the thermal properties are entered in Table 4.3 (Rockhold, et al.,1988, and Hillel, 1980). The soil was assumed to be 82% gas saturated and at 15 °C and 101,350 Pa (approximately atmospheric conditions) before the vitrification process was initiated.

The advancing ISV melt front was considered to be an impermeable boundary to gas and liquid flow and maintained at 1300 °C. The melt front was assumed to move at 2.5 cm/hr (which is typical for pilot-scale ISV operations), approximated by a step-wise process.

A simple model was used for the off-gas hood above the melt. This hood directs contaminants originating from the melt and the soil surrounding the melt into the off-gas treatment system. In the model, the soil surface covered by the hood (4.3 m in diameter) was assumed to be

TABLE 4.3. ISV Site Soil Properties

Absolute Permeability	1.01e-11 m^2
Grain Density	2720 kg/m^3
Porosity	0.398
Thermal Conductivity	1.305 W/m °C
Specific Heat	800 J/kg °C
Capillary Pressure and Relative Permeability (VanGenuchten functions)	α = 5.375 1/Pa n = 2.6889 S_r = .214 S_s = 1.0 P_{max} = 1.0e+5 Pa

maintained at a partial vacuum of -0.25 cm H2O, and 200°C. These numbers are based on typical large-scale, ISV hood operating conditions (Buelt, et al. 1987). These assumptions are worst case because the pilot-scale ISV system usually runs at a higher vacuum than that of the large-scale ISV system, reducing the soil pressures beneath the melt.

To model the waste in the simulated trench, assumptions were made about the amounts of various constituents present. The constituents modeled were metal (12% by volume), combustible materials (68%), and soil (20%). Computational cell sizes were defined with approximately 6 inches on a side to model the expected scale of the waste pieces. The cells of the model falling within the trench region were randomly assigned one of these material types, preserving the assumed volume fractions. The nodes assigned with the metal material type were assumed to have small soil inclusions, making them only slightly permeable to fluid flow. This assumption was necessary to prevent unrealistic pressure buildup due to the numerical approximations of the fluid flow in the soil. The metal was assumed to have thermal properties midway between aluminum and steel. It was also necessary to make the combustible nodes partially permeable to fluid flow. A permeability half the magnitude of soil was used for the combustible nodes.

4.9.2.3 Pyrolysis Model

When the solid organic wastes (such as wood and paper) in the trench beneath the ISV melt reach a certain temperature, they will begin to pyrolyze. In this process the solid waste forms are converted to gas. Combustion will probably not occur because the gas surrounding the melt is predominantly water vapor and deficient in the oxygen necessary for combustion.

Some experimental data is available on the products typically created during slow pyrolysis processes. Below 200°C, water vapor leaves the organic wastes, but no pyrolysis occurs. Above 200°C, pyrolysis occurs with typical products as shown below in Table 4.4 (Emrich, 1985, McKeogh et al., 1985, and Schiefelbein, 1985). The slow pyrolysis process is endothermic, requiring energy from its surroundings. Experimental data indicates that the required heat of vaporization is approximately 710 kJ/kg.

TOUGH2's ability to handle mass sources in the computational domain with specified mass flowrates and specific enthalpies was used to model the pyrolysis process. To use the pyrolysis data in the TOUGH2 code model, some assumptions and approximations were made specifying the regions of the trench undergoing pyrolysis and what gas generation rates and enthalpies were produced.

Figure 4.3 shows a typical temperature profile in the soil outside a moving ISV melt. This profile was calculated by TOUGH2 assuming a 1 in./hr melt progression rate and soils typical of those described in Table 4.3. Computational nodes for this problem were typically 6 inches on a side. Three of these nodes are represented in Figure 4.3 as node 1 (closest to the melt at approximately 900 °C), node 2 (between 6 in. and 1 ft. from the melt at 450°C), and node 3 (1 ft. to 1 ft. 6 in. from the melt at 250°C). From this figure, it is apparent that only the three nodes

9413221.1880

TABLE 4.4. Typical Pyrolysis Products

Between 200°C and 500°C:

- 20% (by volume) light organic smoke (ie. methanol, phenol, etc.) with molecular weights ranging from 30-200 and averaging 100.
- 35% gas in the following percentages:
  - 50% CO
  - 20% CO_2
  - 15% H_2
  - 15% Methane and ethane
- 10% water vapor
- 35% solid char

Above 500°C, the solid char breaks down further into:

- 85% (by volume) gas (CO, CO_2, H_2, methane, and ethane in the same percentages as above)
- 15% water vapor

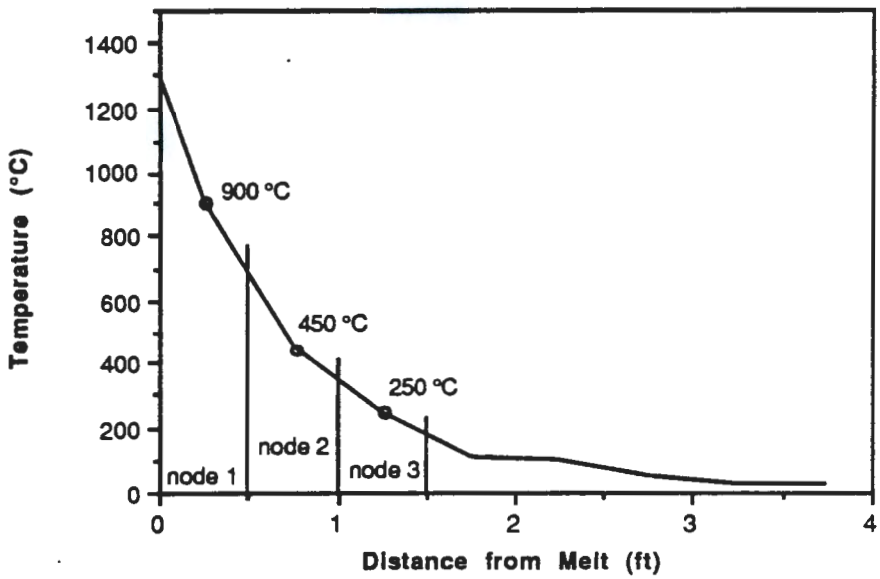


Figure 4.3. Typical Temperature Profile in Soil Surrounding ISV Melt

closest to the melt are pyrolyzing at any time, those at greater radii are below 200°C.

The data suggests that approximately 65% of the organic volume is consumed between 200 and 500°C and the rest is consumed above 500°C. Knowing this, the volume flowrates of gas being generated were determined. For this model, one-third of the solid, organic waste was assumed to be consumed in each of nodes 1, 2, and 3 during a 6 hour period. This defined the volume rate of gas generation for each of the nodes. To convert this to a mass generation rate, a density of 400 kg/m^3 was used for the solid, organic material. The pyrolysis gas mass flowrate was then calculated as:

$$m_{gas} = vol * \rho_{solid}/t_{burn}$$

where: vol = volume of the specific node

ρ_{solid} = 400 kg/m^3, density of solid organic waste

t_{burn} = burn duration time (typically 3 hours)

The specific enthalpy of the pyrolysis products was found by volume weighing specific heats of the species making up the gas and multiplying the result be the node temperatures. The specific heats are functions of temperature and the enthalpies were calculated with respect to 0°C (the reference used by TOUGH2). These values are shown below in Table 4.5.

The mass flowrate and specific enthalpy of the gas mixture generated by the pyrolysis process have been approximated. Unfortunately, TOUGH2 is restricted to use only air and water vapor for injection sources, which have different specific heats and molecular weights than the predicted pyrolysis gases. Therefore, the air or water vapor injection was adjusted to model the actual pyrolysis gases. Two methods were used for this modeling: One assumed the same mass and temperature of injected and actual gas, the other assumed the same number of molecules and energy of the injected and actual gas.

The model conserving mass and maintaining temperature is worst case since it would result in higher calculated pressures than those generated in the actual pyrolysis process. This model assumes:

$$m_{air} = m_{gas}$$

$$h_{air} = Cp_{air}\, T_{node} - h_{exp}$$

where:

m_{gas} = calculated mass flowrate of pyrolysis gases

Cp_{air} = specific heat of air

h_{exp} = experimentally determined specific enthalpy of vaporization, 710,000 J/kg.

TABLE 4.5. Properties of Pyrolysis Products as a Function of Temperature

T (C)	Cp (J/kg K)*	h (J/kg)	MW
250	2621.41	655,353	48
450	2871.85	1,292,331	48
900	3661.21	3,295,085	25

*from VanWylen and Sonntag, 1978.

9413221.1882

This approach significantly over predicts the pressure in the system because the molecular weight of the air is less than the lower temperature pyrolysis gases. This means that for a given mass of air injected, a larger number of molecules and gas volume would be added than with actual pyrolysis gases. The specific heat of air is also significantly smaller than that of the pyrolysis gases. This implies that for a given energy input to a node, the change in air temperature would be greater than for the pyrolysis gases. Also, the specific heat of the pyrolysis gases increases with temperature more dramatically than air, so this effect would be accentuated as temperature increased.

The air mass flowrates vary from node to node, but the specific enthalpies of the injected air are only temperature dependant:

$$h_{air\ 250°C} = -4.49 \times 10^5 \text{ J/kg}$$

$$h_{air\ 450°C} = -2.18 \times 10^5 \text{ J/kg}$$

$$h_{air\ 900°C} = 3.52 \times 10^5 \text{ J/kg}$$

The negative sign simply means that the enthalpy is below the reference enthalpy of 0°C.

The second modeling approach conserves the number of molecules and the energy injected into the system. This approach more accurately models both the energy and the pressure of the system than the first method. The equations governing this model are:

$$m_{air} = MW_{air}/MW_{gas} * m_{gas}$$

$$h_{air} = MW_{gas}/MW_{air} (Cp_{gas}\ T_{node} - h_{exp})$$

where:

MW_{air} = Molecular weight of air
MW_{gas} = Molecular weight of pyrolysis gases

Given a control volume at a known temperature, the same pressure will occur for a specific number of molecules for any species of gas (assuming ideal gas). This means that conserving the number of molecules injected, the modeled pressure should be relatively close to the actual pressure. By definition, the energy delivered to the system in this model is equal to that delivered during the real pyrolysis reaction.

As with the first model, the air mass flowrates vary depending on node volume, but the specific enthalpies are only temperature dependant:

$$h_{air\ 250°C} = -9.06 \times 10^4\ J/kg$$

$$h_{air\ 450°C} = 9.66 \times 10^5\ J/kg$$

$$h_{air\ 900°C} = 2.26 \times 10^6\ J/kg$$

Both of these models were used to model the pyrolysis process for this pilot-scale ISV demonstration. The difference between the resulting pressure is a measure of the impact of the assumptions made.

4.9.2.4 Results from the TOUGH2 Model

Simulations were run using two statistical distributions of waste. One happened to have metal sections well dispersed (random distribution #1) so that they didn't form long impermeable barriers that prevented fluid flow and increased pressure. The other distribution had many such barrier zones (random distribution #2). The distribution of metal sections and the assumptions used in modeling them had a dramatic effect on the calculated results. The specific model used for the pyrolysis process did not have a significant effect on predicted pressures.

Figure 4.4 shows the history of the maximum predicted gas pressure in the soil beneath the melt and the approximate static head of the melt. The data sets plotted show results from runs using different assumptions for the inclusions present in the metal regions and the model used for pyrolysis. With no inclusions, the pressure history show three peaks (one of which is dramatic). These peaks correspond to times when metal sections are surrounding pyrolyzing regions on two sides, with the melt blocking flow in a third direction. This reduces the available routes of escape for the pyrolysis gases which leads to a local increases in pressure. With 1% and 10% inclusions in the metal (these data are coincident in Figure 4.4), some pyrolysis gas is allowed to escape through the metal regions. The permeability of the metal with inclusions was assumed to be the volume average of the metal (zero permeability) and inclusions (soil permeability). This is a realistic assumption since the metal filled regions of the real trench will not be solid, they will be an aggregate of metal pieces interspersed with soil or other waste. The resulting increase permeability of these regions decreases the maximum pressure. The particular distribution of metal in the trench for random distribution #1 did not create a situation where gas was forced to flow through metal regions to escape, there were always pathways through more permeable soil or combustible material.

9413221.1884

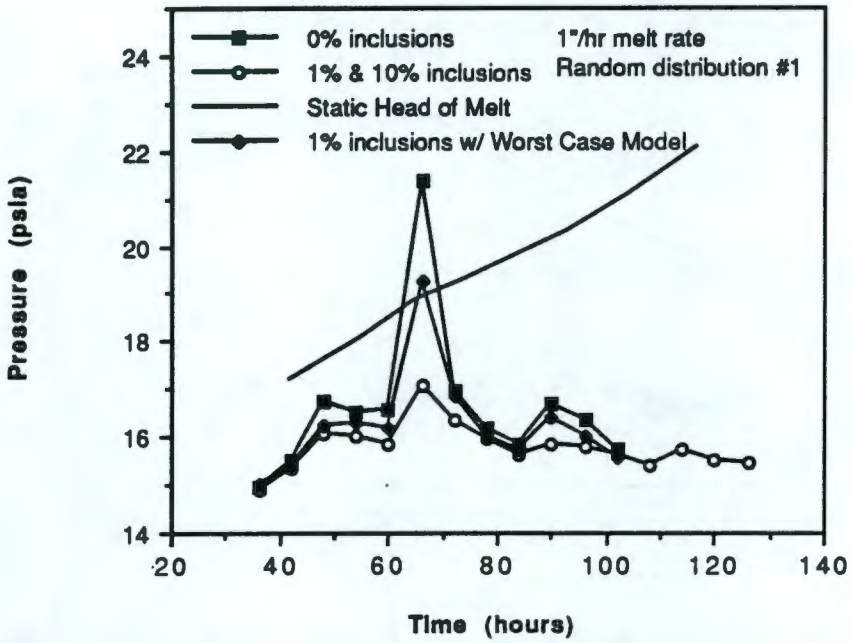


Figure 4.4. Pressure History Beneath the ISV melt with Random Waste Distribution #1

The worst case pyrolysis model, where mass is conserved for the injected gas, shows an increase in pressure over the more realistic pyrolysis model. This was the expected result of these models. It is likely that the pressure created by the actual pyrolysis process would not be as high as predicted with the worst case model.

Figure 4.5 shows the pressure history beneath the melt with random distribution #2 of waste. Since this distribution contained pockets of pyrolyzing material surrounded by metal, the simulation with 0% inclusions in the metal nodes was not possible. Without inclusions the pressure in these region would continue to build up without relief. In this figure, the peaks in pressure occur when the pyrolysis gases are required to escape through metal filled regions. Because flow was forced through the metal zones, a difference is discernible between the 1% and 10% inclusion simulations. The permeability of the 10% inclusion metal nodes was an order of

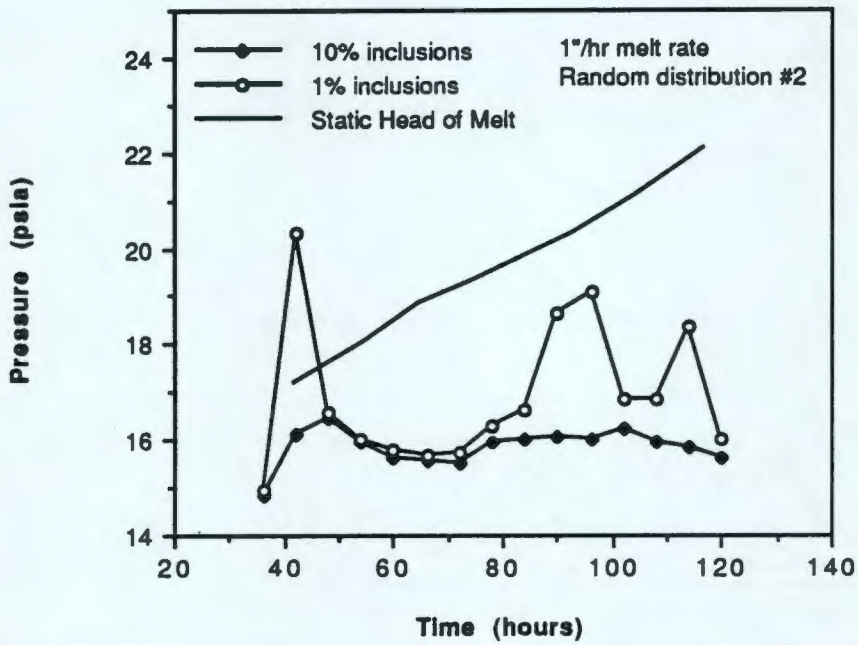


Figure 4.5. Pressure History Beneath the ISV Melt with Random Waste Distribution #2

magnitude greater than the 1% inclusion metal nodes, so the local pressures required to produce a given mass flowrate are reduced.

From these runs, it is apparent that the pyrolyzing gases do effect the pressure beneath the melt, but not strongly. The two methods for modeling the pyrolysis process gave similar results, with the worst case model predicting a higher pressure. The restrictions caused by metal loadings may have as great an impact as the pyrolyzing waste, especially if they form impermeable containment to pyrolyzing material.

It is important to note that these simulations assumed a constant melt progression rate of 1" per hour based on past pilot scale ISV experience. It this possible that the high loading of combustible material for this project would increase the melt progression rate, leading to an increased rate of pyrolysis gas generation.

This modeling work is preliminary and is only intended to suggest the effects of different loading conditions. It is hoped that data will be collected during the demonstration that can be used

9413221.1886

to adjust and partially validate the model for further predictions. The TOUGH2 computer code will be used to investigate the application of ISV for processing the simulated waste for this demonstration. The simulated waste will contain high loadings of solid, compressible waste material, typical of landfills and solid waste trenches. TOUGH2 is an unsaturated groundwater modeling code, capable of treating non-isothermal problems, that predicts pressures underneath the ISV melt (Roberts, Strachan, and Luey 1993). Specifically, TOUGH2 simulations predict whether significant pressure will build beneath an ISV melt. If pressure exceeds the static head, then the displacement of molten soil, due to large, 1 to 2 m diameter gas bubbles rising up through the ISV melt, is possible during processing of combustible waste-loaded sites. These simulations include a moving melt front and simple pyrolysis models and predicts how the gas pressure in the soil below the melt is affected by melt progression rate, soil permeability, combustible and impermeable material loading.

9413221.1887

4.10 ADDITION OF A SOIL BERM INSIDE HOOD

The addition of a soil berm around the inside perimeter of the off-gas hood could subdue the effects of a molten soil displacement. The presence of the berm would control the molten soil overflow so that it would not damage the off-gas hood or pose a risk to site personnel.

4.11 CAMERA

A video camera will be used to observe general conditions inside the off-gas hood. This reduces the frequency that personnel need to enter the control zone and therefore reduces the chances for injury. The video camera will be used to alert operators of the potential for a molten soil event or an outward growth of the melt during the ISV demonstration.

4.12 BENCH-SCALE TESTING

Bench-scale ISV testing was performed to provide a better understanding of the fate of aluminum in an ISV melt and on the affect of aluminum on the ISV process.

Two sets of experiments were performed to investigate the influence of aluminum on the ISV process. The first was a set of crucible melts that were performed to determine the bulk affect on the final ISV product (i.e., the final glass and crystalline product). These crucible tests contained varying mixtures of aluminum metal, soil, stainless steel, and paper. The ranges of compositions were 10 wt% stainless steel, 10-30 wt% paper, 10-30 wt% aluminum, and 30-50 wt% soil. Tests with relatively large pieces of aluminum (approximately 0.5-cm on a side) showed

the aluminum sitting on the top of the final product, while tests with aluminum shavings showed a more uniform distribution of material. These latter tests produced a final product more consistent with typical Hanford soil crucible melts.

Based on the results from the crucible melts, a bench-scale ISV test was performed to evaluate the effect of aluminum on the ISV process. The key parameter of interest during the bench-scale test was the performance of the electrical system during processing. Simulated waste used for bench-scale testing consisted of 10 wt% paper, 10 wt% stainless steel, 50 wt% soil, and 30 wt% aluminum. This material filled a zone that was approximately 36 cm in height. Testing was run for approximately 8 hours at an average power level of 7 kW and was terminated when the melt was half-way into the simulated waste zone (this was done to observe the thermal effects on the unprocessed waste). The presence of a high aluminum and metal loading did not have an apparent adverse affect on the ISV process. Based on the electrical performance of the process, and the observations on the bench-scale block, it is not anticipated that high aluminum loadings will adversely affect the ISV process during pilot-scale testing.

4.13 ENGINEERING CALCULATIONS

4.13.1 High Heat Load and Loss of Hood Vacuum

Engineering calculations were done to determine what the heat load and pressure of the off-gas hood would be during the melting process. Calculation number 100AREA-93-10, which is attached, incorporates all of the preliminary calculations and uses a software program called Hi-Q (Bimillennium Corp., Los Gatos, California) to calculate the hood temperature and pressure as a function of time. Calculation number 100AREA-93-06 (also attached) adds a water spray to the system to see if that will combat the high temperature and pressure spikes that occur as a result of combustion.

Figure 4.6 shows the off-gas hood during ISV operation as the control volume for determining the non-steady state mass and energy balances. The assumptions made to perform the calculations are as follows: 1) all gases behave as ideal gases, 2) the air inlet behaves like flow through an orifice, 3) the air inlet is the only source of air entering the hood and the only other exit when the hood pressure (P_H) is greater than the ambient pressure (P_A) , 4) the hood contents are predominately O_2 and N_2 (air), 5) the off-gas outlet contains all of n_m (the molar flow rate of the base melt gas - H_2O) with the difference being air, 6) the enthalpy of the base melt gas is a linear

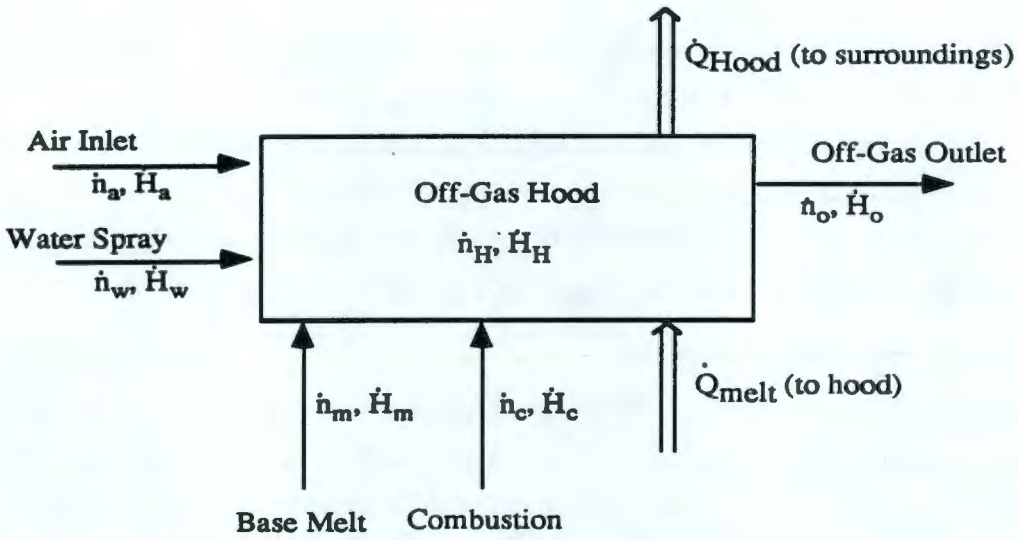


FIGURE 4.6. Flow Diagram of the ISV Melt

function between 373 K and 1473 K, 7) all of the organic matter in the melt zone (cellulose) is combusted in the off-gas hood, 8) the melt shape is cylindrical and combustible materials are encountered at the bottom face only, 9) the net change of moles due to combustion is insignificant relative to the overall system, 10) all water added for the water spray is at 25 °C and all of it is removed from the plenum via the off-gas treatment system, 11) the heat transfer from the off-gas hood to the surroundings results from free convection (no wind) and radiation only, and 12) the heat transfer from the melt to the hood equals the heat transfer from the hood to the surroundings at 573 K and is constant.

The Hi-Q function 'OdeIvpRKF' was used to simultaneously solve the mass and energy balances. This function solves a system of nth-order differential equations subject to some initial conditions and uses an implementation of the Runge-Kutta formulas developed by E. Fehlberg in 1970. Without the water spray system, it is estimated that the temperature in the off-gas plenum has the potential to increase to 785°C due to combustion of organics in the off-gas hood. The pressure in the off-gas hood, however, did not become positive. For runs with the water spray system, the calculations indicate that a set point plenum temperature can be maintained (675°C for

calculation 100AREA-93-06). Again, the pressure in the hood was shown to remain negative relative to the ambient surroundings.

Once the hood temperatures and pressures were estimated with and without a water spray system (100AREA-93-06 and 100AREA-93-10, respectively), a calculation was performed to determine if the external devices located near the off-gas hood (i.e., electrical cables, pneumatic hoses, fibergrate platform, and steps) were in any danger from excessive heat (100AREA-93-07). Based on this analysis, the existing placement of the exterior devices located near the off-gas hood is sufficient to prevent these devices from experiencing significant temperatures.

9413221.1890

4.13.2 Aluminum Oxidation

Calculation number 100AREA-93-05 (attached) predicts the fate of aluminum in the melt based on the standard free energy of formation of oxides as a function of temperature. The estimated melt properties were then used to predict the physical properties of the melt by employing a model based on the Hanford Waste Vitrification Plant (HWVP) glass.

The possibility of a thermite reaction occurring when the aluminum oxidized to alumina was also reviewed. A library search was conducted to determine the conditions required for a thermite reaction and these required conditions were compared to those that will be available during the 100 Area pilot-scale ISV demonstration.

Thermite is a mixture of powdered iron (III) oxide (Fe_2O_3) and powdered or granular aluminum. The aluminum has a higher affinity for O_2 than iron, and if a mixture of iron oxide and aluminum powder is raised to the combustion temperature of aluminum an intense reaction occurs:

$$Fe_2O_3 + 2Al \text{ -------> } Al_2O_3 + 2Fe + 824 \text{ kJ}$$

Under favorable conditions this thermite reaction produces temperatures of about 2,700 °C. This is high enough to turn the newly formed metallic iron into a white-hot liquid that acts as a heat reservoir to prolong and spread the heat (igniting action). Thermite is composed of approximately 73% ferric oxide and 27% fine granular aluminum.

Several factors affect the occurrence of a thermite reaction. For instance, the particle size of the oxide and especially the aluminum can affect the rate of reaction. The physical form of the reactants are important because the surface/weight ratio and the free-running characteristics of the particles assist steady and even combustion when the mass is reacting. Under ideal conditions, the aluminum and iron oxide exist as fine powders. Another important factor that affects the

occurrence of a thermite reaction is the composition of the waste prior to heating. Additions to the mix can absorb heat during the reaction and therefore prevent the high temperatures that can occur when just aluminum and iron oxide are present (Encyclopedia of Chemical Technology, Thorpe's Dictionary of Applied Chemistry).

The conditions that will exist during the 100 Area ISV pilot-scale demonstration do not warrant a thermite reaction. The aluminum will not be in the form of a fine granular powder and there are many other constituents in the simulated waste that will act as heat absorbers to keep any reactions occurring under control.

4.13.3 High CO Levels

Engineering calculation 100AREA-93-12 estimates a maximum steady-state CO concentration level of 9.0% (90,000 ppm). This maximum is based on the assumption that all of the combustible material present in the vitrification zone is converted to CO once in the off-gas hood. Using results from the 1990 large-scale treatability test at the 116-B-6A Crib (Luey et al. 1992b), a calculation to estimate the combustion efficiency of the ISV process was performed. This analysis (100AREA-93-13) predicted a maximum CO concentration for the large-scale test of 2.5% (25,000 ppm). The average CO levels measured during the large-scale test was 0.2% (2000 ppm). This indicates that the ISV process converted 92% of the available carbon to a form other than CO, or that 8% of the maximum CO concentration was observed in the off-gas stack. Using an 8% conversion factor, it is estimated that the levels of CO that will be observed during the 100 Area demonstration will be 0.72% (7200 ppm).

4.13.4 Formation of H_2

As discussed previously, there exists the possibility that steam in the off-gas hood (either from the melt or from the water spray) will convert some of the CO produced from combustion to CO_2 and H_2 gas per the "water gas shift reaction":

$$CO(g) + H_2O(g) \text{ -------> } CO_2(g) + H_2(g) \quad (T = 250°C, \text{ iron oxide catalyst})$$

The concern is the low LEL of H_2 (4%) and the high explosive energy of H_2.

The maximum CO concentration of 9% and the expected concentration of 0.72% were used in calculation 100AREA-93-14 to estimate the amount of H_2 that could be produced during this demonstration. Using an equilibrium relationship identified by Moe (1962), H_2 concentrations

were estimated at 200°C and 350°C. At these temperatures, the reaction is favorable and goes to completion with CO the limiting reactant. Therefore, a maximum H_2 concentration would be 9% with a lower value of 0.72%. It should be noted that this reaction requires an iron catalyst to produce such a favorable conversion to products. Based on the fact that the ISV system does not contain iron suitable for a catalyst, and the expected combustion efficiency for the conversion of material to CO_2, it is not anticipated that the LEL for H_2 would be approached for this demonstration.

4.14 SIZE OF HOOD MUCH LARGER THAN SIZE OF TRENCH

Figure 4.7 illustrates that the dimensions of the base of the pilot-scale off-gas hood is greater than the design of the trench to be used during the demonstration and greater than the dimensions of the projected ISV melt. This control measure alleviates some of the concern of outward growth of the melt beyond the boundaries of the off-gas hood and also alleviates concerns of underground fires extending beyond the boundaries of the off-gas hood. The projected melt shape is based on the results from the ISV computational model and may be a conservative estimate since the ISV model is performed with the assumption of a homogeneous soil site.

4.15 SOIL PRESSURE MEASUREMENTS

The pressure in the soil column and simulated waste will be measured via pressure sensors connected to sampling points by teflon tubing. Pressure data will be initially collected at a nominal rate of once every 30 seconds. This data will be used as an indicator of the gas behavior beneath, and surrounding, the ISV melt.. If the soil pressure trends toward the static head of the melt, operators will be alerted that a molten soil displacement event may be possible and they can begin to reduce the power in order to combat this event.

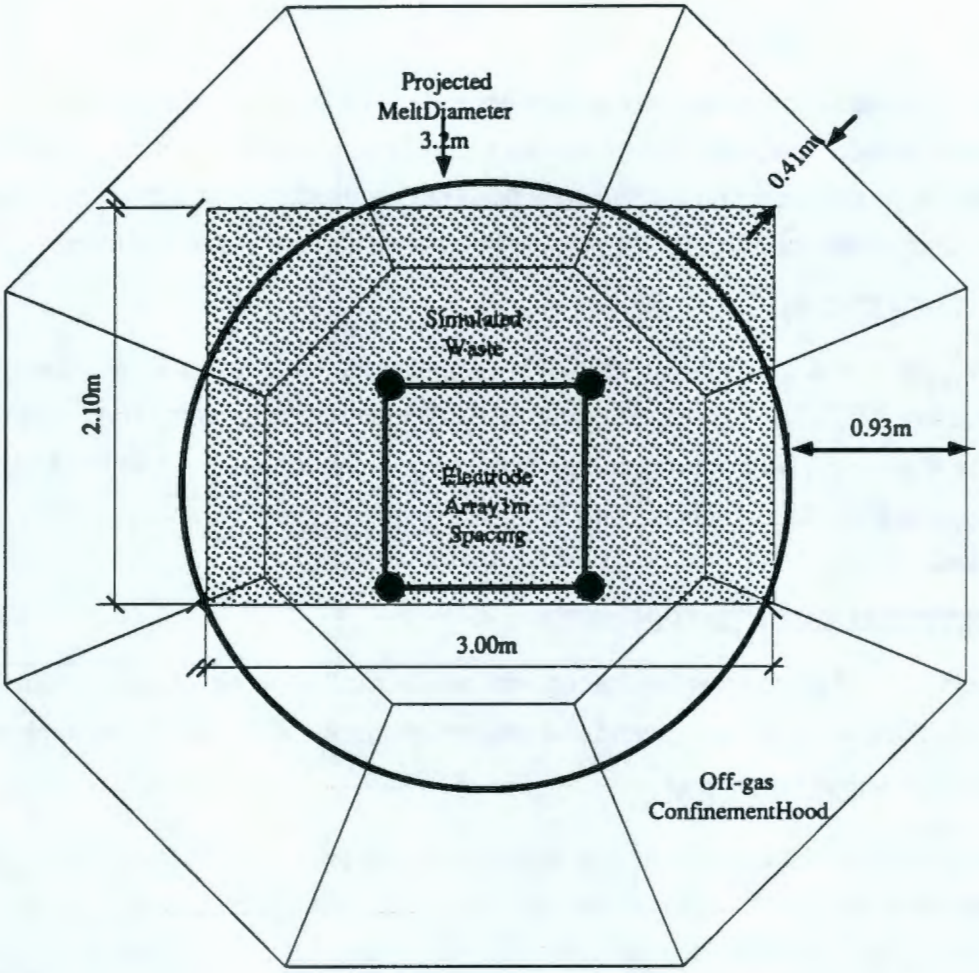


Figure 4.7. Projected Melt Shape Relative to Pilot-Scale Off-Gas Hood

5.0 IMPLEMENTATION

This section describes when each mitigator needs to be implemented and how they should be implemented in order to control and/or prevent each of the test specific potential events. Some mitigators will be implemented on a continuous basis during the demonstration. These mitigators include the control zone, monitoring, the passive hood vent, and the use of a camera.

5.1 HIGH HEAT LOAD

During the pilot-scale demonstration, if the hood temperature is trending upwards and a temperature above 425 °C is reached, the water spray system will be implemented. As previously described, the water spray will remove energy from the gases in the off-gas hood by evaporative cooling, thus mitigating the high heat load. If the water spray system is unsuccessful, then power will be reduced.

5.2 ELECTRICAL SHORTING IN MELT

The criteria and procedures for dealing with an electrical shorting situation are discussed in the SOP for the pilot-scale ISV equipment and will not be discussed further in this analysis.

5.3 LOSS OF HOOD VACUUM

The inclusion of a passive hood vent will be arranged prior to the start-up of the pilot-scale demonstration to aid in preventing the hood from becoming overly pressurized. This passive system will be in place the entire demonstration. In addition to this passive vent, a seal pot vent system also exists on the off-gas hood. This will allow for controlled in-leakage during normal operations and also allows for passive venting during pressurizations.

During the pilot-scale demonstration, if the passive hood vent is not sufficient and the hood pressure increases to 2.5 cm W.C. (the design limit for the hood is 12.7 cm. W.C.), then the water spray system will be implemented. As previously described, the water spray will remove energy from the gases in the off-gas hood by evaporative cooling, thus mitigating the pressure increases associated with transient gas releases from the ISV melt upon combustion. If the water spray is insufficient and the pressure in the off-gas hood increases to a value greater than 2.5 cm W.C., then the back-up blower system for the pilot-scale unit will be employed (see the SOP for the pilot-scale ISV equipment for a description of the back-up blower system). A set point of 4 cm W.C. will be used as a trigger for the back-up blower. If the hood continues to increase with both the

9413221.1894

water spray and back-up blower systems actuated, then the hood pressurization will be combated by slowing down the rate of gas and heat evolution from the ISV melt with a reduction in power.

5.4 HIGH CO/CO2 EMISSIONS

Ambient and stack CO and CO_2 concentrations will be monitored using infrared equipment. The frequency of these measurements will be between 1 s and 10 minutes. If the concentrations are found to exceed the ACGIH limits (Table 4.2) or 10% of the LEL, the melt rate will be slowed by reducing the power until the stack conditions decrease and warrant the use of full power again. This procedure was successfully demonstrated during the large-scale operations at the 116-B-6A Crib (Luey et al. 1992).

9413221.1895

5.5 OUTWARD MELT GROWTH

The best mitigator for the prevention of an outward growth of melt, is the design of the waste simulation and off-gas hood prior to the pilot-scale test. A random placement of the simulated waste will hopefully prevent preferential outward growth of the melt. In addition, a control zone around the pilot-scale test site will help prevent injuries to site personnel in the event of significant outward growth of the ISV melt by establishing a "safe distance" from the ISV off-gas hood.

During the pilot-scale demonstration, the molten zone will be monitored with type K and type C thermocouples every 1 - 30 minutes in order to detect any outward growth of melt. In addition, the use of the video camera can also alert operators that the melt is growing outward.

5.6 UNDERGROUND FIRES

During the pilot-scale demonstration, the path of advancing melt front will be monitored with type K and type C thermocouples every 1 - 30 minutes in order to detect any underground fires. Since the off-gas hood will be much larger than the trench, any underground fires that occur will not propagate beyond the boundaries of the hood and therefore should pose no danger.

5.7 MOLTEN SOIL DISPLACEMENT

The primary indication of the potential for a molten soil event will be the pressure measurements from the vitrification zone. If the pressure beneath and/or surrounding the ISV melt being to trend upwards and approach the static head of the molten glass, then power will be reduced to slow down the rate at which gases are generated in the vitrification zone. The addition

of a soil berm around the inside perimeter of the pilot-scale off-gas hood and the use of the control zone will help prevent injuries to site personnel in the event of a molten soil displacement. The use of a video camera during the ISV melt will also assist operators by allowing characterization of the melt surface during processing.

9413221.1896

6.0 REFERENCES

Buelt, J.L., C.L. Timmerman, K.H. Oma, V.F. FitzPatrick, and J.G. Carter. 1987. In Situ Vitrification of Transuranic Waste: An Updated Systems Evaluation and Applications Assessment. PNL-4800 Suppl.1, Pacific Northwest Laboratory, Richland, Washington.

Callow, R.A., L.E. Thompson, J.R. Weidner, C.A. Loehr, B.P. McGrail, and S.O. Bates. 1991. In Situ Vitrification Application to Buried Waste: Final Report of Intermediate Field tests at Idaho National Engineering Laboratory. EGG-WTD-9807, Idaho National Engineering Laboratory, Idaho Falls, Idaho.

Emrich, W. 1985. Handbook of Charcoal Making, The Traditional and Industrial Methods. Solar Energy R&D in the European Community, Series E, Volume 7, Energy from Biomass. D. Reidel Publishing Company.

Encyclopedia of Chemical Technology, 3rd Edition, Vol. 2 and Vol. 5. John Wiley and Sons.

Geosafe Corporation. 1993. Investigation into the Causes and Application Significance of the Melt Displacement Event Occurring During Geosafe Operational Acceptance Test #2 (OAT-2). GSC-2301, Geosafe Corporation, Richland, Washington.

Hillel, Daniel. 1980. Fundamentals of Soil Physics. Academic Press, New York.

Luey, J., T.D. Powell, W.O. Heath, and R.L. Richardson. 1992a. Evaluation of New Concepts for In Situ Vitrification: Power System, Melt Insulation, and Off-Gas Containment. PNL-8231, Pacific Northwest Laboratory, Richland, Washington.

Luey, J., S.S. Koegler, W.L. Kuhn, P.S. Lowery, and R.G. Winkleman. 1992b. In Situ Vitrification of a Mixed-Waste COntaminated Soil Site: The 116-B-6A Crib at Hanford. PNL-8281, Pacific Northwest Laboratory, Richland, Washington.

McKeough, P. et. al.1985. Techno-Economic Assessment of Direct Biomass Liquefaction Processes. Technical Research Centre of Finland, Research Report #337, Espoo, Finland.

Nickelson, D.F., J. Luey, and R.A. Callow. 1992. ISV Technology Development Plan for Buried Waste. EGG-WTD-10325, Idaho National Engineering Laboratory, Idaho Falls, Idaho.

Powell, T.D. 1993. In Situ Vitrification Pilot-Scale Test System: Safe Operating Procedure #49. PNL-8729, Pacific Northwest Laboratory, Richland, Washington.

Pruess, K. 1987. TOUGH User's Guide. LBL-20700, Lawrence Berkeley Laboratory, University of California, Berkeley, California.

Pruess, K. 1990. TOUGH2 - A General - Purpose Numerical Simulator for Multiphase Fluid and Heat Flow. LBL-29400, Lawrence Berkeley Laboratory, University of California, Berkeley, California.

9413221.1897

Roberts, J.S., C.W. Strachan, and J. Luey. 1993. Investigation of Potential for Occurrence of Molten Soil Displacement Events During In Situ Vitrification of Combustible Wastes. PNL-SA-21870, Pacific Northwest Laboratory, Richland, Washington.

Roberts, J.S., S.L. Woosley, D.L. Lessor, and C.W. Strachan. 1992. Preliminary Investigation of the Potential for Transient Vapor Release Events During In Situ Vitrification Based on Thermal-Hydraulic Modeling. PNL-8170, Pacific Northwest Laboratory, Richland, Washington.

Rockford, M.L., M.J. Fayer, and G.W. Gee. 1988. Characterization of Unsaturated Hydraulic Conductivity at the Hanford Site. PNL-6488, Pacific Northwest Laboratory, Richland, Washington.

Schiefelbein, G.F. 1985. Biomass Gasification Research: Recent Results and Future Trends. PNL-SA-12841, Pacific Northwest Laboratory, Richland Washington.

Thorpe's Dictionary of Applied Chemistry, 4th Edition, Vol. 11. Longmans.

Tixier, J.S., L.A. Corathers, and L.D. Anderson. 1992. Vitrification of Underground Storage Tanks: Technology Development, Regulatory Issues, and Cost Analysis. In *Waste Management '92*, vol 2, ed. R. G. Post, pp. 1521-1528. March 1-5, 1992, Tucson, Arizona.

Van Wylen, G.J., and R.E. Sonntag 1978. Fundamentals of Classical Thermodynamics. Second Edition, Revised Printing, SI Version. John Wiley and Sons, Inc.

9413221.1898

DOE/RL-93-45
Draft A

ATTACHMENT A

Engineering Calculations

9413221.1899

THIS PAGE INTENTIONALLY
LEFT BLANK

ESTIMATION OF 100 AREA SOLID WASTE COMPOSITION

BASED ON WHC-SD-EN-FDC-003 "MATERIAL HANDLING AND ANALYTICAL SYSTEMS FUNCTIONAL DESIGN CRITERIA FOR THE 100-B/C AREA MACROENGINEERING PROTOTYPE PROJECT"

LEAD = 71.80 TONS
ALUMINUM = 255.0 TONS
Pb/Cd = 319.90 TONS
BORON = 2.6 TONS
MERCURY = 1.05 TONS
GRAPHITE = 0.64 TONS
OTHER = 761 TONS
} SEE TABLE 2 (ATTACHED).

(OTHER = SOFT WASTE, DESICCANT AND MISC. MATERIAL).

ASSUMPTIONS

- TREAT LEAD AND Pb/Cd AS LEAD. (ρ = 11,340 kg/m³)
- CONSIDER ALUMINUM AS SOLID ALUMINUM. (ρ = 2,700 kg/m³)
- DO NOT CONSIDER MINOR QUAN. OF MERCURY, GRAPHITE AND BORON.
- TREAT "OTHER" AS PAPER (ρ = 700 kg/m³)

DENSITIES FROM CRC HANDBOOK OF CHEMISTRY AND PHYSICS, 63rd ED.

- ASSUME 15 WT % SOIL (ρ = 1650 kg/m³, HANFORD SOIL).

TOTAL MASS LEAD = 391.70 TONS = 355,660 kg (.454 kg/lb)
TOTAL MASS ALUMINUM = 255.0 TONS = 231,540 kg
TOTAL MASS PAPER = 761.0 TONS = 690,990 kg. (2000 lbs/ton)

TOTAL MASS SOIL:

$$\frac{\text{MASS SOIL}}{\text{MASS SOIL + WASTE}} = 0.15 \Rightarrow \text{MASS SOIL} = 0.15(\text{SOIL}) + 0.15(\text{WASTE})$$

$$(\text{SOIL})0.85 = 0.15(1{,}278{,}190 \text{ kg})$$

$$\text{SOIL} = 225{,}560 \text{ kg.}$$

∴ TOTAL MASS IN SOLID WASTE TRENCH = 1,503,750 kg.

WT % SOIL = 15%
WT % LEAD = 23.7%
WT % ALUM. = 15.4%
WT % PAPER = 45.9%

VOLUME PERCENT OF SOLID WASTE TRENCH:

		VOLUME %
VOLUME SOIL = 225,560 kg / (1650 kg/m³)	= 136.70 m³	11.0
VOLUME LEAD = 355,660 kg / (11,340 kg/m³)	= 31.36 m³	2.5
VOLUME ALUM. = 231,540 kg / (2,700 kg/m³)	= 85.76 m³	6.9
VOLUME PAPER = 690,990 kg / (700 kg/m³)	= 987.13 m³	79.6
	1,240.95 m³	100.00

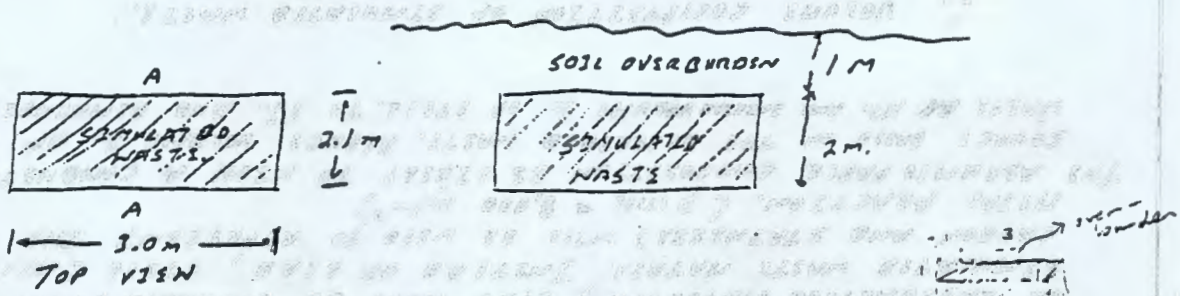
9413221.0900

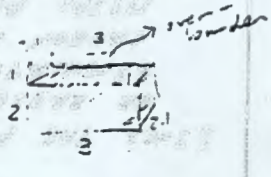
LARGE-SCALE SIMULATIONS PERFORMED BY J.S. ROBERTS WERE BASED ON CALCULATION 100AREA-92-01 WHICH ASSUMED: 50% BY VOLUME COMB. (WOOD)
15% BY VOLUME METAL
35% BY VOLUME SOIL.

PILOT-SCALE SIMULATIONS WILL USE THE RANGE OF COMPOSITIONS GIVEN IN THIS CALCULATION AND 100AREA-92-01. THIS CALCULATION IS THE MORE CONSERVATIVE AND WORST CASE AND PROVIDES ESTIMATION OF WASTE LOADING EFFECTS.

ESTIMATION OF PILOT-SCALE COMPOSITION

CONFIGURATION OF SIMULATED WASTE TRENCH WILL BE:





TOTAL VOLUME OF WASTE = (2 m)(2.1 m)(3.0 m) = 12.6 m^3
TOTAL VOLUME OF OVERBURDEN = (1 m)(2.1 m)(3.0 m) = 6.3 m^3

SINCE THE PILOT-SCALE ISV TEST WILL NOT USE REGULATED, HAZARDOUS, OR RADIOACTIVE MATERIALS, LEAD WILL BE EXCLUDED FROM THIS SIMULATED WASTE MATRIX. INSTEAD OF LEAD, STEEL (MIXTURE OF CARBON AND STAINLESS) WILL BE USED TO REPRESENT THE LEAD METAL FRACTION. (ρ_{STEEL} = 8,000 kg/m^3)
THE ASSUMED PAPER COMPOSITION IS LIKELY TO HIGH A COMBUSTIBLE SOURCE BASED ON THE DESCRIBED WASTE. REDUCE VOLUME % OF PAPER WASTE BY 15% AND INCREASE VOLUME % OF STEEL TO 5% AND REMAINDER FOR SOIL

∴ VOLUME COMPOSITION OF SIMULATED WASTE:

SOIL = 20.4 VOLUME %
PAPER = 67.7 VOLUME % = 85(7%)
ALUM = 6.9 VOLUME %
STEEL = ~~X~~5.0 VOLUME %.

		WT %
⟹ WEIGHT SOIL = (0.204)(12.6 m^3)(1650 kg/m^3)	= 4,241.1 kg	24.1
WEIGHT PAPER = (0.677)(12.6 m^3)(700 kg/m^3)	= 5,971.1 kg	33.9
WEIGHT ALUM = (.069)(12.6 m^3)(2700 kg/m^3)	= 2,347.4 kg	13.3
WEIGHT STEEL = (0.050)(12.6 m^3)(8,000 kg/m^3)	= 5,040.0 kg	28.7
	17,599.6 kg	100.0.

9413221.1901

COMPOSITION OF ENTIRE SIMULATED WASTE SETTING.

MASS OVERBURDEN = (6.3 m^3)(1650 kg/m^3) = 10,395 kg.

∴ TOTAL MASS (SOIL OVERBURDEN + SIM. WASTE) = 27,994.6 kg.

WT% OF SETTING.

SOIL = (10,395 + 4741.1)/27,994.6 = 52.3 WT%
PAPER = 5,971.1 / 27,994.6 = 21.3 WT%
ALUM = 2,347.4 / 27,994.6 = 8.4 WT%
STEEL = 5,040.0 / 27,994.6 = 18.0 WT%
100.0.

9411322.1902

ESTIMATION OF 100 AREA SOLID WASTE COMPOSITION

BASED ON "PNL-SS-BH-FEL-001 "[illegible] HANDLING AND PHYSICAL SYSTEMS FUNCTIONAL DESIGN CRITERIA FOR THE 100-B/C AREA MACROENGINEERING PROTOTYPE PROJECT"

LEAD = 71.80 TONS
ALUMINUM = 255.0 TONS
Pb/Cd = 319.90 TONS
BORON = 2.6 TONS
MERCURY = 1.05 TONS
GRAPHITE = 0.64 TONS
OTHER = 761 TONS
} SEE TABLE 2 (ATTACHED)

(OTHER = SOFT WASTE, DESICCANT AND MISC MATERIAL).

ASSUMPTIONS

- TREAT LEAD AND Pb/Cd AS LEAD. (ρ = 11,340 kg/m³)
- CONSIDER ALUMINUM AS SOLID ALUMINUM. (ρ = 2,700 kg/m³)
- DO NOT CONSIDER MINOR QUAN OF MERCURY, GRAPHITE AND BORON.
- TREAT "OTHER" AS PAPER (ρ = 700 kg/m³)

DENSITIES FROM CRC HANDBOOK OF CHEMISTRY AND PHYSICS, 63rd ED.

- ASSUME 15 WT % SOIL (ρ = 1650 kg/m³, HANFORD SOIL).

TOTAL MASS LEAD = 391.70 TONS = 355,660 kg (.454 kg/lb)
TOTAL MASS ALUMINUM = 255.0 TONS = 231,540 kg
TOTAL MASS PAPER = 761.0 TONS = 690,990 kg.

TOTAL MASS SOIL:

$$\frac{\text{MASS SOIL}}{\text{MASS SOIL + WASTE}} = 0.15 \Rightarrow$$

MASS SOIL = 0.15 (SOIL) + 0.5 (WASTE)
(SOIL)0.85 = 0.15 (1,278,190 kg)
SOIL = 225,560 kg.

∴ TOTAL MASS IN SOLID WASTE TRENCH = 1,503,750 kg.

WT % SOIL = 15 %
WT % LEAD = 23.7 %
WT % ALUM. = 15.4 %
WT % PAPER = 45.9 %

VOLUME PERCENT OF SOLID WASTE TRENCH:

		VOLUME %
VOLUME SOIL = 225,560 kg / (1650 kg/m³)	= 136.70 m³	11.0
VOLUME LEAD = 355,660 kg / (11,340 kg/m³)	= 31.36 m³	2.5
VOLUME ALUM. = 231,540 kg / (2,700 kg/m³)	= 85.76 m³	6.9
VOLUME PAPER = 690,990 kg / (700 kg/m³)	= 987.13 m³	79.6
	1,240.95 m³	100.00

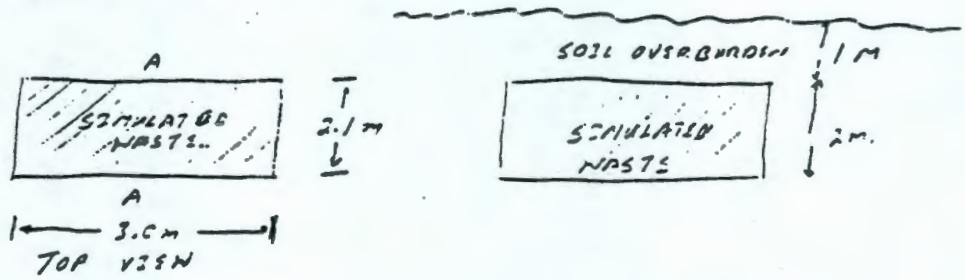
9413221.1903

LARGE-SCALE SIMULATIONS PERFORMED BY J.S. ROBERTS WERE BASED ON CALCULATION [illegible] WHICH ASSUME: 50% BY VOLUME CONC. CHUNKS, 12% BY VOLUME METAL, 38% BY VOLUME SOIL.

PILOT-SCALE SIMULATIONS WILL USE THE RANGE OF COMPOSITIONS GIVEN IN THIS CALCULATION AND [illegible]. THIS CALCULATION IS THE MOST CONSERVATIVE AND WORST CASE AND PROVIDES ESTIMATION OF WASTE LOADING EFFECTS.

ESTIMATION OF PILOT-SCALE COMPOSITION

CONFIGURATION OF SIMULATED WASTE TRENCH WILL BE:



TOTAL VOLUME OF WASTE = (3 m)(2.1 m)(3.0 m) = 18.9 m^3
TOTAL VOLUME OF OVERBURDEN = (1 m)(2.1 m)(3.0 m) = 6.3 m^3

SINCE THE PILOT-SCALE ISV TEST WILL NOT USE REGULATED, HAZARDOUS, OR RADIOACTIVE MATERIALS, LEAD WILL BE EXCLUDED FROM THE SIMULATED WASTE MATRIX. INSTEAD OF LEAD, STEEL (MIXTURES OF CARBON AND STAINLESS) WILL BE USED TO REPRESENT THE LEAD METAL FRACTION. (ρ_{STEEL} = 8,000 kg/m^3)
THE ASSUMED PAPER COMPOSITION IS LIKELY TO HIGH A COMBUSTIBLE SOURCE BASED ON THE DESCRIBED WASTE. REDUCE VOLUME % OF PAPER WASTE BY 15% AND INCREASE VOLUME % OF STEEL TO 5% AND REMAINDER FOR SOIL

∴ VOLUME COMPOSITION OF SIMULATED WASTE:

SOIL = 20.4 VOLUME %
PAPER = 67.7 VOLUME %
ALUM = 6.9 VOLUME %
STEEL = 5.0 VOLUME %

		WT %
⟹ WEIGHT SOIL = (0.204)(18.9 m^3)(1650 kg/m^3)	= 4,241.1 kg	24.1
WEIGHT PAPER = (0.677)(18.9 m^3)(700 kg/m^3)	= 5,971.1 kg	33.9
WEIGHT ALUM = (0.069)(18.9 m^3)(2700 kg/m^3)	= 2,347.4 kg	13.3
WEIGHT STEEL = (0.050)(18.9 m^3)(8,000 kg/m^3)	= 5,040.0 kg	28.7
	17,599.6 kg	100.0

9413221.1904

COMPOSITION OF ENTIRE SIMULATED WASTE SETTLING.

MASS OVERBURDEN = (6.3 m^3)(1650 kg/m^3) = 10,395 kg.

∴ TOTAL MASS (SOIL OVERBURDEN + SIM. WASTE) = 27,994.6 kg.

WT% OF SETTLING.

SOIL = (10,395 - 4741.1)/27,994.6 = 52.3 WT%
PAPER = 5,971.1 / 27,994.6 = 21.3 WT%
ALUM = 2,347.4 / 27,994.6 = 8.4 WT%
STEEL = 5,040.0 / 27,994.6 = 18.0 WT%
100.0.

9413221.1905

From Calculation No. 100Area 92-03:

Estimated Mass of Process Volume components =

2619 kg Al
511 kg Cr
207 kg Ni
4913 kg Fe
28.41 kg C
295 kg K_2O
494 kg Na_2O
2221 kg Al_2O_3
982 kg CaO
1563 kg Fe_2O_3
471 kg MgO
9968 kg SiO_2
319 kg other (TiO_2, P_2O_5, ZrO_2)

24616.4 kg Total

Estimated Weight %'s of Process Volume:

10.6 % Al(s)
2.08 % Cr(s)
0.72 % Ni(s)
20 % Fe(s)
0.12 % C(s)
1.2 % K_2O
2 % Na_2O
9.04 % Al_2O_3
3.99 % CaO
6.35 % Fe_2O_3
1.9 % MgO
40.5 % SiO_2
1.3 % other

Based on conversations with Rick Merrill (Melter Group), you can not use the standard reduction potentials used in calc. No. 100Area 9 to predict what will oxidize and what will reduce because these equated for acidic solutions rather than molten soil. Instead I used Fig 7.7 (attached) which gives standard free energy of form of oxides as a function of temperature and is from F.D. Rich and J.H.E. Jeffes, J. "Iron Street Inst.", 160, 261 (1948) and modified L.S. Darken and R.W. Gurry, "Physical Chemistry of Metals", McGraw Hill, New York, 1953.

You can get a ΔG° (kcal) value from the figure for an assumed melt temperature of 1600°C. The greater the magnitude of a negative ΔG° the more favorable is the formation of the products.

9413221.1906

ΔG° values @ 1600°C :

$4/3\,Al + O_2 = 2/3\,Al_2O_3$ $\Delta G^\circ = -170$ Kcal = 3

$4/3\,Cr + O_2 = 2/3\,Cr_2O_3$ $\Delta G^\circ = -100$ Kcal = 3

$2Ni + O_2 = 2NiO$ $\Delta G^\circ = -30$ Kcal = 3

$3/2\,Fe + O_2 = 1/3\,Fe_3O_4$ $\Delta G^\circ = -55$ Kcal = 1

$C + O_2 = CO_2$ $\Delta G^\circ = -95$ Kcal - negligible amount

$4K + O_2 = 2K_2O$ no intersection @ 1600°C ∴ dissociate

$4Na + O_2 = 2Na_2O$ no intersection @ 1600°C ∴ dissociate

$2Ca + O_2 = 2CaO$ $\Delta G^\circ = -209$ Kcal = 3

$2Mg + O_2 = 2MgO$ $\Delta G^\circ = -169$ Kcal = 10

$Si + O_2 = SiO_2$ $\Delta G^\circ = -128$ Kcal = 3

$Ti + O_2 = TiO_2$ $\Delta G^\circ = -136$ Kcal = 3 } (negligible amount

$2/3\,P_2 + O_2 = 2/3\,P_2O_5$ $\Delta G^\circ = -70$ Kcal = 1 }

Based on these ΔG° values and conversations with Matt Cooper, Charlie Freeman, and Rich Merrill we can assume that all the Fe_2O_3 will reduce to $Fe(s) + O_2$ and enough SiO_2 will reduce to $Si(s)$ and O_2 to allow complete oxidation of the $Al(s)$ to Al_2O_3.

(1) $Fe_2O_3 \rightarrow 2Fe + 3/2\,O_2$

1563 kg Fe_2O_3 = 9.79 kmol

$9.79\text{ kmol } Fe_2O_3 \left(\frac{3/2\text{ kmol } O_2}{1\text{ kmol}}\right) = 14.69\text{ kmol } O_2$ produced

$9.79\text{ kmol } Fe_2O_3 \left(\frac{2\text{ kmol } Fe}{1\text{ kmol}}\right) = 19.58\text{ kmol } Fe(s)$ produced

(2) for complete oxidation of Al(s) :

$4/3\,Al + O_2 \rightarrow 2/3\,Al_2O_3$

2619 kg Al = 97 kmol Al

$97\text{ kmol Al} \left(\frac{1\text{ kmol } O_2}{4/3\text{ kmol}}\right) = 72.75\text{ kmol } O_2$ needed

$97\text{ kmol Al} \left(\frac{2/3\text{ kmol } Al_2O_3}{4/3\text{ kmol}}\right) = 48.5\text{ kmol } Al_2O_3$ produced

9413221.1907

To completely oxidize Al to Al_2O_3 need 72.75 Kmol O_2

→ have 14.69 Kmol O_2 from reduction of Fe_2O_3

∴ need 58.06 Kmol O_2 from reduction of SiO_2

(3) $SiO_2 \longrightarrow Si(s) + O_2$

$$9965\,kg\ SiO_2 = 165.75\ Kmol\ SiO_2$$

$$58.06\ Kmol\ O_2\ produced \left(\frac{1\ Kmol\ SiO_2}{1\ Kmol\ O_2}\right) = 58.06\ Kmol\ SiO_2\ reacted$$

$$= 58.06\ Kmol\ Si(s)\ produced$$

In Summary:

Assumptions =
- Only O_2 source is from the soil
- All Fe_2O_3 reduces to $Fe(s)$ and O_2
- Enough SiO_2 reduces to allow complete oxidation of $Al(s)$
- During melt all metals in a reduced state drop out and form a residual metal waste
- Na_2O and K_2O dissociate to ions and remain conductive

Estimated Mass of melt (oxides Only):

7173 kg	Al_2O_3
982 kg	CaO
471 kg	MgO
6479 kg	SiO_2
319 kg	other (TiO_2, P_2O_5, ZrO_2)
15424 kg	

Estimated Weight % 's of melt:

46.5% Al_2O_3
6.37% CaO
3.06% MgO
42% SiO_2
2.07% other

Estimated Mass of metal Residual:

511 kg	Cr
227 kg	Ni
6006 kg	Fe
1631 kg	Si
8375 kg	

9413221.1908

Estimated weight % of metal residual:

6.1 % Cr
2.7 % Ni
71.7 % Fe
19.5 % Si

Spoke to Pavel Hrma and gave him the estimated oxide compositions in the glass so that he could approximate the physical properties with his model.

For a glass with 46.5 wt % Al_2O_3
6.37 wt % CaO
2.06 wt % MgO
42 wt % SiO_2
2.07 wt % (TiO_2, P_2O_5, ZrO_2)

Pavel said that at these compositions you actually have a metallurgical slag and that his model would not be able to approximate the properties very accurately. His model is based on the HLWVP glass at 1150°C and its boundaries are only within the HLWVP glass compositions.
His model predicts the following properties:

Rough Estimates based on HLWVP Model
- melts @ ~ 1300°C
- viscosity @ 1300°C ≈ 1-7 Pa·s ⇒ low viscosity
- electrical conductivity @ 1300°C ≈ 10 $\Omega^{-1}m^{-1}$ ⇒ low because no alkali oxides
- durability = not very high because low silica

Pavel suggested using the book, Turkdogan, E.T. "Physicochemical Properties of Molten Slags and Glasses", 1983 The Metals Society, London.

Table 1.22 - Viscosity of CaO - Al_2O_3 - SiO_2 melts
(assume melt = 40% SiO_2, 50% Al_2O_3, 10% CaO)

η = 3.9 P @ 1500°C = 0.39 Pa·s

Electrical conductivity is not apparent from diagrams.

Also: see attachment B which shows melt temperature for a CaO - Al_2O_3 - SiO_2 composite.

From PNL-4800 you can get the physical properties of MOLTEN Hanford Soil and compare them to those of the melt.

Fusion Temp ≈ 1100°C
Electrical conductivity ≈ 2 $\Omega^{-1}m^{-1}$? PREDICTED. Estimates for Hanford Soil
Viscosity ≈ 50 Pa·s

Title	Project
Aluminum Oxidation Potential - 2	100 Area ISV Pilot Scale Demo

Prepared by:	Date	Reviewed by:	Date
Gill Carlson	2/8/93	[signature]	2/11/93

9413221.1909

Attachment A pg. 5/

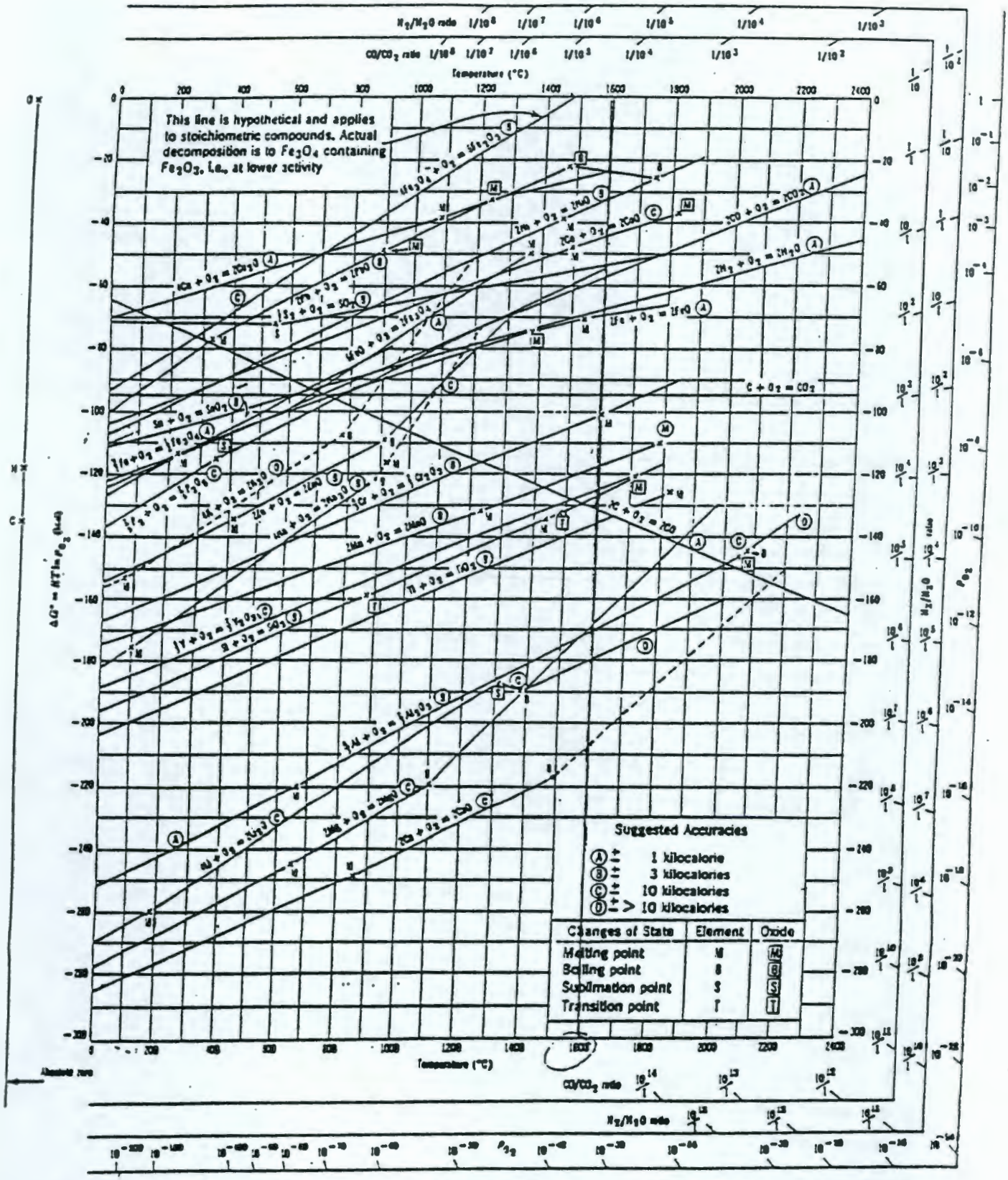


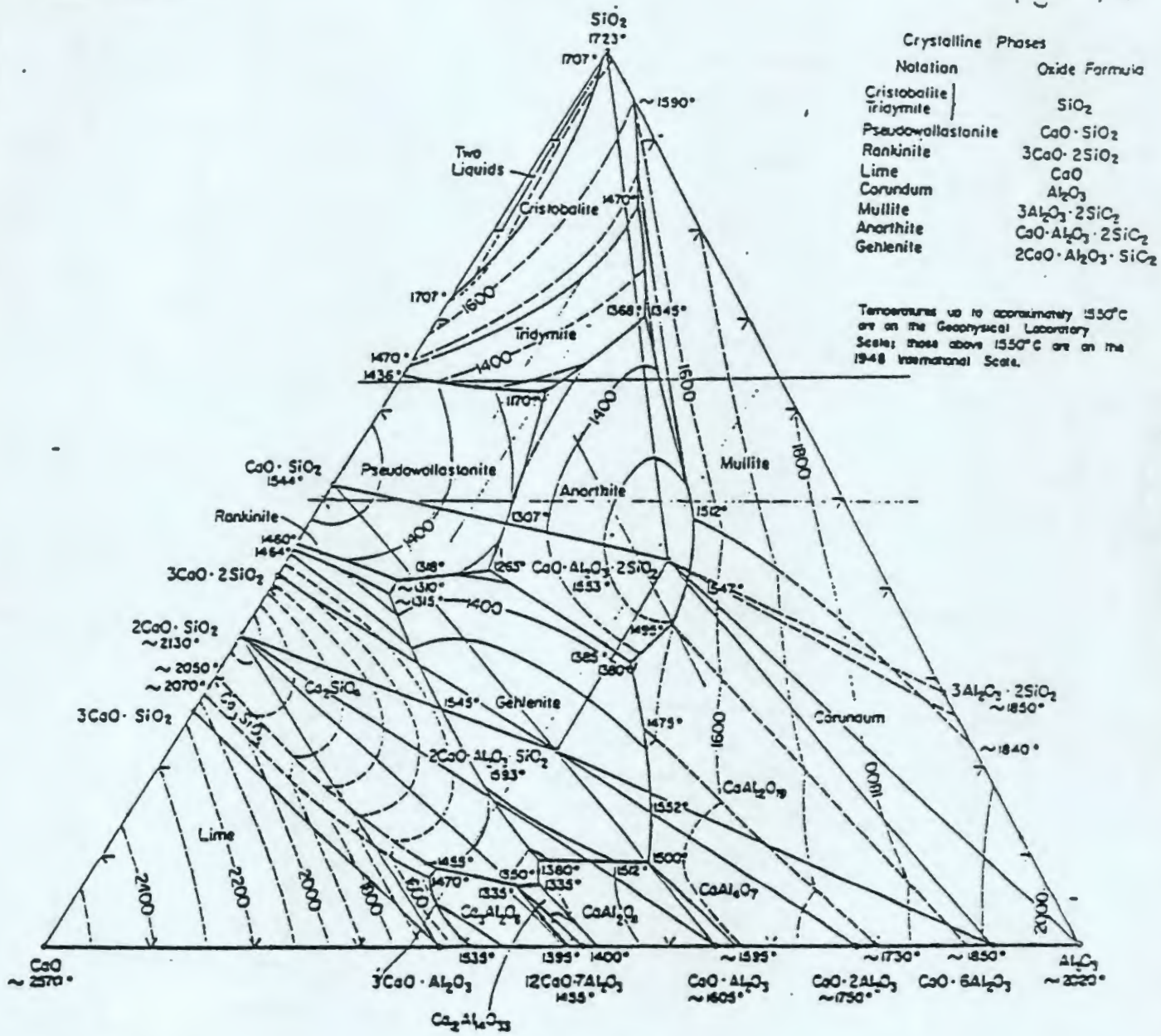
Fig. 7.7 Standard free energy of formation of oxides as a function of temperature. From F. D. Richardson and J. H. E. Jeffes, *J. Iron Steel Inst.*, 160, 261 (1948). Modified by L. S. Darken and R. W. Gurry, *Physical Chemistry of Metals*, McGraw-Hill, New York, 1953.

greater magnitude of a negative ΔG, the more favorable is the formation of products

94-3221-1910

Attachment C
pg 6/10

$CaO-Al_2O_3-SiO_2$



Crystalline Phases

Notation	Oxide Formula
Cristobalite / Tridymite	SiO_2
Pseudowollastonite	$CaO \cdot SiO_2$
Rankinite	$3CaO \cdot 2SiO_2$
Lime	CaO
Corundum	Al_2O_3
Mullite	$3Al_2O_3 \cdot 2SiO_2$
Anorthite	$CaO \cdot Al_2O_3 \cdot 2SiO_2$
Gehlenite	$2CaO \cdot Al_2O_3 \cdot SiO_2$

Temperatures up to approximately 1550°C are on the Geophysical Laboratory Scale; those above 1550°C are on the 1948 International Scale.

FIG. 630.—System $CaO-Al_2O_3-SiO_2$; composite.

E. F. Osborn and Arnulf Muan, revised and redrawn "Phase Equilibrium Diagrams of Oxide Systems," Plate 1, published by the American Ceramic Society and the Edward Orton, Jr., Ceramic Foundation, 1960.

Principal References

A. L. Day, E. S. Shepherd, and F. E. Wright, *Am. J. Sci.* (4th series), 22, 265–302 (1906).
J. H. Welch and W. Gutt, *J. Am. Ceram. Soc.*, 42, 11–15 (1959).
N. L. Bowen and J. W. Greig, *J. Am. Ceram. Soc.*, 7, 238–54 (1924); corrections, *ibid.*, 410.
N. A. Toropov and F. Ya. Galakhov, *Voprosy Petrograf. i Mineral., Akad. Nauk S.S.S.R.*, 2, 245–55 (1953).
G. A. Rankin and F. E. Wright, *Am. J. Sci.* (4th Series), 39, 1–79 (1915).
J. W. Greig, *Am. J. Sci.* (5th Series), 13, 1–44; 133–54 (1927).
N. E. Filonenko and I. V. Iavtov, *Zhur. Prik. Khim.*, 23, 1040–46 (1950); *J. Appl. Chem.* (*U.S.S.R.*), 23, 1105–12 (1950) (English translation).
Shigeo Aramaki and Rustum Roy, *J. Am. Ceram. Soc.*, 42, 644–45 (1959).

94B3221.1911

Battelle
Pacific Northwest Laboratories

ENGINEERING WORKSHEET

Prepared By: J Luey & [illegible] | Date: 2/17/93 | Project: 100 AREA TSV DEMO | 100BRA-93-04

Title/Subject: EVALUATION OF WATER SPRAY SYSTEM

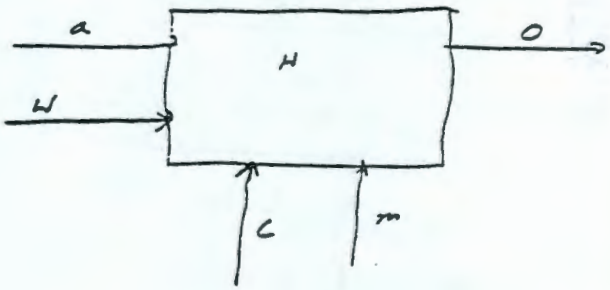
Reviewed By: SMCalley
Date: 2/18/93

BASED ON CALCULATIONS (100BRA-93-04), THE TEMPERATURE IN THE OFF-GAS HOOD MAY EXCEED THE DESIGN LIMITS OF THE PILOT-SCALE OFF-GAS HOOD.[1] THESE LIMITS ARE EXCEEDED ASSUMING:

1) ALL OF THE ORGANIC MATTER IN THE MELT ZONE (CELLULOSE) IS COMBUSTED IN THE OFF-GAS HOOD.
2) THE SYSTEM IS ADIABATIC WITH NO HEAT TRANSFER FROM THE HOOD TO THE AMBIENT SURROUNDINGS.
3) OFF-GAS HOOD CONTENTS ARE WELL-MIXED AND EQUILIBRATES INSTANTANEOUSLY.

HOW WILL ADDITION OF A WATER SPRAY AFFECT SYSTEM?

OFF-GAS HOOD TEMPERATURE INCREASES DUE TO COMBUSTION OF CELLULOSE IN THE HOOD PLENUM. COMBUSTION ADDS ENERGY TO THE SYSTEM.
PREVIOUS CALCULATIONS AND ENGINEERING-SCALE TESTS[2] HAVE SHOWN THAT THE ADDITION OF WATER WILL REMOVE ENERGY FROM THE GASES IN THE HOOD.



MATERIAL BALANCE: $\frac{dn_H}{dt} = \dot{n}_a + \dot{n}_m + \dot{n}_c + \dot{n}_W - \dot{n}_o$

ENERGY BALANCE: $\frac{dH}{dt} = \dot{H}_a + \dot{H}_m + \dot{H}_c - \dot{H}_o + \dot{H}_W$

ASSUMING ALL WATER ADDED IS AT 25°C AND ALL OF IT EXITS:

$\dot{H}_W = \dot{n}_W (H_{in} - H_{out})$

$H_{in} = 104.7$ kJ/kg [FELDSA + ROUSSEAU]
$= 1.89$ kJ/mole.
$H_{out} = 0.0417\, T_H + 32.6$ kJ/mole [100BRA-93-04]

$\therefore \dot{H}_W = \dot{n}_W (1.89 - 0.0417\, T_H - 32.6)$
$= \dot{n}_W (-0.0417\, T_H - 30.7)$

[1] THE DESIGN LIMIT IS 470°C (743 K). ATTACHMENT A ILLUSTRATES THE OFF-GAS HOOD TEMPERATURE (IN K) FOR COMBUSTIBLE EVOLUTION RATE OF 0.14 moles/s. SEE ATTACHMENT A.

[2] LUEY ET al. 1992. "EVALUATION OF NEW CONCEPTS FOR IN SITU VITRIFICATION: POWER SYSTEM, MELT INSULATION, AND OFF-GAS CONTAINMENT. PNL-8231

9413221.1912

Battelle
Pacific Northwest Laboratories

ENGINEERING WORKSHEET

Prepared By: J. Luey J. Luey	Date: 2/18/93	Project: 100 AREA 324 DSTF	100FRSA-93-06
Title/Subject: EVALUATION OF WATER SPRAY SYSTEM.		Reviewed By: S. Chalkley Date: 2/18/93	

WHAT IS AFFECT ON SYSTEM? MODIFY HIQ PROGRAM SO THAT A WATER SPRAY SYSTEM IS TRIGGERED WHEN $T_H > 700K$.

RUN 1: $\dot{m}_W = 1$ mole/s ; STEP = 1, FINISH = 60 [ATTACHMENT B]
COMPARISON BETWEEN ATTACHMENT B WITH ATTACHMENT A SHOWS THE RATE OF TEMPERATURE INCREASE IS LESS WHEN THE WATER SPRAY IS USED. HOWEVER, THE INCREASE IS STILL POSITIVE.

RUN 2; $\dot{m}_W = 2$ mole/s ; STEP = 1, FINISH = 60 [ATTACHMENT C]
AS SEEN PREVIOUSLY, THE RATE OF TEMPERATURE INCREASE IS DIMINISHED. FURTHER INCREASE IN THE WATER ADDITION RATE MAY BRING THE SYSTEM TO AN EQUILIBRIUM.

RUN 3; $\dot{m}_W = 4$ mole/s ; STEP = 1, FINISH = 60 [ATTACHMENT D]
AS SHOWN IN ATTACHMENT D, A WATER SPRAY FLOW OF 4 mole/s (4.3 L/MIN OR 1.1 GPM) WILL ALMOST ENTIRELY COMPENSATE FOR THE COMBUSTION OF CELLULOSE IN THE HOOD.

SINCE THE DESIGN LIMIT OF THE HOOD IS ≈ 740K, CAN THE WATER SPRAY MAINTAIN THE HOOD AT A LOWER TEMPERATURE (i.e. 675 K)?

RUN 4; $\dot{m}_W = 4$ mole/s ; STEP = 1, FINISH = 60, TRIGGER @ 675K [ATTACHMENT E]
THE WATER SPRAY SYSTEM DID NOT BRING THE SYSTEM TO STEADY-STATE.
∴ INCREASE WATER FLOW.

RUN 5; $\dot{m}_W = 4.25$ mole/s ; STEP = 1, FINISH = 60, TRIGGER @ 675K [ATTACHMENT F]
AS SHOWN, THE OFF-GAS HOOD TEMPERATURE EQUILIBRATES AROUND 675K
FURTHER INCREASE IN $\dot{m}_W$ WILL RESULT IN TEMPERATURE DECREASES. A FLOW OF 4.25 mole/s = 4.59 L/min = 1.21 GPM.

NOTE: ONCE A TERM FOR HEAT TRANSFER FROM HOOD TO SURROUNDINGS IS DETERMINED, REQUIRED WATER FLOW WILL DECREASE.

THE HIQ PROGRAM USED FOR THIS CALCULATION IS SHOWN ON ATTACHMENT G.

9413221.1913

ATTACHMENT A

nc = 0.14.rev 1

Time	Th	Nh	Ph	Na
0	573.0	583.0	100.6292	7.93
1	583.2	576.7	101.3248	0.14
2	590.8	569.4	101.3246	0.20
3	598.5	562.0	101.3244	0.24
4	606.3	554.8	101.3242	0.28
5	614.3	547.6	101.3238	0.33
6	622.4	540.4	101.3234	0.38
7	630.7	533.3	101.3230	0.42
8	639.2	526.3	101.3225	0.47
9	647.8	519.2	101.3220	0.52
10	656.6	512.3	101.3214	0.57
11	665.6	505.4	101.3207	0.62
12	674.7	498.5	101.3200	0.67
13	684.1	491.7	101.3192	0.72
14	693.6	484.9	101.3184	0.78
15	703.3	478.2	101.3174	0.83
16	713.2	471.6	101.3164	0.88
17	723.4	465.0	101.3153	0.94
18	733.7	458.4	101.3141	0.99
19	744.2	451.9	101.3128	1.05
20	754.9	445.5	101.3114	1.11
21	765.9	439.1	101.3099	1.17
22	777.0	432.8	101.3084	1.23
23	788.4	426.6	101.3066	1.29
24	800.0	420.4	101.3049	1.35
25	811.8	414.2	101.3029	1.41
26	823.9	408.2	101.3009	1.48
27	836.1	402.2	101.2988	1.54
28	848.7	396.2	101.2965	1.61
29	861.4	390.4	101.2940	1.68
30	874.4	384.6	101.2915	1.74
31	887.6	378.8	101.2888	1.81
32	901.0	373.2	101.2860	1.88
33	914.7	367.6	101.2830	1.95
34	928.6	362.1	101.2799	2.02
35	942.8	356.6	101.2766	2.09
36	957.2	351.2	101.2731	2.17
37	971.8	345.9	101.2695	2.24
38	986.7	340.7	101.2657	2.32
39	1001.9	335.5	101.2618	2.39
40	1017.2	330.5	101.2577	2.47
41	1032.8	325.5	101.2534	2.55
42	1048.6	320.5	101.2489	2.63
43	1064.7	315.7	101.2443	2.70
44	1080.9	310.9	101.2394	2.78
45	1097.4	306.2	101.2344	2.86
46	1114.1	301.6	101.2292	2.95
47	1131.0	297.1	101.2238	3.03
48	1148.1	292.7	101.2183	3.11
49	1165.4	288.3	101.2125	3.19
50	1182.9	284.0	101.2065	3.28
51	1200.5	279.8	101.2004	3.36
52	1218.3	275.7	101.1941	3.44
53	1236.3	271.7	101.1876	3.53
54	1254.4	267.8	101.1810	3.61
55	1272.7	263.9	101.1741	3.70
56	1291.0	260.1	101.1671	3.78
57	1309.5	256.4	101.1600	3.87
58	1328.1	252.8	101.1527	3.95
59	1346.7	249.3	101.1452	4.04
60	1365.4	245.9	101.1376	4.12

9413221.1914

ATTACHMENT B

100ARSA-93-06

nw = 1.0

Time	Th	Nh	Ph	Na
0	573.0	583.0	100.6292	7.93
1	583.2	576.7	101.3248	0.14
2	590.8	569.4	101.3246	0.20
3	598.5	562.0	101.3244	0.24
4	606.3	554.8	101.3242	0.28
5	614.3	547.6	101.3238	0.33
6	622.4	540.4	101.3234	0.38
7	630.7	533.3	101.3230	0.42
8	639.2	526.3	101.3225	0.47
9	647.8	519.2	101.3220	0.52
10	656.6	512.3	101.3214	0.57
11	665.6	505.4	101.3207	0.62
12	674.7	498.5	101.3200	0.67
13	684.1	491.7	101.3192	0.72
14	693.6	484.9	101.3184	0.78
15	702.5	478.7	101.3024	1.43
16	709.9	473.7	101.3010	1.47
17	717.5	468.7	101.2996	1.52
18	725.2	463.7	101.2982	1.56
19	733.0	458.8	101.2967	1.60
20	740.9	453.9	101.2951	1.65
21	748.9	449.0	101.2935	1.69
22	756.9	444.2	101.2918	1.73
23	765.1	439.5	101.2901	1.78
24	773.4	434.8	101.2883	1.82
25	781.8	430.1	101.2864	1.87
26	790.2	425.5	101.2845	1.92
27	798.8	420.9	101.2825	1.96
28	807.5	416.4	101.2805	2.01
29	816.2	411.9	101.2783	2.06
30	825.1	407.5	101.2761	2.10
31	834.0	403.1	101.2739	2.15
32	843.1	398.8	101.2716	2.20
33	852.2	394.5	101.2692	2.25
34	861.4	390.3	101.2667	2.30
35	870.7	386.1	101.2642	2.35
36	880.2	381.9	101.2616	2.40
37	889.7	377.8	101.2589	2.45
38	899.2	373.8	101.2561	2.50
39	908.9	369.8	101.2533	2.55
40	918.7	365.9	101.2504	2.60
41	928.5	362.0	101.2474	2.65
42	938.4	358.2	101.2443	2.70
43	948.4	354.4	101.2412	2.76
44	958.4	350.7	101.2380	2.81
45	968.6	347.0	101.2348	2.86
46	978.7	343.4	101.2314	2.91
47	989.0	339.8	101.2280	2.96
48	999.3	336.3	101.2245	3.02
49	1009.7	332.8	101.2210	3.07
50	1020.1	329.4	101.2174	3.12
51	1030.6	326.0	101.2137	3.18
52	1041.1	322.7	101.2099	3.23
53	1051.7	319.5	101.2061	3.28
54	1062.3	316.3	101.2022	3.34
55	1072.9	313.1	101.1983	3.39
56	1083.6	310.0	101.1943	3.44
57	1094.3	307.0	101.1902	3.49
58	1105.0	304.0	101.1861	3.55
59	1115.8	301.0	101.1819	3.60
60	1126.5	298.2	101.1776	3.65

9413221.1915

ATTACHMENT C

JROFR:SA-93-06

nw = 2.0

Time	Th	Nh	Ph	Na
0	573.0	583.0	100.6292	7.93
1	583.2	576.7	101.3248	0.14
2	590.8	569.4	101.3246	0.20
3	598.5	562.0	101.3244	0.24
4	606.3	554.8	101.3242	0.28
5	614.3	547.6	101.3238	0.33
6	622.4	540.4	101.3234	0.38
7	630.7	533.3	101.3230	0.42
8	639.2	526.3	101.3225	0.47
9	647.8	519.2	101.3220	0.52
10	656.6	512.3	101.3214	0.57
11	665.6	505.4	101.3207	0.62
12	674.7	498.5	101.3200	0.67
13	684.1	491.7	101.3192	0.72
14	693.6	484.9	101.3184	0.78
15	701.6	479.2	101.2795	2.03
16	706.6	475.8	101.2779	2.07
17	711.8	472.4	101.2766	2.09
18	716.9	469.0	101.2752	2.12
19	722.1	465.6	101.2739	2.15
20	727.3	462.2	101.2724	2.18
21	732.6	458.9	101.2710	2.21
22	737.8	455.6	101.2696	2.24
23	743.1	452.4	101.2681	2.27
24	748.4	449.2	101.2666	2.30
25	753.8	446.0	101.2650	2.33
26	759.2	442.8	101.2635	2.36
27	764.6	439.7	101.2619	2.39
28	770.0	436.6	101.2603	2.42
29	775.4	433.5	101.2587	2.45
30	780.9	430.5	101.2570	2.48
31	786.4	427.4	101.2553	2.51
32	791.9	424.5	101.2536	2.54
33	797.4	421.5	101.2519	2.57
34	803.0	418.6	101.2502	2.60
35	808.6	415.7	101.2484	2.63
36	814.1	412.8	101.2466	2.67
37	819.8	410.0	101.2448	2.70
38	825.4	407.2	101.2429	2.73
39	831.0	404.4	101.2411	2.76
40	836.7	401.7	101.2392	2.79
41	842.3	399.0	101.2373	2.82
42	848.0	396.3	101.2354	2.85
43	853.7	393.7	101.2334	2.88
44	859.3	391.1	101.2314	2.91
45	865.0	388.5	101.2294	2.94
46	870.7	385.9	101.2274	2.97
47	876.5	383.4	101.2253	3.00
48	882.2	380.9	101.2233	3.04
49	887.9	378.5	101.2212	3.07
50	893.6	376.0	101.2192	3.10
51	899.3	373.6	101.2171	3.13
52	905.0	371.3	101.2149	3.16
53	910.8	368.9	101.2128	3.19
54	916.5	366.6	101.2106	3.22
55	922.2	364.3	101.2085	3.25
56	927.9	362.1	101.2063	3.28
57	933.6	359.9	101.2041	3.31
58	939.2	357.7	101.2019	3.34
59	944.9	355.5	101.1997	3.37
60	950.6	353.4	101.1974	3.40

9413221.1916

ATTACHMENT D

100AREA-93-0

nw = 4.0

Time	Th	Nh	Ph	Na
0	573.0	583.0	100.6292	7.93
1	583.2	576.7	101.3248	0.14
2	590.8	569.4	101.3246	0.20
3	598.5	562.0	101.3244	0.24
4	606.3	554.8	101.3242	0.28
5	614.3	547.6	101.3238	0.33
6	622.4	540.4	101.3234	0.38
7	630.7	533.3	101.3230	0.42
8	639.2	526.3	101.3225	0.47
9	647.8	519.2	101.3220	0.52
10	656.6	512.3	101.3214	0.57
11	665.6	505.4	101.3207	0.62
12	674.7	498.5	101.3200	0.67
13	684.1	491.7	101.3192	0.72
14	693.6	484.9	101.3184	0.78
15	700.0	480.0	101.2174	3.12
16	700.3	479.7	101.2085	3.25
17	700.7	479.5	101.2083	3.25
18	701.1	479.2	101.2081	3.25
19	701.5	479.0	101.2080	3.26
20	701.8	478.7	101.2079	3.26
21	702.2	478.5	101.2077	3.26
22	702.6	478.2	101.2075	3.26
23	702.9	478.0	101.2073	3.26
24	703.3	477.7	101.2072	3.27
25	703.6	477.5	101.2071	3.27
26	704.0	477.2	101.2069	3.27
27	704.3	477.0	101.2068	3.27
28	704.7	476.8	101.2066	3.28
29	705.0	476.5	101.2064	3.28
30	705.4	476.3	101.2063	3.28
31	705.7	476.1	101.2062	3.28
32	706.1	475.8	101.2061	3.28
33	706.4	475.6	101.2059	3.28
34	706.7	475.4	101.2057	3.29
35	707.1	475.2	101.2056	3.29
36	707.4	475.0	101.2055	3.29
37	707.7	474.7	101.2053	3.29
38	708.0	474.5	101.2052	3.29
39	708.3	474.3	101.2051	3.30
40	708.7	474.1	101.2049	3.30
41	709.0	473.9	101.2048	3.30
42	709.3	473.7	101.2047	3.30
43	709.6	473.5	101.2045	3.30
44	709.9	473.3	101.2044	3.31
45	710.2	473.1	101.2043	3.31
46	710.5	472.9	101.2041	3.31
47	710.8	472.7	101.2040	3.31
48	711.1	472.5	101.2039	3.31
49	711.4	472.3	101.2037	3.31
50	711.7	472.1	101.2036	3.32
51	712.0	471.9	101.2035	3.32
52	712.3	471.7	101.2034	3.32
53	712.6	471.5	101.2032	3.32
54	712.8	471.3	101.2031	3.32
55	713.1	471.1	101.2030	3.32
56	713.4	470.9	101.2029	3.33
57	713.7	470.7	101.2028	3.33
58	714.0	470.6	101.2026	3.33
59	714.2	470.4	101.2025	3.33
60	714.5	470.2	101.2024	3.33

9413221.1917

ATTACHMENT E

100PRSA-93-06

nc = 4.0 (Th = 675K)

Time	Th	Nh	Ph	Na
0	573.0	583.0	100.6292	7.93
1	583.2	576.7	101.3248	0.14
2	590.8	569.4	101.3246	0.20
3	598.5	562.0	101.3244	0.24
4	606.3	554.8	101.3242	0.28
5	614.3	547.6	101.3238	0.33
6	622.4	540.4	101.3234	0.38
7	630.7	533.3	101.3230	0.42
8	639.2	526.3	101.3225	0.47
9	647.8	519.2	101.3220	0.52
10	656.6	512.3	101.3214	0.57
11	665.6	505.4	101.3207	0.62
12	674.7	498.5	101.3200	0.67
13	675.3	497.5	101.2188	3.10
14	675.9	497.1	101.2186	3.11
15	676.4	496.7	101.2184	3.11
16	677.0	496.3	101.2182	3.11
17	677.5	495.9	101.2179	3.11
18	678.1	495.5	101.2177	3.12
19	678.6	495.2	101.2175	3.12
20	679.1	494.8	101.2173	3.12
21	679.7	494.4	101.2171	3.13
22	680.2	494.0	101.2168	3.13
23	680.7	493.6	101.2166	3.13
24	681.2	493.3	101.2164	3.14
25	681.7	492.9	101.2162	3.14
26	682.2	492.5	101.2160	3.14
27	682.7	492.1	101.2158	3.15
28	683.2	491.8	101.2156	3.15
29	683.7	491.4	101.2154	3.15
30	684.2	491.1	101.2152	3.15
31	684.7	490.7	101.2150	3.16
32	685.2	490.4	101.2148	3.16
33	685.7	490.0	101.2146	3.16
34	686.2	489.7	101.2144	3.17
35	686.7	489.3	101.2142	3.17
36	687.1	489.0	101.2140	3.17
37	687.6	488.6	101.2138	3.17
38	688.1	488.3	101.2136	3.18
39	688.6	488.0	101.2134	3.18
40	689.0	487.7	101.2132	3.18
41	689.5	487.3	101.2130	3.19
42	689.9	487.0	101.2128	3.19
43	690.4	486.7	101.2126	3.19
44	690.8	486.4	101.2125	3.19
45	691.3	486.0	101.2123	3.20
46	691.7	485.7	101.2121	3.20
47	692.2	485.4	101.2119	3.20
48	692.6	485.1	101.2117	3.20
49	693.0	484.8	101.2115	3.21
50	693.5	484.5	101.2114	3.21
51	693.9	484.2	101.2112	3.21
52	694.3	483.9	101.2110	3.21
53	694.7	483.6	101.2108	3.22
54	695.2	483.3	101.2107	3.22
55	695.6	483.0	101.2105	3.22
56	696.0	482.7	101.2103	3.22
57	696.4	482.5	101.2101	3.23
58	696.8	482.2	101.2099	3.23
59	697.2	481.9	101.2098	3.23
60	697.6	481.6	101.2096	3.23

9413221.1918

ATTACHMENT F

100AASA-73-0

nw = 4.25 (Th = 675K)

Time	Th	Nh	Ph	Na
0	573.0	583.0	100.6292	7.93
1	583.2	576.7	101.3248	0.14
2	590.8	569.4	101.3246	0.20
3	598.5	562.0	101.3244	0.24
4	606.3	554.8	101.3242	0.28
5	614.3	547.6	101.3238	0.33
6	622.4	540.4	101.3234	0.38
7	630.7	533.3	101.3230	0.42
8	639.2	526.3	101.3225	0.47
9	647.8	519.2	101.3220	0.52
10	656.6	512.3	101.3214	0.57
11	665.6	505.4	101.3207	0.62
12	674.7	498.5	101.3200	0.67
13	675.0	497.7	101.2090	3.24
14	675.0	497.7	101.2083	3.25
15	675.0	497.7	101.2083	3.25
16	675.0	497.7	101.2083	3.25
17	675.1	497.7	101.2083	3.25
18	675.1	497.7	101.2083	3.25
19	675.1	497.7	101.2083	3.25
20	675.1	497.7	101.2082	3.25
21	675.1	497.7	101.2082	3.25
22	675.1	497.7	101.2082	3.25
23	675.1	497.7	101.2082	3.25
24	675.1	497.7	101.2082	3.25
25	675.1	497.6	101.2082	3.25
26	675.1	497.6	101.2082	3.25
27	675.2	497.6	101.2082	3.25
28	675.2	497.6	101.2082	3.25
29	675.2	497.6	101.2082	3.25
30	675.2	497.6	101.2082	3.25
31	675.2	497.6	101.2082	3.25
32	675.2	497.6	101.2082	3.25
33	675.2	497.6	101.2082	3.25
34	675.2	497.6	101.2082	3.25
35	675.2	497.6	101.2082	3.25
36	675.2	497.6	101.2082	3.25
37	675.3	497.6	101.2082	3.25
38	675.3	497.6	101.2082	3.25
39	675.3	497.5	101.2082	3.25
40	675.3	497.5	101.2082	3.25
41	675.3	497.5	101.2082	3.25
42	675.3	497.5	101.2082	3.25
43	675.3	497.5	101.2082	3.25
44	675.3	497.5	101.2082	3.25
45	675.3	497.5	101.2081	3.25
46	675.3	497.5	101.2082	3.25
47	675.3	497.5	101.2082	3.25
48	675.3	497.5	101.2081	3.25
49	675.4	497.5	101.2081	3.25
50	675.4	497.5	101.2081	3.25
51	675.4	497.5	101.2081	3.25
52	675.4	497.5	101.2081	3.25
53	675.4	497.5	101.2081	3.25
54	675.4	497.5	101.2081	3.25
55	675.4	497.5	101.2081	3.25
56	675.4	497.4	101.2081	3.25
57	675.4	497.4	101.2081	3.25
58	675.4	497.4	101.2081	3.25
59	675.4	497.4	101.2081	3.25
60	675.4	497.4	101.2081	3.25

9413221.1919

ATTACHMENT 6

100AREA-93-06

HiQ. PROGRAM INCLUDING WATER SPRAY.

```
00001 project ivpEqns0, initx, ivpMatrix0;
00002
00003 local start, finish, stepSize, relError, absError;
00004 start = 0;
00005 finish = 60;
00006 stepSize = 1;
00007 relError = 1.e-6;
00008 absError = 1.e-6;
00009
00010
00011 Function ivpEqns0(t, x)
00012
00013 nm = 1.65;
00014 nc = 0.14;
00015 n0 = 9.3;
00016 vh = 27.6;
00017 mw = 29;
00018 pa = 101.325;
00019 R = 8.314e-3;
00020 Ta = 298;
00021 Tr = 298;
00022 cp = 0.0296;
00023 Hc = 3012;
00024 Tm = 1473;
00025 namin = 47.6*nc;
00026 cpc = 0.4798;
00027
00028 ph = x[2]*R*x[1]/vh;
00029
00030 a = (n0-nm) / (0.9541*mw);
00031 b = (0.3125*ph/pa + 0.6875) * (pa*mw/R/Ta*(pa-ph))^0.5;
00032 c = (0.3125*pa/ph + 0.6875) * (x[2]*mw/vh*(ph-pa))^0.5;
00033 d = nm + nc - n0;
00034
00035 //  x[1] is Th, x[2] is nh.
00036
00037 e = nm*(0.0417*Tm + 32.6) - (n0-nm)*cp*(x[1]-Tr) - nm*(0.0417*x[1] + 3
00038
00039 if (x[1]>675) then
00040
00041 nw = 4.25;
00042 Hw = nw*(-0.0417*x[1] - 30.7);
00043
00044 else
00045
00046 nw = 0;
00047 Hw = 0;
00048
00049 end if;
00050
00051 if (ph<pa) then
00052
00053 na = a*b;
00054
00055 else
00056
00057 na = -a*c;
00058
```

9413221.1920

ATTACHMENT 6

100AR:A-93:DL

```
00059 end if;
00060
00061 if (na>namin) then
00062
00063 ncHc = nc*Hc;
00064
00065 else
00066
00067 ncHc = nc*Hc*na/namin + (1 - na/namin)*nc*cpc*(Tm - x[1]);
00068
00069 end if;
00070
00071 if (ph<pa) then
00072
00073 dxdt[1] = (cp*(Tr-x[1])*(a*b+d)+a*b*cp*(Ta-Tr) + e + ncHc + Hw)/cp/x[2]
00074 dxdt[2] = a*b + d + nw;
00075
00076 else
00077
00078 dxdt[1] = (cp*(Tr-x[1])*(-a*c+d) - a*c*cp*(x[1]-Tr) + e + Hw + nc*(cpc'
00079 dxdt[2] = -a*c + d + nw;
00080
00081 end if;
00082
00083     return dxdt;
00084 end function;
00085
00086 [ivpMatrix0,ivpVector0,finalAbserr0] = OdeIvpRKF(ivpEqns0, initx, start
00087
00088
```

9413221.1921

Heat Transfer Effects for Intermediate-Scale ISV Stainless Steel Hood @ INEL - Calc. No. 89-024-TC-01

Author: J.S. Tixier

Date: May 10, 1990

Problem: Determine whether or not the heat transfer from the hood poses a danger to the external devices located nearby (ie electrical cables, pneumatic hose, fibergate platform and steps)

Results: (assuming $T_H = 743$ K)

Convection HT

- Convection Heat Transfer from top of hood (horizonal disc) $= 48.8 \times 10^3$ Btu/hr
- minimum distance from hood to fibergate at 150 °F $= 0.18$ in
  - ↳ the fibergate is several inches above the hood so it should not reach allowable maximum temp.
- Convection heat transfer from inclined plate of hood $= 421 \times 10^3$ Btu/hr
- Boundary layer thickness @ top of the inclined side $= 0.58$ in
  - ↳ If cables and hoses are located farther than 0.58 in from the inclined side of the hood they will be unaffected by convection HT from the side of the hood

Radiation HT

- Total radiation HT from hood $= 1.081 \times 10^6$ Btu/hr
- Radiation HT to cables/hoses $= 18.8 \times 10^3$ Btu/hr
- minimum distance allowable between hood side surface and cables/hoses $= 1\frac{3}{8}$ in
  - ↳ if cable/hose surface is located farther than $1\frac{3}{8}$ in from surface of the hood, its integrity will not be compromised
- Minimum allowable distance between the top of the hood surface and the fibergrate $= 3.5$ in
  - ↳ if the grate remains farther than 3.5 in it will not be thermally compromised.

Title	Project
Heat Effects on External Devices	100 Area ISV Pilot Scale Demo

Prepared by:	Date	Reviewed by:	Date
SH Caley	2/18/93	J. Paul Guey	2/23/93

9413221.1922

Summary and Conclusions:

① Equipment Configuration on the Side of the Hood:

In actuality, the cables, hoses, & fiberglass steps are located at least 8 inches away from the surface of the hood and this distance lies well outside of the free convection boundary layer and is also free from dangerous thermal radiation effects.

② Equipment configuration on the top of the Hood:

The fibergrate is located 4" from the hood surface on the top and the cables & hoses lie on top or above the fibergrate so they are in no thermal danger as they are designed.

③ Heat Transfer from the hood to the surroundings

Total convective HT = 469.8×10^3 Btu/hr

Total radiation HT = 1.081×10^6 Btu/hr

Total HT from hood = 1.55×10^6 Btu/hr

See calculation No. 89-024-TC-01 which is attached.

RECOMENDATIONS:

1) PERFORM CALCULATIONS FOR $T_\infty = 25°C$

2) DETERMINE h_a AS A FUNCTION OF T

3) DETERMINE h_a FOR FORCED CONVECTION.

Title	Project
Heat Effects on External Devices	100 Area ISV Pilot-Scale Demo

Prepared by:	Date	Reviewed by:	Date
SM Caley	2/18/93	[signature]	2/23/93

9413221.1923

Attachment 4

Heat Transfer Effects for Intermediate-Scale ISV Stainless Steel Hood at INEL
Calculation no. 89-024-TC-01

J. S. Tixier, Jr.
May 10, 1990

9H/722.1921

PROBLEM: Determine whether or not the heat transfer from the new stainless steel hood poses a danger to the external devices located nearby (i. e., electrical cables, pneumatic hoses, fibergrate platform and steps.)

SOLUTION CONTENTS:

1) Hood Configuration and Surface Area Calculations
2) Convection Heat Transfer
   a) Horizontal Top
   b) Estimate Minimum Distance from Top
   c) Inclined Sides
   d) Boundary Layer (Minimum Distance from Side)
3) Radiation Heat Transfer
   a) Total
   b) To Cables and Hoses
   c) Minimum Allowable Distance from Side
   d) Minimum Allowable Distance from Top
4) Energy Balance Check
5) Summary and Conclusions
6) Reference

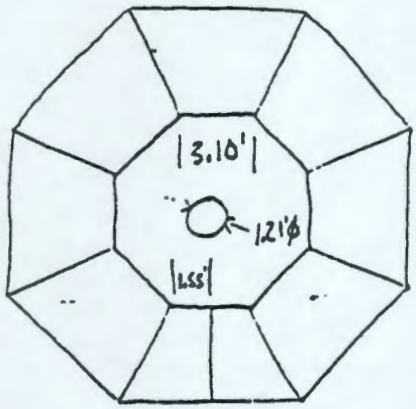
Prepared by _____ Date 5/11/90

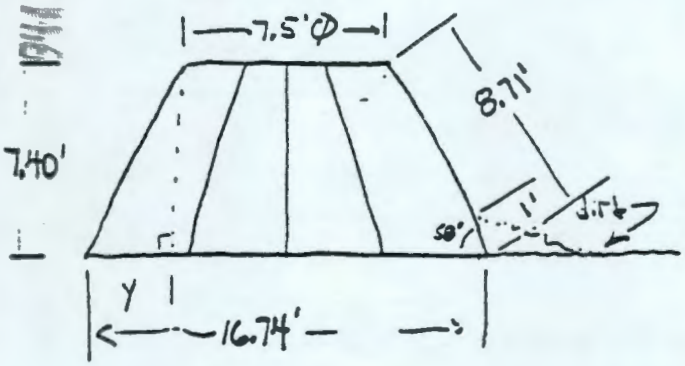
Checked by _____ Date 5-14-90

ENGINEERING WORKSHEET

Prepared By: JOHN TINER | Date: 5/8/90 | Project: INEL ISV Intermediate Scale 12234

Title/Subject: Heat Transfer Calculations from SS Hood to Electrical cables and Pneumatic Hoses and Fibergrate





$Y = \frac{1}{2}(16.74' - 7.5') = 4.62'$

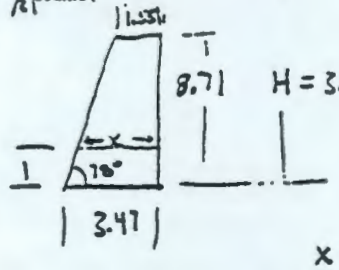
ref dim: worksheet no. WS-X-57973 pp 2,4,6/16

1) Calculate Surface Area of Hood

ASSUMPTIONS:
- top is a disk of dia 7.5'
- 16 - 1/2 pannels on side (neglect door configuration)
- bottom 1' of sides covered with soil

a) $A_{TOP} = \frac{\pi}{4}(7.5^2 - 1.21^2) = 43.0\ ft^2$

b) $A_{1/2\,pannel}$



$H = 3.47 \tan 78° = 16.32'$

$x = 15.32\left(\frac{3.47}{16.32}\right) = 5.2$

$A_{1/2\,pannel} = \frac{1}{2}(1.55 + 3.47)(8.71) = 21.9\ ft^2$

$A'_{1/2\,pannel} = A_{1/2\,exposed\,pannel}$

$= \frac{1}{2}(1.55 + 3.26)(7.71) = 18.5\ ft^2$

c) $A_{HOOD} = A_{TOP} + 16\,A_{1/2\,pannel}$

$= 43.0 + 16(21.9)$

$\boxed{A_{HOOD} = 393\ ft^2}$

$\frac{43}{340} = 12.6\%$ A_{TOP}

d) $A'_{HOOD} = A_{HOOD\ EXPOSED}$

$= A_{TOP} + 16\,A'_{1/2\,pannel}$

$= 43.0 + 16(18.5)$

$\boxed{A'_{HOOD} = 339\ ft^2}$

e) Calculate area fractions

$\frac{A_{TOP}}{A'_{HOOD}} = \frac{43}{339} = 12.7\%$

$\frac{A'_{1/2\,pannel}}{A'_{HOOD}} = \frac{18.5}{339} = 5.46\%$

$(100\% = 12.7 + 16(5.46))$ ✓

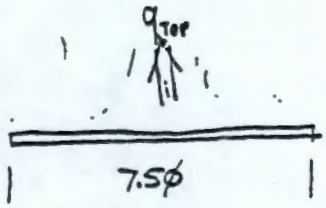
Prepared By: John Tixier | Date: 5/3/90 | Project: INEL Intermediate Scale ISU

Title/Subject: Heat Transfer Calculations

2) Calculate Convection Heat Transfer from Hood

ASSUMPTIONS:
- Uniform surface temp of 470°C
- Top is disk of $\phi = 7.5'$
- Ambient temperature of 100°F (38°C)
- Free convection (no wind)

a) HT from Horizontal Disk



Governing equation: (Holman pp 281, 275)

$Nu = 0.15 (Gr_L Pr)^{1/3}$ $\quad 8 \times 10^6 < Gr_L Pr < 10^{11}$ (turb.

where $L = .9D$ for disk

Properties of air evaluated at film Temp

(Kays & Crawford p 38B)

$$T_f = \frac{T_w + T_\infty}{2} = \frac{470+38}{2} = 254°C = 527K$$

$k = 41.18 \times 10^{-3}$ W/m·°C $= .02379$ Btu/hr ft °F

$Pr = 0.699$

$$g\beta/\nu^2 = 111 \times 10^5 \frac{1}{m^2 K} \cdot \frac{K}{1.8°F} \cdot 0.0283 \frac{m^3}{ft^3} = 1.745 \times 10^5 \frac{1}{ft^3 °F}$$

confirm turbulence:

$$GrPr = (g\beta/\nu^2 \Delta T L^3) Pr$$

$$= (1.745 \times 10^5)(470-38)\left(\frac{1.8F}{°C}\right)[(0.9)(7.5)]^3 (.$$

$$= 2.917 \times 10^{10}$$ ∴ within turbulent range

$$\overline{Nu} = \frac{\bar{h}L}{k} = 0.15(2.917 \times 10^{10})^{1/3} = 461.7$$

$$\bar{h} = \frac{461.7(0.02379)}{(7.5)}$$

$$\boxed{\bar{h} = 1.46 \text{ Btu/hr ft}^2 °F}$$

9413221.1926

Prepared By: John Tixier | Date: 5/10/90 | Project: INEL · Intermediate-Scale ISV .: 122

Title/Subject:

2) Calculate Convection Heat Transfer from Hood

a) HT from Horizontal Disk - CONTINUED

$$Q_{top} = hA(T_w - T_\infty)$$

$$= 1.46(43)(470-38)(1.8\,°F/°C)$$

$$\boxed{Q_{top} = 48.8 \times 10^3 \text{ Btu/hr}}$$

9413221.1927

b) Estimate the distance from the top of the hood to the fiberglass at 150°F (66°C). Assume thermal conduction through the air (not a great assumption, but will give an order of magnitude estimation)

$$Q_{top} = kA\frac{\Delta T}{\Delta x} \longrightarrow \Delta x = \frac{kA\Delta T}{Q_{top}}$$

$$= \frac{(0.02379)(43)(470-66)(1.8\,°F/°C)}{48.8 \times 10^3}$$

$$\boxed{\Delta x = 0.18 \text{ in}}$$

∴ The fiberglass being several inches above the hood should not reach its maximum allowable temperature.

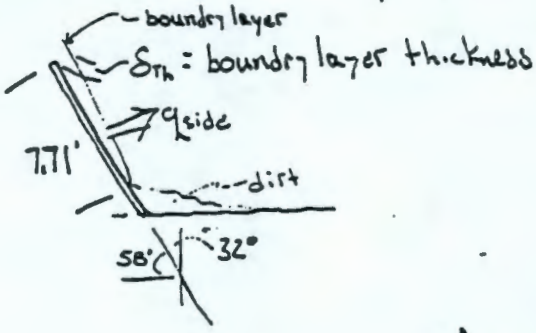
ENGINEERING WORKSHEET

Prepared By: John Tixier | Date: 5/9/90 | Project: INEL Intermediate Scale ISV - 1223

Title/Subject: Heat Transfer Calculations from SS Hood to Electrical Cables and Pneumatic Hoses

2) Convection from hood - Continued

c) HT from inclined plate



governing equation: (Holman p 282

$$\overline{Nu}_e = 0.14\left[(Gr_e Pr_e)^{1/3} - \underbrace{(Gr_c Pr_e)^{1/3}}_{\sim 1.5\times10^9}\right] + 0.56(Gr_e Pr_e \cos\theta)^{1/4}$$

with properties evaluated at

$$T_e = T_w - 0.25(T_w - T_\infty)$$

except $\beta = \frac{1}{T_\beta}$, $T_\beta = T_\infty + 0.25(T_w - T_\infty)$

$$T_e = 470 - 0.25(470-38) = 362C = 635K$$

Holman Table A-5

$k_e = 0.04865$ W/mK $= 0.02811$ Btu/hr ft F

$Pr_e = 0.681$

$\nu_e = 56.36 \times 10^{-6}$ m²/s

$$T_\beta = 38 + 0.25(470-38) = 146C = 419K$$

$$\beta = \frac{1}{T_\beta} = \frac{1}{419} = 2.39\times10^{-3}\ \frac{1}{K}$$

$$Gr_e = \frac{g\beta}{\nu_e^2}(T_w - T_\infty)x^3$$

$$= \frac{(9.81)(2.39\times10^{-3})}{(56.36\times10^{-6})^2}(470-38)\left(\frac{7.71}{3.281\ \frac{ft}{m}}\right)^3$$

$$Gr_e = 4.14\times10^{10}$$

$$\overline{Nu}_e = 0.14\left\{\left[(4.14\times10^{10})(0.681)\right]^{1/3} - \left[(1.5\times10^9)(0.681)\right]^{1/3}\right\} + 0.56\left[(4.14\times10^{10})(0.681)(\cos 58°)\right]^{1/4}$$

32

$$\overline{Nu}_e = \frac{\bar{h}x}{k_e} = 501 \qquad \bar{h} = \frac{501}{7.71}(0.02811)$$

$$\boxed{\bar{h} = 1.83\ \text{Btu/hr ft}^2\,°F}$$

$$Q_{side} = hA'_{side}(T_w - T_\infty) \quad \text{where } A'_{side} = 16A'_{panel}$$

$$= (1.83)16(18.5)(470-38)\left(\frac{1.8°F}{°C}\right)$$

$$\boxed{Q_{side} = 421\times10^3\ \text{Btu/hr}}$$

9413221.1928

ENGINEERING WORKSHEET

Prepared By: John Tinier	Date: 5/9/90	Project: INEL Intermediate Scale Hood 12234

Title/Subject: Heat Transfer Calculations from SS Hood to Electrical Cables and Pneumatic hoses

2) Convection from Hood - CONTINUED

d) Determine boundry layer thickness (δ) at top of the inclined side

For convection on vertical heated surface (Holman p 270)

$$Nu_x = \frac{hx}{K} = \frac{2x}{\delta} \longrightarrow \delta = \frac{2K}{h} \quad \text{and} \quad \bar{h} = \frac{4}{3} h_{x=L}$$

to account for the 32° inclined surface

$$\delta = \frac{2K}{h\cos\theta} = \frac{2K}{\frac{3}{4}\bar{h}\cos\theta}$$

$$= \frac{2(0.02811)}{3/4(1.83)\cos 32}\left(12\,\text{in}/\text{ft}\right)$$

$$\boxed{\delta = 0.58\text{ in}}$$

CONCLUSION: IF THE CABLE AND HOSES ARE LOCATED FARTHER THAN 0.58 in FROM THE INCLINED SIDE OF THE HOOD, THEY WILL BE UNAFFECTED BY CONVECTION HEAT TRANSFER FROM THE SIDE OF THE HOOD.

9413221.1929

ENGINEERING WORKSHEET

Prepared By: John Tizier	Date: 5/9/90	Project: INEL Intermediate Scale ISV 12234

Title/Subject:

3) Determine Effect of Radiation on Cables and Hoses aligned on the side of the hood

ASSUMPTIONS:
- Uniform hood surface temp of 470C (743K)
- 8 · 350 MCM cables and 16 hoses aligned side by side
- Ambient air temp of 100F (38C, 311K)

a) Estimate total radiation heat transfer from hood

$$Q_{rad} = \sigma A'_{hood} \epsilon (T_w^4 - T_\infty^4)$$

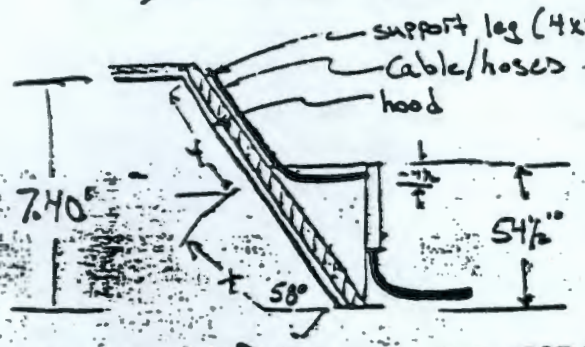
$$= \sigma (339)(0.6)(743^4 - 311^4)\left(\frac{1.8F}{C}\right)^4$$

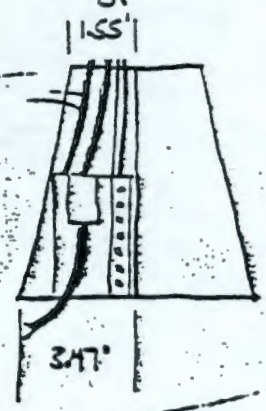
$$\boxed{Q_{rad} = 1.081 \times 10^6 \text{ Btu/hr}}$$

$\sigma = .1714 \times 10^{-8}$ Btu/hr ft² F⁴

although the emissivity of 304SS under these conditions is not readily referenced an estimate of 0.6 can be obtained from Holman Table A-10

b) Estimate fraction of radiation energy directly affecting the cables/hose





8 · 350 MCM cable ~ 1 Ø = 8"
8 · 3/8 hose ~ 29/32" = 5 7/4"
8 · 1/4 hose ~ 19/32 = 4 3/4"

Total side-to-side width = 18.5
= 1.54

this is equivalent to the width at the top of the ½ pannel

dimensions ref drawing no. H-3-57975 p4/8
H-3-57970 p2/2

$x + y = 8.71'$ (ref pl)

$x \approx \frac{50}{\sin 58} = 58.95" = 4.91'$

$y = 8.71 - 4.91 = 3.8'$

∴ estimate effective radiative surface as a 3.8' x 1.55' rectangle and the exposed surface (cables and hos as an equivalent, parallel rectangle

$A_{hose} = 3.8 \times 1.55 = 5.89 \text{ ft}^2$

$$\therefore Q_{eff} = Q_{rad}\left(\frac{A_{eff}}{A'_{hood}}\right) = (1.081 \times 10^6)\left(\frac{5.89}{339}\right) = \boxed{18.8 \times 10^3 \text{ Btu}}$$

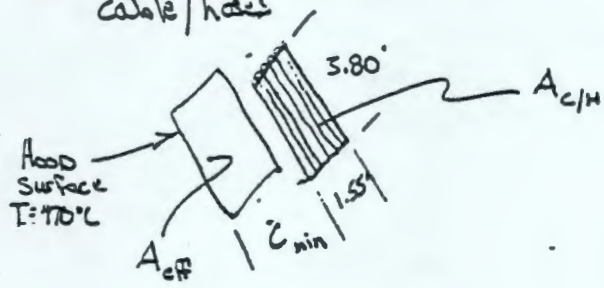
9413221.1930

Prepared By: John Tixier | Date: 5/9/90 | Project: INEL Intermediate Scale Hood 1223

Title/Subject:

3) HT radiation effect on cables and hoses - CONTINUED

c) calculate minimum distance allowable (c_{min}) between Hood Side Surface and cable/hose



$A_{eff} = A_{c/H}$

Thermal properties of the cable were discussed with the manufacturer (Anixter) and said to allow a maximum of 90°C temp rise

With rubber having a melting temp ~ 250°F and neoprene air hose being better than that, a Limiting Temp of the cable/hose is chosen of 90°C (194 F) 363K

A radiation energy balance for the system as shown is given as:

$$Q_{eff} = Q_{c/H} + Q_{space}$$

That is, the energy radiated from the hood surface will either be absorbed by the cables/hoses or the space outside of the cable/hose surface.

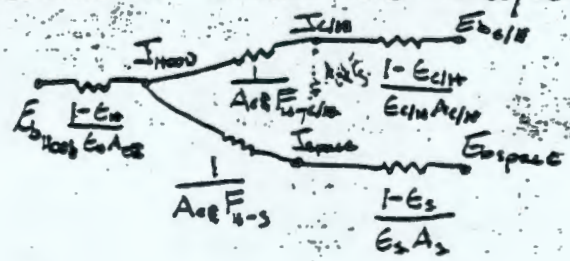
The area of the space outside the cable/hose surface is shown by:

$$A_s = 2(1.55)c + 2(3.8)c = 10.7c$$

This surface is comprised of the Hood Supports and open space and estimated to have an emissivity of $\epsilon = 0.9$ (white painted surface), also at 90°C

The cable/hose surface is also estimated to have a (conservative) emissivity of $\epsilon = 0.9$ for black rubber (even though the hose is red rubber and probably lower)

An electrical resistance equivalent network (Holman p 332) for the system can be drawn and analyzed:



where $E_b = \sigma T_b$
and F_{1-2} is the shape factor from surface 1 to 2

Thus

$$Q_{eff} = Q_{c/H} + Q_{space} = \frac{E_{b\,HOOD} - E_{b\,c/H}}{\frac{1-\epsilon_H}{\epsilon_H A_{eff}} + \frac{1}{A_{eff}F_{s-c/H}} + \frac{1-\epsilon_{c/H}}{\epsilon_{c/H}A_{c/H}}} + \frac{E_{b\,HOOD} - E_{b\,space}}{\frac{1-\epsilon_H}{\epsilon_H A_{eff}} + \frac{1}{A_{eff}F_{H-S}} + \frac{1-\epsilon_S}{\epsilon_S A_S}}$$

9413221.1931

ENGINEERING WORKSHEET

Prepared By: John Tixier | Date: 5/9/90 | Project: INEL Intermediate Scale ISV 1223

Title/Subject:

3) HT Radiation effect on cables and hoses

c) min distance from side - CONTINUED

Known relationships: $A_{eff} = A_{c/H}$

$F_{H-c/H} + F_{H-s} = 1 \longrightarrow F_{H-s} = 1 - F_{H-c/H}$

$\frac{A_s}{A_{c/H}} = \frac{10.7c}{5.89} = 1.82c$

$$Q_{eff} = Q_{c/H} + Q_{space} = \frac{A_{eff}\sigma(T_H^4 - T_{c/H}^4)}{\frac{1-\epsilon_H}{\epsilon_H} + \frac{1}{F_{H-c/H}} + \frac{1-\epsilon_{c/H}}{\epsilon_{c/H}}} + \frac{A_{eff}\sigma(T_H^4 - T_s^4)}{\frac{1-\epsilon_H}{\epsilon_H} + \frac{1}{1-F_{H-c/H}} + \frac{1-\epsilon_s}{\epsilon_s \frac{A_s}{A_{c/H}}}}$$

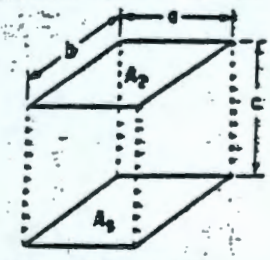
$$= A_{eff}\sigma(T_H^4 - T_{c/H}^4)\left[\left(\frac{1}{\epsilon_H} + \frac{1}{\epsilon_{c/H}} + \frac{1}{F_{H-c/H}} - 2\right)^{-1} + \left(\frac{1}{\epsilon_H} + (\epsilon_s \cdot 1.82c)^{-1} - (1.82c)^{-1} + (1-F_{H-c/H})^{-1} - 1\right)^{-1}\right]$$

$$\frac{18.8\times10^3\left(\frac{5}{9}\right)^4}{(5.89)(0.1714\times10^{-8})(743^4 - 363^4)} = \left[\frac{1}{0.6} + \frac{1}{0.9} + \frac{1}{F_{H-c/H}} - 2\right]^{-1} + \left[\frac{1}{.6} + \frac{1}{(0.9)(1.82c)} - \frac{1}{1.82c} + \frac{1}{1-F_{H-c/H}} - 1\right]^{-1}$$

$$0.617 = \left[0.778 + (F_{H-c/H})^{-1}\right]^{-1} + \left[0.667 + (16.38c)^{-1} + (1-F_{H-c/H})^{-1}\right]^{-1}$$

Thus, the Radiation Heat Transfer has been expressed as a function of the distance (c) between the two parallel surfaces. Note the shape factor ($F_{H-c/H}$) can be expressed as a relationship between the three dimensions involved in the system (with two of them known; i.e., a = 1.55' and b = 3.80') as shown in Siegel p 824

11



Identical, parallel, directly opposed rectangles.

$X = \frac{a}{c} \quad Y = \frac{b}{c}$

$$F_{1-2} = \frac{2}{\pi XY}\left\{\ln\left[\frac{(1+X^2)(1+Y^2)}{1+X^2+Y^2}\right]^{\frac{1}{2}} + X\sqrt{1+Y^2}\tan^{-1}\frac{X}{\sqrt{1+Y^2}} + Y\sqrt{1+X^2}\tan^{-1}\frac{Y}{\sqrt{1+X^2}} - X\tan^{-1}X - Y\tan^{-1}Y\right\}$$

(note: make sure to run the program in radi and not degrees

9413221.1932

Prepared By: John Tixier | Date: 5/9/90 | Project: INEL Intermediate Scale ISV 122

Title/Subject:

3) HT Radiation effect on cables and hoses

c). min distance from : Se - CONTINUED

The minimum distance (c_{min}) allowable between the two surfaces can now be solved itteratively by substituting values for (c) into the function until converging on the function value of 0.617

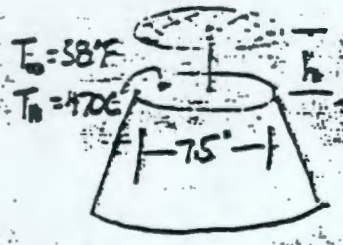
c (ft)	$F_{H-c/H}$	f(c)
1.0	0.447	0.726
0.75	0.538	0.723
0.50	0.655	0.705
0.25 (3in)	0.805	0.660
0.1667 (2in)	0.864	0.636
0.083 (1in)	0.929	0.604
0.11545 (~1 3/8 in)	0.903	0.617 (exact)

∴ if the cable/hose surface is located farther than 1 3/8 in from the surface of the hood, its integrity will not be compromised

d) determine the minimum allowable distance (h_{min}) between the top of the hood surface and the fiber grate.

ADDITIONAL ASSUMPTIONS:

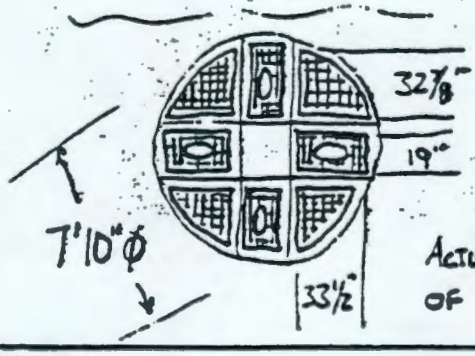
- model the fibergrate as a flat disk parrallel to the top and having the same diameter (7.5') and emissivity of $\varepsilon = .9$. This is very conservative due to the actual shape, size and configuration of the grate (dwg. no. H-3-57970 p1, 2/2)
- maximum allowable temp of fibergrate is 150°F



The fraction of energy radiated from the hood top

$$Q_{Top} = \frac{A_{top}}{A'_{hood}} Q_{rad} = (0.127)(1.081 \times 10^6)$$

$$= 0.137 \times 10^6 \text{ Btu/hr}$$



ACTUAL 8-PIECE CONFIGURATION OF FIBERGRATE PLATFORM

94-3221.1933

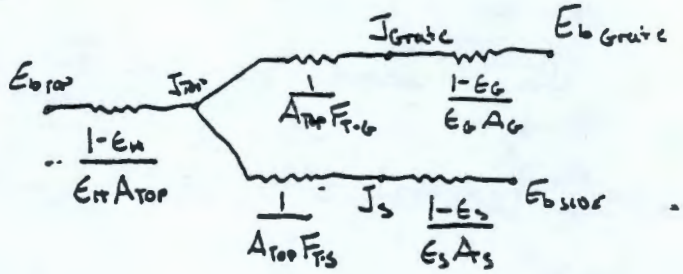
Prepared By: John Tixier | Date: 5/9/90 | Project: INEL Intermediate Scale ISV 122

Title/Subject:

3) HT Radiation effect on cables and hoses

d) min distance from top - CONTINUED

An electrical resistance equivalent network can be drawn and analyzed.



where
$\epsilon_{Grate} = .9$
$\epsilon_{Hood} = .6$
$\epsilon_{side} = .9$
$A_{top} = A_{Grate}$
$A_{side} = \pi d h$ $\quad \frac{A_s}{A_T} =$
$F_{top\text{-}Grate} + F_{top\text{-}side} = 1$

$$Q_{TOP} = Q_{Grate} + Q_{side}$$

$$= \frac{E_{b\,top} - E_{b\,Grate}}{\frac{1-\epsilon_H}{\epsilon_H A_{top}} + \frac{1}{A_{top}F_{T\text{-}G}} + \frac{1-\epsilon_G}{\epsilon_G A_G}} + \frac{E_{b\,top} - E_{b\,side}}{\frac{1-\epsilon_H}{\epsilon_H A_{top}} + \frac{1}{A_{top}F_{T\text{-}S}} + \frac{1-\epsilon_S}{\epsilon_S A_S}}$$

$$= \frac{A_{top}\sigma\left(T_H^4 - T_G^4\right)}{\frac{1}{\epsilon_H} - 1 + \frac{1}{F_{T\text{-}G}} + \frac{1}{\epsilon_G} - 1} + \frac{A_{top}\sigma\left(T_H^4 - T_S^4\right)}{\frac{1}{\epsilon_H} - 1 + \frac{1}{F_{T\text{-}S}} + \frac{1}{\epsilon_S 4h/d} - \frac{1}{4h/d}}$$

$$= (\quad) + \frac{(\quad)}{\frac{1}{\epsilon_H} - 1 + \frac{1}{1-F_{TG}} + \frac{d(1-\epsilon_S)}{\epsilon_S 4h}}$$

$$\frac{0.137 \times 10^6}{(43)(0.1714 \times 10^{-8})} = \frac{\left[(743)^4\left(\frac{9}{5}\right)^4 - (150+460)^4\right]}{\frac{1}{.6} - 1 + \frac{1}{F_{TG}} + \frac{1}{.9} - 1} + \frac{\left[(743)^4\left(\frac{9}{5}\right)^4 - (38+460)^4\right]}{\frac{1}{.6} - 1 + (1-F_{TG})^{-1} + \frac{7.5(1-0.9)}{(0.9)(4)h}}$$

$$1.86 \times 10^{12} = \frac{3.06 \times 10^{12}}{0.778 + \frac{1}{F_{TG}}} + \frac{3.14 \times 10^{12}}{0.667 + (1-F_{TG})^{-1} + (4.80h)^{-1}}$$

9413221.1934

Prepared By: John Tixier | Date: 5/9/90 | Project: INEL Intermediate Scale ISV 12234

Title/Subject:

3) HT Radiation effect on cables and hoses

d) min distance from top - CONTINUED

Again, the Radiation Heat Transfer has been expressed as a function of the distance between the two surfaces, since the shape factor F_{r-6} is also a function of the distance

From Siegel p. 826 the shape factor between two parallel discs can be expressed as follows:

$$F_{r-6} = \frac{1}{2}\left[X - (X^2-4)^{1/2}\right] \quad \text{where} \quad X = 1 + \frac{1+\left(\frac{r}{h}\right)^2}{\left(\frac{r}{h}\right)^2} = 2 + \left(\frac{h}{r}\right)^2$$

substituting for X and simplifying

$$= 2 + 4\left(\frac{h}{d}\right)^2 \quad \text{and } d = 7.5'$$

$$F_{r-6} = 1 + 2\left(\frac{h}{d}\right)^2 - 2\frac{h}{d}\left(1 + \frac{h^2}{d^2}\right)^{1/2}$$

once again, h_{min} can be itterated from the function

h (ft)	F_{r-6}	f(h)
1.0	0.767	2.08×10^{12}
0.75	0.812	2.02
0.5	0.875	1.94
0.33	0.915	1.87
0.275	0.929	1.85
0.2911 (~3.5in)	0.926	1.86 (exact)

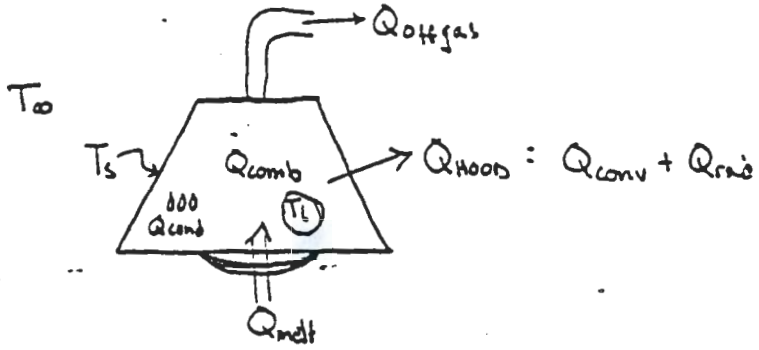
∴ If the grate remains farther than 3.5in it will not be thermally compromised. Note that this result was based on extremely conservative values and configuration. Even if the existing grate were this close it should not be affected.

9413221.1935

Prepared By: John Tinier | Date: 5/9/90 | Project: INEL ISV Intermediate Scale 12234

Title/Subject:

H) Check Energy balance on the Hood System



ASSUMPTIONS: (conservative)

- $T_s = T_i = 470°C$
- $T_\infty = 100°F = 38°C$
- From Timmerman

$Q_{in} = 469{,}000 \ \frac{Kcal}{hr}$

$= 1.86 \times 10^6 \ Btu/hr$

$Q_{offgas} = 348 \times 10^3 \ Btu/hr$

$Q_{in} = Q_{out}$

$Q_{in} = Q_{offgas} + Q_{conv} + Q_{rad}$

$= Q_{offgas} + (Q_{side} + Q_{TOP})_{conv} + Q_{rad}$

$1.86 \times 10^6 = 0.348 \times 10^6 + (0.0488 \times 10^6 + 0.421 \times 10^6) + 1.081 \times 10^6$

$\boxed{1.86 \times 10^6 \approx 1.90 \times 10^6 \ Btu/hr}$ ✓

This shows that the overall energy balance is accurate, even under conservative assumptions.

9113224.1936

9413221.1937

5) SUMMARY AND CONCLUSIONS

a) Pertaining to the Equipment Configuration on the Side of the Hood:

In actuality, the cables and hoses and fiberglass steps will be located at least 8 inches away from the surface of the hood. The analytical results show that this distance lies well outside of the free convection boundary layer and is also free from dangerous thermal radiation effects. The lowest fiberglass step is located at least 4 inches from the hood surface at its closest point with subsequent steps increasingly further away until the top step is at least 8 inches away at its closest point. Therefore, the steps are also outside the boundary layer. Furthermore, considering the conservative assumptions (no wind, high ambient temperature), when these conditions are relaxed it will serve to further lessen the heat transfer from the cables and hoses to the hood.

b) Pertaining to the Equipment Configuration on the Top of the Hood:

Considering that the convection heat transfer from the top of the hood is merely 10.3% of the total convection heat transfer, and the radiation heat transfer from the top merely 12.7% of the total radiation heat transfer; that the fibergrate is located on the top at least 4 inches from the surface of the hood and the cables and hoses lie on top or above the fibergrate; that the effective area of the hoses and cables is small compared to the radiative surface of the top; that the fibergrate acts somewhat as a radiation shield between the top and the cables and hoses as well as the grid pattern contributing to free convection cooling of itself; and that all assumptions have been very conservative; it is concluded that the cables, hoses and fibergrate on top are in no thermal danger as currently designed.

5) Summary and Conclusions - CONTINUED

c) Heat Transfer from the Equipment Itself:

These calculations show that the hoses, cables and fibergrate are safe from dangerous thermal effects of heat transfer from the hood, even under conservative assumptions. An even more conservative situation is that heat transfer from the equipment itself has been assumed to be zero which, of course, is not true. These thermal effects are even lower in actuality than shown here.

9413221.1938

6)REFERENCES

Holman, J. P., Heat Transfer. McGraw-Hill, 1981.

Kays, William M. and Michael E. Crawford, Convective Heat and Mass Transfer. McGraw-Hill, 1980.

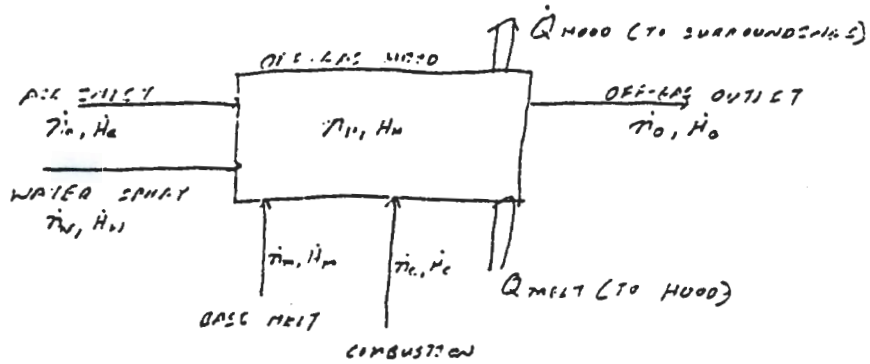
Siegel, Robert and John R. Howell, Thermal Radiation Heat Transfer. McGraw-Hill, 1981.

Timmerman, C. L., "Combustion Calculations: Intermediate-Scale @ INEL," June 20, 1989.

PNL Drawings:
H-3-57970 Pilot Scale - ISV Hood and Electrode Feed Arrgt
H-3-57975 Pilot Scale - ISV Fabric Hood Structure Details
WS-X-57973 Pilot Scale - ISV Metal Hood Assembly

9413221.1939

PREVIOUS NON-STEADY-STATE MATERIAL AND ENERGY BALANCE CALCULATIONS (100AREA-93-02 AND 100AREA-93-04) HAVE NEGLECTED HEAT TRANSFER FROM THE SURFACE OF AN ISV MELT TO THE HOOD AND TRANSFER FROM THE HOOD TO AMBIENT SURROUNDINGS. CALCULATIONS 100AREA-93-08 AND 100AREA-93-09 ESTIMATE THE HEAT TRANSFER FROM THE HOOD TO AMBIENT SURROUNDINGS FOR FREE CONVECTION AND FORCED CONVECTION, RESPECTIVELY. QUANTIFICATION OF THE HEAT TRANSFER FROM THE ISV MELT SURFACE HAS NOT BEEN PERFORMED; THEREFORE, IT WILL BE ESTIMATED FOR THIS CALCULATION.



STEADY-STATE VALUES FOR THE PILOT-SCALE ISV HOOD (FROM 100AREA-93-02)

$V_H = 27.6\ m^3$ $\quad P_H = 100.677\ kPa$ $\quad T_H = 573\ K$ $\quad n_H = \frac{PV}{RT} = 583$ moles
($R = 8.314\ m^3 \cdot Pa/mole\ K$)

$\dot{V}_o = 12.5\ m^3/mole$ (STANDARD) $\Rightarrow \dot{n}_o = 9.3$ mol/s.

$P_a = 101.325\ kPa$ $\quad T_a = 298\ K$

THE DETERMINATION OF $\dot{n}_m$ ASSUMED NO COMBUSTION AND $Q_{MELT} = Q_{HOOD} = 0$. SINCE Q_{MELT} IS NOT KNOWN, ASSUME $Q_{MELT} = Q_{HOOD}$ @ 573 K. ALSO, FOR THE TEMP. RANGE 573 K → 743 K, USE AN AVERAGE h_a (FROM 100AREA-93-08) AND IGNORE FORCED CONVECTION.

$$\therefore Q_{HOOD} = 324.07(T_H - 298) + 1.07\times10^{-6}(T_H^4 - 7.89\times10^9) \quad \text{[EQ. 5, 100AREA-93-08]}$$

$$= 324.07(573-298) + 1.07\times10^{-6}(573^4 - 289\times10^9)$$

$$= 196{,}022\ J/s = 196.02\ kJ/s$$

$\Rightarrow Q_{MELT} = 196.02$ kJ/s ; ASSUME CONSTANT.

Title	Project
MATERIAL & ENERGY BALANCE WITH CONVECTION	100 AREA ISV DEMONSTRATION

Prepared by:	Date	Reviewed by:	Date
[illegible]	3/22/93	[illegible]	3/22/93

9413221.1940

SUMMARY OF MATERIAL AND ENERGY BALANCES:

MATERIAL: $\frac{dn_H}{dt} = \dot{n}_a + \dot{n}_m + \dot{n}_c + \dot{n}_N - \dot{n}_o$

IN TERMS OF n_H AND T_H;

$P_H < P_a$ (FLOW INTO HOOD THROUGH AIR INLET): [$\dot{n}_m, \dot{n}_c, \dot{n}_o$ ASSIGNED VALUES]

$$\frac{dn_H}{dt} = \left(\frac{\dot{n}_a - \dot{n}_m}{0.7941 \cdot MW_a}\right)\left(0.3125\left(\frac{n_H R T_H}{P_a V_H}\right) + 0.6875\left(\frac{P_a MW_a}{R T_a}\right)^{1/2}\left(P_a - \frac{n_H R T_H}{V_H}\right)^{1/2}\right) + \dot{n}_m + \dot{n}_c - \dot{n}_o + \dot{n}_N$$

$P_H > P_a$ (FLOW OUT OF HOOD THROUGH AIR INLET):

$$\frac{dn_H}{dt} = \left(\frac{\dot{n}_m - \dot{n}_a}{0.7941 \cdot MW_a}\right)\left(0.3125\left(\frac{P_a V_H}{R T_H}\right) + 0.6875\left(\frac{n_H R T_H}{V_H}\right)^{1/2}\left(\frac{n_H R T_H}{V_H} - P_a\right)^{1/2}\right) + \dot{n}_m + \dot{n}_c - \dot{n}_o + \dot{n}_N$$

ENERGY: $\frac{dH_H}{dt} = \dot{H}_a + \dot{H}_m + \dot{H}_c + \dot{H}_N - \dot{H}_o + Q_{MELT} - Q_{HOOD}$ [kJ/s]

FOR COMPLETE COMBUSTION, DEFINE $\dot{n}_{a,MIN} = 47.6\,\dot{n}_c$

∴ IN TERMS OF n_H AND T_H;

$P_H < P_a$:

$\dot{n}_a > \dot{n}_{a,MIN}$;

$$C_{PH} n_H \frac{dT_H}{dt} = C_{PH}(T_{REF} - T_H)\frac{dn_H}{dt} + \dot{n}_a C_{Pa}(T_a - T_{REF}) + \dot{n}_m[0.0417\,T_m + 32.6] + \dot{n}_c \Delta H_c$$
$$- (\dot{n}_o - \dot{n}_m) C_{Pa}(T_H - T_{REF}) - \dot{n}_m[0.0417\,T_H + 32.5] + 196.02$$
$$- [324.07(T_H - 298) + 1.07 \times 10^{-6}(T_H^4 - 7.89 \times 10^9)] + \dot{n}_N[-0.0417\,T_H - 30.7]$$

$\dot{n}_a < \dot{n}_{a,MIN}$, $\dot{n}_o > 0$;

REPLACE $\dot{n}_c \Delta H_c$ WITH $\dot{n}_c \frac{\dot{n}_a}{\dot{n}_{a,MIN}} \Delta H_c + \left(1 - \frac{\dot{n}_a}{\dot{n}_{a,MIN}}\right)\dot{n}_c C_{Pc}(T_m - T_H)$

$P_H > P_a$:

$$C_{PH} n_H \frac{dT_H}{dt} = C_{PH}(T_{REF} - T_H)\frac{dn_H}{dt} + \dot{n}_a C_{Pa}(T_a - T_{REF}) + \dot{n}_m(0.0417\,T_m + 32.6)$$
$$+ \dot{n}_c C_{Pc}(T_m - T_H) - (\dot{n}_o - \dot{n}_m) C_{Pa}(T_H - T_{REF}) - \dot{n}_m(0.0417\,T_H + 32.5)$$
$$+ \dot{n}_N(-0.0417\,T_H - 30.7) + 196.02 - [324.07(T_H - 298) + 1.07 \times 10^{-6}(T_H^4 - 7.89 \times 10^9)]$$

PNL-7322 1941

Q TERMS WERE INSERTED INTO HI-Q PROGRAM AND THE EQUATIONS CHECKED WITH $\dot{m}_c = 0$. RESULTS SHOWN ON ATTACHMENT 1. T_m AND $\dot{m}_c$ REMAIN AT INITIAL LEVELS; THEREFORE, Q TERMS ENTER CORRECTLY.

DETERMINATION OF EFFECT OF COMBUSTION, $\dot{m}_c > 0$. SEE ATTACHMENT 2. TERMS = Q → 60; SIEF = 1.

INCLUDING HEAT TRANSFER FROM THE HCCO INDICATES THAT THE HCCO WILL EQUILIBRATE AT ≈ 785K. PRIOR RUNS DID NOT SHOW SUCH A PLATEAU IN TEMPERATURE.

PREVIOUS CALCULATIONS (100ARIA-93-08) SHOW THAT A WATER SPRAY CAN COMBAT THE THERMAL EFFECTS FROM COMBUSTION. THEREFORE, AN ADDITIONAL CALCULATION IS NOT SHOWN HERE.

BEST AVAILABLE COPY

ATTACHMENT 1

Hi-Q RESULTS. INCLUDES TERMS FOR Q INTO AND OUT OF HOOD WITH $\dot{m}_c = 0$. CHECK OF EQUATIONS.

	Th	nh
1	5.73e+2	5.83e+2
2	5.73e+2	5.83e+2
3	5.73e+2	5.83e+2
4	5.73e+2	5.83e+2
5	5.73e+2	5.84e+2
6	5.73e+2	5.84e+2
7	5.73e+2	5.84e+2
8	5.73e+2	5.84e+2
9	5.73e+2	5.84e+2
10	5.73e+2	5.84e+2
11	5.73e+2	5.84e+2
12	5.73e+2	5.84e+2
13	5.73e+2	5.84e+2
14	5.73e+2	5.84e+2
15	5.73e+2	5.84e+2
16	5.73e+2	5.84e+2
17	5.73e+2	5.84e+2
18	5.73e+2	5.84e+2
19	5.73e+2	5.84e+2
20	5.73e+2	5.84e+2
21	5.73e+2	5.84e+2
22	5.73e+2	5.84e+2
23	5.73e+2	5.84e+2
24	5.73e+2	5.84e+2
25	5.73e+2	5.84e+2
26	5.73e+2	5.84e+2
27	5.73e+2	5.84e+2
28	5.73e+2	5.84e+2
29	5.73e+2	5.84e+2
30	5.73e+2	5.84e+2
31	5.73e+2	5.84e+2
32	5.73e+2	5.84e+2
33	5.73e+2	5.84e+2
34	5.73e+2	5.84e+2
35	5.73e+2	5.84e+2
36	5.73e+2	5.84e+2
37	5.73e+2	5.84e+2
38	5.73e+2	5.84e+2
39	5.73e+2	5.84e+2
40	5.73e+2	5.84e+2
41	5.73e+2	5.84e+2

9413221.1943

ATTACHMENT
$\dot{m}_c = 0.14$ mo

Time	Th	Nh	Ph	Na
0	573.0	583.0	100.6292	7.93
1	583.1	576.9	101.3238	0.34
2	590.3	569.8	101.3221	0.51
3	597.6	562.9	101.3197	0.69
4	604.8	556.1	101.3166	0.87
5	612.0	549.6	101.3126	1.06
6	619.1	543.2	101.3078	1.25
7	626.2	537.1	101.3023	1.43
8	633.2	531.1	101.2959	1.63
9	640.1	525.3	101.2886	1.82
10	646.9	519.7	101.2804	2.01
11	653.7	514.3	101.2714	2.20
12	660.3	509.1	101.2616	2.40
13	666.8	504.1	101.2510	2.59
14	673.2	499.2	101.2396	2.78
15	679.4	494.6	101.2274	2.97
16	685.5	490.2	101.2146	3.16
17	691.4	485.9	101.2011	3.35
18	697.1	481.9	101.1870	3.54
19	702.7	478.0	101.1723	3.72
20	708.1	474.3	101.1573	3.90
21	713.3	470.7	101.1418	4.07
22	718.3	467.4	101.1261	4.24
23	723.1	464.2	101.1101	4.41
24	727.7	461.2	101.0939	4.57
25	732.1	458.3	101.0777	4.73
26	736.3	455.6	101.0615	4.88
27	740.3	453.1	101.0454	5.03
28	744.2	450.7	101.0294	5.17
29	747.8	448.4	101.0135	5.31
30	751.3	446.3	100.9980	5.44
31	754.6	444.3	100.9828	5.56
32	757.7	442.4	100.9679	5.68
33	760.6	440.6	100.9535	5.80
34	763.4	439.0	100.9394	5.91
35	766.0	437.4	100.9259	6.01
36	768.4	435.9	100.9128	6.11
37	770.8	434.6	100.9003	6.20
38	772.9	433.3	100.8882	6.28
39	774.9	432.1	100.8767	6.37
40	776.8	431.0	100.8657	6.44
41	778.6	430.0	100.8552	6.52
42	780.3	429.0	100.8453	6.59
43	781.8	428.1	100.8359	6.65
44	783.2	427.3	100.8189	6.76
45	784.1	426.7	100.7868	6.97
46	784.7	426.3	100.7542	7.18
47	784.9	426.0	100.7279	7.34
48	785.0	425.9	100.7100	7.45
49	784.9	425.9	100.6996	7.52
50	784.9	425.9	100.6949	7.54
51	784.8	425.9	100.6938	7.55
52	784.7	426.0	100.6947	7.54
53	784.7	426.0	100.6963	7.54
54	784.6	426.0	100.6979	7.53
55	784.6	426.0	100.6992	7.52
56	784.6	426.0	100.7001	7.51
57	784.6	426.1	100.7006	7.51
58	784.6	426.0	100.7008	7.51
59	784.6	426.0	100.7009	7.51
60	784.7	426.0	100.7008	7.51

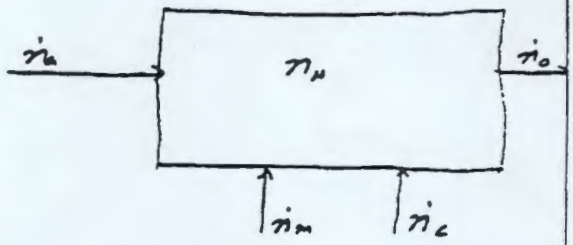
9413221.1944

PROBLEM:

DUE TO THE PROPOSED HIGH COMBUSTIBLE LOADING FOR THE ISV DEMONSTRATION (67.7 vol %, 33.9 wt %), THERE EXISTS THE POTENTIAL FOR CO LEVELS TO APPROACH THE LEL (LOWER EXPLOSIVE LIMIT). THE LEL FOR CARBON MONOXIDE IS 12.5%.

SOLUTION:

FROM 100AREA-93-02.



$\dot{n}_c = 0.14$ moles/s [ASSUME = CELLULOSE]
$\dot{n}_m = 1.65$ moles/s
$\dot{n}_o = 9.3$ moles/s
$\dot{n}_a = f(P_H)$

ASSUMPTIONS:
1) NO CO IN n_m STREAM
2) NO CO IN AIR INLET STREAM
3) C_{CO} IN OUTLET = C_{CO} IN HOOD.
4) C_{CO} IN HOOD = 0 @ TIME 0.
5) $C_{xo} = C_{xH}$

a = AIR INLET
c = COMBUSTIBLES
H = HOOD
m = BASE MELT GASES
o = OUTLET.

MATERIAL BALANCE:

$$\frac{d(X_H)}{dt} = \dot{X}_a + \dot{X}_m + \dot{X}_c - \dot{X}_o \qquad \text{WHERE } X = CO$$

$$\frac{d(C_{xH} n_H)}{dt} = \cancel{C_{xa}\dot{n}_a}^{\,0} + \cancel{C_{xm}\dot{n}_m}^{\,0} - C_{xo}\dot{n}_o + \dot{X}_c$$

$$C_{xH}\frac{dn_H}{dt} + n_H\frac{dC_{xH}}{dt} = \dot{X}_c - C_{xo}\dot{n}_o \qquad \text{FOR FLOW INTO HOOD.}$$

$$C_{xH}\frac{dn_H}{dt} + n_H\frac{dC_{xH}}{dt} = -C_{xo}\dot{n}_o - C_{xo}\dot{n}_o + \dot{X}_c \qquad \text{FOR FLOW } \cancel{\text{INTO}} \text{ out of HOOD.}$$

CASE 1:

ASSUME INCOMPLETE COMBUSTION. $\therefore$ $C_6H_{10}O_5 + 3O_2 \rightarrow 6CO + 5H_2O$

$\Rightarrow \dot{X}_c = 6\dot{n}_c = 0.84$ moles/s

@ STEADY-STATE, $\frac{dn_H}{dt} = \frac{dC_{xH}}{dt} = 0$

$\therefore$ FOR $P_H \le P_a$ (FLOW INTO HOOD)

$0 = \dot{X}_c - C_{xo}\dot{n}_o$
$0 = 0.84$ moles/s $- C_{xo}(9.3$ moles/s$)$
$C_{xo} = 0.090$

$\Rightarrow$ MAX. C_{CO} PREDICTED WOULD BE 9.0%. LEL = 12.5%

Title	Project
ESTIMATES OF CO CONCENTRATIONS	100 AREA ISV DEMO

Prepared by:	Date	Reviewed by:	Date
J. LUEY	5/13/93		5/10/93

Battelle
Pacific Northwest Laboratories

ENGINEERING WORKSHEET

Prepared By: J. Luey J. Luey | Date: 5/19/93 | Project: 100 AREA DEMONSTRATION 100ARSA-93-13

Subject: ESTIMATION OF COMBUSTION EFFICIENCY

PROBLEM: WHAT IS THE COMBUSTION EFFICIENCY DURING ISV PROCESSING.

SOLUTION: purpose/issue?

THE 116-B-6A CRIB (LUEY ET al., 1992) PROVIDES FULL-SCALE DATA TO ESTIMATE COMBUSTION EFFICIENCY.

ATTACHMENT 1 ILLUSTRATES 116-B-6A CRIB. SOLID WOODEN TOP EXPECTED TO PRODUCE HIGHEST LEVEL OF CO + CO_2 DUE TO ORGANIC DENSITY.

MELT RATE = 1"/hr. ✓

$\dot{V}_{wood}$ CONSUMED = (MELT RATE X CROSS SECTIONAL AREA) ✓
= (1"/hr X 144" + 144")
= 20,736 cu. in./hr. ✓
= 339,802 cm^3/hr ✓
= 94.39 cm^3/s ✓

(neglect electrode oxidation JEJ)

$\dot{m}_{wood} = \rho_{wood} \dot{V}_{wood} = (0.44 g/cm^3 X 94.39 cm^3/s) = 41.5$ g/s ✓

ASSUME WOOD = CELLULOSE ∴ $C_6H_{10}O_5$ = M.W = 162 g/mole. ✓

$\dot{n}_{wood} = (41.5 g/s)/(162 g/mole) = 0.256$ mole/s. ✓

FOR INCOMPLETE COMBUSTION; $C_6H_{10}O_5 + 3O_2 \rightarrow 6CO + 5H_2O$ ✓

$\Rightarrow \dot{n}_{CO} = 6\dot{n}_{wood} = 1.54$ mole/s ✓ (moles CO/sec. produced) JEJ

@ STEADY-STATE $CO_{in} = CO_{out}$

ASSUME ONLY CO_{in} IS FROM MELT AND ONLY CO_{out} IS THROUGH STACK ✓

$\dot{n}_{CO} = C_{CO} \dot{n}_o$

FOR 116-B-6A, OUTLET FLOW = 83 m^3/min (STANDARD)

$\dot{n}_o = \dot{V}_o / (\dot{V}_{STD} / n_{STANDARD})$
= (83 m^3/min)/(.0221 m^3/mole)
= 3,755 mole/min
= 62.6 mole/s.

9413221.1946

Battelle
Pacific Northwest Laboratories

ENGINEERING WORKSHEET

Prepared By: J. Luey J. Luey | Date: 5/19/93 | Project: 100 AREA DEMO | 100AREA-93-12

Title/Subject: ESTIMATION OF COMBUSTION EFFICIENCY

SOLVING FOR C_{co}:

$$C_{co} = \dot{n}_{co}/\dot{n}_o = (1.54 \text{ mole/s})/(62.6 \text{ mole/s})$$
$$= 0.0246 \checkmark$$
$$= 2.46\% \checkmark$$
$$= 24{,}600 \text{ ppm} \leftarrow$$

FROM LUEY ET AL. (1992), AVERAGE CO LEVEL DURING PROCESSING OF TOP ≈ 2000 ppm

∴ FRACTION OF WOOD CONVERTED TO CO; $X_{co} = 2000/24{,}600$
$= 0.08$
$= 8\%$

5/19/93
(accounts for CO conversion to CO_2 in heat plenum)

THEREFORE, ESTIMATED CO LEVELS FOR 100 AREA DEMO:

$$C_{co,est.} = X_{co}\, C_{co,max}$$
$$= (0.08 \times .09)$$
$$= .0072 \leftarrow *$$
$$= 0.72\%$$

This assumes same plenum conversion efficiency from large- to pilot-scale.

NOTE: THIS VALUE MAY STILL BE CONSERVATIVE RESULTS FOR 116-B-6A
– SUGGEST CO MONITORS WERE READING HIGH

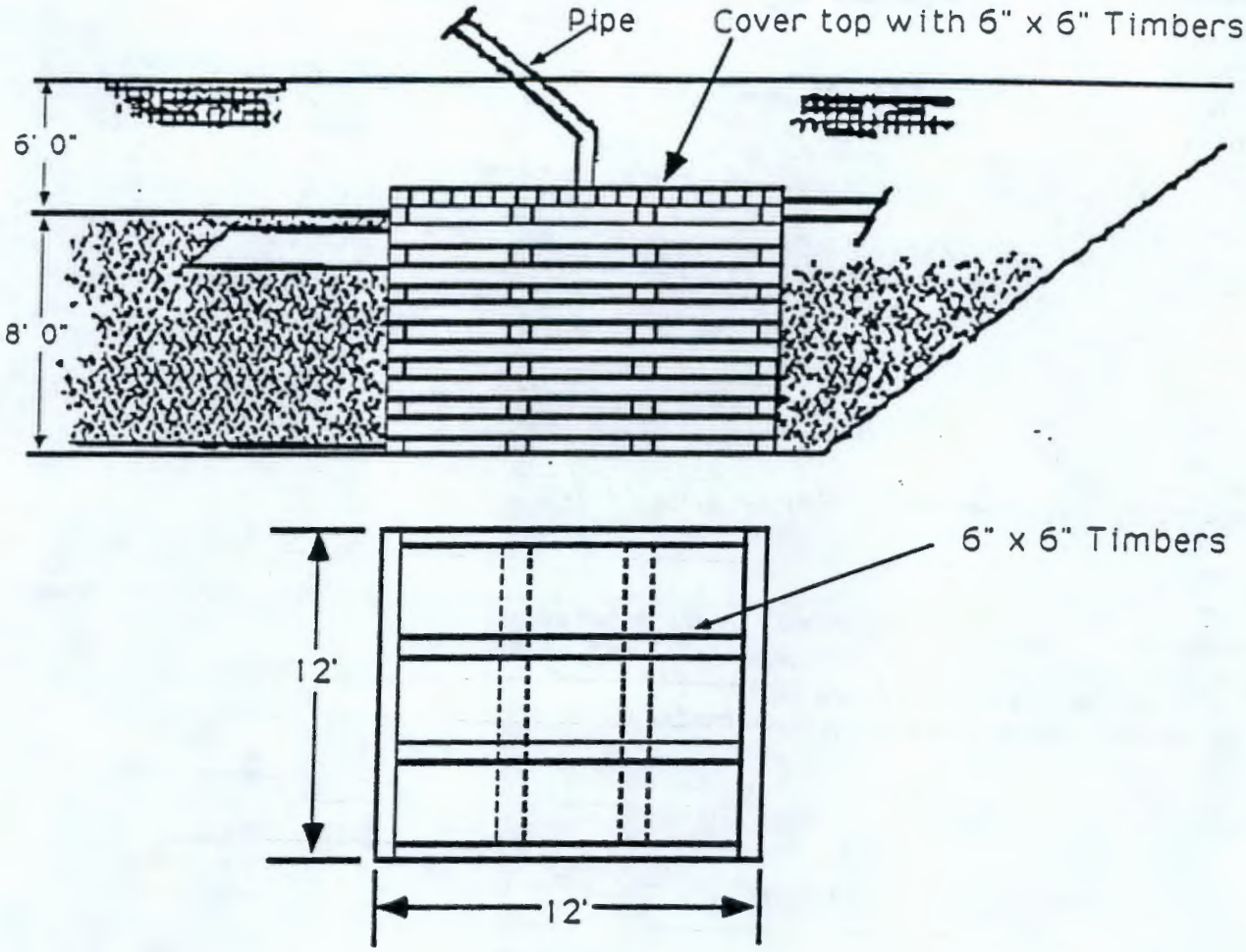
reviewed C E Thompson 5/20/93
define conc. CO max at .09 *
where does this value come from.
all else ok.

– 0.09 MAXIMUM CO CALCULATED FROM 100AREA-93-12 AND IS BASED ON WASTE LOADING FOR 100 AREA DEMONSTRATION.

J. Luey 5/2

9413221.1947

ATTACHMENT 1 [illegible]
PAGE [illegible]



9413221.1948

PROBLEM:

DURING ISV PROCESSING OF SITES CONTAINING HIGH COMBUSTIBLE LOADINGS, THERE POTENTIAL EXISTS FOR CREATING HIGH LEVELS OF CO VIA INCOMPLETE COMBUSTION. 100ARSA-93-12 ESTIMATES A MAX. CO LEVEL = 9% AND 100ARSA-93-13 ESTIMATES AN EXPECTED VALUE OF 0.72%.

SINCE STEAM IS PRESENT (FROM MELT OR FROM WATER SPRAY SYSTEM) THERE IS THE POTENTIAL TO FORM H_2 VIA:

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad \text{WATER-GAS SHIFT RXN.}$$

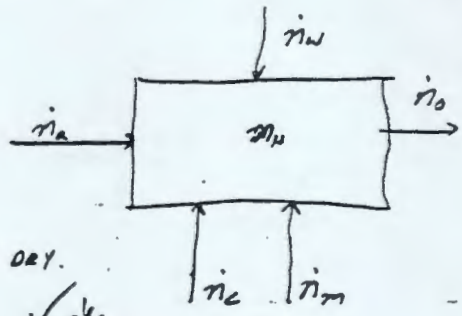
THIS IS OF CONCERN IF THE CONCENTRATION OF H_2 APPROACHES THE LEL (4%).

WHAT IS ESTIMATED RANGE OF $[H_2]$?

SOLUTION:

WATER-GAS SHIFT REACTION WIDELY USED TO CREATE H_2 (MOE, ATTACHED) ✓
- PRESSURE RANGES FROM AMBIENT → 500 psi
- IRON OXIDES USED AS CATALYST
- 5-15% Cr_2O_3 USED AS PROMOTER.

BALANCE ON H_2O:



$$\frac{dn_H}{dt} = C_{Wa}\dot{n}_a + \dot{n}_N + \dot{n}_m + C_{Wc}\dot{n}_c - C_{WH}\dot{n}_o$$

ASSUME AIR AND COMBUSTION STREAM (c) ARE DRY.

∴ @ STEADY-STATE $0 = \dot{n}_N + \dot{n}_m - C_{WH}\dot{n}_o$ ✓ ok

FOR $\dot{n}_N = 4.25$ mole/s (100ARSA-93-10)
$\dot{n}_m = 1.65$ mole/s (100ARSA-93-02)
$\dot{n}_o = 9.3$ mole/s (100ARSA-93-02)

$$\Rightarrow C_{WH} = \frac{\dot{n}_N + \dot{n}_m}{\dot{n}_o} = \frac{4.25 + 1.65}{9.3} = 0.63$$

CONSERVATIVE SINCE WATER SPRAY SYSTEM NOT USED CONTINUOUSLY ✓ ok

ASSUMING OFF-GAS HOOD HAS SUFFICIENT IRON FOR CATALYST, THEN

$$K = \exp(8240/T - 4.33) \quad T \text{ in } R^\circ,\ K = \text{eq. const. (MOE)}$$

Title	Project
ESTIMATION OF H_2 CONCENTRATION	100 ARSA ISV DEMO.

Prepared by:	Date	Reviewed by:	Date
J. Luey	5/25/93	LE Thompson	5/26/93

9413271.1949

@ $T = 350°C = 1,121\ °R \Rightarrow K = \exp.(8240/1121 - 4.33)$
$= 1038$

@ $T = 200°C = 851\ °R \Rightarrow K = \exp.(8240/851 - 4.33)$
$= 221,365$

∴ REACTION FAVORED AT LOWER TEMPERATURES.

EVALUATION @ 200°C :

$[CO]_0 = 0.09 \quad [H_2O]_0 = 0.63$

LET $X = [H_2] = [CO_2]$ @ eq. AND THAT $[CO_2]_0 = [H_2]_0 = 0$

$$\Rightarrow \quad K = \frac{[H_2][CO_2]}{[CO][H_2O]} = \frac{x^2}{(0.09-x)(0.63-x)} = 221,365$$

$$\checkmark \quad \frac{x^2}{0.0567 - .72x + x^2} = 221,365$$

$$x^2 = 12,551 - 159,382x + 221,365x^2$$

$$0 = 221,364x^2 - 159,382x + 12,551$$

$$\checkmark \quad x = \frac{-b \pm (b^2 - 4ac)^{1/2}}{2a}$$

$$= \frac{159,382 \pm ((159,382)^2 - 4(221,364)(12,551))^{1/2}}{2(221,364)}$$

$$= 0.63 \text{ OR } 0.09$$

∴ $[H_2] = 0.09$ SINCE CO LIMITING.

FOR $[CO]_0 = 0.0072 \quad [H_2O]_0 = 0.63$

$$x^2 = 221,365(0.0072 - x)(0.63 - x)$$

$$x^2 = 1,009 - 141,053x + 221,365x^2$$

$$0 = 1,009 - 141,053x + 221,364x^2$$

$$x = \frac{-141,053 \pm ((141,053)^2 - 4(221,364)(1009))^{1/2}}{2(221,364)}$$

$$x = 0.63 \text{ OR } 0.0072$$

∴ $[H_2] = 0.0072$ SINCE CO LIMITING.

Title	Project
ESTIMATION OF H_2 CONCENTRATION	100 AREA ISV DSMO

Prepared by:	Date	Reviewed by:	Date
J. Lusy	5/25/93		5/26/93

9413221.1950

EVALUATION @ 350°C.

FOR $[CO]_0 = 0.09$, $[H_2O]_0 = 0.63$, $K = 1038$

$$x^2 = 1038(0.09 - x)(0.63 - x)$$

$$x^2 = 58.85 - 747x + 1038x^2$$

$$0 = 58.85 - 747x + 1037x^2$$

$$x = \frac{747 \pm ((747)^2 - 4(58.85)(1037))^{1/2}}{2(1037)}$$

$$x = 0.63 \text{ OR } x = 0.09$$

$\Rightarrow [H_2] = 0.09$ SINCE CO LIMITING.

SUMMARY:

1) $[H_2]$ LIMITED BY AMOUNT OF CO PRESENT.
2) WATER-GAS SHIFT REACTION REQUIRES IRON CATALYST
3) REACTION IS RELATIVELY INDEPENDENT OF PRESSURE.

CONCLUSION:

ISV DEMONSTRATION SHOULD NOT REACH LEL OF H_2 (4%) SINCE

1) MINIMUM ACCESS TO IRON CATALYST (OFF-GAS HOOD NOT IDEAL CATALYST)
2) EXPECT >90% CONVERSION OF ORGANICS TO CO_2 (HOOD HAS EXCESS O_2)

$\therefore$ [CO] EXPECTED < 0.9%.

Reviewed: JE Thompson 5/26/93

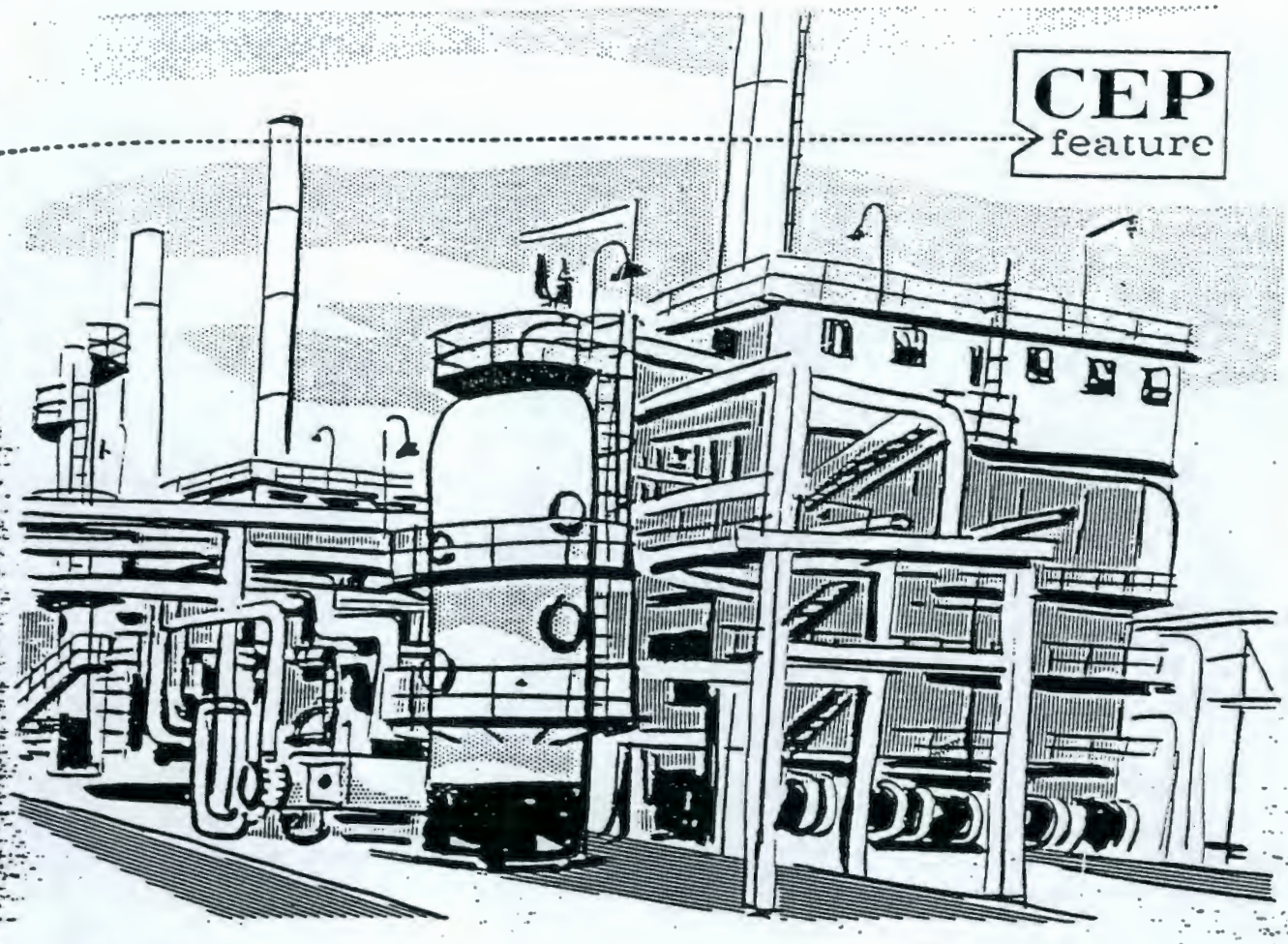
I agree with the conclusion especially since many factors do not favor this reaction (e.g. iron catalyst is a steel panel coated with "ash" the Fe catalyst generally used is small pellets for high surface area). The question that should be addressed is are there other reactions or mechanisms that could generate significant amounts of H_2? Consider water-gas rxn:

$$C_{graphite} + H_2O \xrightarrow{\Delta\ 800°C} H_2 + CO$$

Title	Project
ESTIMATION OF H_2 CONCENTRATION	100 ARIA ISV DEMONSTRATION

Prepared by:	Date	Reviewed by:	Date
J. Lusy	5/26/93	JE Thompson	5/26/93

9413221.1951



JAMES M. MOE
Chemetron Corp.

Design of water-gas shift reactors

Rate equations and factors that affect this important industrial reaction are given here to assist the designer.

THE WATER-GAS SHIFT REACTION is widely used for the manufacture of hydrogen; however, in spite of the importance of this reaction there has been relatively little published concerning the design of shift reactors.

Industrial shift reactions are carried out at pressures ranging from atmospheric pressure to about 500 lb./sq.in. gauge. The composition of the water gas may range from 80% CO to less than 3% CO. Because of the wide variation in gas composition and processing conditions, a rate equation valid throughout the range of the variables encountered is a practical necessity.

Practically all commercially available shift catalysts are manufactured from iron oxides and contain 5-15% Cr_2O_3 as a promoter. The discussion herein applies to this type of catalyst.

Rate equations

The shift reaction is represented stoichiometrically as follows:

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

The extent to which the reaction proceeds is limited by thermodynamic equilibrium. Accurate thermodynamic data are available from publications by the National Bureau of Standards; however, for the purposes of developing rate equations, it is convenient to have a functional relationship for the equilibrium constant. A sufficiently accurate relationship which is applicable to the range of temperatures encountered in using iron-base shift catalysts (600-900°F) is

$$K = \exp.\ (8240/T - 4.33)$$

where T is °Rankine.

The rate equation given by Laupichler (*1*) appears most frequently in the literature. This rate equation assumes the reaction is first order with respect to displacement of CO from its equilibrium concentration. The integrated form of this equation for a flow reactor is:

$$k = SV_m \log \frac{1}{1 - x/x_e} \qquad (1)$$

where:

$SV_w = \frac{\text{Vol. of inlet dry gas and steam}}{\text{(hour)(Catalyst Volume)}}$

x = CO converted.

x_e = CO converted at equilibrium.

k = Rate constant (assumed to be of the Arrhenius form).

A number of inaccuracies were noted when using this equation, so a series of experiments were carried out to re-evaluate the rate equation. The experimental procedure was essentially as described in a previous publication from this laboratory (2), although a larger reactor was used. Some of the results are shown in Table 1. It is apparent that the rate constant of Equation 1 varies with the steam to gas ratio.

Another rate equation was developed by assuming the reaction rate is proportional to the displacement of the gas composition from its thermodynamic equilibrium value. The equation for the reaction rate is, therefore, written:

$$r = k\left(ab - \frac{cd}{K}\right) \qquad (2)$$

where:

a,b = Concentration of reactants.

c,d = Concentration of products.

K = Thermodynamic equilibrium constant.

k = Reaction rate constant.

Let A,B and C,D be the initial concentration of reactants and products (in molar units), and x be the conversion. Then, Equation 2 can be written:

$$r = k\left[(A - x)(B - x) - \frac{(C + x)(D + x)}{K}\right] \qquad (3)$$

This equation for r is substituted into the following:

$$\frac{1}{SV} = \int_0^x \frac{dx}{r}$$

Table 1. Experimental data for determining rate constant from Equation 1. Calculated rate constants using Equation 4 are given also. See note** below for details.

Steam-gas ratio	*Inlet CO, % of dry gas	Temperature, °F	First order rate constant	Eq. 4 rate constant
2.44	26.3	600	1655	5500
1.91	26.0	600	1510	5150
1.16	26.0	600	790	4710
3.63	23.1	650	2450	7110
1.44	23.2	650	2010	7750
.921	21.4	650	1780	8410
2.28	25.0	750	4870	12300
1.96	21.8	750	4550	15600
1.10	22.1	750	3720	13900
1.78	41.7	750	5300	14200
1.59	52.9	750	4800	13900
1.66	52.4	750	3420	13000

*Balance of dry gas was hydrogen.

**The catalyst size was ¼-in. diameter x ¼-in. long tablets in all tests. The reaction rate has the units of: cubic feet of gas converted per hour per cubic foot of catalyst. The perfect gas law was assumed, and engineering units used. The space velocity in Equations 1 and 4 is, therefore, referred to 60°F and 1 atm. The rate constant of Equation 4, from the above data, is given by the relation: $k = \exp. -17{,}500/RT + 16.88$.

Integration performed at constant temperature results in the following:

$$\frac{k}{SV} = \frac{K}{\sqrt{-q}}\left\{\ln\left[\frac{2\,wx - u - \sqrt{-q}}{2\,wx - u + \sqrt{-q}}\right] - \ln\left[\frac{-u - \sqrt{-q}}{-u + \sqrt{-q}}\right]\right\} \qquad (4)$$

where:

$w = K - 1$

$u = K(A + B) - (C + D)$

$\sqrt{-q} = \sqrt{u^2 - 4wv}$

$v = K(AB) - (CD)$

At thermodynamic equilibrium,

$$2\,wx = +u - \sqrt{-q}$$

Variation of rate constants

The values of the rate constants calculated from Equation 4 are listed in Table 1. The correlation is good and within the limits of accuracy imposed by the experiments.

The rate constants of Equations 1 and 2 have different units: for Equation 1 the units are $(\text{time})^{-1}$, while the units are $(\text{volume})\,(\text{time})^{-1}\,(\text{mols})^{-1}$ for Equation 2. It is customary and convenient to correlate the results with space velocity, which has the units of $(\text{hours})^{-1}$. Thus, the numerical values for the rate constants used herein have been adjusted to define space velocity. In using Equation 1, any set of consistent units may be used for x and x_e. For Equation 2, however, the sum of the inlet gas concentration must be 1.0 to be consistent with the numerical values of the rate constant.

The rate constants of Equations 1 and 2 are related to temperature by an equation of the Arrhenius form

$$k = Q\exp.(E/RT)$$

where Q is a constant characteristic of the particular catalyst and E is the energy of activation. It has been

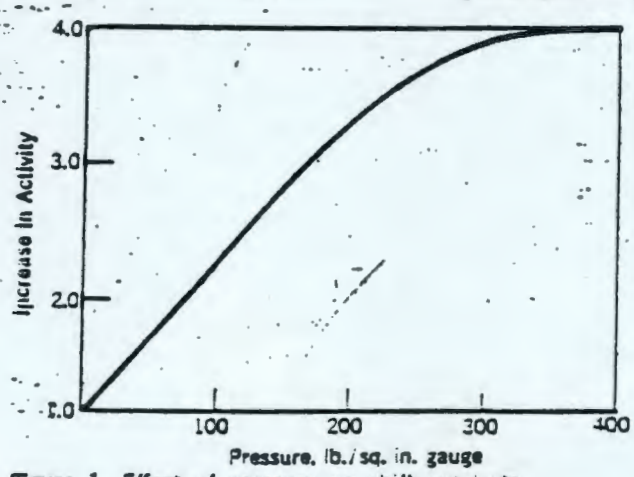


Figure 1. Effect of pressure on shift catalysts.

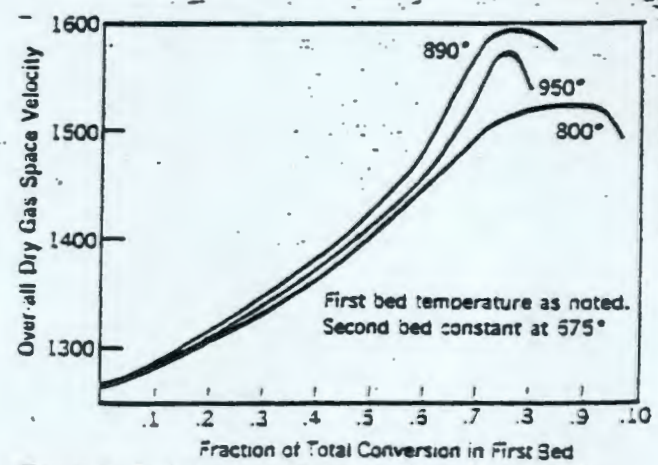


Figure 2. Optimum conditions obtained for example.

94132 21.1953

found that all iron-base shift catalysts tested have essentially the same value of E, although the linear multiplier, Q, may be quite different. Using 1.987 for the gas constant and temperatures in degrees Rankine, the value of E in the Equation 2 rate constant is −17,500 Btu/lb. mol. The value of E in the Equation 1 rate constant is −33,900. This latter number is, however, the value obtained by dividing the Equation 2 rate constant by the thermodynamic constant, K. Thus, the Equation 1 rate constant is actually a composite value of both the rate constant and the thermodynamic constants.

Adiabatic reactors

Equation 4 applies to an isothermal reactor. Analytical integration of Equation 3 for an adiabatic reactor is not practical, so recourse must be made to graphical or approximate methods. A good approximation is to take for K (in Equation 4) a value equivalent to the outlet temperature of the reactor and to assume for k a value corresponding to the arithmetical average of the inlet and outlet temperatures. This procedure leads to low values for the space velocity if the total temperature rise across the reactor is greater than 100°F and when at the same time the gas composition approaches equilibrium at the reactor outlet. For these cases it is best to subdivide the temperature internal into two or three increments and sum the values of $1/SV$ for each increment.

The temperature rise (°F) in an adiabatic reactor is given with sufficient accuracy by the simple relation:

$$\text{mols CO converted} = \frac{[9\ (\text{steam/gas ratio} \div 7]\Delta t}{164}$$

This relationship is based on 100 mols of dry gas entering the reactor.

Role of the catalyst

Particle size, time on stream, and pressure are factors which affect the observed reaction rate over shift catalysts. These three factors are interdependent, which can lead to misinterpretation of the results. It has been found that, at atmospheric pressure, 3/8-in. diameter x 3/8-in. long cylindrical tablets have a rate constant (as per Equation 3) that is 10% less than the rate constant of ¼-in. x ¼-in. tablets. At 450 lb./sq.in. gauge, the observed rate constant of 3/8-in. tablets is 20-30% less than 1/4-in. tablets. Using the concepts of Wheeler (3), it appears that about 60% of the total surface area of a ⅜-in. tablet is available during the reaction.

A freshly prepared shift catalyst will have a surface area of 100 sq. m./g., but after 50-100 hr. operation at 750°F, the surface area will be approximately 30-50 sq.m./g. Catalyst removed from commercial reactors after 12 months use may have a surface area of less than 15 sq.m./g. The catalyst apparently sinters, thereby resulting in a loss of surface area. Hoogschagen and Zwietering (4) studied the sintering phenomena quantitatively and found that the decrease in surface area could be correlated by the following equation:

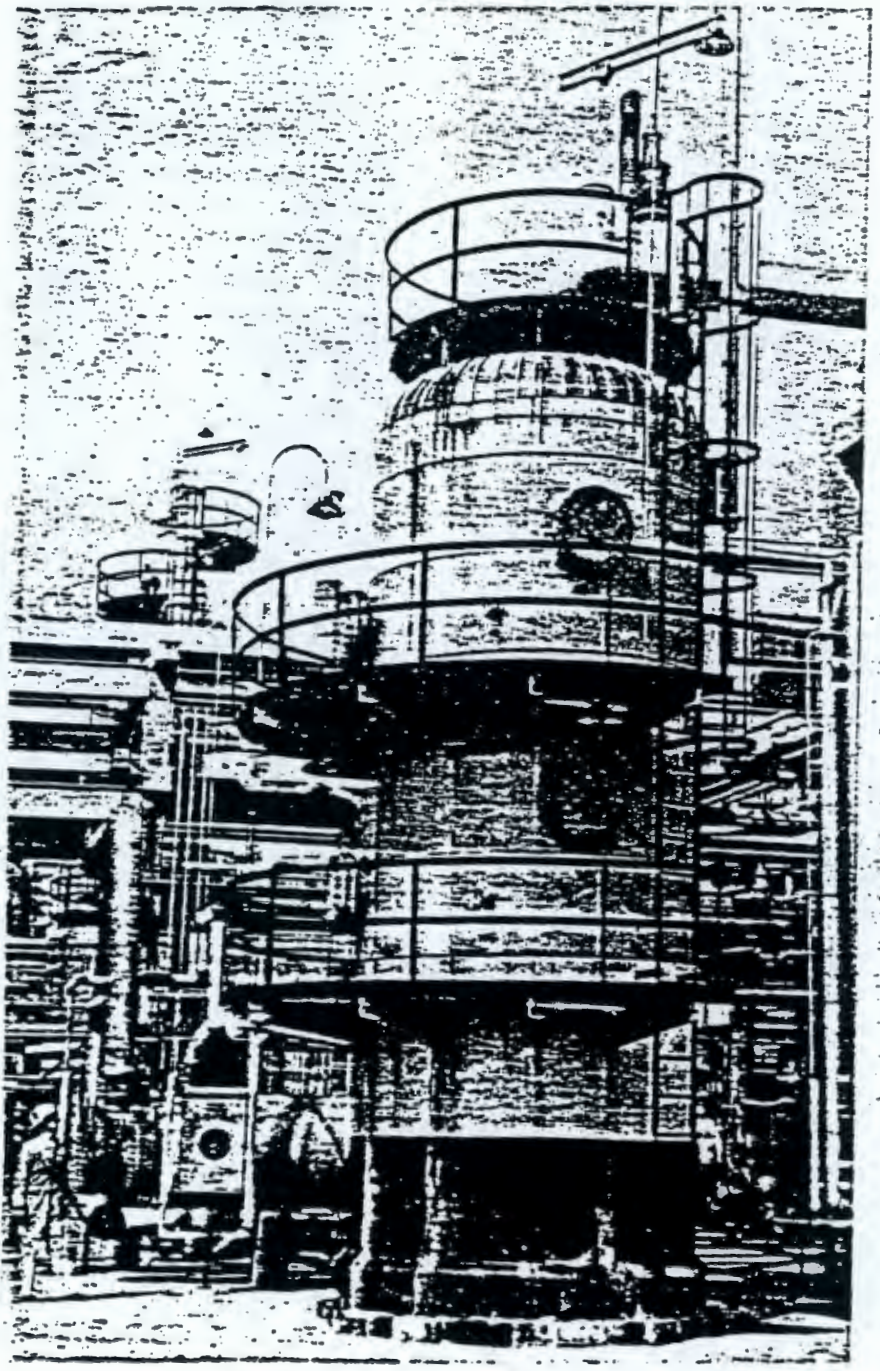
$$\frac{1}{A^n} - \frac{1}{A_0^n} = Kt \exp(-E/RT) \qquad (5)$$

where:

A_0 = Original surface area.
t = Time.
n = Experimentally determined constant.

The constant, n, varies with the method of preparation and was reported to be decreased by an increase in the chromium content of the catalyst. This observation suggests the chromia serves to stabilize the surface area, since chromia alone has very slight activity for the shift reaction.

The activity of the catalyst decreases with decreasing surface area, although there appears to be no sim-



James Moe has been in catalyst manufacturing, research and technical service work since graduating from Univ. of Colorado in 1950. He has been with the Girdler Catalysts department of Chemetron's Chemical Products Division since 1958.

ple relationship between activity and surface area (4). It is likely that the observed activity decline is related in part to the availability of the surface area.

The activity of freshly prepared shift catalyst undergoes a rapid decline during the first 24-72 hr. of operation. Thereafter, the rate of decline becomes more gradual. This characteristic of the catalyst complicates the selection of the rate constant which will be used for design purposes. Lengthy experiments and experience derived from industrial reactors are the best guides to determine the appropriate rate constant. The catalyst manufacturer can usually provide a value for the rate constant which defines the activity of the catalyst after extended operation.

The design rate constant for one commercially available shift catalyst (Girdler Catalysts' type G-3A) is:

$$\log_{10} k = 6.947 - 3830/°R$$

This gives the value at atmospheric pressure; the rate constant is multiplied by the activity factor from Figure 1 for higher pressures. Pressure serves to increase the observed rate constant of the shift reaction, although the equilibrium of the reaction is not influenced by pressure. The increase in the rate constant with pressure seems to be related to the availability of the internal surface area. Using 20 mesh catalyst, a pressure of 250 lb./sq.in. gauge will increase the observed rate constant by a factor of 2.2, as compared to atmospheric pressure. With ¼-in. x ¼-in. tablets, however, the rate constant will be increased by a factor of 4.0. Figure 1 shows the effect of pressure on the rate constant. This curve can be generally applied to the catalyst sizes (1/4-in. and 3/8-in.) used in commercial reactors.

Optimizing the process

Returning to Equation 2, it is natural to inquire how the catalyst volume required to achieve a given conversion may be minimized. This can be answered by taking the partial derivative of r with respect to temperature. The result, which has been previously reported by Denbigh (5), is as follows:

$$\frac{T_e - T_m}{T_e T_m} = \frac{R}{E - E_p} \cdot \ln \frac{E_p}{E} \qquad (6)$$

where:

T_e = Equilibrium temperature.
T_m = Temperature at which the reaction rate is a maximum.
E = Energy of activation of the reaction (−17,500).
$E - E_p$ = −(heat of reaction). This may be taken as 16,400 for the water-gas reaction in the region of 700°F. The value of E_p is, therefore, (−33,900).

Substituting the appropriate numerical values into Equation 6, it is found that the catalyst volume is minimized when Tm is approximately 100°F less than the equilibrium temperature. However, an approach to equilibrium of 100°F often imposes awkward limitations upon the operating temperature, and it has been found entirely satisfactory to design for a 50°F approach to equilibrium. The optimum is not particularly sharp for most gas compositions, especially at temperatures less than approximately 350°F. Varying the approach to equilibrium between 30°F to 100°F generally effects less than a 3% change in the catalyst volume.

The statement of the design requirement, *e.g.*, the inlet gas composition and the desired conversion, thus enables one to proceed directly to define the optimum operating conditions.

Because the shift reaction is exothermic, it is often advantageous to divide the catalyst volume into two or more beds so that the operating temperature can be kept closer to an optimum value. This presents the problem of how best to operate the different beds. Consider, as an example, a two bed reactor. The expression for the over-all space velocity can be written:

$$\frac{1}{SV} = \int_0^{x_1} \frac{dx}{r_1} + \int_{x_1}^{x_t} \frac{dx}{r_2}$$

where:

x_1 = Conversion in the first bed.
x_t = Total conversion.

Consider that x_t is fixed by the statement of the problem. It is required to minimize the space velocity and, by equating $\partial(1/SV)/\partial x_1$ to zero, the following is obtained:

$$r_{1(x_1)} = r_{2(x_1)} \qquad (8)$$

Substituting into Equation 8 the appropriate equation for r yields

$$k_1\left(1 - \frac{\psi}{K_1}\right) = k_2\left(1 - \frac{\psi}{K_2}\right) \qquad (9)$$

where:

$$\psi = \frac{(C + x_1)(D + x_1)}{(A - x_1)(B - x_1)}$$

The subscripts designate the bed in the reactor. It should be noted that this result applies to both adiabatic and isothermal reactors.

It has been assumed that x_t is fixed, so from the methods of the preceding discussion the approach to equilibrium, and thus the outlet temperature, of the second bed can thereby be determined. Fixing the second bed temperature defines k_2 and K_2. Equation 9 may then be used to determine k_1 and K_1 as a function of x_1. If the first bed is to be optimized by the method previously described, a trial-and-error solution of Equation 9 can be used to find the unique value of x_1 which makes the equivalent temperature of K_1 approximately 100°F less than the gas temperature.

Figure 2 illustrates the type of optimum that is obtained. The inlet gas stream considered had the following composition:

CO	—	11.85 mols
H_2	—	75.44 mols
CO_2	—	9.98 mols
H_2O	—	125.0 mols

Pressure is atmospheric and the desired conversion is 10.8 mols of CO.

The statement of the problem fixes the operating temperature of the second bed at 675°F. The operating temperature of the first bed is shown in Figure 2 for the various values of x_1.

Acknowledgement

The author wishes to express his thanks to D. W. Allen for his many helpful discussions and to Girdler Catalysts, Chemical Products Div., Chemetron Corp., for permission to publish the data herein.

LITERATURE CITED

1. Lawpichler, F. G., *Ind. Eng. Chem.*, 30, 578-86 (1938).
2. Atwood, K., M. R. Arnold, and E. G. Appel, *Ind. Eng. Chem.*, 42, 1600-1602 (1950).
3. Wheeler, A. "Catalysis," Vol. II (Emmett).
4. Hoogschagen, J. and P. Zwietering, *J. Chem. Phys.*, 21 No. 12, 2224 (1953).
5. Denbigh, K. G., *Trans. Faraday Soc.*, 40, 352-373 (1944).

APPENDIX B

Sampling and Analysis Plan

9413221.1956

THIS PAGE INTENTIONALLY
LEFT BLANK

1.0 SITE BACKGROUND 1

2.0 SAMPLING OBJECTIVES 1

3.0 SAMPLE LOCATION AND FREQUENCY 2
3.1 Electronic Samples 2
3.2 Test Material Samples
3.2.1 Core Samples 3
3.2.2 Soil Samples 4
3.2.3 Off-Gas Samples 4

4.0 SAMPLE DESIGNATION 4
4.1 Electronic Samples 4
4.2 Material Samples 5
4.2.1 Core Samples 5
4.2.2 Soil Samples 5
4.2.3 Off-Gas Samples 5

5.0 SAMPLE EQUIPMENT AND PROCEDURES 5
5.1 Electronic Samples 6
5.2 Test Material Samples
5.2.1 Core Samples 7
5.2.2 Soil Samples 7
5.2.3 Off-Gas Samples 7

6.0 SAMPLE HANDLING AND ANALYSIS 7
6.1 Electronic Samples 7
6.2 Test Material Samples 8
6.2.1 Vitrified Product Composition 9
6.2.2 Vitrified Product Strength 9
6.2.3 Vitrified Product Chemical Durability 9
6.2.4 Off-Gas Characterization 9

7.0 Sample Chain-of-Custody 9

8.0 References 11

9413221.1957

THIS PAGE INTENTIONALLY
LEFT BLANK

1.0 SITE BACKGROUND

The 100 Area ISV Pilot-Scale Demonstration will be conducted at the 300W ISV test facility directly west of the 300 area. The ISV test facility has been used for numerous large and pilot scale ISV tests and is maintained free of hazardous or radioactive soil contamination.

The specific test location will be excavated for placement of the simulated waste into the ground as well as the test measuring equipment associated with the test. Detailed characterization of the test site (simulated waste and instrument location)will be essential to analyze the performance of the ISV technology as a waste stabilization technique.

2.0 SAMPLING OBJECTIVES

The test objectives and the sampling which will support these test objectives are separated into three distinct objectives. These objectives are:

1) Demonstrate ISV as a stabilization technique for combustible and compactable waste.

2) Define the ISV operating envelope for the processing combustible and compactable waste.

3) Demonstrate ISV on a site that contains significant quantities of combustible material.

To demonstrate ISV as a stabilization technique for combustible and compactable waste, a determination of the ability of the ISV process to eliminate potential mechanisms for future subsidence must be made. The ISV process eliminates these future subsidence mechanisms through densification and the creation of a stable, durable product. Analyses to qualify and/or quantify the elimination of these subsidence mechanisms, thus demonstrating ISV as a stabilization technique, include post-test examination of the ISV product to determine fraction void space, strength tests on core samples from the ISV product, and durability testing of the ISV product.

Determination of the ISV operating envelope for application to combustible and compactable waste will be achieved via computations and verifying the computational prediction(s) with field data collected on a staged site within the identified envelope. In addition, performance will be measured through the completeness of field data collected to support design of full-scale equipment and the identification of full-scale operating procedures.

To demonstrate ISV on a site that contains significant quantities of combustible material, the ISV process must treat a site that contains significant quantities of combustible material without a molten soil displacement event. Experience with sealed containers and other situations that constrain the flow of vapor from underneath the advancing ISV melt have illustrated the potential for a molten soil displacement event. Successful completion of the pilot-scale demonstration without a molten soil displacement event, combined with verification of computational predictions, will serve as the primary measure of success for this objective.

With the exception of off-gas and core sampling the cooled glass monolith, much of the sampling associated with this demonstration will be electronic data collected on a computer data acquisition system. Therefore, much of the sampling and quality assurance contained in this plan will detail these electronic samples.

3.0 SAMPLE LOCATION AND FREQUENCY

Samples for this demonstration are divided into two categories; 1) Electronic process data and 2) Test material samples.

3.1 Electronic Samples

Because the main objective of this demonstration is to evaluate a technology application, the majority of the information gathered will be data on the performance of the processing equipment. The pilot-scale ISV equipment is equipped with electronic measuring devices to provide process monitoring and performance data. This data can later be used to evaluate the performance of individual system components and help provide an accurate evaluation of the process application. The type, location and frequency of the electronic process data associated with the operation of the ISV processing equipment are listed in Table 1. Process data is recorded both on a computer data acquisition system and manually by process operators every hour. In addition to the benefit of direct monitoring of the process equipment by recording hand written data, the hand data can be used as a quality check to validate the automatic computer collected data. All electronic instruments will be calibrated to a traceable standard prior to performing the demonstration and immediately after the conclusion of ISV processing. Figure 1 shows the off-gas treatment system components.

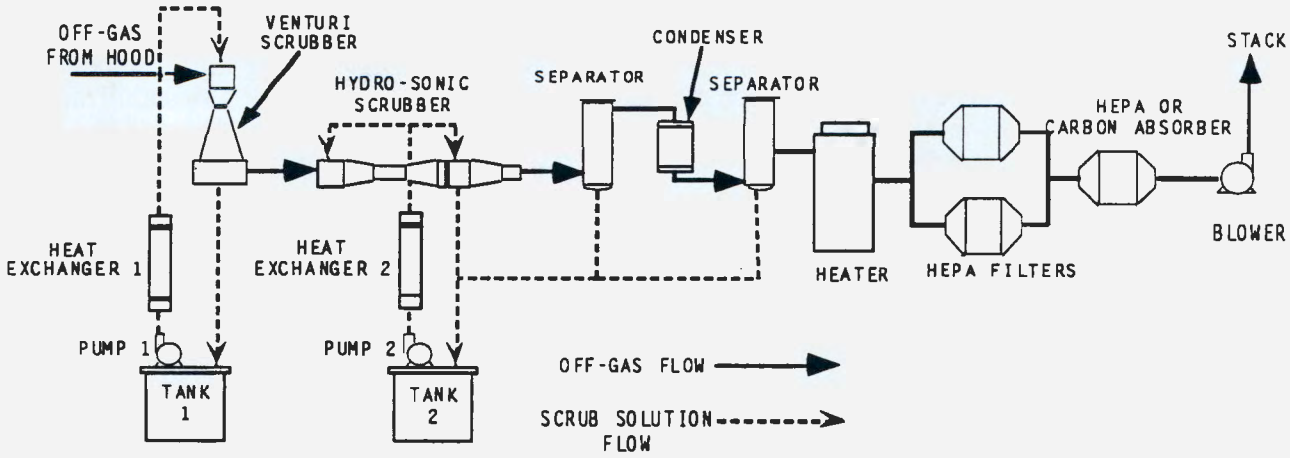


Figure 1. ISV Pilot-Scale Off-Gas System Schematic

Table 1. ISV Processing Equipment Data Points

Sample Type	Instrument Location	Minimum Sample Frequency
Differential Pressure	Off-Gas Venturi	10 min
Differential Pressure	Off-Gas Hydrosonic	10 min
Differential Pressure	Off-Gas Condenser	10 min
Pressure	Scrub Pump 1	10 min
Pressure	Scrub Pump 2	10 min
Pressure	Off-gas Hood	60 sec
Differential Pressure	Off-Gas Hepa Filter	10 min
Pressure	Off-Gas Blower	10 min
Level	Scrub Tank 1	10 min
Level	Scrub Tank 2	10 min
Flow	Scrub Pump 1	10 min
Flow	Scrub Pump 2	10 min
Flow	Off-Gas	60 sec
Flow	Hood Air Inlet	60 sec
Flow	Heat Exchanger	10 min
CO	Off-Gas Stack	60 sec
CO_2	Off-Gas Stack	60 sec
O_2	Off-Gas Stack	60 sec
Temperature	Hood Plenum	60 sec
Temperature	Off-Gas @ Venturi	10 min
Temperature	Scrub Tank 1 Liquid	10 min
Temperature	Scrub Tank 2 Liquid	10 min
Temperature	Heat Exchanger Liquid	10 min
Temperature	Off-Gas @ Stack	60 sec
Temperature	Ambient Air	60 sec
Heat Flux	Hood Skin	5 min
Temperature	Hood Skin	5 min

In addition to the data collected on the ISV processing equipment during operation, data will also be collected from instruments placed in the soil and simulated waste. Type "K" and "C" thermocouples will be used to track the advancing melt front throughout the vitrification process and pressure transducers will be used to monitor pressure gradients in the adjacent soil and simulated waste. The exact location and frequency of collection of these instruments as well as the pressure transducers to be placed in the soil and simulated waste are detailed in the 100 Area ISV Pilot-Scale Demonstration Test Plan.

3.2 Test Material Samples

3.2.1 Core Samples

Core samples of the cooled glass monolith and pre-test soil will be collected for analysis. The locations for core drilling will be determined once the actual shape and size of the resulting

glass monolith has been determined at the completion of the ISV operation. The project laboratory record book will be utilized to record all assumptions, observations and other information used to determine the location and number of core samples to be taken. Sample location selection will be based on the need to evaluate the minimization of future subsidence mechanisms and to determine the degree of product stability. Information regarding the actual core sampling operation details such as angle and direction of drilling, etc. will be recorded in the laboratory record book.

3.2.2 Soil Samples

Soil samples representative of the soil to be vitrified (from both the waste matrix and surrounding soil) will be collected for analysis and archived for later analysis if required. Soil samples will be used to determine soil moisture content, bulk soil density and inorganic composition. These samples will be collected during the backfilling of the simulated disposal trench. Information regarding sample location, depth and any other pertinent observations made during sample collection will be recorded in the laboratory record book.

3.2.3 Off-Gas Samples

Both particulate and gas samples will be collected from the off-gas stream prior to off-gas treatment. Samples will be collected over a two hour period for each of the following predetermined periods of processing. For the startup phase, samples will be collected at 6-8 hours and 12-14 hours of cumulative processing time. Sampling at this time will help determine a particulate generation rate for startup. The next sampling will occur while processing the cover soil over the simulated waste. The electrode depth will be used as an indicator to initiate sampling with samples being collected as the melt front achieves a depth of 40 and 80cm. Based on a projected downward melt rate of 2.5cm per hour, these samples are estimated to be taken at approximately 16 and 32 hours cumulative ISV processing time. The last sampling period will be as the melt is advancing through the simulated waste region. Again electrode depth will be used to indicate sample time. Samples will be collected as the electrode depth reaches 150, 200, 250cm with an estimated cumulative processing time of 60, 80 and 100 hours.

A Modified Method 5 stack sampling system will be used to collect particulate samples and water vapor in the off-gas stream. Gas samples will be collected using an evacuated Suma canister. The gas samples will be taken and analyzed using method TO 14 as a guide. All the off-gas samples will be taken upstream of off-gas treatment to provide an accurate

4.0 SAMPLE DESIGNATION

4.1 Electronic Samples

Electronic samples for the demonstration are divided into two categories; 1) Process Equipment Samples and, 2) Soil Array Samples. The process equipment samples are designated by the name of the equipment in which the measurement is being taken and a description of the type of measurement. These sample designations will appear both on the computer recorded data files and on the computer visual display. For example, the differential pressure measurement for off-gas flow across the venturi scrubber would be "Venturi DP". Process equipment sample names and type are shown in Table 1.

9413221.1961

The soil array samples will use a standardized numbering system based on cylindrical coordinates. This system denotes the instrument type, depth from grade, angular position relative to north (clockwise) and radial distance from the vertical centerline of the electrode array placement. These sample designations will appear both on the computer recorded data files and on the computer visual display and will also be used for reference when recording observations in the laboratory record book. For example, the sample designation "TCK090270810" indicates a type K thermocouple (TCK), located at the 90 cm depth (090), at a position of 270° relative to north (270) at a radial distance of 810 cm from the vertical centerline (810). Each position description will use three digits to define its location; therefore, the first three numbers will always indicate depth, the next three numbers designate angular position, etc.

All samples collected will have a time stamp indicating the date (mdy), and time (hms) in which the sample was collected. The time stamp will be recorded in the computer data file for each sample frequency.

4.2 Material Samples

Test material samples will contain the following information on a white self adhesive label affixed to the sample container: 1) initials of sampler, 2) date and time of sample collection, 3) sample type, 4) unique sample identification number. Information designating test material samples will be recorded in the laboratory record book. The information recorded will contain all the information placed on the sample label plus any observations made during sample collection.

4.2.1 Core Samples

Core samples of the cooled glass monolith will be designated by borehole number and the individual sample depth from insertion. An example would be, BH1-300. This sample would be from bore hole #1 at a depth of 300 cm from insertion. Each individual core sample will be wrapped in plastic and secured with vinyl tape.

4.2.2 Soil Samples

Soil samples will be collected with a clean garden spade and placed into a pre-cleaned 250 ml plastic wide mouth sample bottle. The garden spade shall be appropriately cleaned after each sample collection.

4.2.3 Off-Gas Samples

Particulate and condensate samples retrieved from the MM5 system will be handled as described in 40 CFR App. A Method 5. These retrieved samples will be logged into the data sheets which are used for each sample run.

5.0 SAMPLE EQUIPMENT AND PROCEDURES

The majority of the sample equipment to be used for this demonstration will be electronic data collection equipment. The information describing the Computer data acquisition equipment is

contained in section 5.1 and the 100 Area ISV Pilot-Scale Demonstration Test Plan. The only material samples to be collected will be core samples from the cooled glass monolith and archive samples of the soil which will be placed into the trench with the simulated waste.

5.1 Electronic Samples

The data acquisition hardware to be used for the collection of electronic samples will be one Macintosh IIcx series computer with instrumentation interface equipment from National Instruments®. The instrumentation interface equipment includes NB-MIO-16 and NB-MIO-16X multifunction input/output boards (16 single-ended or 8 differential channels), SCXI-1100 signal conditioning modules (multiplexes and amplifies 32 differential channels), SCXI 1300 terminal blocks (provides a method for connecting signals to the data acquisition system), and a NB-GPIB (IEEE-488 talker/listener/controller). A combination of the above instrumentation interface hardware will be used for data collection activities to allow greater than 150 instrumentation inputs to be read and recorded.

The data acquisition software used will be LabView® 2 (Laboratory Virtual Instrument Engineering Workbench), developed by National Instruments. LabView is a software system designed specifically for the Macintosh family of computers. The software provides a complete integrated environment for scientific applications involving instrument control, data acquisition, data analysis, data display, data management and report generation. The data collection activities will make extensive use of the data acquisition, display and management features of LabView.

Data storage will be both on the built in Macintosh hard disks as well as backed up onto a removable hard disk. UltraDrive 50R (GCC Technologies) will be used to back up field data collected. The removable hard disk has a storage capacity up to 45 MB. Data files created by LabView will be periodically and automatically backed up onto the removable hard disk and the hard disk removed once full.

Configuration of the LabView software will be recorded in the logbook and/or a separate document. Information to be included in such documentation: operation of front panels, configuration of panels with data acquisition hardware (e.g. computer boards), engineering unit conversions, data file labeling system, data file creation frequency, and data backup file creation frequency.

An operations manual will be developed for operation of the data acquisition system which details use of the system hardware and software. The manual will specifically address requirements in this document as well as other applicable project documents. The manual is written by the application programmer after the data acquisition program is configured and will become part of the project file.

5.2 Test Material Samples

5.2.1 Core Samples

Test material samples consist of pre-test soil samples and glass core samples taken from the glass monolith and will be taken using a rotary coring device. The procedure to be used for core drilling is contained in WHC-CM-7-7 "Environmental Investigations and Site Characterization Manual" Appendix C "Drilling with a Special-Purpose Drill Rig".

5.2.2 Soil Samples

Soil samples are to be collected using the a small garden trowel and placed into a 250ml plastic sample bottle. Since soil analysis will consist only of bulk composition and total water present, no extensive tool cleaning procedures as if contaminates were present in the soil

5.2.3 Off-Gas Samples

Particulate sampling will be conducted using EPA Method 5 as a guide for sampling. Gas samples collected from the off-gas stream will use EPA TO-14 as a guide. Offgas will be collected in a suma canister for laboratory analysis.

6.0 SAMPLE HANDLING AND ANALYSIS

6.1 Electronic Samples

The electronic sample data will be stored on electronic storage media and backed up on a removable storage disk. The backup electronic data will be stored as write protected files and filed in the project file for security. The procedure for handling electronic data at the completion of data acquisition activities is as follows:

1) At the completion of data acquisition, transfer the data files from the data acquisition system internal hard disk to a 45 Mbyte removable hard disk. Secure the write protect selection on the removable hard disk and verify that all the files transferred and are readable.

2) Label the cartridge to include; project number and name, date, data type.

3) Verify that the backup copies of the data are also complete and readable. Place the backup copies into the project file for security.

4) Remove the data files from the data acquisition system internal hard disk to prevent uncontrolled access.

The project manager will maintain control of the data and will issue the working copy to staff for reduction and analysis. All files created during data reduction and analysis will be saved as new files and contain the following information for indexing into the project files:

1) File name
2) Date, time
3) File type
4) Information describing the file contents

This information will be recorded into a data file index located in the project file. The file created will be transferred to a removable hard disk which will contain all the reduced and analyzed data and will be returned to the project file at completion of the analysis.

6.2 Test Material Samples

Test material samples to be collected for the ISV demonstration are shown in Table 1.

Table 2. Sample Requirements

Sample Type	Qty	Sample Size	Container	Analysis
Soil	3	250 g.	250 ml plastic sample jar	Bulk Density % moisture Inorganic Composition (6010)
Vitrified Product (Core)	>3	*	Plastic Sheath	Inorganic Composition (6010) Compression Strength (ASTM D2938) Splitting Tensile Strength (ASTM 3967) Product Consistency (PCT)
Metal Phase (Core)	3	100 g.	250 ml plastic sample jar	Inorganic Composition (6010)
Scrub Solution	3	150 ml	250 ml plastic sample jar	pH Inorganic composition (6010)
Offgas Gas sample	7	NA	Suma Canister	TO-14
Offgas Particulate	7	NA	Petri dish,	Gravimetric

* Sample size is determined in accordance with ASTM D4543, "Standard Practice for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances."

9413221.1965

Soil samples will be collected and analyzed to determine bulk density, percent moisture and inorganic composition. Core samples will be wrapped in plastic and labeled upon removal from the core bit. The samples will be stored in a designated sample cabinet for safe storage. Analyses of core samples will consist of chemical composition, strength and durability.

6.2.1 Vitrified Product Composition

Core samples which receive strength and durability analysis will also be analyzed for total composition. The samples will be prepared for analysis using a $NaHO_2$ fusion and a KOH fusion. Both of these sample solutions will be analyzed using the standard EPA Method 6010 (ICP) to determine total inorganic composition. The procedure for preparing the samples by fusion for analysis using the EPA Method 6010 is included as Attachment 1.

6.2.2 Vitrified Product Strength

Core samples will be selected for analysis in accordance with the requirements stated in ASTM D4543, "Standard Practice for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances." The dimensional, shape, and surface tolerances of the core specimens defined as defined in ASTM D4543 are important for determining structural properties of intact specimens. The core samples selected will be analyzed for axial compression strength, ASTM D2938, splitting tensile strength, ASTM D3967 and chemical composition.

6.2.3 Vitrified Product Chemical Durability

A selected set of core samples will be analyzed for chemical durability using the Product Consistency Test (PCT).

6.2.4 Off-Gas Characterization

Gas samples collected in the Suma canister will be analyzed using TO-14 as a guide. Primary interest will be in identifying and quantifying the incomplete combustion by-products found in the off-gas.

7.0 Sample Chain-of-Custody

Sample chain-of-custody forms will be used to track sample location and custody during the project. All samples at the time of collection and labeling will be entered into the project Laboratory Record Book sample log, and the sample chain-of-custody form. Sample chain-of-custody forms can be obtained from the project manager. The project manager is the sample custodian. A sample chain-of-custody form must remain with the sample at all times. Samples must be secure at all times by being in a locked cabinet or in the possession of the individual signed as "received by" on the chain-of-custody form. All pertinent information relative to sampling in the field must be entered into the project Laboratory Record Book. A copy of the sample chain-of-custody from is included as Attachment 2.

The following procedure for using the chain-of-custody form will be used for the 100 Area ISV Pilot-Scale Demonstration.

1) Field records will be completed at the time the sample is collected with samplers initials, date and time.

2) Samples collected for each sampling period will be recorded on the chain-of-custody form. Each sample will be given a unique sample identification number as described in section 4.2 of the Sample & Analysis Plan

3) At the end of each sampling period, samples will be locked in the sample cabinet at the ISV site along with the chain-of custody form.

4) The sample chain-of custody form must be used when transferring samples to the lab for analysis. If a courier is used for transport, the courier must sign for possession of samples and release possession of the samples to the lab in the same manner.

9413271.1967

8.0 References

WHC . 1991. "Drilling With A Special Purpose Drill Rig." Appendix C in Environmental Investigations and Site Characterization Manual. WHC-CM-7-7.

American Society for Testing Materials. 1992. "Standard Practice for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances." ASTM D4543. In *1992 Annual Book of Standards*. Vol. 04.08, pp. 837-840.

American Society for Testing Materials. 1992. "Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens." ASTM D2938. In *1992 Annual Book of Standards*. Vol. 04.08, pp. 390-391.

American Society for Testing Materials. 1992. "Standard Test Method for Splitting Tensile Strength of Intact Rock Specimens." ASTM D3967. In *1992 Annual Book of Standards*. Vol. 04.08, pp. 565-567.

C. M. Jantzen, N. E. Bibler, D. C. Beam, W. G. Ramsey, B. J. Waters. Westinghouse Savannah River Co. 1991. " Standard Test Method Relative to Durability of Nuclear Waste Glasses: The Product Consistency Test (PCT)."

United States Environmental Protection Agency. 1986. "Test Methods for Evaluating Solid Waste" SW-846. Volume 1, Section A.

Code of Federal Regulations 40, Part 60 App. A, Method 5 "Determination of Particulate Emissions Form Stationary Sources."

THIS PAGE INTENTIONALLY
LEFT BLANK

9413221.1969

Attachment 1

FUSION DISSOLUTION PROCEDURE FOR VITRIFIED SAMPLES

THIS PAGE INTENTIONALLY
LEFT BLANK

Fusion Procedure

1.0 APPLICABILITY

This procedure provides the method for the dissolution of solid samples which contains high concentrations of silicates and/or refractory compounds which will not completely or readily dissolve in mineral acids. Fusion procedures are used to dissolve these samples. Since an alkali metal ion is added during the fusion, two fusions are performed on each sample so that all the major metal ions are analyzed on each sample. The potassium hydroxide fusion is done in a nickel metal crucible and the sodium peroxide fusion is done in a zirconium metal crucible. When specialized analyses are required, the fusion can be made using a different flux and/or a different type of crucible.

2.0 DEFINITIONS

2.1 "Flameless" Electric Bunsen Burner - A nickel and chromium alloy resistance heating element which directs radiant heat to the sample with a maximum temperature of 1000° C.

2.2 Flux - The melt material used to decompose the silicate based or refractory sample. The two flux materials generally used in this procedure are potassium hydroxide (KOH) and sodium peroxide (Na_2O_2).

2.3 Oxidizer - Carbon or some carbonaceous materials which may be present in some samples are not oxidized by potassium hydroxide. Potassium nitrate is added to all KOH fusions as an oxidizer.

3.0 RESPONSIBILITY

3.1 Responsible Scientist

3.2 Cognizant Staff

4.0 QUALIFICATION OF PROCESS

Solid samples containing high silicate or several of the refractory compounds are not readily dissolved in a mineral

9413221.1970

acid or a mixture of mineral acids unless one of the acids is hydrofluoric acid. Hydrofluoric acid should not be used as one of the mineral acids since several of the metal ions such as rare earths, alkaline earth metals, and chromium III form fluoride compounds with low solubility products.

When one checks the literature, there are several fusion methods used for the dissolution of silicate and refractory samples. Some of the flux materials used are Na_2CO_3, NaOH, KOH, $Na_2S_2O_7$, and Na_2O_2. Sodium carbonate was not selected since the fusion is performed in a platinum crucible for one hour in a muffle furnace at 1100° C. The $Na_2S_2O_7$ fusion was not selected since sulfates form insoluble salts with alkaline earth metal ions. The KOH fusion was selected since the fusion can be made in a nickel metal crucible at a temperature below 1000° C. Since potassium and nickel must be analyzed in several of the samples, the second fusion method selected was Na_2O_2 using a zirconium metal crucible.

When the sample analyses are performed using both the KOH and the Na_2O_2 fusions, the two fusions are duplicate analysis of most of the elements in the sample. The only elements which are not analyzed in duplicate are Na, K, Ni, and Zr. The reproducibility of the analyses between the two fusions should be within the relative percent difference (RPD) of 20% as required by the US-EPA CONTRACT LABORATORY PROGRAM.

9M3221.1971

5.0 PROCEDURE

5.1 Check that the sample has been logged according to the SAMPLE LOG-IN PROCEDURE, APSL-01.

5.2 Check the ANALYTICAL REQUEST FORM from procedure APSL-01 to determine whether the sample is radioactive. If the sample is radioactive, perform the sample preparation and all subsequent analyses in room 146, 324 Building.

5.3 All solid samples must be crushed and passed through a 140 mesh sieve before performing a sample fusion.

5.3.1 Crush the solid sample using the tool steel mortar and pestle.

5.3.2 Transfer the sample from the mortar into a 140 mesh sieve and sieve the sample. Any portion of the sample which does not pass through the 140 mesh sieve is transferred back into the tool steel mortar.

5.3.3 Crush the sample in the mortar and pestle.

5.3.4 Transfer the crushed sample into the 140 mesh sieve and sieve the sample. Repeat steps 5.3.2 and 5.3.3 until all the sample has been sufficiently crushed to pass through the 140 mesh sieve.

5.4 After all the sample has been crushed and passed through a 140 mesh sieve, accurately weigh two separate 0.250 ± 0.075 gram of sample on an analytical balance and transfer the two samples into a nickel and a zirconium metal crucible. (Note: The nickel metal crucibles are scribed with a letter and the zirconium metal crucibles are scribed with a number.)

5.5 Record the weights of both samples to the nearest 0.1 mg along with the scribed crucible designation in the appropriate section of a Xerox copy of the FUSION PROCEDURE WORK SHEET (Figure 1).

5.6 The potassium hydroxide (KOH) fusion is performed in the nickel (Ni) metal crucible.

5.6.1 Weigh 1.8 ± 0.4 gram (about 20 pellets) of KOH and transfer the pellets into the nickel metal crucible containing the sample from step 5.4. Add 0.2 ± 0.1 gram of potassium nitrate to the nickel metal crucible. Record these weights on the Xerox copy of the FUSION PROCEDURE WORK SHEET.

5.6.2 Swirl the mixture in the Ni crucible so that the ground sample is mixed with the flux material.

5.6.3 Preheat the electric Bunsen burner using a variac set at 100. This variac setting should melt the KOH pellets in about 3 minutes. If the KOH pellets do not melt in about 3 minutes, increase the variac setting to increase the temperature of the electric Bunsen burner. Continue heating the Ni crucible for a total melt time of about 10 minutes. (Note: The composition of some of the samples to be fused will be different. If a significant portion of the sample remains as an "aggregate" on the bottom of the crucible during the fusion, the sample may require a higher variac setting to obtain a higher fusion temperature or longer fusion period to completely dissolve the sample.)

5.6.4 Remove the sample from the electric Bunsen burner and allow the melt to cool to room temperature.

5.6.5 Slowly add approximately 10 mL of demineralized water to the crucible to dissolve the melt. (Note: To hasten the dissolution of the sample on the bottom of the crucible, tip the crucible on its side so that a small portion of the fused mixture (melt) is exposed from under the water. Dissolution of the melt at the water and air interface is very rapid.)

5.6.6 When all the melt on the bottom of the Ni crucible has dissolved, transfer the liquid slurry into a 250 mL volumetric flask or a tared borosilicate glass bottle. If a glass bottle is used, record the tare weight of the glass bottle on the Xerox copy of the FUSION PROCEDURE WORK SHEET. Use demineralized water to wash the slurry from the Ni crucible. If all the melt in the crucible was not completely dissolved causing an incomplete transfer of the melt, add another 10 mL of demineralized water and repeat steps 5.6.5 and 5.6.6 until all the sample has been transferred from the crucible.

5.6.7 After completing the sample transfer from the crucible, dilute the solution in the container to about 100 mL with demineralized water. Acidify the solution with 25 ± 5 mL of concentrated hydrochloric acid.

5.6.8 Swirl the solution in the container to mix the acid added in step 5.6.7. Acidification of the solution should dissolve the sample. If the sample is not completely solubilized (eg, a flocculent, whitish precipitate), add 0.3 ± 0.1 gram of oxalic acid crystals to the solution. Swirl the solution to dissolve the oxalic acid. If the solution does not clear in about 15 minutes, gently heat the solution on a hot-plate. If the sample is still not completely dissolved, notify the Responsible Scientist.

5.6.9 Continue with step 5.8 of this procedure to complete the KOH fusion.

5.7 The sodium peroxide (Na_2O_2) fusion is performed in the zirconium (Zr) metal crucible.

5.7.1 Weight 2.0 ± 0.2 gram of Na_2O_2 and transfer the Na_2O_2 into the zirconium metal crucible containing the sample from step 5.5. Record the weight of Na_2O_2 added on the Xerox copy of the FUSION PROCEDURE WORK SHEET.

5.7.2 Swirl the mixture in the Zr crucible so that the ground sample is mixed with the flux material.

5.7.3 Preheat the electric Bunsen burner by setting the variac to read 110. This variac setting should melt the Na_2O_2 in about 3 minutes. If the Na_2O_2 does not melt in about 3 minutes, increase the variac setting to increase the temperature of the electric Bunsen burner. Continue heating the Zr crucible for a total melt period of about 10 minutes. (Note: The composition of some samples will be different. If a significant portion of the sample remains as an aggregate on the bottom of the crucible during the fusion, the sample may require a higher variac setting for a higher fusion temperature or a longer fusion period to completely dissolve the sample.)

5.7.4 Remove the sample from the electric Bunsen burner and allow the melt to cool to room temperature.

5.7.5 Slowly add a few drops of demineralized water to the crucible and let initial vigorous, effervescent reaction of the water on the fused mixture (melt) to subside. Continue the slow addition of water to the crucible until the total volume of water added is approximately 5 mL. To hasten the dissolution of the melt in the bottom of the crucible, tip the crucible on its side so that a small portion of the fused sample is exposed from under the surface of the water. The dissolution of the melt at the water and air interface is very rapid. Continue rotating the crucible until all the sample is dissolved.

5.7.6 When all the melt has dissolved, transfer the liquid slurry into a 250 mL volumetric flask or a tared borosilicate glass bottle. If a glass bottle is used, record the tare weight of the bottle on the Xerox copy of the FUSION PROCEDURE WORK SHEET. Wash the remaining slurry from the Zr crucible using demineralized water. If the sample in the bottom of the crucible was not completely dissolved and transferred, add about 10 mL of demineralized water and repeat step 5.7.5. Continue repeating step 5.7.5 and 5.7.6 until all the melt has been removed from the crucible.

5.7.7 After completing the sample transferred from the

Zr crucible, dilute the solution in the container to approximately 100 mL with demineralized water. Acidify the solution with 25 ± 5 mL of concentrated hydrochloric acid.

5.7.8 Swirl the solution in the container to mix the acid added in step 5.7.7. Acidifying the solution should dissolve the sample. If the sample is not completely solubilized (eg, a flocculent, whitish precipitate), add 0.3 ± 0.1 gram of oxalic acid crystals to the solution. Swirl the solution to dissolve the oxalic acid. If the solution does not clear in about 15 minutes, gently heat the solution on a hot-plate. If the sample is still not completely dissolved, notify the Responsible Scientist.

5.7.9 Continue with step 5.8 of this procedure.

5.8 If the container used in the KOH and/or the Na_2O_2 fusion is a 250 mL volumetric flask, fill the flask with demineralized water to the fill mark on the neck of the flask. Cap the flask and thoroughly mix the solution. Record the volume of the dilution on the Xerox copy of the FUSION PROCEDURE WORK SHEET.

5.9 If the container used in the KOH and/or the Na_2O_2 fusion is a borosilicate bottle, fill the bottle with demineralized water to the 250 mL graduation line on the bottle. Weigh the bottle with lid on a balance and record the sample plus bottle weight on the Xerox copy of the FUSION PROCEDURE WORK SHEET. Also sign and date the entry along with the balance M&TE number on the Xerox copy of the FUSION PROCEDURE WORK SHEET.

PH3271.1975

Figure 1
FUSION PROCEDURE WORK SHEET
Analytical and Process Support Laboratory

1.0 **Laboratory Number (LN)** _____

2.0 **Customer's Sample Identification** _____

3.0 **Fusion**

	Potassium Hydroxide	Sodium Peroxide
Crucible Used	_____	_____
Sample Weight	_____ gram	_____ gram
Flux Added	_____ gram	_____ gram
Potassium Nitrate Added	_____ gram	

Balance Used M&TE _____

Signature and Date _____

4.0 **Dilution**

Using a Volumetric Flask

	Potassium Hydroxide	Sodium Peroxide
Volume	_____ ml	_____ ml
Sample Concentration	[ ] ug/ml	[ ] ug/ml

Using a Borosilicate Bottle

Solution + Bottle with Lid Weight	_____ gram	_____ gram
Bottle with Lid Weight (Tare)	_____ gram	_____ gram
Solution Weight	_____ gram	_____ gram
Sample Concentration	[ ] ug/ml	[ ] ug/ml

Balance Used M&TE _____

Signature and Date _____

9413221.1976

THIS PAGE INTENTIONALLY
LEFT BLANK

9413221.1977

Attachment 2

CHAIN OF CUSTODY FORM

THIS PAGE INTENTIONALLY
LEFT BLANK

Battelle
Pacific Northwest Laboratories
Battelle Boulevard
Richland, Washington 99352

CHAIN OF CUSTODY

C-of-C:

Test User ID:

Company Contact: _____ Telephone: _____

Samples Collected by: _____ Date: _____ Time: _____

ID/Sample No.: _____

Ice Chest No.: _____ Field Logbook Page No.: _____

Remarks: _____

Possible Sample Hazard Identification: _____

Destination: _____ Carrier/Waybill No.: _____

Ground-Water _____ Soil _____ Other _____

Shipping container internal temperature when samples sealed in it _____.

Shipping container internal temperature when opened in laboratory _____.

Sample Identification

Chain of Possession

Relinquished by:	Received by:	Date/Time:
Relinquished by:	Received by:	Date/Time:
Relinquished by:	Received by:	Date/Time:
Relinquished by:	Received by:	Date/Time:
	Disposal Record No.:	Date/Initials:

THIS PAGE INTENTIONALLY

DOE/RL-93-45
Draft A

APPENDIX C

Quality Assurance Project Plan

9413221.1979

THIS PAGE INTENTIONALLY
LEFT BLANK

100 AREA ISV PILOT-SCALE

DEMONSTRATION PROJECT

QUALITY ASSURANCE PROJECT PLAN No. WTC-072, Rev. 1

PREPARED BY

PACIFIC NORTHWEST LABORATORY
P.O. BOX 999
RICHLAND, WASHINGTON 99352

9413221.1980

Issue Date:07/28/93

Approvals:		Dates
Project Manager	Ja-Kael Luey	7/29/93
Project Quality Engineer	SE Walker	7-27-93
Process and Hardware Technical Group Leader	JE McGarrah	7/27/93
In Situ Vitrification (ISV) Technical Group Leader	~~JS Tixier~~ LE Thompson	7/28/93

THIS PAGE INTENTIONALLY
LEFT BLANK

2.0 TABLE OF CONTENTS

Section Number	Section Title	Pages
1.	TITLE PAGE	1
2.	TABLE OF CONTENTS AND DISTRIBUTION	2
3.	QUALITY ASSURANCE PROGRAM	1
	Exhibit 3.1	2
4.	PROJECT DESCRIPTION	1
5.	PROJECT ORGANIZATION AND RESPONSIBILITIES	1
	Exhibit 5.1	1
	Table 5.1	1
6.	DATA QUALITY OBJECTIVES	8
	Table 6.1	1
	Table 6.2	1
	Figure 6.1	
	Figure 6.2	
7.	SAMPLING PROCEDURES	1
8.	SAMPLE CUSTODY	1
9.	CALIBRATION PROCEDURES AND FREQUENCY	1
10.	ANALYTICAL PROCEDURES	1
11.	DATA REDUCTION, VALIDATION AND REPORTING	2
	Exhibit 11.1	1
12.	INTERNAL QUALITY CONTROL CHECKS	1
13.	PERFORMANCE AND SYSTEM AUDITS	1
14.	PREVENTIVE MAINTENANCE	1
	Figure 14.1	2
15.	CORRECTIVE ACTION	1
16.	QUALITY ASSURANCE REPORTS TO MANAGEMENT	1
17.	RECORDS	1
18.	PROCUREMENT CONTROL	1
19.	STAFF TRAINING	1
20.	NONCONFORMANCES AND DEFICIENCIES	1
21.	DOCUMENT CONTROL	1
22.	DOCUMENT REVIEWS	1
23.	REFERENCES	1

Modifications or revisions to this QA Project Plan are discussed in Section 21, Document Control.

Distribution:

PNL

SM Caley
J Luey
JE McGarrah
TD Powell
JS Roberts
RT Tessier
JS Tixier
SE Walker
PQD File

WHC

JB Duncan
JG Woolard

9W43221.1982

3.0 QUALITY ASSURANCE PROGRAM

This Quality Assurance (QA) project plan applies to the Pacific Northwest Laboratory (PNL) 100 Area ISV Pilot-Scale Demonstration activities. These activities are staffed by members of the In Situ Vitrification Group of the Waste Treatment Technology Department of the Waste Technology Center with support from members of the Computational Physics Section of the Analytical Sciences Department of the Applied Physics Center.

The QA program described herein was developed to address the U.S. Environmental Protection Agency's (EPA) QAMS-005/80, Interim Guidelines for Preparing Quality Assurance Project Plans. This QA Project Plan refers to PNL's Quality Assurance Manual, PNL-MA-70.

PNL's current Quality Assurance program (PNL-MA-70) is based on ASME NQA-1-1989, Quality Assurance Program Requirements for Nuclear Facilities and meets a majority of the requirements of DOE 5700.6C. Further enhancements to the program with special emphasis on the use of Continuous Improvement (CI) processes are in progress. PNL's plan to implement the requirements of 5700.6C was submitted to DOE-RL in April 1992. The approach is to incorporate the principles of 5700.6C into PNL's Total Quality Management (TQM) initiative. Deployment of TQM throughout PNL is a considerable task requiring time and resources to achieve its intent. It is expected that the implementation phase will be initiated in 1994.

The work conducted under this Quality Assurance Project Plan has been determined overall to be PNL Impact Level II. Several Impact Level III tasks have been identified. The project Work Breakdown Structure (WBS) is attached (see Exhibit 3.1). Specific client requirements stated on the Statement of Work for Work Order ED3276 will be followed.

9413221.1983

Exhibit 3.1

Battelle

WBS Impact Level

Project #20082

Date 07/27/93 Rev. No. 1

Index No.	WBS Element Level 1	2	3	4	5	6	WBS Element Title	WBS Element Code	Impact Level I	II	III	Remarks
1	X						**100 Area ISV Demonstration**	0.0		X		
2		X					**Project Management**	1.0		X		
3			X				QA Support and QAPiP preparation	1.1		X		
4			X				Project Management Support	1.2			X	
5			X				Project Administration	1.3		X		
6			X				ISV Tax	1.4			X	
7			X				300 West Compliance Plan	1.5			X	
8		X					**Test Documentation**	2.0		X		
9			X				Test Plan	2.1		X		
10			X				Test Parameters	2.2		X		
11			X				Contingency Plan	2.3		X		
12			X				Waste Disposal	2.4		X		
13			X				Support and Reviews	2.5			X	
14			X				Sample and Analysis Plan	2.6		X		
15			X				Health and Safety Plan	2.7		X		
16			X				Operation and Maintenance Planning	2.8			X	
17			X				Installation and Start-up	2.9			X	
18			X				NEPA documentation	2.10		X		
19			X				SOPs/RWPs	2.11		X		
20		X					**Site and Equipment Preparation**	3.0		X		
21			X				Task Management	3.1		X		
22			X				Hood Maintenance	3.2			X	
23			X				Transformer Maintenance	3.3			X	
24			X				Off-Gas System	3.4			X	
25			X				DAS Development	3.5		X		

Exhibit 3.1

Battelle

WBS Impact Level

Project #20082

Date 07/27/93 Rev. No. 1

Index No.	WBS Element Level 1	2	3	4	5	6	WBS Element Title	WBS Element Code	Impact Level I	II	III	Remarks
26			X				Trial Run Off-Gas Equipment	3.6			X	
27			X				Site Preparation, Instrument Procurement, Placement, and Calibration	3.7		X		
28			X				Equipment Procurement and Placement	3.8		X		
29			X				Training	3.9		X		
30			X				Operational Readiness Review (ORR)	3.10		X		
31		X					**Operations**	4.0		X		
32			X				Operations (Test Performance	4.1		X		
33		X					**Return to Standby**	5.0			X	
34			X				Return System to Standby	5.1			X	
35			X				Return Site to Standby	5.2			X	
36			X				Waste Management	5.3			X	
37		X					**Sampling and Analysis**	6.0		X		
38			X				Process Sampling	6.1		X		
39			X				Block Samples	6.2		X		
40		X					**Reporting**	7.0		X		
41			X				Quick Look Report	7.1			X	
42			X				Detailed Data Reduction	7.2		X		
43			X				Final Report	7.3		X		

4.0 PROJECT DESCRIPTION

The goal of this project is to conduct a pilot-scale field test, perform laboratory and engineering analyses, and develop a test report to assess the applicability of in situ vitrification (ISV) as a stabilization technique for compactable wastes that have been excavated from the 100 Area and disposed in a 200 Area central landfill. This activity is will performed to fulfill the 100-DR-1 milestone for the 100 Area Operable Unit.

The test will be performed at the 300W ISV site on a simulated waste disposal trench. Material used for the test will be nonhazardous, non-regulated, and nonradioactive and be representative of material to be retrieved from the 100 Area. The waste configuration and composition to be tested will be based on engineering analyses performed before the field test. A single melt setting with the pilot-scale ISV unit will be performed to assess the applicability of ISV as a stabilization technique for compressible waste. The results from this pilot-scale field test will also be used to identify the operating envelope and provide the basis for the design of full-scale ISV equipment for this application.

4.1 Change Control (Scope, Schedule, Budget)

Requests by PNL project management for changes in project scope, schedule, or budget from that detailed in the Project SOW for WO ED3276 will be formally submitted to the client (WHC). A Change Request/Record and Change Control Log (reference PNL-MA-95, Research Project Management Manual, Section 4.5) must be used by the project manager to document changes in scope, schedule, or budget that are requested by project management or the client. Changes other than changes in scope, schedule, or budget are discussed in the appropriate Sections of this QA project plan.

Changes in QA/QC needs shall be evaluated, established and instituted at the time a change in scope is made.

9413221.1986

5.0 PROJECT ORGANIZATION AND RESPONSIBILITIES

Line authority, Quality Assurance authority and support within PNL, and interfaces with Westinghouse Hanford Company (WHC) are shown in Exhibit 5.1.

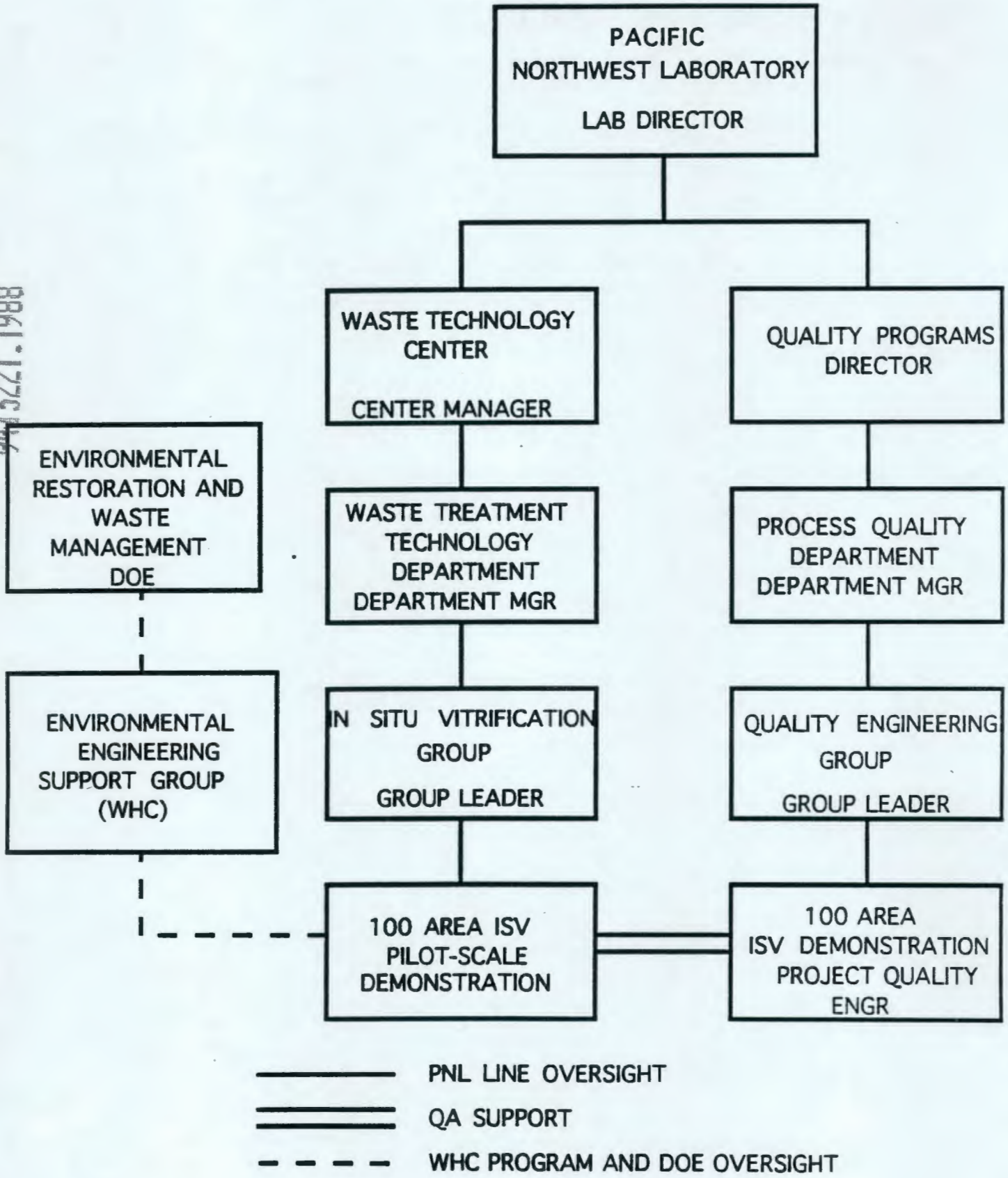
Changes to organizational/interface structures shown in Exhibit 5.1, with exception of the Project Manager, that do not reflect a change in the overall scope of the activities or a change of requirements will not require a QA project plan revision but will be incorporated in the next required revision of the QA Project Plan.

The responsibilities of key PNL personnel are summarized in Table 5.1.

9413221.1987

EXIHIBIT 5.1

100 AREA ISV DEMONSTRATION PROJECT ORGANIZATION CHART



9413221.1988

TABLE 5.1. Responsibilities of Key Personnel

Personnel	Responsibilities
Waste Treatment Technology Department Manager	Provides management review of the project. Assures appropriate and qualified staff are available.
Project Manager Ja-Kael Luey	Interfaces with WHC project lead and provides twice monthly reports of activities. Provides overall direction of the PNL project and day-to-day activities necessary to accomplish all PNL project objectives. Ensures that the QA project plan is prepared and implemented, and that data, QA information, and reports are produced in a timely manner. Has direct contact with the PNL Quality Engineer. Coordinates all Quality Control (QC) activities including the scheduling and submittal of QC samples to PNL laboratories, and evaluates the results. Transmits documents and records to WHC at project completion.
Quality Engineer SE Walker	Provides the Project Manager with QA requirements interpretation and implementation assistance. Provides for Quality Assurance training as necessary. Provides for independent quality assurance reviews, surveillances, and data quality and traceability audits. Is responsible for reviewing and has sign-off authority for QA project plans.
Technical Specialist	Primary duties include preparation of the operating equipment and test site. Coordinates crafts and other services necessary to accomplish these tasks. Prepares site specific and test specific operating procedures and supports the preparation of the Test Plan, Sampling and Analysis Plan, Radiation Work Permit, and the Health and Safety Plan.
Research Engineer	Performs computational modelling of the test to identify potential safety concerns and to identify critical parameters that need to be measured in the field. Assists in the development and identification of the test configuration, simulated waste material, and location of field instrumentation. Aids in the interpretation and analysis of generated data and in the preparation of a technical report in collaboration with the Project Manager.

9413272.1989

6.0 DATA QUALITY OBJECTIVES

Alternatives for remediating the 100 Area were developed and screened in the 100 Area feasibility study phases 1 and 2 (DOE-RL 1992a). The feasibility study provides a starting point for identifying treatability study data needs to support focused feasibility studies (FFS) for Interim Remedial Measure, Interim Remedial Measure Design, final remedy selection, and design phases for Operable Unit remediation. One screened alternative for solid waste in the 100 Area involves removal, treatment, and disposal (DOE-RL 1992b). The disposal phase would involve disposal in trenches/pits and then capping with an engineered barrier. Stabilization of the retrieved waste has been identified as a necessary step to assure the long-term performance of the engineered barriers placed over the disposal sites.

In situ vitrification (ISV) has been identified as a potential stabilization technology for this retrieved solid waste. A pilot-scale treatability study is to be conducted to provide the information necessary to make a decision on whether the ISV technology is suitable as a stabilization technique. The primary measures for such a decision will be the characteristics of the final product and the successful processing of the solid waste by ISV. In addition to this data, the pilot-scale demonstration will result in data that will be used as a basis for full-scale conceptual design and cost estimates for this application. This later data can be divided into two groups, process measurement systems and off-gas treatment system.

This section provides background information on the technology, both in general and for this application, and discusses the performance criteria for each of the data groups to be collected for this pilot-scale demonstration: precision, accuracy, completeness, comparability, and representativeness (PARCC).

6.1 BACKGROUND INFORMATION

In situ vitrification is a patented thermal treatment process developed by PNL for the in-place destruction and immobilization of hazardous chemicals and/or radionuclides in soil (Brouns, Buelt and Bonner 1983; Buelt et al. 1987; Hansen and Fitzpatrick 1991). PNL's research has led to the development of the ISV process as a viable remediation technology for contaminated soils and the creation of a commercial supplier of ISV services, Geosafe Corporation. Development efforts for ISV applications other than treatment of contaminated soils has shown the process to be feasible for remediating buried waste sites (Callow et al. 1991) and underground storage tanks (Tixier, Corathers, and Anderson, 1992). Field experience with these two applications show that the nature of these waste sites can lead to significant pressures beneath the advancing ISV melt that can lead to molten soil displacement events that compromise the integrity of the ISV off-gas containment hood (Roberts et al. 1992).

The 100 Area ISV Pilot-Scale demonstration will not be performed on a simulated waste site containing confined spaces such as drums and underground storage units. However, due to the high loading of gas generating material in the simulated waste site, computational modeling of the ISV process will be performed to assess the potential for a molten soil displacement event during the demonstration. Preliminary work performed to date for a full-scale simulation

9413221.1990

of this application shows the key parameters to preventing such an event are waste loading, site permeability, and processing rate (Roberts, Strachan, and Luey 1992). Data collected during the pilot-scale demonstration will be used to verify the computational modeling method. Once verified, the computational model will be used to define the ISV operating envelope for application to combustible and compactable waste. In addition to data that will be used to verify the computational model, data will be collected to characterize the overall ISV process to assist in the design of full-scale equipment for this application and to provide a basis for cost estimates to this application.

6.2 ISV PROCESS

Figure 6.1, ISV Operating Sequence, illustrates the ISV process. An array of graphite electrodes is inserted a few centimeters into the ground. Because soil is not electrically conductive when its moisture has been driven off, a conductive mixture of graphite and glass frit is placed between each electrode to serve as a starter path. An electrical potential is applied to the electrodes to establish an electrical current in the starter path. The flow of current heats the starter path and surrounding soil to well above the initial soil-melting temperatures of 1100°C to 1400°C. Once the soil becomes molten, it becomes electrically conductive, and the molten region grows outward and downward. Nonvolatile radionuclides and inorganics become incorporated into the molten soil, which is processed at temperatures between 1450°C and 2000°C. Organic components in the soil are destroyed by pyrolysis. The pyrolyzed byproducts migrate to the surface, where they combust in the presence of air. A hood placed over the area being vitrified directs the gaseous effluents to an off-gas treatment system, where they are scrubbed and filtered before being released to the atmosphere. Upon cooling, the solidified glass and crystalline monolith is highly resistant to leaching and is estimated to be stable for geologic periods. For expansive contaminated areas, adjacent settings of the process result in the formation of a single, contiguous monolith.

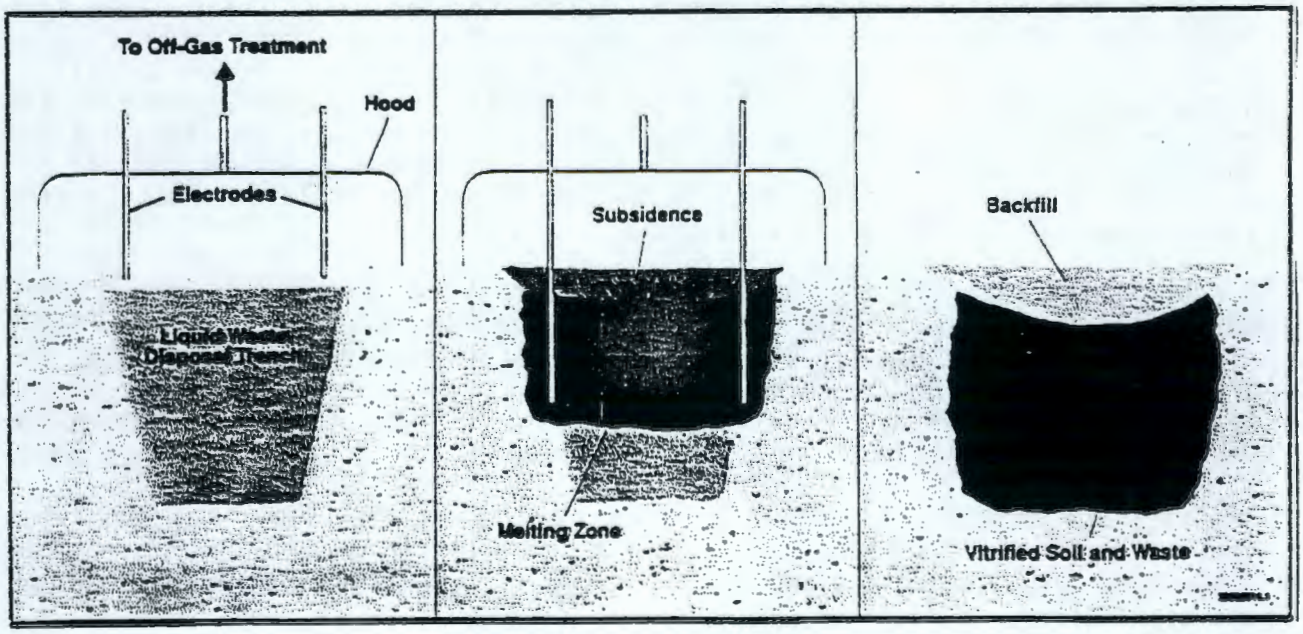


Figure 6.1 ISV Process

9413221.1991

6.3 DATA TO BE COLLECTED

Figure 6.2, ISV Process Data Elements, illustrates the elements of the ISV process from which data will be collected. Descriptions of these elements and their functions during the demonstration are detailed later in this section.

Tables 6.1 "Process System" and 6.2 "Off-Gas Treatment System" identify the instrumentation to be used to collect data from the different elements of the ISV process. Tables 6.1 and 6.2 also identify the sampling frequency and required accuracy for the measurement. The data to be collected with the instrumentation identified in these tables will help meet the demonstration objective for defining the ISV technology operating envelope for application to combustible and compactable waste.

To meet the objective of demonstrating the ISV technology as a stabilization technique, analysis of the final product is required. The specific analyses to be performed are discussed in Section 6.2 of the Sampling and Analysis Plan for the 100 Area ISV Pilot-Scale Demonstration project.

Combustion Air Inlet - The combustion air inlet provides a continuous source of oxygen in the off-gas containment hood to support the combustion of volatilized organic material. Since the off-gas containment hood is kept at a slight negative pressure relative to ambient, the normal flow of gases through the inlet line is into the off-gas hood. If the pressure becomes greater relative to ambient, the air inlet provides a filtered release point. Temperature, pressure and flow rate for the air inlet stream are necessary data points for a material and energy balance on the off-gas containment hood. Such a balance is needed to adequately design a full-scale off-gas hood and off-gas treatment system.

Off-Gas Exhaust - The off-gas exhaust refers to either the off-gas exit line from the containment hood to the off-gas treatment system or the exhaust from the off-gas treatment system stack. Flow from the off-gas hood is provided by the primary blower in the off-gas treatment system. This flow provides the slightly negative pressure in the off-gas hood. Characterization of the off-gas exit temperature and the off-gas stack temperature, flow rate, and composition is necessary for complete material balance on the off-gas hood. Since the pilot-scale demonstration will not contain any radioactive or hazardous material, the primary off-gas constituents of interest that will be measured continuously are oxygen, carbon monoxide, and carbon dioxide. Periodic samples at the off-gas exit will be taken to collect data on the amount of particulate emanating from the melt and to determine the completeness of combustion.

Electrode Seal Air Bleed - The electrode seal air bleed provides air to the positive pressure seals that fit onto the graphite electrodes. These seals prevent potentially uncontrolled releases of gases from the off-gas hood at the insertion points for the electrodes. As with the combustion air inlet, temperature, pressure and flow rate are necessary data points for a complete material and energy balance on the off-gas hood.

Graphite Electrodes - The graphite electrodes provide the means for supplying power to the advancing ISV melt. The amount of power input into the ISV melt is controlled by adjusting the amount of current or voltage added. Measurement of these parameters is necessary to determine full-scale power requirements.

9413221.1992

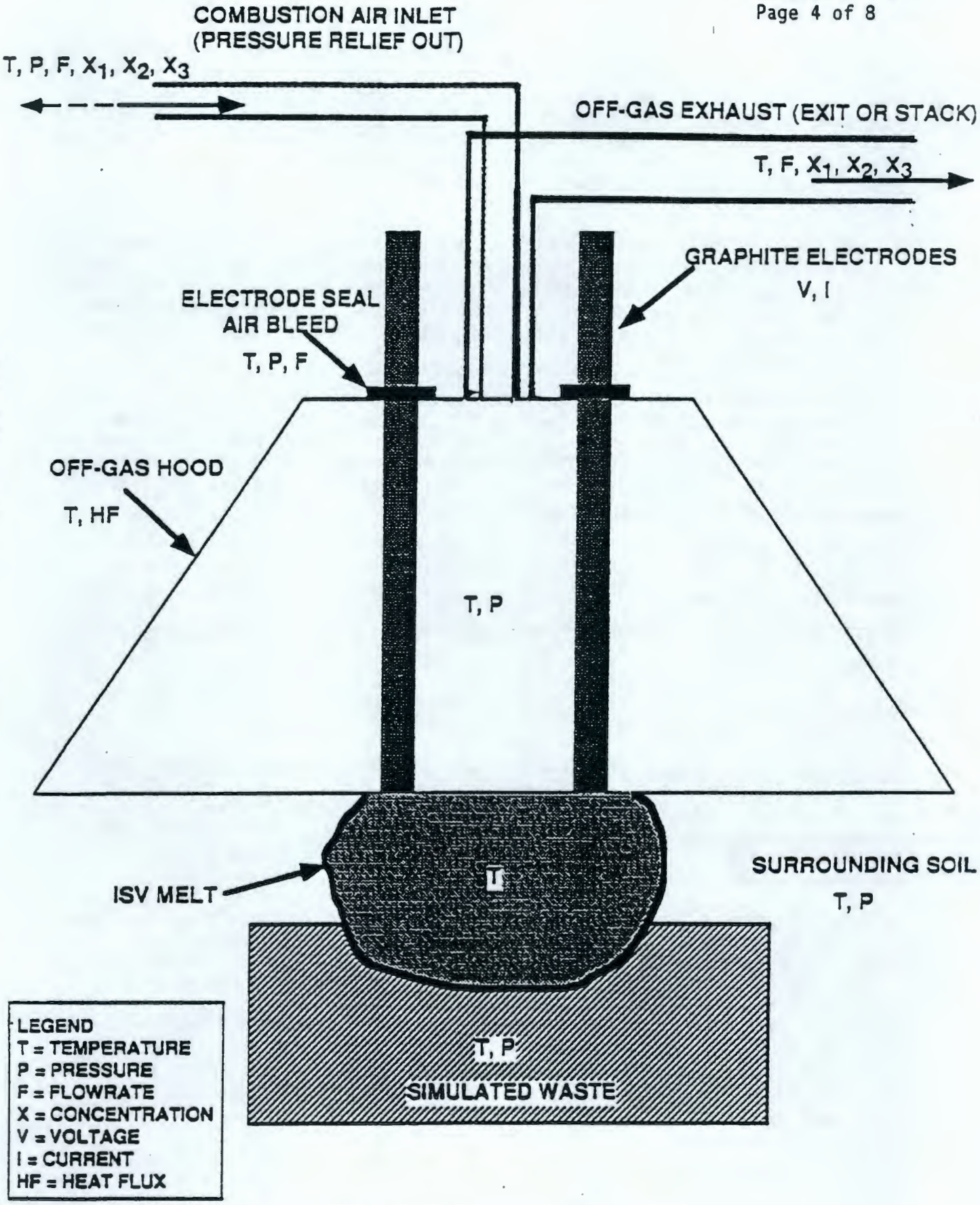


Figure 6.2 ISV Process Data Elements

9413221.1993

Off-Gas Hood - This term refers to both the off-gas hood itself and the volume contained by the off-gas hood. The off-gas hood confines gases and particulate evolving from the ISV melt for processing in the off-gas treatment system. Important parameters to evaluate the performance of the off-gas hood include the temperature of the off-gas hood (both the atmosphere inside the hood and the hood structure), pressure within the off-gas hood, and the flux of energy from the off-gas hood. These parameters are necessary for the design of full-scale equipment.

Process Zone (ISV Melt, Surrounding Soil, and Simulated Waste) - The process zone is the area affected by the ISV process. Characterization of this zone is needed to verify computational model predictions and provide operating information for full-scale equipment design and cost estimations. The primary parameters are a) temperature and pressure in the simulated waste site and surrounding soil and b) temperature in the melt.

Off-Gas Treatment System - In addition to the ISV process data shown in Figure 6.2, data will be collected on the off-gas treatment system. This system uses a wet scrubbing system to capture particulate evolved from the ISV process and to remove acid and other gases from the off-gas stream before it is released to the environment. A complete description of the off-gas treatment system may be found in the Safe Operating Procedure (SOP) for the Pilot-Scale ISV system.

9413221.1994

6.4 DQO DEFINITIONS

PARCC factors discussed in this section are Precision, Accuracy, Representativeness, Completeness, and Comparability. Revision to the PARCC factor definitions for specific analyses will be addressed in each of the PARCC definition sections.

ACCURACY - a measure of the bias of a system or measurement. It is the closeness of agreement between observed and real values.

Product Characteristics - For this project, accuracy will be determined through user verification that analytical equipment is within manufacturer's specifications. This verification procedure will be used in place of standards because standards for the ISV process are not available. Documentation that the analytical equipment is within specifications will be a requirement in the statement of work for the laboratory work performed.

Process Measurement Systems - For this project, accuracy of process measurement data will be determined through user verification that instrumentation is within manufacturer's specifications. Such verification of instrumentation will be recorded on data sheets and/or in the laboratory record book. Refer to section 9 for calibration procedures and frequency. Since the process measurement data will be collected by a data acquisition system (DAS), the connections to the DAS will be checked using a calibrated source to simulate the signal from a measurement instrument. The signal recorded by the DAS must be within 15% of the input signal. This verification will be recorded on data sheets and/or the laboratory record book.

Off-Gas Treatment System - For this project, accuracy of off-gas treatment system data will be determined through user verification that instrumentation is within

manufacturer's specifications. Such verification of instrumentation will be recorded on data sheets and/or in the laboratory record book. Refer to section 9 for calibration procedures and frequency. Since the process measurement data will be collected by a data acquisition system (DAS), the connections to the DAS will be checked using a calibrated source to simulate the signal from a measurement instrument. The signal recorded by the DAS must be within 15% of the input signal. This verification will be recorded on data sheets and/or the laboratory record book.

PRECISION - a measure of mutual agreement among individual measurements of the same property, usually under prescribed similar conditions.

Product Characteristics - For this project, precision applies to the chemical laboratory analyses that will be performed on the final ISV product (i.e., analysis for durability and chemical composition). Laboratory duplicates will be prepared by subdividing selected core samples prior to delivery for laboratory analysis. Precision can be expressed in terms of the relative percent difference (RPD).

$$RPD = \frac{(C1 - C2)}{[(C1 + C2)/2]} x100$$

RPD = relative percent difference
C1 = larger of the two observed values
C2 = smaller of the two observed values

For chemical durability testing, the RPD must be less than 50% for duplicate samples. For chemical composition, the RPD must be less than 50% for the major constituents of duplicate samples. Major constituents shall be defined as any chemical component that is greater than 10% by weight.

For physical laboratory analyses, precision is not applicable because the core sample submitted for analysis is compromised during the analysis (i.e., the analysis is a destructive analysis).

Process Measurement Systems - Precision is not applicable because the measurements taken are a function of time. Therefore, it is not possible to measure the same property to achieve a value for mutual agreement.

Off-Gas Treatment System - Precision is not applicable because the measurements taken are a function of time. Therefore, it is not possible to measure the same property to achieve a value for mutual agreement.

9413221.1995

COMPLETENESS - a measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under normal circumstances.

For this project, completeness will be expressed as:

$$\%C = 100 x \frac{V}{N}$$

V = number of valid data points acquired
N = total number of data points

Because of the nature of the data to be collected for the ISV project (i.e., a combination of electronic and analytical data), it is necessary to further define the total number of data points for each type of data.

Product Characteristics - Samples collected for structural analyses, chemical durability, and chemical composition, will be obtained via coring of the final ISV monolith. This coring will result in numerous samples of the ISV product, not all of which will be analyzed. For this project, completeness for product characteristics will be defined based on the number of samples sent to a laboratory for analysis. A minimum of 50% completeness must be obtained for each of the three analyses of the product with a minimum of six samples being submitted for each analyses. If 50% completeness is not achieved for any given analyses, then a second set of samples will be sent to achieve the 50% completeness target.

Process Measurement System - Due to the nature of the ISV process, much of the instrumentation placed into the soil will not survive the entire test. For these instruments, the total number of data points that is expected will be based on the life of the instrument. Type K thermocouples and pressure sensors are expected to fail at a temperature of 1200°C. For type C thermocouples, the instruments are expected to fail at 1800°C. For the remainder of the process measurement instrumentation, the total number of expected data points is determined by the sampling frequency and duration of the pilot-scale demonstration. For a typical pilot-scale test, this will be about 10,000 data points. Completeness for the process measurement system data must be greater than 75% to ensure sufficient data for analysis.

Off-Gas Treatment System - The total number of expected data points from the off-gas treatment system is determined by the sampling frequency and the duration of the pilot-scale demonstration. For a typical pilot-scale test, this will be about 10,000 points. Completeness for the off-gas treatment system data must be greater than 50% to ensure sufficient data for evaluating the off-gas treatment system.

9/4/3221.1996

REPRESENTATIVENESS - expresses the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition.

Product Characteristics - The final ISV product is a monolith with a sintered zone surrounding a glass and crystalline material. Coring of this final product will result in multiple samples from a cross section of this monolith. Samples selected for analyses will be from multiple locations from within the ISV product to ensure that data from these samples is representative of the entire final product.

Process Measurement System - For measurement of temperature and pressure in the soil and simulated waste zone, an overabundance of instrumentation will be used. Because the purpose of this data is to track the advancing melt front as a function of time, instrumentation is to be placed at multiple locations throughout the soil and simulated waste regions. Exact placement of the instruments into the soil and simulated waste at predefined locations is not required; however, knowing the location of the instrumentation once they are placed is. For the remainder of the process measurement system instrumentation, knowing the location of instrument placement is likewise of greater importance than placement of predefined locations. This will not compromise the representativeness of the data since the data collected will still obtain the desired process information (i.e., melt rate, melt shape, heat flux, etc.).

Off-Gas Treatment System - Representativeness of the data collected from the off-gas treatment system will be verified by a check of the placement of the instrumentation relative to the piece of equipment being monitored.

COMPARABILITY - expresses the confidence with which one data set can be compared to another.

Comparability for this project will not be quantified, but will be addressed through the use of accepted data analysis methods. The use of standard reporting units also will facilitate comparability with other data sets. Comparability of other data will be discussed, when appropriate, in the final report.

9413221.1997

Table 6.1

PROCESS MEASUREMENT SYSTEMS

Test Parameter	Measurement Instrument	Sampling Frequency	Range Eng. Units	Required Accuracy
Air Inlet Temperature (T)	Type T Thermocouple	60 s	0-1200°C	± 5°C
(ambient)	Type K Thermocouple	60 s	0-1200°C	± 20°C
Air Inlet Pressure (P)	Barograph	1 hr	AP* in. Hg	±.075" Hg
Air Inlet Flowrate (F)	Pitot Tubes	60 s	0-15 m^3/min.	± 2%
Off-Gas Temperature (T)				
Exit Line	Type K Thermocouple	60 s	0-1200°C	± 20°C
Off-Gas Treatment Stack	Type T Thermocouple	60 s	0-1200°C	± 5°C
Off-Gas Flowrate (F)				
Off-Gas Treatment Stack	Pitot Tube	60 s	0-15 m^3/min.	± 2%
Off-Gas Concentration (X)				
Ambient O_2 Concentration	Electrochemical	5 min	0-25%	± 4% Full Scale
Stack O_2 Concentration	Electrochemical	60 s	0-25%	± 4% Full Scale
Ambient CO Concentration	Infrared	5 min	0-1900 ppm	± 5% Full Scale
Stack CO Concentration	Infrared	60 s	0-1900 ppm	± 5% Full Scale
Ambient CO_2 Concentration	Infrared	5 min	0-15%	± 2% Full Scale
Stack CO_2 Concentration	Infrared	60 s	0-15%	± 2% Full Scale
Electrode Seal Air Temperature (T)	Type T Thermocouple	10 min	0-1200°C	± 5°C
Electrode Seal Air Pressure (P)	Pressure Regulator	30 min	0-40 kPag	± 1.0 kPa
Electrode Seal Air Flowrate (F)	Float Tube	30 min	0-100 L/min	± 50 L/min
Graphite Electrode Voltage (V)	Digital Volt Meter	60 s	0-1000 VAC	±0.5% or 5 Volts
Graphite Electrode Current (I)	Digital Volt Meter	60 s	0-1000 Amps AC	±0.1% or 5
Off-Gas Hood Temperature (T)				
Plenum	Type K Thermocouple	60 s	0-1200°C	± 20°C
Off-Gas Hood Skin	Type K Thermocouple	5 min	0-1200°C	± 20°C
Off-Gas Hood Pressure (P)	Differential Pressure Gauges	60 s	0-17 kPag	± 0.05 kPa
Off-Gas Hood Heat Flux (HF)	HT-50 (Heat Flux Sensor)	5 min	0-1000 BTU/hr	± 10% Full-scale
ISV Melt Temperature (T)	Type C Thermocouple	30 min	0-2300°C	± 20°C
Surrounding Soil Temperature (T)	Type K Thermocouple	5 min	0-1200°C	± 20°C
Surrounding Soil Pressure (P)	Pressure Xducer	60 s	3-35 kPag	± 1 kPa
Simulated Waste Temperature (T)	Type K Thermocouple	5 min	0-2300°C	± 20°C
Simulated Waste Pressure (P)	Pressure Xducer	60 s	0-35 kPag	± 1 kPa

09/22/1998

9413221.1999

Table 6.2

Off-Gas Treatment System

Test Parameter	Measurement Instrument	Sampling Frequency	Eng. Units Range	Required Accuracy
Off-Gas Treatment System				
Gas Differential Pressure @ Venturi	Diff. Pressure Xdcer	10 min	0-30 in. wc	± 2%
Gas Differential Pressure @ Hydrosonic	Diff. Pressure Xdcer	10 min	0-90 in. wc	± 2%
Gas Differential Pressure @ Condenser	Diff. Pressure Xdcer	10 min	0-30 in. wc	± 2%
Gas Differential Pressure @ HEPA	Diff. Pressure Xdcer	10 min	0-3 in. wc	± 2%
Pump 1 Outlet Pressure	Pressure Transducer	10 min	0-125 psi	± 2%
Pump 2 Outlet Pressure	Pressure Transducer	10 min	0-50 psi	± 2%
Pump 1 Flow	Electronic Flowmeter	10 min	0-50 gpm	± 5%
Pump 2 Flow	Electronic Flowmeter	10 min	0-30 gpm	± 5%
Glycol Coolant Flowrate	Electronic Flowmeter	10 min	0-100 gpm	± 5%
Glycol Coolant Temperature	Type K Thermocouple	10 min	0-1200°C	± 20°C
Pressure @ Blower	Diff. Pressure Xdcer	10 min	0-140 wc	± 2%
Tank 1 Liquid Level	Diff. Pressure Xdcer	10 min	0-350 L	± 2%
Tank 2 Liquid Level	Diff. Pressure Xdcer	10 min	0-350 L	± 2%
Off-Gas Temperature @ Venturi	Type K Thermocouple	10 min	0-1200°C	± 20°C
Off-Gas Temperature @ Stack	Type K Thermocouple	10 min	0-1200°C	± 20°C
Tank 1 Liquid Temperature	Type K Thermocouple	10 min	0-1200°C	± 20°C
Tank 2 Liquid Temperature	Type K Thermocouple	10 min	0-1200°C	± 20°C

7.0 SAMPLING PROCEDURES

Sampling procedures are detailed or referenced in Section 5. of the Sampling and Analysis Plan for the 100 Area ISV Pilot Scale ISV Demonstration Project.

9413221.2000

8.0 SAMPLE CUSTODY

8.1 Sample Chain-of-custody

The chain-of-custody for samples submitted for laboratory analysis will be initiated by PNL. Sample chain-of-custody will be documented and maintained per procedure detailed or referenced in Section 7. of the Sampling and Analysis Plan for the 100 Area Pilot Scale ISV Demonstration Project.

8.2 Corrections to Documentation

If an entry error is made on any field or laboratory documentation, an individual may correct the error by drawing a line through the error and entering the correct information. The error shall not be obliterated. All non-editorial corrections shall be initialled and dated.

9413221.2001

9.0 CALIBRATION PROCEDURES AND FREQUENCY

All measurement and test equipment (M&TE), for which PNL is responsible, must be controlled in accordance with PNL-MA-70 Administrative Procedure **PAP-70-1201, Calibration Control System.**

Category 1 M&TE is calibrated by an approved metrology organization. All organizations providing Category 1 calibration services must be evaluated by the PNL Process Quality Department in accordance with PNL-MA-70 Quality Assurance Procedure **QAP-70-701, Preaward Evaluations/Surveys**, before being utilized.

Category 2 M&TE is calibrated by the user. Requirements for documenting user calibration of Category 2 M&TE are included in PNL-MA-70 Administrative Procedure **PAP-70-1201, Calibration Control System.**

Any analytical lab performing work will be designated in the Statement of Work as responsible for calibration of analytical equipment. Category 3 M&TE is not calibrated but is performance checked in the field and is for indication only. Performance checks are recorded on the Field Record Form.

9413221.2002

10.0 ANALYTICAL PROCEDURES

Analytical Procedures to be used are detailed or referenced in Section 6.2 of the Sampling and Analysis Plan for the 100 Area ISV Pilot-Scale Demonstration project.

9413221.2003

11.0 DATA REDUCTION, VALIDATION, AND REPORTING

Data to be collected for the 100 Area pilot-scale demonstration includes;

- site and equipment preparation activities such as identification and placement of sensors used in measurement systems;
- process data including temperature (in the off-gas system, soil, and simulated waste site), pressure (in the off-gas system, soil, and simulated waste), flow rate (inlet and outlet streams for the off-gas hood) heat flux (from the off-gas hood) and applied current and voltage;
- and post test characterization of the ISV product (laboratory analysis and observations).

This data will be recorded via bound laboratory record books (LRBs), photographs, data sheets, analytical laboratory reports, and electronic data files. Data validation will be performed via signed reviews of the data by the shift engineer at the time of data collection; signed review by either the shift engineer, project manager, task leader, or equipment specialist of the data collection source (i.e., data acquisition system); and/or calibration records (signed by the equipment custodian and calibrator).

9413221.2004

11.1 Data Management and Reporting Procedures

The data recording methods will be managed as follows:

LRBs: The first entry on a page in the LRB will be signed and dated; successive entries on the same page will be dated and/or timed and initialed. When appropriate, entries into the LRB will also include the time of entry. The LRB will be reviewed quarterly for both technical content and completeness of entries. A copy of the LRB will be included in the project file at the completion of the project.

Photographs: Photographs documenting the site and equipment preparation, test operations, and post test examination of the ISV product will be taken. The first frame for each roll of film will be a photograph of a card denoting the date and time. Entries will be made into the LRB denoting when photographs are taken and describe the object for which photos are being taken. Proof sheets will be made for each roll of film and the negatives indexed for future prints. A set of the proof sheets will be kept in the project files. The ISV site location is documented in section 3.0, "Test Objectives" of the "Test Plan for the 100 Area ISV Pilot Scale Demonstration".

Data Sheets: Data sheets will be used during the pilot-scale demonstration to periodically record selected data by hand. The data sheets to be used are located in Appendix E of the Test Plan. Entries onto the data sheets will be initialed and dated. Upon the completion of a data sheet, the shift engineer will review the entries and sign the data sheet as being complete. Upon the completion of the pilot-scale demonstration, the original data sheets will be stored in the project files and a copy inserted into the LRB.

Analytical Laboratory Reports: The analytical laboratory reports will be kept in the project files. The SOW for analytical work will require the laboratory performing the analysis to maintain analytical records until completion of the project. These records shall include calibration and verification checks of analytical instrumentation used, sample preparation methods, and any deviation

from a procedure. These record requirements will be stated in the SOW for analytical work. In addition, the SOW will contain instructions pertinent to the transfer of records, test method, procedures, validation, surveillance, deficiency reporting, nonconformance reporting, and chain-of-custody.

Electronic Data Files: The original electronic data files will be controlled by the project manager and formatted as read only files. Reduction of the electronic data will be performed using working files that are copies of the original data. Manipulation of the data will be documented either in the LRB or by a memo to the project manager summarizing the manipulation performed. PNL Administrative Procedure PAP-70-301 will be used to control Hand Calculations. (see 11.3 below)

9413221.2005

11.2 Process for Handling Suspect or Unacceptable Data

When the initial data review identifies suspect data, that data must be investigated to establish whether it reflects true conditions or an error. The investigation must be documented using a Request for Data Review (Exhibit 11.1). The Project Manager shall issue RDR numbers and maintain a log of all RDRs generated identifying their status (i.e., date issued, and date closed).

If a data value is determined to be in error, the source of the error must be investigated, the correct value established if possible, and the erroneous value replaced with the correct value. If the investigation concludes that the data are suspect (possibly in error) but a correct value cannot be determined, the data must be flagged in the comments column to indicate its suspect status.

If the source of the error was noncompliance with an established requirement or procedure, a Deficiency Report (DR) must be generated in accordance with PNL-MA-70 Administrative Procedure **PAP-70-1502, Controlling Deviations from QA Requirements and Established Procedures**. If the source of error was due to the nonconformance of an item, then a Nonconformance Report (NCR) must be generated in accordance with PNL-MA-70 Administrative Procedure **PAP-70-1501, Nonconformance Reports**. As a minimum, the Project Manager and the Quality Engineer must be copied on the data investigation documentation (RDR). Nonconformance and Deficiency reports shall be sent to the WHC cognizant engineer and cognizant QAE for disposition concurrence prior to initiating the disposition.

11.3 Engineering Calculations and Computer Modeling

Hand calculations used for determination of various test parameters, data conversion, and data reduction will be controlled and validated in accordance with PAP-70-301 "Hand Calculations, General." Data reduction performed with the aid of commercial "spread sheet" software will also be Controlled and validated in accordance with PAP-70-301.

Complex calculations (computer modeling) and data reduction involving development or modification of software will be controlled, validated, and reported in accordance with PNL MA-70 SCPs "Software Control Procedures."

EXHIBIT 11.1

1 ***Request for Data Review (RDR)*** ***No.:*** _____

Originator: _____ Date: _____ Phone #: _____ MSIN: _____

Project: _____ Manager: _____ Phone #: _____ MSIN: _____

Sample #: _____ Well #: _____ Collection Date: _____

Constituent: _____ Value: _____ Other: _____

---

2 ***Reason for Review***

---

3 ***Data Review Findings***

Reviewer: _____ Date: _____ Attachments: _____

---

4 ***Response/Action***

Laboratory Coordination: _____ Date: _____
Signature When Complete

---

5 ***Data Base Management Action***

Data Base: _____ Date: _____
Signature When Complete

---

6 ***RDR Closure***

_____
Project Manager Leader Signature Date

_____ _____
Originator's Signature Date Quality Engineer Signature Date

---

7 ***Distribution***

Originator Project Manager Reviewer
RDR Logbook (original) Quality Engineer

ADDITIONAL DISTRIBUTION AFTER CLOSURE:

9413221.2006

12.0 INTERNAL QUALITY CONTROL CHECKS

12.1 Physical and Chemical Test Quality Control Checks

Characterization Analyses: The requirements for an internal laboratory QC program that is implemented through the laboratory's analytical procedures will be passed to the Analytical Chemistry Laboratory (ACL) via Statement of Work (SOW). In the case of a non-PNL laboratory being used, requirements will be forwarded via authorizing documentation ie. Work Order, Letter of Understanding (LOI), SOW, etc.(see section 18.2).

QC checks for the chemical analyses are specified in the test method or procedure.

12.2 Acceptable Limits/Results Requiring Action

The acceptance limit for blind standards is ±2 standard deviations (s.d.). In inter-laboratory comparisons using actual field samples, difference between laboratory results of 2.8 s.d is allowed. This criterion is based on the reproducibility limit, with 95% confidence that random error is not responsible for the difference.

9413221.2007

13.0 PERFORMANCE AND SYSTEM AUDITS

Surveillances are, in a sense, mini-audits that provide the project manager with the ability to view the status of the project on a more frequent, snapshot-in-time, basis. In addition, they provide a cost effective means to view a wide range of project and analytical processes.

Compliance, real-time, and data traceability surveillances are performed by Quality Engineers of the Quality Verifications Department (QV). Compliance surveillances are performed to ensure that a specific requirement, or set of requirements, is being implemented. Real-time surveillances are performed during the work or analytical process to ensure that specific standardized procedures are being implemented. Data traceability surveillances are performed to ensure that the resultant project data are traceable back through the analytical process, through sample handling and transportation, back to the date, time, location, staff, and technique used to collect the sample or record the data. Surveillances are performed in accordance with PNL-MA-70 Quality Assurance Procedure **QAP-70-1001, Planning and Performing Surveillance.**

A minimum of two (2) surveillances will be performed during the life of this project. Once to aid in determination of operational readiness and again during test performance.

System audits, or simply audits, are performed by the PNL Quality Verification Department on a periodic basis. Audits are planned and performed in accordance with PNL-MA-70 Quality Assurance Procedure **QAP-70-1801, Internal Audits.** Quality Assurance audit personnel are qualified in accordance with PNL-MA-70 Quality Assurance Procedure **PAP-70-204, QA Audit Personnel Qualification.**

The results of surveillances and audits will be made available to project and line management as well as to individuals contacted.

9413221.2008

14.0 PREVENTIVE MAINTENANCE

Routine equipment and facility maintenance and instrument services ensure the timely and effective completion of a measurement effort. The Research and Development nature of the ISV equipment is not conducive to a regular preventative maintenance schedule due to its infrequent use. Because of this infrequent use, the equipment is thoroughly checked prior to use and then monitored during testing. Back-ups for every piece of critical equipment are not available. However, sufficient spare parts are on hand to allow repairs on the critical equipment. Exhibit 14.1 list the critical spare parts to be maintained for this project.

This infrequent usage of equipment also extends to the M&TE used in the field. This equipment is also calibrated and checked prior to use. The relatively short duration of use (less than 6 months) does not necessitate the need for calibration during testing.

Analytical laboratory equipment maintenance is the responsibility of the manager of the analytical laboratory.

9413221.2009

FIGURE 14.1
CRITICAL SPARE PARTS

Scrub pump spare seals (1 ea, 2 sizes #800 CD-SP and #600 CD-SP).
Chart paper L&N 0 to 1200°C #545827 and L&N 0 to 1500°C #545862.
Data acquisition program blank formatted data disks.
Vacuum transfer lines and drum fittings.
CVI files, drawings, for all systems.
Fire extinguishers.
Clip boards.
Tool box with bailing wire.
Chairs.
Extensions ladders (2 ea), steps (2 ea), step stools (1 ea).
Flashlights and batteries.
Extension cord plug strips (4 ea).
Extension lights (2 ea).
Shop vacuum, attachments and filters.
Power recorder.
Track light bulbs.
Light bulbs (100 W), and spotlight bulbs.
Long nylon chokers (2 ea).
Insulating blankets (3 ea).
Drum pump hose and fittings.
Brooms, dust pans, and garbage cans.
Step-off pads.
Rubber mat (1 roll).
CAM (if required).
Portable eye wash (2 ea).
Plastic buckets (8 ea).
Terry towels (loose).
Safety belts (2 ea).
Toilet paper (6 rolls).
Boxes for sample shipping.
Miscellaneous stainless steel fittings.
Nuts, bolts, and washers (miscellaneous).
Poly tubing (3/8 in., 1/2 in., 3/4 in.).
Ph paper.
De-Ice (winter only).
Miscellaneous office supplies (pencils, paper, yellow tags, etc.).
Radiation waste boxes (if needed).
Large plastic bags (1 roll).
First aid kit (1 ea).
Spill kit (1 ea).
55-gal drums (if needed).
Fire-retardant plastic (20 ft x 100 ft).
Camera, flash, film.
Stack air sample tubes.
Vacuum pump oil.
Automatic transmission fluid.
WD-40 (2 cans).
Electra Clean (6 cans).
Garden hoses (2 ea).
Window cleaner and soap.
Water containers--drinking (2 ea).
Full face masks.
Half face masks.
Hard hats.
Safety glasses.
Dark face shield (2 ea).
Clear face shield (2 ea).
Noise protection (head sets and plugs).
Leather gloves (size 8).
Leather gloves (size 9).
Leather gloves (size 10).
Viton gloves.
Radiation gloves (canvas).
Surgical gloves (sizes: 7-1/2, 8, 8-1/2, and 9).
Rain gear (disposable).
Canvas shoe covers.

9413221.2010

FIGURE 14.1
CRITICAL SPARE PARTS

Radiation coveralls (medium, large, and extra-large).
Radiation caps.
Radiation hoods.
Radiation rubber shoe covers.
Blue coveralls - short sleeve (medium, large, and extra-large).
Blue coveralls - long sleeve (medium, large, and extra-large).
Blue lab coats (medium and large).
Towels.
Disposable coveralls (medium, large and extra-large).
Rubber boots - nonradioactive (3 sizes).
Electrical high voltage gloves.
Fiber tape (shipping).
Duct tape.
Marking tape.
Electrical tape (specify #33).
Fiberglass tape.
White plastic tape.
Fuses - 500 amps.
Fuse fast acting 100 V, 1 A, bus #KTK1.
Fuse dual element 600 V, 3 A, bus #FNQ3.
Fuse 250 V, 1/2 A, bus KTK 1/2.
MOV varister, G.E. #V480PA80A.
IC Op-amp, MC3503L K8503.
IC Op-amp, GE H11C1 8446.
IC Op-amp, MC1741CP 1 L8442.
IC Op-amp, MC14001B CPZG8447.
IC Op-amp, NE556N.
SCR triggering board.
Fuse (3/4 A one time fuse), bus.
Heater, G.E. C19.8B.
Heater, G.E. C4.19A.
Heater, G.E. C33.0B.
Heater, G.E. C3.26A.
Heater, G.E. C1.48A.
Heater, G.E. C9.55A.
Fence posts (24 ea).
Fence post driver.
Fence rope, yellow (600 ft).
Signs: Authorized Personnel Only and High Voltage (4 ea).
Aluminum sealer.
Red RTV.
Magnehelic gauge -5 to +5 in. H_2O.
Shovels (3 ea).
Pick axe (1 ea).
Sledge hammer (1 ea).
Metal rake (1 ea).
6-ft folding rulers (4 ea).
Electrode lifting swivel.
Kao Wool (2 rolls).
Never Seize.
8" Off-Gas flex pipes (2 ea).
Strap wrenches (2 ea).
GX-4000 Gas Analyzer.
Hand pump and appropriate dregger tubes.
Spare pump for Tanks 3 & 4.
High temp filters for pre-filter absorbers.

9413221.2014

9413221.2012

15.0 CORRECTIVE ACTION

Corrective action must be initiated by the Project Manager or cognizant Task Leader when unplanned deviations from procedural, contractual or regulatory requirements occur. The need for corrective action may be revealed by observations of measurement system response, during data reasonableness checks (brief comparison of newly collected data against observed historical trends), when discrepancies are noted during instrument calibration, or during data analysis. Planned deviations are discussed in section 15.2, below.

15.1 Measuring and Test Equipment (M&TE) Calibration Discrepancies

Instruments or equipment found to be operating outside acceptable operating ranges (as specified in the applicable technical procedure or manufacturer's instructions) must be investigated. A Calibration Discrepancy must be initiated in accordance with PNL-MA-70 Administrative Procedure **PAP-70-1201, Calibration Control System**, when it is determined that M&TE is not within calibration and/or when data have been collected after the calibration expired.

15.2 Deviations from Procedures or Requirements

Unplanned deviations from procedural, contractual, or regulatory requirements must be documented by completing a Deficiency Report (DR) in accordance with PNL-MA-70 Administrative Procedure **PAP-70-1502, Controlling Deviations from QA Requirements and Established Procedures**. The DR must identify the requirement deviated from, the cause of the deviation, whether any results were effected, and corrective action needed to remedy the immediate problem and to prevent recurrence.

Planned deviations, documented on the test plan, test procedure, SOP, and/or in the Laboratory Record Book (including justification) and approved by the Project Manager or Task Leader in advance, do not constitute a deficiency as defined in PAP-70-1502 and do not require development of a DR.

15.3 Corrective Action for Significant Conditions Adverse to Quality

When significant conditions adverse to quality are identified, the cause of the conditions and the corrective action taken to preclude repetition will be documented and reported to Immediate line management for review and assessment by a Corrective Action Request (CAR) in accordance with PNL-MA-70 Administrative Procedure **PAP-70-1602, Corrective Action.** "Significant" conditions are identified in Section 4.2.1.1 of PAP-70-1602.

16.0 QUALITY ASSURANCE REPORTS TO MANAGEMENT

Deviations from this QA project plan, as well as the results of surveillances and audits, must be documented, described and reported to the Project Manager. Quality Assurance related information must be reviewed by the cognizant PNL Quality Engineer.

Problems identified by project personnel must be reported to the project manager immediately for resolution. Problems involving data quality or sample integrity, must be thoroughly documented.

Line management must be included on the distribution of all audit reports. Significant problems encountered in day-to-day operations must be reported to line management immediately by the Project Manager.

9413221.2013

17.0 RECORDS

Definitions

- **Working Files** - Documents (record material) supporting a task or activity that become quality assurance records when the task or activity is completed.

- **Quality Assurance Records** - Completed records that furnish evidence of the quality of items and/or activities affecting quality. When a deliverable, task, or activity is completed, working files become quality assurance records.

17.1 Records Management

Project records must be indexed and maintained in accordance with PNL-MA-70 Administrative Procedure **PAP-70-1701, Records System.** A Records Inventory and Disposition Schedule (RIDS) must be prepared and submitted for review and approval by the Records Specialist and Quality Engineer. Records retention schedules shall be based on DOE Order 1324.2A, Records Disposition, and applicable regulatory requirements as delineated by PNL-MA-68 "Records Management and Document Control".

- The Project Manager must assure that documents are reviewed for technical adequacy, accuracy, and completeness to verify that the documents support fitness for operation and conformance to specifications and procedures.

- Any problems or deficiencies noted in the records must be properly resolved and documented in accordance with PNL's deficiency/nonconformance system (see Section 20).

17.2 Turnover of Records To WHC

Project records will be transferred to the PNWD Records Center at least annually. Within 30 days after project completion, all remaining records will be transferred to the PNWD Records Center. All PNL generated record copy, Quality affecting documents shall be transmitted to WHC within 90 days after completion of the project. These activities must be coordinated through the PNL Records Specialist. Records generated by the analytical laboratory will be handled as defined in section 11 of this QA Project Plan.

9413221.2014

18.0 PROCUREMENT CONTROL

18.1 Purchase Requisitions and Subcontracts

Procurement of items and subcontracted services are governed by PNL-MA-70 Administrative Procedure **PAP-70-401, Preparation, Review, and Approval of Purchase Requisitions.**

18.2 Work Orders and Work Package Authorizations

Work Package Authorizations (WPAs) or Work Orders (WOs) to individuals or groups outside the project organization must be generated and issued in accordance with PNL-MA-70 Administrative Procedure **PAP-70-404, Obtaining Services Via Work Orders.** As appropriate (as specified in PAP-70-404), a letter of instruction (LOI) or statement of work (SOW) must accompany each WO or WPA.

9413221.2015

19.0 STAFF TRAINING

Staff performing activities affecting quality shall be issued documented training assignments including applicable administrative and technical Procedures and this QA project plan, according to **PAP-70-201, Indoctrination and Training.** Documentation of other than project specific training shall be maintained by Laboratory Training and/or the individual's reporting organization. Project specific training records will be maintained in the project files.

Requirements for the training of analytical staff to the procedures or methods to be performed shall be passed to the analytical laboratories via Statement of Work in accordance with Section 18.0, Work Orders and Work Package Authorizations.

9443221.2016

20.0 NONCONFORMANCES AND DEFICIENCIES

For materials found to be in nonconformance with specifications, a Nonconformance Report (NCR) must be generated and the item(s) dispositioned in accordance with PNL-MA-70 Administrative Procedure **PAP-70-1501, Nonconformance Reports**.

Unplanned deviations from Procedures, plans, specifications, or related documents shall be documented using a Deficiency Report (DR) in accordance with the requirements in PNL-MA-70 Administrative Procedure **PAP-70-1502, Controlling Deviations from QA Requirements and Established Procedures**. Potentially impacted data shall be segregated or flagged by the project manager pending evaluation of the deficiency's impact on the data and final disposition of the DR.

Planned deviations, documented on the test plan, test procedure, or in the Laboratory Record Book (including justification) and approved by the Project Manager or Task Leader in advance, do not constitute a deficiency as defined in PAP-70-1502 and do not require development of a DR.

See also Section 11, Data Reduction, Validation and Reporting, for handling suspect or unacceptable data and Section 15, Corrective Actions, for corrective actions.

Control of Non-Conformance and Deficiencies will be passed to the analytical laboratories via Statement Of Work, SOW, in accordance with Section 18.0, Work Orders and Work Authorizations.

9413221.2017

21.0 DOCUMENT CONTROL

21.1 QA Project Plan Control

Distribution and control of this QA project plan shall be performed in accordance with PNL-MA-70 Administrative Procedure **PAP-70-205, Quality Assurance Plans.**

Modifications to this QA project plan shall be made in accordance with Section 4.6 of PNL-MA-70 administrative Procedure **PAP-70-205, Quality Assurance Plans,** that is, either by revision or by issue of an Interim Change Notice (ICN). Any PNL staff member may request an interim change to this QA project plan at any time by submitting a Document Change Request (DCR) to the Project Manager or Quality Engineer.

21.2 Technical Procedure Control

Deviations from existing procedures shall be thoroughly documented in a Laboratory Record Book in accordance with the **GPS, Section 4.2.2, Experiment Performance,** and **Section 5.2.1, Laboratory Record Books.**

Laboratory Record Books shall be maintained in accordance with additional requirements in PNL-MA-70 Administrative Procedure PAP-70-1701.

New technical Procedures must be developed in accordance with PNL-MA-70 Administrative Procedure **PAP-70-1101, Test Planning, Performance,** and **Evaluation** and controlled in accordance with Administrative Procedure **PAP-70-601, Document Control.** All technical Procedures shall be distributed and controlled by PNL Document Control.

21.3 Change Control

Changes to procedures will be controlled as prescribed in section 15.2, last paragraph "Deviations from Procedures or Requirements.

9413221.2018

22.0 Document Reviews

Document reviews of technical reports to the client shall be performed in accordance with the requirements in Administrative Procedure, **PAP-70-604, Independent Technical Review.**

9447221.2019

23.0 References

Brouns, R.A., J.L. Buelt, and W.F. Bonner (Battelle Memorial Institute),. 1983. U.S. Patent 4,376,598.

Hansen, J.E. and V.F. Fitzpatrick. 1991. "In Situ Vitrification Applications," Geosafe corporation, Kirkland, Washington.

Callow, R.A., L.E. Thompson, J.R. Weidner, C.A. Loehr, B.P. McGrail, and S.O. Bates. 1991. In Situ Vitrification Application to Buried Waste: Final Report of Intermediate Field Tests at Idaho National Engineering Laboratory. EGG-WTD-9807, Idaho National Engineering laboratory, Idaho Falls, Idaho.

Roberts, J.S., D.L. Lessor, S.L. Woosley, and C. Strachan. 1992. Preliminary Investigation of the Potential for Transient Vapor Release Events During In Situ Vitrification Based on Thermal-Hydraulic Modeling. PNL-8170, Pacific Northwest Laboratory, Richland, Washington.

Roberts, J.S., C. Strachan, and J. Luey. 1993. PNL-SA-21870, Pacific Northwest Laboratory, Richland, Washington.

Tixier, J.S., L.A. Corathers, and L.D. Anderson. 1992. Vitrification of Underground Storage Tanks: Technology Development, Regulatory Issues, and Cost Analysis. In Waste Management '92, vol 2, ed. R. G. Post, pp. 1521-1528. March 1-5, 1992, Tucson, Arizona.

9413221.2020

APPENDIX D

Data Sheets

9413221.2021

THIS PAGE INTENTIONALLY
LEFT BLANK

THIS PAGE INTENTIONALLY
LEFT BLANK

9413221.2022

Page ___ of ___

Line Item #	M&TE Control #	M&TE Description	Location	Calibration Interval	Custodian	Calibration Agency	Category	Remarks
1	2	3	4	5	6	7	8	

The following information is provided to clarify what is required for each column on the M&TE Control Listing.

1. Line Item Number - 1, 2, 3, 4, etc...
2. Control Number - For WHC calibrated M&TE, use the WHC Code #. For PNL calibrated M&TE use, in order of preference, property number, manufacturers' serial number, or assign a unique number.
3. Description (e.g., spectrum analyzer, oscilloscope).
4. Location (where M&TE is used or stored - list the room number, building, and area).
5. Calibration Interval (e.g., 3 months, 12 months, 2 years, during use, etc...).
6. Custodian (e.g., individual responsible for controlling or maintaining the M&TE).
7. Calibration Agency (e.g., WHC, Craft Services, User).
8. Category
9. The Listing shall be considered complete after signature/date by the preparer and the appropriate Cognizant Manager or Task Leader.
10. Project/Activity Number (or the title if not numbered).
11. QA Plan Number (when applicable).

Prepared by: _____ (9) _____
Signature/Date

Cognizant Manager or Task Leader: _____ (9) _____
Signature/Date

Project/Activity Number: _____ (11) _____

QA Plan: _____ (11) _____

M&TE CONTROL LISTING

Off-Gas Treatment System Data

Test # 100 AREA ISV Pilot-Scale Demo

Collection Interval [1] Sheet # [2]

Date:	[3]							
Time:	[4]							
Operator:	[5]							
Gas Diff. Press. at Venturi (kPa)	[6]							
Gas Diff. Press. at Hydrosonic (kPa)	[6]							
Gas Diff. Press. at Condenser (kPa)	[6]							
Gas Diff. Press. at HEPA (kPa)	[6]							
Pump 1 Outlet Pressure (kPa)	[7]							
Pump 2 Outlet Pressure (kPa)	[7]							
Pump 1 Flow (L/min)	[8]							
Pump 2 Flow (L/min)	[8]							
Glycol Coolant Flowrate (L/min)	[9]							
Glycol Coolant Temperature (C)	[10]							
Pressure at Blower (kPa)	[11]							
Off-Gas Temperature at Venturi (C)	[12]							
Off-Gas Temperature at Stack (C)	[12]							
Off-Gas Temp at Hydrosonic Inlet (C)	[12]							
Off-Gas Temp at HEPA Inlet (C)	[12]							
Ambient O2 Concentration (%)	[13]							
Stack O2 Concentration (%)	[13]							
Ambient CO Concentration (ppm)	[14]							
Stack CO Concentration (ppm)	[14]							
Ambient CO2 Concentration (ppm)	[15]							
Stack CO2 Concentration (ppm)	[15]							

The following information is provided to clarify what is required for each column on the General Process Data Sheet.

[1] Freq. of readings determined prior to the test by the PM.
[2] Sheet Number - 1,2,3,etc.
[3] Date reading is taken.
[4] Time reading is taken.
[5] Operator's Initials.
[6] Measured with a differential pressure transducer.
[7] Outlet press. at pumps measured with press. transducers.
[8] Pump flowrates measured with electronic flowmeters.
[9] Coolant flowrate measured with an electronic flowmeter.
[10] Coolant temperature measured with a type K T/C.
[11] Blower press. measured with a diff. press. transducer.
[12] Off-gas temps. measured with type K thermocouples.
[13] Ambient and stack O2 conc. measured electrochemically.
[14] Ambient and stack CO conc. measured with infrared.
[15] Ambient and stack CO2 conc. measured with infrared.
[16] At the end of each shift, the shift engineer (defined in SOP 49 Rev. 9) will review the measurements and then sign and date the data sheet.

Reviewed By: [16] Date: [16]

General Process Status Sheet

Test # 100 AREA ISV Pilot-Scale Demo

Collection Interval [1] Sheet # [2]

Date:	[3]							
Time:	[4]							
Operator:	[5]							
Air Inlet Temperature (C)	[6]							
Air Inlet Pressure (kPa)	[7]							
Air Inlet Flowrate (m3/min)	[8]							
Hood Exit Line Temperature (C)	[9]							
Stack Temperature (C)	[10]							
Stack Flowrate (m3/min)	[11]							
Hood Vacuum (in. W.C.)	[12]							
Hood Plenum Temperature (C)	[13]							
Off-Gas Hood Skin Temp. (C)	[14]							
Hood Heat Flux	[15]							
Electrode A1 Seal Air Temp. (C)	[16]							
Electrode A1 Seal Air Pressure (kPa)	[17]							
Electrode A1 Seal Air Flowrate	[18]							
Electrode A2 Seal Air Temp. (C)	[16]							
Electrode A2 Seal Air Pressure (kPa)	[17]							
Electrode A2 Seal Air Flowrate	[18]							
Electrode B1 Seal Air Temp. (C)	[16]							
Electrode B1 Seal Air Pressure (kPa)	[17]							
Electrode B1 Seal Air Flowrate	[18]							
Electrode B2 Seal Air Temp. (C)	[16]							
Electrode B2 Seal Air Pressure (kPa)	[17]							
Electrode B2 Seal Air Flowrate	[18]							

The following information is provided to clarify what is required for each column on the General Process Data Sheet.

[1] Freq. of readings determined prior to the test by the PM.
[2] Sheet Number - 1,2,3,etc.
[3] Date reading is taken.
[4] Time reading is taken.
[5] Operator's Initials.
[6] Inlet air temp. measured with a type T thermocouple.
[7] Inlet air pressure measured with a Barograph.
[8] Inlet air flowrate measured with pitot tubes.
[9] Exit line temp. measured with a type K thermocouple.
[10] Stack temperature measured with a type T thermocouple.
[11] Stack flowrate measured with a pitot tube.
[12] Hood vacuum measured with a differential press. gauge.
[13] Hood plenum temp. measured with a type K T/C.
[14] Hood skin temp. measured with a type K thermocouple.
[15] Hood heat flux measured with a HT-50 (heat flux sensor).
[16] Electode seal air temps. measured with type T T/C.
[17] Electrode seal air press. measured with press. regulators.
[18] Electrode seal air flowrates measured with float tubes.
[19] At the end of each shift, the shift engineer (defined in SOP 49 Rev. 9) will review the measurements and then sign and date the data sheet.

Reviewed By: [19] Date: [19]

9/11/2021 2024

9413221.2025

Soil Temperature Array

Collection Interval [1] Sheet # [2] Test # 100 AREA ISV Pilot-Scale Demo

	Date:	[3]							
	Time:	[4]							
	Operator:	[5]							
T/C # [6]	UNITS	TEMP	TEMP	TEMP	TEMP	TEMP	TEMP	TEMP	TEMP
[6]	°C	[7]							
	°C								
	°C								
	°C								
	°C								
	°C								

The following information is provided to clarify what is required for each column on the Soil Pressure Array data Sheet.

[1] Frequency of readings determined prior to the test by the Project Manager.
[2] Sheet Number - 1,2,3,etc.
[3] Date reading is taken.
[4] Time reading is taken.
[5] Operator's Initials
[6] Prior to the test, the T/C #'s will be filled in and a map will show where each one is located.
[7] Due to the large number of T/C's, temperatures will only be recorded after the T/C reaches 200 C and then every 2 hours as the T/C progresses upward to 1200 C.
[8] At the end of each shift, the shift engineer (defined in SOP 49 Rev. 9) will review the measurements and then sign and date the data sheet.

Reviewed By: [8] Date: [8]

9413221.2026

Soil Pressure Array

Collection Interval [1] Sheet # [2] Test # 100 AREA ISV Pilot-Scale Demo

	Date:	[3]							
	Time:	[4]							
	Operator:	[5]							
P/T #	UNITS	PRESSURE	PRESSURE	PRESSURE	PRESSURE	PRESSURE	PRESSURE	PRESSURE	PRESSURE
[6]	kPa	[7]							
	kPa								
	kPa								
	kPa								
	kPa								
	kPa								

The following information is provided to clarify what is required for each column on the Soil Pressure Array data Sheet.

[1] Frequency of readings determined prior to the test by the Project Manager.
[2] Sheet Number - 1,2,3,etc.
[3] Date reading is taken.
[4] Time reading is taken.
[5] Operator's Initials
[6] Prior to the test, the P/T #'s will be filled in and a map will show where each one is located.
[7] Pressure Transducer reading
[8] At the end of each shift, the shift engineer (defined in SOP 49 Rev. 9) will review the measurements and then sign and date the data sheet.

Reviewed By: [8] Date: [8]

Power Readings Data Sheet

Test # 100 AREA ISV Pilot-Scale Demo

Collection Interv [1] Sheet # [2]

Date	Time	Operator	A Phase				B Phase				Tap Efficiency (V/Vt)
			E (V)	I (A)	R (Ohms)	P (kW)	E (V)	I (A)	R (Ohms)	P (kW)	
[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]

The following information is provided to clarify what is required for each column on the Power Readings Data Sheet.

[1] Frequency of readings determined prior to the test by the Projet Manager.
[2] Sheet Number - 1,2,3,etc.
[3] Date the reading was taken.
[4] Time the reading was taken.
[5] Operator's Initials.
[6] Emf measurement for A Phase in volts.
[7] Current measurement for A Phase in amps.
[8] Melt Resistance measurement fo A Phase in Ohms.
[9] Power measurement for A Phase in kilo-watts.
[10] Emf measurement for B Phase in volts.
[11] Current measurement for B Phase in amps.
[12] Melt Resistance measurement for B Phase in Ohms.
[13] Power measurement for B Phase in kilo-watts.
[14] Tap Efficiency calculation = Voltage/Max. Voltage at that tap.
[15] At the end of each shift, the shift engineer (defined in SOP 49 Rev. 9) will review the measurements and then sign and date the data sheet.

Reviewed By: [15] Date: [15]

9413221.2027

9413221.2028

Electrode Depth Data Sheet

Collection Interval [1] Sheet # [2] Test # 100 AREA ISV Pilot-Scale Demo

Date:	[3]							
Time:	[4]							
Operator:	[5]							
A1	[6]							
A2	[7]							
B1	[8]							
B2	[9]							
Date:								
Time:								
Operator:								
A1								
A2								
B1								
B2								
Date:								
Time:								
Operator:								
A1								
A2								
B1								
B2								

The following information is provided to clarify what is required for each column on the Electrode Depth data Sheet.

[1] Frequency of readings determined prior to the test by the Project Manager.
[2] Sheet Number - 1,2,3,etc.
[3] Date reading is taken.
[4] Time reading is taken.
[5] Operator's Initials.
[6] The depth of electrode A1 with units.
[7] The depth of electrode A2 with units.
[8] The depth of electrode B1 with units.
[9] The depth of electrode B2 with units.
[10] At the end of each shift, the shift engineer (defined in SOP 49 Rev. 9) will review the measurements and then sign and date the data sheet.

Reviewed By: [10] Date: [10]

THIS PAGE INTENTIONALLY
LEFT BLANK