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7. Abstract

A multiphase program was initiated in 1994 to test commercially available melter technologies for the vitrification of the low-level waste (LLW) stream from defense wastes stored in underground tanks at the Hanford Site in southeastern Washington State. Phase 1 of the melter demonstration tests using simulated LLW was completed during fiscal year 1995. This document is the melter offgas report on testing performed by the U.S. Department of the Interior, Bureau of Mines, Albany Research Center in Albany, Oregon. The Bureau of Mines (one of the seven vendors selected) was chosen to demonstrate carbon electrode melter technology (also called carbon arc or electric arc) under WHC subcontract number MMI-SVV-384216. The report contains description of the tests, observations, test data and some analysis of the data as it pertains to application of this technology for LLW vitrification. Testing consisted of melter feed preparation and three melter tests, the first of which was to fulfill the requirements of the statement of work (WHC-SD-WM-RD-044), and the second and third were to address issues identified during the first test. The document also contains summaries of the melter offgas report issued as a separate document, U. S. Bureau of Mines, Phase 1 Hanford Low-Level Waste Melter Tests: Melter Offgas Report" (WHC-SD-WM-VI-032).

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U.S BUREAU OF MINES, PHASE 1 HANFORD LOW-LEVEL WASTE MELTER TESTS: FINAL REPORT

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U.S BUREAU OF MINES, PHASE 1 HANFORD LOW-LEVEL WASTE MELTER TESTS: FINAL REPORT

EXECUTIVE SUMMARY

The U.S. Bureau of Mines was selected under Request for Proposal Number W-045792-LR, "Glass Melter System Technologies for Vitrification of High-Sodium Content Low-Level Radioactive Liquid Wastes" (dated February 15, 1994) to demonstrate electric arc furnace (EAF) melting technology. To this end, low-level waste (LLW) simulant was blended with sugar and carbon reductants and industrial minerals, pelletized, and heated to prepare dry denitrified furnace feed appropriate to melting in an EAF. Melting of the highly alkaline material was successfully demonstrated, and product glass with nominal 25% waste loading was produced. A pilot-scale 3-phase EAF was used with a hearth area of 1.12 m^2 (12 ft^2); three 10.16-cm (4-in.) or 20.32-cm (8-in.) graphite electrodes in a triangular configuration; and water-cooled sidewalls, roof, and glass-tapping fixture. Key technical issues were identified for resolution to allow implementation of EAF melting technology to processing of radioactive wastes.

Program Implementation

- LLW simulant was processed with reductants and glass-forming minerals to prepare 9,550 kg (21,000 lb) of dry, pelletized, non-hygroscopic, denitrified furnace feed material by two methods designated A and B. Both feeds were formulated to produce LD6-5510 glass with 25% waste loading. LD6-5510 is one of five pre-approved formulations developed by Pacific Northwest Laboratory for Phase 1 melter testing.

- A 24-hour demonstration test of EAF melting technology was conducted during which about 5,900 kg (13,000 lb) of Methods A and B feed were melted.

- Steady-state operation with both feed materials was achieved, and the ability to stop, restart, and idle for an extended period was demonstrated.

- Technical problems, including overly complex air pollution control system (APCS), high glass temperature, and vaporization of certain LLW components, were identified.

- Two subsequent 8-hour EAF melting tests of 3,650 kg (8,000 lb) of A and B feeds were conducted at no additional cost to Westinghouse Hanford Company to decrease glass temperature and resolve other technical and procedural problems with the furnace and APCS.

- An additional melting test to evaluate auxiliary heat in the tap hole area as a means to decrease the thermal gradient between center and sidewall of the furnace and to accomplish remote opening of the tap hole is scheduled following preparation of more furnace feed.

Findings and Conclusions

Preparation of Furnace Feed:

- Dry, homogeneous, denitrified furnace feed was prepared by absorbing LLW simulant into previously prepared pellets containing solid reductants (powdered sugar and activated C) and glass-former oxides obtained as industrial minerals followed by heating to remove moisture and induce reaction between reductants and nitrates/nitrites. Industrial minerals were selected for economy, availability in tonnage quantities, and low alkali content. This method was labeled A.

- Furnace feed of similar quality was prepared in a single step by mixing solid reductants, glass-former oxides, and LLW simulant to induce agglomeration followed by heating as in Method A. This method, labeled B, required fewer processing steps.

- Decomposition of nitrates and nitrites by reduction resulted in evolution of 65% to 80% of the N as the element (N_2), whereas thermal decomposition of nitrates and nitrites produces NO_x.

- Gaseous components in the final feed resulting from residual unreacted nitrogenous species and undecomposed carbonates and hydroxides were determined by weight loss to be about 11%.

24-hour Demonstration Test, WHC1-1995: This test to fulfill obligations of the contract was conducted with 10.16-cm (4-in.) diameter graphite electrodes, 240 minimum phase voltage, and APCS to treat combustible and acidic exhaust gases. The APCS consisted, in order from the EAF, of thermal oxidizer, evaporative gas cooler, cyclone, baghouse, acid gas scrubber, cooler/condenser to increase gas density, induced draft blower, activated C filter, high-efficiency particulate air filter, and stack.

- Technical difficulties were experienced with the APCS including excessive draft and inability to maintain the temperature of the baghouse above the dew point of acid gases. The thermal oxidizer was found to cause problems by increasing the temperature and corrosive properties of condensible fumes (alkali borates).

- Continuous feeding and melting of dry material and tapping of glass was achieved over 1.5 hours under steady-state conditions with 429-kW power input, 338 kg/h (745 lb/h) feed rate, and 1620 °C (2948 °F) glass temperature. Expressed in terms of hearth area, the melt-in rate was 304 $kg/m^2/h$ (62 $lb/ft^2/h$).

- A total of 84.8% of material in the feed reported to the product glass and 6.0% to solids collection stations in the APCS.

- Electrode power density and melting energy over the steady-state interval were 1.76 kW/cm^2 (11.4 kW/in^2) and 1.27 kW.h/kg (0.58 kW.h/lb).

- The ability to stop for 1 hour and restart was successfully demonstrated.

- The ability to idle for 2 hours was successfully demonstrated, but restarting was compromised by vaporization loss of glass fluidizers (Na, K, and B) during the idle because of excessive minimum power input. The loss of fluidizers increased glass viscosity and required CaO addition to resume continuous tapping of glass.

- Product glass was reasonably consistent with only minor chords indicating inhomogeneity and minor metallic Mo crystalline phase.

- Mean boria and soda (B_2O_3 and Na_2O) concentrations in the product glass during the test were 2.65% and 15.92%, compared to target values of 5.17% and 18.66%.

- Normalized release rates for silicon, boron, sodium, and potassium from product glass, as determined by the product consistency test, confirmed glass durability in excess of minimum standards.

9.75-hour Test, WHC2-1995: This test to resolve technical and procedural problems with the furnace and APCS was conducted with 10.16-cm (4-in.) diameter graphite electrodes, power supply reconfigured to provide 100-V minimum phase voltage, and modified APCS to include baghouse preheater and variable speed control on the induced draft blower.

- The baghouse preheater maintained the temperature of the baghouse above the dew point of acid gases, but problems persisted with the thermal oxidizer, which continued to exacerbate the corrosive properties of condensible fumes.

- The furnace was readily maintained at the desired pressure by varying the blower speed.

- Decreased electrode voltage improved furnace operation. Vaporization of important components in the feed, glass temperature, and melting energy decreased significantly.

- Continuous feeding, and melting, and tapping of glass were achieved over 1.5 hours under steady-state conditions with 178-kW power input, 163 kg/m^2/h (33 lb/ft^2/h) melt-in rate, and 1480 °C (2696 °F) glass temperature.

- Electrode power density and melting energy over the steady-state interval were 0.73 kW/cm^2 (4.7 kW/in^2) and 0.98 kW.h/kg (0.45 kW.h/lb).

- A total of 88.3% of material in the feed reported to the product glass and 0.57% to solids collection stations in the APCS.

- Mean boria and soda concentrations in the product glass during the test were 3.80% and 17.54%, which represent improvements of 43% and 10% over WHC1.

8.5-hour Test, WHC3-1994: This test was conducted with 100-V minimum phase voltage, 20.32-cm (8-in.) diameter graphite electrodes, and simplified APCS substituting the thermal oxidizer and evaporative gas cooler with air dilution cooling of furnace exhaust gases.

- Dilution cooling of exhaust gases was shown to be entirely satisfactory. Corrosion of refractories in the APCS was eliminated.

- Larger electrodes provided greatly decreased electrode current density resulting in decreased residual arc length between electrodes and glass and decreased thermal gradient between the center and walls of the furnace with commensurate lower glass temperature and decreased vaporization of B and the alkali metals.

- Continuous feeding and melting of dry material and tapping of glass was achieved over 3 hours under quasi steady-state conditions with 241-kW power input, 228 $kg/m^2/h$ (47 $lb/ft^2/h$) melt-in rate, and a glass temperature that ranged from 1480 °C (2696 °F) at the beginning of the period to 1320 °C (2408 °F) at the end. Declining glass temperature indicated inadequate power for the feed rate. The test was terminated because of the lack of furnace feed.

- Electrode power density and melting energy over the steady-state interval were 0.25 kW/cm^2 (1.6 kW/in^2) and 0.95 kW.h/kg (0.43 kW.h/lb).

- A total of 89.3% of material in the feed reported to the product glass and 1% to solids collection stations in the APCS.

- Mean boria and soda concentrations in product glass during the test were 4.01% and 18.10%, which are improvements of 24.9% and 31.9% over WHC2.

It is reasonable to conclude on the basis of the incremental improvements attained with each test iteration that EAF melting technology is viable for vitrifying the subject LLW. In the final test 88.4% of the boria and nominally 100% of soda in the feed were retained in the product glass. Glass temperature met the goal of 1350 °C (2462 °F) at the end of the test confirming adequate fluidity at that temperature, but continuous tapping of glass at that temperature was not demonstrated. A scheduled test providing for additional heat at the entrance to the glass-tapping fixture is expected to provide for continuous tapping of glass at the target temperature, in addition to demonstrating remote opening of the glass tap hole. Adding heat at the tap hole entrance also will decrease the thermal gradient between the center of the furnace and the sidewall, which is expected to decrease thermochemical reactions within the furnace and further decrease vaporization losses.

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APPENDIXES

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U.S BUREAU OF MINES, PHASE 1 HANFORD LOW-LEVEL WASTE MELTER TESTS: FINAL REPORT

1.0 INTRODUCTION

Thermochemical processes involving metals and minerals require a source of energy, and for processes conducted at temperatures greater than about 1200 °C (2192 °F) the electric arc furnace (EAF) with carbon or graphite electrodes is usually the melter of choice, as opposed to cupolas, reverberatory furnaces, or other fossil fuel-fired units. The EAF also is often selected where a versatile and robust unit with large output is needed. The EAFs with nominal 30 MT capacity achieve steel production rates of more than 300,000 MT/year. Industrial applications include pig iron, calcium carbide, phosphorus, ferro-alloys (chromium, manganese, molybdenum, nickel, silicon, and titanium), copper and nickel mattes, glass wool, mineral wool, high-titania slags, fused refractories (chromia alumina spinel, mullite, alumina, and magnesite), and various cements. Melting rates vary from a few to more than 3,000 tonne/day of mineral materials, and EAFs operate at power inputs exceeding 100 MW melting materials with tapping temperatures exceeding 2500 °C (4532 °F).

The thermal waste treatment facility at the Albany Research Center in Albany, Oregon, is based on a pilot-scale EAF with an 800-kVA power supply. The unit was constructed in 1990 in cooperation with the American Society of Mechanical Engineers to vitrify municipal waste combustor residues, combined ash from a multiple-hearth waste water treatment sludge combustor, and fly ash from a waste to energy plant that burned refuse-derived-fuel (Hartman et al. 1993, Oden and O'Connor 1994). The initial design was updated in 1992 and 1993 to accommodate other feed materials including five categories of simulated incinerated radioactive and mixed wastes and soils from the Radiation Waste Management Complex at the Idaho National Engineering Laboratory (INEL) (Oden et al. 1995, Oden et al. 1993). In 1994, the facility was provided with an extensive air pollution control system (APCS) to allow processing of simulated as-retrieved radioactive and mixed wastes and soils from the Radioactive Waste Management Complex containing combustibles and chlorinated hydrocarbons, combustion residues from a circulating fluidized bed utility boiler burning refuse-derived-fuel, and hazardous wastes generated by electric utilities in the course of day-to-day operation including asbestos, contaminated soils, contaminated concrete, and metal hydroxide sludges generated by cleaning heat exchanger tubes. The configuration of the facility during Westinghouse Hanford Company (WHC) melting tests described in this report is shown in Figures 1-1 and 1-2, which are plan and elevation views, respectively. The latter also indicates the locations of analysis ports and monitoring locations. Two additional electrode entry ports in the sidewall of the furnace have been added and do not appear on the figures. These ports provide electrodes for heating glass at the entrance to the tap hole as a means to decrease glass-tapping temperature by decreasing the thermal gradient between the center and sidewalls of the furnace.

Figure 1-1. Plan View of Thermal Waste Treatment Facility.

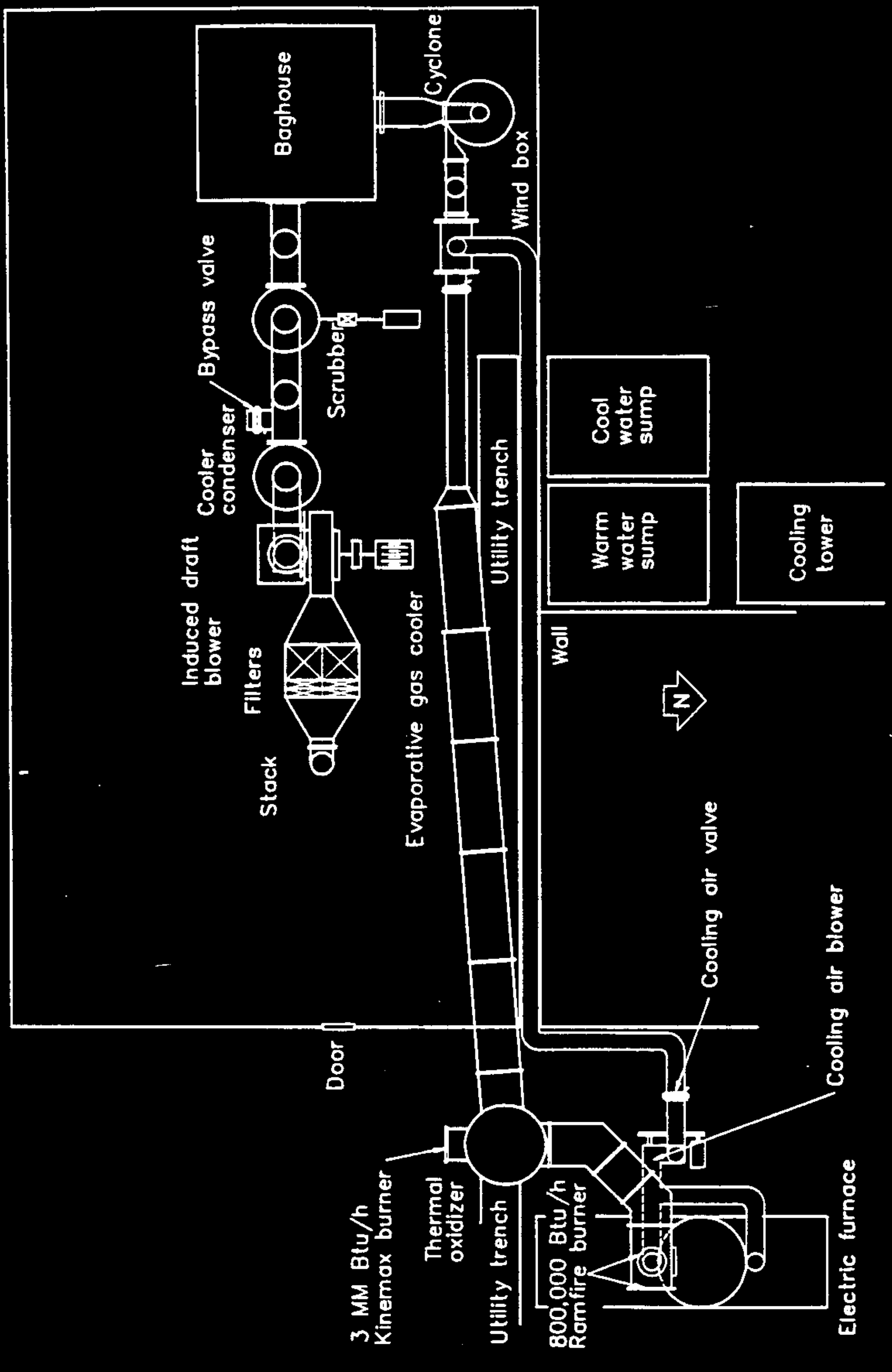
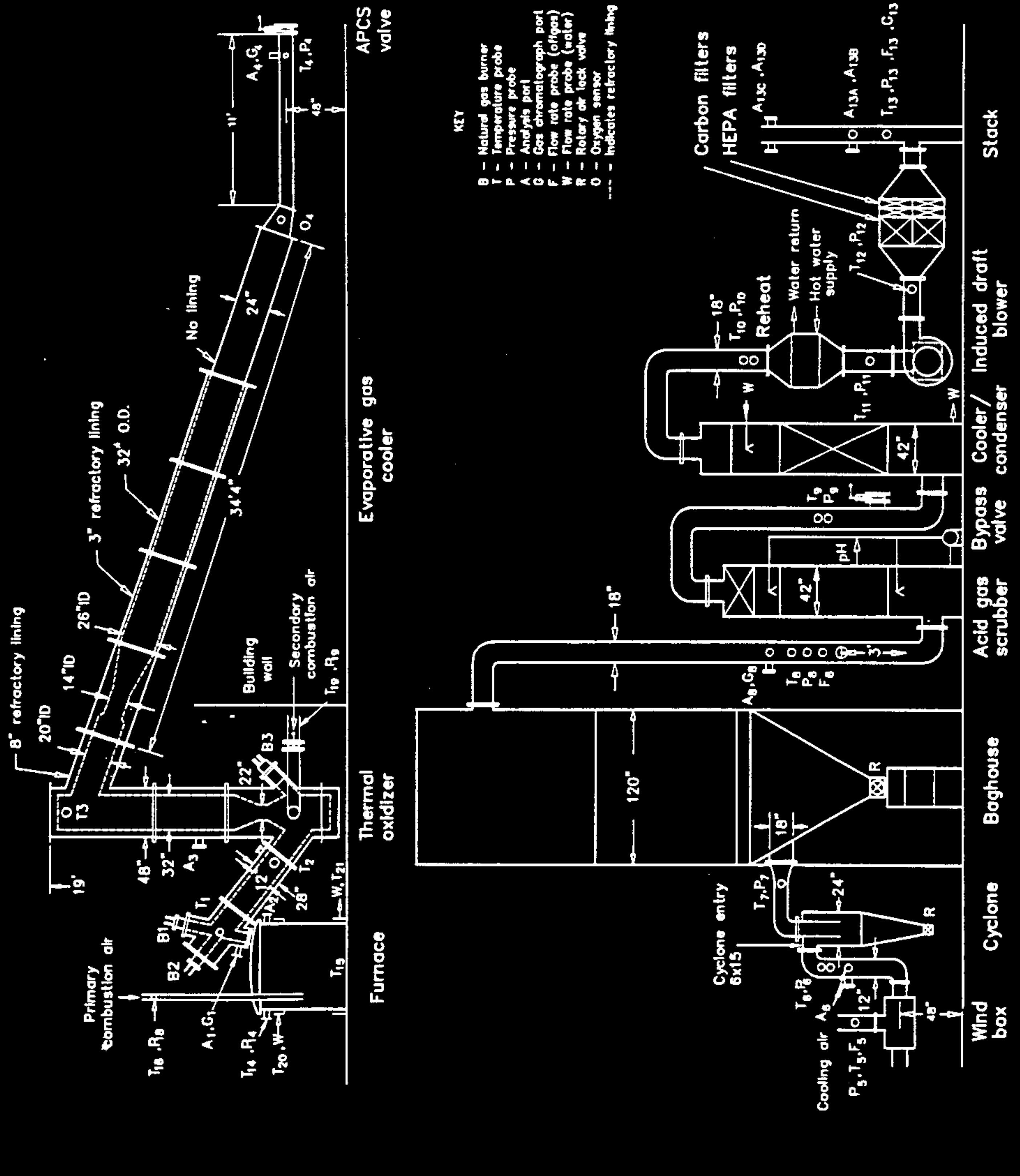


Figure 1-2. Elevation View of Thermal Waste Treatment Facility Indicating Monitoring Locations.



The U.S. Bureau of Mines (USBM) was selected in 1994 under Request for Proposal Number W-045792-LR, "Glass Melter System Technologies for Vitrification of High-Sodium Content Low-Level Radioactive Liquid Wastes" (WHC 1994) to demonstrate the application of electric arc furnace (EAF) melting technology to the subject waste from the Hanford Site. Liquid materials are not usually processed by EAF technology; therefore, the simulated high-Na content low-level (liquid) waste (LLW) was processed with reductants and glass-forming minerals to prepare dry, pelletized, non-hygroscopic, denitrified furnace feed material. Under Patent Application Case Number MIN-3564, "Process for Preparing Liquid Wastes," two methods designated A and B were developed to prepare feed which after melting produced LD6-5510 glass, one of five pre-approved formulations developed by Pacific Northwest Laboratory (PNL) for Phase 1 melter testing.

Method B feed and Method B material containing reductants, nitrates, and nitrites (i.e., before reaction to decompose nitrates and nitrites), were successfully melted in a 50-kW single-phase EAF (13.6-kg [29.28-lb] charge) in tests conducted preliminary to large-scale tests. Glass was freely tapped from the furnace at 1350 °C (2462 °F) in both cases. About 5,910 kg (13,000 lb) of denitrified A and B feeds were melted in March 1995 during the 24-hour demonstration test designated WHC1-1995. Procedural and operational deficiencies and high glass temperatures ranging from 1550 to 1650 °C (2822 to 3002 °F) encountered during that test were addressed in an 9.75-hour test in April 1995 (WHC2-1995) during which 1,088 kg (2,394 lb) of B feed were melted using decreased electrode voltage. Operation was significantly improved, and glass temperatures decreased about 100 °C (180 °F) but still exceeded the goal of 1350 °C (2462 °F). A third test of 8.5 hour duration (WHC3-1995) of 2,415 kg (5,312 lb) of A and B feed was conducted in May 1995 using a simplified APCS and 20.32-cm (8-in.) diameter electrodes to decrease electrode energy density.

Vaporization of alkalis and B and the glass temperature were significantly decreased with each test iteration, but the desired glass temperature could not be sustained over the long term because of cooling of the molten pool by the water-cooled tapping fixture. The furnace is currently being modified with two additional 5.08 cm (2-in.) diameter graphite electrodes entering through the sidewall on either side of the tap hole to maintain the temperature of the glass as it approaches the tap hole.
A melting test (WHC4-1995) to evaluate auxiliary heat in the tap hole area is scheduled following preparation of furnace feed. The additional melting tests were conducted at no expense to WHC, and the operating procedure plans did not go through WHC review.

1.1 OBJECTIVES

The objectives of the tests were as follows.

- Prepare dry denitrified furnace feed from LLW simulant appropriate to melting in an EAF to produce glass of the LD6-5510 composition with 25% waste loading.
- Demonstrate 3-phase electric furnace melting technology in a 24-hour continuous demonstration melting test.

- Demonstrate steady-state operation including continuous feeding of Method B feed and continuous tapping of glass.
- Demonstrate the ability to stop for an extended time and restart with Method B feed.
- Demonstrate the ability to idle for an extended time with Method B feed.
- Demonstrate steady-state operation including continuous feeding of Method A feed and continuous tapping of glass.
- Demonstrate that the EAF can be operated in a practical and acceptable manner to minimize reduction of metal oxides.
- Demonstrate the inherent reliability, versatility, and maintainability of the EAF.
- Demonstrate the capability of the EAF to vitrify feed materials containing NaOH, $NaNO_3$, $NaNO_2$, and $NaAlO_2$ as significant constituents, PO_4^{-3}, SO_4^{-2}, Cl^-, and F as minor constituents, and regulated components including Ba, Cd, Cr, and Pb.
- Demonstrate the capability of the EAF to produce a durable, consistent, and homogeneous glass containing minimum 25% waste loading.
- Demonstrate the capability of the EAF to process the LLW simulant in compliance with applicable NO_x and SO_x requirements.
- Determine the distribution of LLW components among glass, fume solids, and offgas products.
- Determine composition and flow rate of offgas and quantities and composition of entrained particulates as related to feed chemistry.
- Collect and compile experimental electrical and process data that can be scaled to the requisite 200 MT/day LLW vitrification plant to support engineering studies, technology evaluation, and life-cycle cost analysis, and to evaluate life expectancy, reliability, and maintenance requirements.

1.2 CHRONOLOGY OF EVENTS

Date/Time:	Activity:
10-10-94	Received 47 barrels of LLW simulant.
01-05-95	Received all glass-former materials including industrial minerals, reductants, and binders.
01-15-95	Received and installed 9.3-m^3 (100-ft^3) capacity double ribbon mixer, 15.24-m (50-ft) belt conveyor with 14,000-W total capacity

overhead heaters, and replacement controllers for the existing steel belt dryer. All scales were certified. Installed pumps for metering liquid LLW simulant.

01-24-95 Completed mixing of minerals, reductants, and binders to prepare dry material for Method A pellets.

01-25-95 Began preparation of Method B feed by mixing dry minerals, reductants, LLW simulant, and water as needed to induce pellet formation.

02-03-95 Completed preparation of 89 batches of Method B pellets each 227 kg (500 lb), which provided 11,887 kg (26,155 lb) of dry reacted furnace feed that was contained in 104 barrels with an average weight of 114.3 kg (251.5 lb) and a bulk density of about 0.53 g/cm^3 (33 lb/ft^3).

02-09-95 Completed pelletizing and drying of Method A pellets.

02-14-95 Completed contacting of Method A pellets with LLW simulant to provide 25% waste loading in the product glass.

02-16-95 Completed thermal treatment of dried, loaded Method A pellets to induce reaction between reductants and nitrates/nitrites to provide 1,784 kg (3,925 lb) of dry, pelletized Method A furnace feed. The feed was contained in 21 barrels with an average weight of 85.0 kg (186.9 lb) and a bulk density of about 0.43 g/cm^3 (27 lb/ft^3).

1.2.1 Melting Test WHC1-1995

03-06-95

1800 Began preheating the refractory-lined ducts with manual control of burners to achieve a 28 °C/h (50 °F/h) heating rate. At 2306, the entire Albany Research Center lost electrical power, and the preheat was interrupted.

03-07-95

2100 Electrical power was provided, and the burners were restarted.

03-08-95

0430 Completed preheating of refractory-lined ducts to 870 °C (1600 °F).

0455 Began melting finely divided limestone, Bayer alumina, and coarse silica sand to heat furnace refractories.

1022 Began feeding Method B feed.

2330 T = 0 hours: The clock was started to demonstrate steady-state operation with Method B furnace feed.

03-09-95

0735 T + 8 hours: Began demonstration of ability to stop for extended time (1 hour) and restart.

1530 T + 16 hours: Began demonstration of ability to idle for extended time (2 hours) and restart.

2000 T + 20 hours 30 minutes: Began feeding Method A feed to demonstrate steady-state operation with Method A feed.

03-10-95

0030 T + 24 hours: Completed 24-hour demonstration test.

0330 T + 27 hours: Terminated test without tapping the hearth. Residual glass remained in the furnace.

1.2.2 Melting Test WHC2-1995

04-05-95 Reconfigured power supply to remove the 250-kVA transformers from the circuit. The resulting voltage phase-to-phase on transformer Tap D was decreased from 240 to 100 V.

Installed heater in cooling air duct to preheat baghouse and maintain temperature of exhaust gases above the dew point of acid gases.

04-10-95

0735 Started furnace on existing glass remaining in the furnace. By 1130, contents of the furnace were molten to the hearth.

1135 Began feeding and melting Method B feed.

1240 Began tapping glass at 1375 °C (2507 °F).

1724 Test was terminated without draining the furnace to improve heat retention in preparation for INEL and Idaho Waste Processing Facility (IWPF) melting tests the following day.

1.2.3 Melting Test WHC3-1995

05-01-95 Installed air-cooled stainless steel lance and porous ceramic plug in the bottom drain of the furnace to allow injection of oxygen into the molten pool to investigate modification of oxidation potential of the glass and oxidation of metals within the furnace.

Installed 20.32-cm (8-in.) diameter by 30.48-cm (12-in.) long graphite electrode segments on the 10.16-cm (4-in.) electrodes to decrease electrode current density. Electrode voltage was unchanged from WHC2.

05-04-95

0634 Loaded furnace with 45 kg (100 lb) of carbon steel punchings and about 273 kg (600 lb) of crushed glass from the previous INEL melting test. Started cooling air to the stainless steel lance, and established argon flow at 13.7 L/m (29 cfh) through the lance orifice to prevent fouling of the porous ceramic plug.

0713 Started furnace.

1028 Achieved continuous tapping of INEL glass at 1565 °C (2849 °F).

1035 Began oxygen injection tests.

1102 Added 91 kg (200 lb) of carbon steel punching to the furnace through the rotary air lock.

1409 Completed oxygen injection tests.

1447 Began melting cold top preparing to drain furnace and change feed.

1637 Opened bottom drain.

1646 Began feeding Method B feed.

1852 Began tapping glass at 1400 °C (2552 °F).

1927 Tap temperature decreased to 1320 °C (2408 °F), but flow was sluggish.

2009 Cold top (30 cm [1 ft]) melted in place greatly enlarging the molten pool, and tapping ceased.

2020 Added 138 kg (303 lb) lime (CaO) through rotary air lock to fluidize glass and deepen the molten pool.

2148 Achieved fluid tap. Began feeding Method B.

2210 Attempted 250-kW steady-state operation.

0145 Opened bottom drain to terminate test.

2.0 PREPARATION OF FURNACE FEEDS

Furnace feed was prepared by Methods A and B and sampled as described in Appendix A. A complete list of feed samples and samples of furnace products collected during WHC1-1995 to satisfy the Phase 1 Test Plan (WHC-SD-WM-VI-021) is provided as Appendix C. Samples selected for analysis are listed in Table 2-1.

2.1 MATERIALS FOR FEED PREPARATION

Low-level waste simulant of analyzed concentration 8.85 M Na (8.85 moles/liter Na) equal to 203.5 g/L Na was provided for preparing furnace feeds. However, calculations for formulating feeds were based on 9.92 M Na (228.1 g/L Na). All calculated glass concentrations, unless otherwise indicated, are based on the latter value. More details are provided in Section 3.3.4.

Furnace feeds were prepared from LLW simulant, solid reductants, and glass-former oxides obtained as readily available industrial commodities. The latter were selected for economy, availability in tonnage quantities, and low alkali content. Glass formers were selected to provide adequate, but not excessive, absorptive capacity for liquid LLW simulant; propensity to form pellets by agglomeration; and the desired glass composition on melting. Sucrose, corn starch, urea, silicon, aluminum, and activated carbon were evaluated and found to be satisfactory reductants for nitrates and nitrites in the LLW simulant. Best results were obtained with a combination of sucrose as powdered sugar and activated carbon. Sugar initiated the reaction at <200 °C (392 °F) to minimize thermal decomposition of nitrates and nitrites and also functioned as a green pellet binder. Carbon, the reductant of choice but with an initiation temperature of about 350 °C (662 °F), completed the reaction with minimum gas generation. Reductants were included in the mixture of solids to simplify preparation of furnace feed. Table 2-2 lists the quantities of materials used to prepare feeds by Methods A and B.

2.2 METHOD A

This method is a two-step process requiring independent preparation of pellets containing reductants and glass former oxides and subsequent loading of pellets with liquid LLW simulant. Although cumbersome for small-scale batch operation, the method could be appropriate for radioactive wastes in that pellet formation could be conveniently done offsite to minimize handling of radioactive materials.

Reaction stoichiometry for reducing nitrates and nitrites with sugar and carbon to form CO_2, CO, N_2, H_2O, and Na_2O as reaction products was investigated over the range 50% to 150% of stoichiometry based on Equations 1 through 4 in the Operating Procedures (see Appendix A). The stoichiometry was recalculated upon suggestion by G. E. Stegen of WHC according to Equations 1 through 4 below to yield CO_2, N_2, H_2O, and Na_2O as products. The recalculated values for

Table 2-1. Shipping Log for Samples of Furnace Feeds and WHC1-1995 Products.

Sample Number	Sample Date	Time Sampled	Sampler Initials	Sample Matrix	Sample Point	Sample Destination	Shipment Date
M1APR-001U	03/15/95	16:00	BOC	Method A dry feed pellets	Belt dryer exit	USGS	03/16/95
M1APR-001C	03/15/95	15:30	BOC	Method A dry feed pellets	Belt dryer exit	Corning	03/16/95
M1APR-002U	03/15/95	16:00	BOC	Method A dry feed pellets	Belt dryer exit	USGS	03/16/95
M1BPR-022U	03/15/95	16:00	BOC	Method B dry feed pellets	Belt dryer exit	USGS	03/16/95
M1BPR-022C	03/15/95	15:30	BOC	Method B dry feed pellets	Belt dryer exit	Corning	03/16/95
M1BPR-022P	03/15/95	15:30	BOC	Method B dry feed pellets	Belt dryer exit	PNL	03/16/95
M1BPR-026U	03/15/95	16:00	BOC	Method B dry feed pellets	Belt dryer exit	USGS	03/16/95
M1BPR-043U	03/15/95	16:00	BOC	Method B dry feed pellets	Belt dryer exit	USGS	03/16/95
M1BPR-050U	03/15/95	16:00	BOC	Method B dry feed pellets	Belt dryer exit	USGS	03/16/95
M1G1-002U	03/12/95	14:00	BOC	Product glass	Furnace glass tap	USGS	03/16/95
M1G1-002C	03/12/95	14:00	BOC	Product glass	Furnace glass tap	Corning	03/16/95
M1G1-004U	03/12/95	14:00	BOC	Product glass	Furnace glass tap	USGS	03/16/95
M1G1-004C	03/12/95	14:00	BOC	Product glass	Furnace glass tap	Corning	03/16/95
M1G1-005U	03/12/95	14:00	BOC	Product glass	Furnace glass tap	USGS	03/16/95
M1G1-005C	03/12/95	14:00	BOC	Product glass	Furnace glass tap	Corning	03/16/95
M1G1-008U	03/12/95	14:00	BOC	Product glass	Furnace glass tap	USGS	03/16/95
M1G1-008C	03/12/95	14:00	BOC	Product glass	Furnace glass tap	Corning	03/16/95
M1G1-008P	03/12/95	14:00	BOC	Product glass	Furnace glass tap	PNL	03/16/95
M1G1-010U	03/12/95	14:00	BOC	Product glass	Furnace glass tap	USGS	03/16/95
M1G1-010C	03/12/95	14:00	BOC	Product glass	Furnace glass tap	Corning	03/16/95
M1G1-011U	03/12/95	14:00	BOC	Product glass	Furnace glass tap	USGS	03/16/95
M1G1-011C	03/12/95	14:00	BOC	Product glass	Furnace glass tap	Corning	03/16/95
M1G1-011P	03/12/95	14:00	BOC	Product glass	Furnace glass tap	PNL	03/16/95
M1G1-012U	03/12/95	14:00	BOC	Product glass	Furnace glass tap	USGS	03/16/95
M1G1-012C	03/12/95	14:00	BOC	Product glass	Furnace glass tap	Corning	03/16/95
M1T3-001U	03/15/95	14:00	BOC	Glass	Thermal oxidizer base	USGS	03/16/95
M1T3-001C	03/15/95	15:00	BOC	Glass	Thermal oxidizer base	Corning	03/16/95
M1C4-001U	03/14/95	10:00	BOC	Cyclone catch	Cyclone	USGS	03/16/95
M1C4-001C	03/14/95	10:00	BOC	Cyclone catch	Cyclone	Corning	03/16/95
M1B5-001U	03/13/95	16:00	BOC	Baghouse catch	Baghouse hopper	USGS	03/16/95
M1B5-001C	03/13/95	16:00	BOC	Baghouse catch	Baghouse hopper	Corning	03/16/95
M1S6-006P	03/09/95	02:05	BOC	Scrubber solution	Scrubber	PNL	03/16/95
M1S6-008P	03/09/95	06:00	BOC	Scrubber solution	Scrubber	PNL	03/16/95
M1S6-010P	03/09/95	10:30	BOC	Scrubber solution	Scrubber	PNL	03/16/95
M1S6-011P	03/09/95	12:00	SG	Scrubber solution	Scrubber	PNL	03/16/95
M1S6-013P	03/09/95	15:50	SG	Scrubber solution	Scrubber	PNL	03/16/95
M1S6-016P	03/09/95	21:50	SG	Scrubber solution	Scrubber	PNL	03/16/95
M1S6-017P	03/10/95	00:45	SG	Scrubber solution	Scrubber	PNL	03/16/95
M1S6-018P	03/10/95	13:00	BOC	Scrubber solution	Scrubber	PNL	03/16/95

Table 2-2. Materials for Feed Preparation.

Material	Method A kg (lb)	Method B kg (lb)
Bayer alumina	77 (170)	566 (1,245)
Boric acid	151 (332)	972 (2,138)
Southern bentonite	51 (112)	0
Limestone	0	942 (2,072)
Diatomite	717 (1,577)	4,822 (10,608)
Micro-Cell*	260 (571)	0
-200 silica	140 (307)	1,825 (4,016)
Powdered sugar	47 (104)	305 (672)
Activated carbon	45 (98)	286 (629)
LLW simulant	1,505 (3,310)	9,691 (21,320)
Subtotal	2,991 (6,581)	1,941 (42,700)
Water	525 (1,154) estimate	324 (712)
Total	3,516 (7,735)	19,733 (43,412)

*Micro-Cell is a trademark of Celite Corp.

LLW = Low-level waste

Methods A and B feed are 30.8% of stoichiometric sucrose as powered sugar and 61.6% of stoichiometric activated C as NUSORB LN100-325X.*

Sucrose reductant:

$$5\ C_{12}H_{22}O_{11} + 48\ NaNO_3 \rightarrow 24\ Na_2O + 24\ N_2 + 60\ CO_2 + 55\ H_2O \qquad (1)$$

$$3\ C_{12}H_{22}O_{11} + 48\ NaNO_2 \rightarrow 24\ Na_2O + 24\ N_2 + 36\ CO_2 + 33\ H_2O \qquad (2)$$

Carbon reductant:

$$5\ C + 4\ NaNO_3 \rightarrow 2\ Na_2O + 2\ N_2 + 5\ CO_2 \qquad (3)$$

$$3\ C + 4\ NaNO_2 \rightarrow 2\ Na_2O + 2\ N_2 + 3\ CO_2. \qquad (4)$$

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*NUSORB is a trademark of NUCON International, Inc. for their wood-derived activated carbon.

2.2.1 Deviations from Operating Procedures for Feed Preparation (see Appendix A)

Section 5.1 of the Operating Procedures (see Appendix A) was followed without significant exception for Steps 1, 2, and 3. Step 4 (contacting dried pellets with LLW simulant by dipping pellets in the liquid) was modified because of excess absorption capacity of the pellets. The modified procedure consisted of spraying LLW simulant onto dry pellets while tumbling the pellets in a cement mixer. A subtle problem was encountered while attempting to contact dry A pellets with LLW simulant in a cold environment. The dry pellets readily accepted LLW simulant as a fine spray at temperatures greater than about 13 °C (55 °F), whereas the simulant accumulated on the surface of the pellets causing agglomeration of pellets at lower temperatures of about 1.7 °C (35 °F). Also significant was the observation of large dependency of the viscosity of the simulant with temperature. The simulant could not be moved by a Randolph pump at 1.7 °C (35 °F).

Loaded A pellets were partially dried by radiant heating on a belt conveyor and subjected to thermal treatment in the steel belt dryer in accordance with Step 6. Drying was completed on the steel belt, and then reaction between reductants and nitrogenous species occurred. The maximum air temperature measured within the steel belt dryer while processing loaded A pellets was about 350 °C (662 °F).

A small proportion of A pellets was >1.3 cm (0.5 in.) diameter, which could have caused plugging in the furnace feed delivery system. Product pellets were separated by screening, and the oversized were crushed to minus 1.3 cm (0.5 in.) with a gyratory crusher.

2.2.2 Feed Statistics and Characteristics

Dry materials for pelletization were mixed in six 167.7-kg (369-lb) batches and one 335.4-kg (738-lb) double batch according to the Operating Procedures for Feed Preparation, Table 3, Column I (see Appendix A).

- Batch weight: Bayer alumina 8.75 kg (19.25 lb), boric acid 17.05 kg (37.52 lb), Southern bentonite 5.75 kg (12.64 lb), diatomite 81.00 kg (178.20 lb), Micro-Cell[*] 29.32 kg (64.50 lb), -200 mesh silica 15.76 kg (34.68 lb), powdered sugar 5.36 kg (11.79 lb), and NUSORB LN100-325X activated carbon 5.01 kg (11.03 lb).

- Water for pelletizing was not determined.

- Loss of material due to pelletizing and handling was 7.7% based on 1,342 kg (2,952 lb) of mixed materials and 1,239 kg (2,725 lb) of dry pellets.

- Bulk density of dry Method A pellets was 0.30 g/cm^3 (19.0 lb/ft^3).

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[*] Micro-Cell is a trademark of Celite Corp.

Low-level waste simulant was sprayed onto pellets in 22.7-kg (50-lb) batches in the ratio 25.4-kg (56-lb) LLW:22.7 kg (50 lb) pellets, or 1,387 kg (3,052 lb) LLW:1,239 kg (2,725 lb) pellets. That ratio was selected experimentally to compensate for 15.6% volatile matter remaining in the dry pellets.

- Weight loss due to drying and reacting was 32.06%.
- Residence time on the conveyor for pre-drying and within the steel belt dryer to complete drying and initiate reaction varied over the narrow range of 45 to 60 minutes, and 20 to 25 minutes, respectively.
- Total Method A furnace feed production was 1,784 kg (3,925 lb), which was contained in 21 barrels with an average weight of 85.0 kg (186.9 lb).
- Bulk density of Method A dry furnace feed was about 0.45 g/cm^3 (28 lb/ft^3).

Ambient air at four locations (belt dryer exit, beside the belt dryer, near the mixer, and at the weigh station) was continuously monitored by NO_x detectors during thermal treatment of Method A feed. At no time did the detectors indicate the presence of NO_x.

The characteristics of furnace feed prepared by Method A typify the qualities of ideal feed material for melting technologies that function optimally with dry feed, i.e., homogeneous, free flowing, low melting temperature with narrow melting range (nonsticking), and low gas release. Adjustment of the composition to tailor the absorptivity of the pellets to the LLW, and optimization of the mixing, pelletizing, drying, and reaction processes would further refine the characteristics to decrease the proportion of fines and the concentrations of residual nitrogen and carbon.

2.3 METHOD B

Low-level waste simulant provides the liquid for pellet formation by agglomeration in Method B. This method is more amenable to batch operation and was the method of choice for the present application.

2.3.1 Deviations from Operating Procedures for Feed Preparation (see Appendix A)

Section 5.2.1 of the Operating Procedures (see Appendix A) was followed without change. A subtle but distinct difference in the tendency of dry materials to agglomerate with addition of LLW simulant to the mixer and appearance of the mixed materials was observed from day to night. The observed difference is explained by the dependence of rheological properties of the LLW simulant upon temperature discussed under Method A. During the day, the product from the mixer was dull in appearance, whereas the product was glossy and wet in appearance during the night. Furnace feed prepared during the night generally contained more dark unreacted material because of less-effective agglomeration at lower temperature and less-effective drying and a larger fraction of fine material likely to be entrained as dust during melting.

The maximum temperature measured within the steel belt dryer while processing B pellets was about 350 °C (662 °F); however, it is known from other experiments that individual pellets of A and B are heated to the range of 550 to 600 °C (1022 to 1112 °F) by the reaction enthalpy. Figure 2-1 indicates the air temperature (light line) and the temperature of the interior of a single spherical pellet of B feed (dark line) as the pellet was heated in a stream of hot air at about 40 °C/min (72 °F/min). Pellet temperature lagged air temperature during initial heatup to about 200 °C (360 °F) at which point pellet temperature rapidly overtook air temperature. The reaction enthalpy carried the pellet to about 575 °C (1067 °F), which is 325 °C (585 °F) higher than the air temperature. Initial pellet weight was 1.6565 g, and final weight was 1.3675 g (weight loss of 21.13%).

A sample of partially dry Method B material obtained from the conveyor belt before entry into the steel belt dryer was heated within a flowing atmosphere of argon in the laboratory-scale Feed Adjustment Reactor at PNL, and the offgases were analyzed by gas chromatography (H_2, CO_2, N_2O, CO, O_2, and N_2) and chemiluminescent analyzer (NO/NO_x). A Fourier transform infrared (FTIR) spectrometer provided backup analysis for each of these gases plus NH_3, except for H_2, and detection of other infrared (IR) sensitive species including volatile organics and cyanide.

Data from the test, labeled DryOut Test 5 2/10/95 Offgas Profile, are listed in tabular form in Table 2-3 and shown graphically on Figure 2-2. The chemistry of nitrogen is complex, but it is known that N_2O is a weak acid, less stable than the other oxides, favored by low temperature, and indicative of low O_2 potential. High O_2 potential favors the higher oxides, and high temperature favors NO over NO_2. Note that about 20% of the nitrogen was liberated before and during the start of the principal reaction as NO_x (NO_2 and NO), probably by thermal decomposition of nitrates and/or nitrites. About 65% of the nitrogen was liberated during the principal reaction as elemental N_2. The N_2O production peaked with N_2 and CO_2, which indicates that reaction between NO_2 and NO on the surface of carbon to form N_2O and CO_2 according to Equation 5 is the likely source of N_2O.

$$NO + NO_2 + C = N_2O + CO_2. \qquad (5)$$

The stoichiometric ratio of N_2 to CO_2 is 0.4 for reduction of $NaNO_3$ with sugar or carbon (Equations 1 and 3), 0.67 for reduction of $NaNO_2$ with sugar or carbon (Equations 2 and 4), and 0.487 for the mixture of nitrate and nitrite in the LLW simulant. The observed ratio based on N_2/CO_2 in the gases is 0.640 and 0.889 if the nitrogen oxides are expressed as N_2. The larger ratio observed in the reaction gases is likely the result of CO_2 retention in the reacted pellets by chemical reaction with hydroxides. Note in Figure 2-2 that the pellets were heated in increments to about 250 °C (450 °F) where the reaction became self-sustaining, and the temperature of the pellet increased to about 575 °C (1067 °F) because of heat liberated by the exothermic reaction.

Figure 2-1. Temperature of Method B Pellet During Heating.

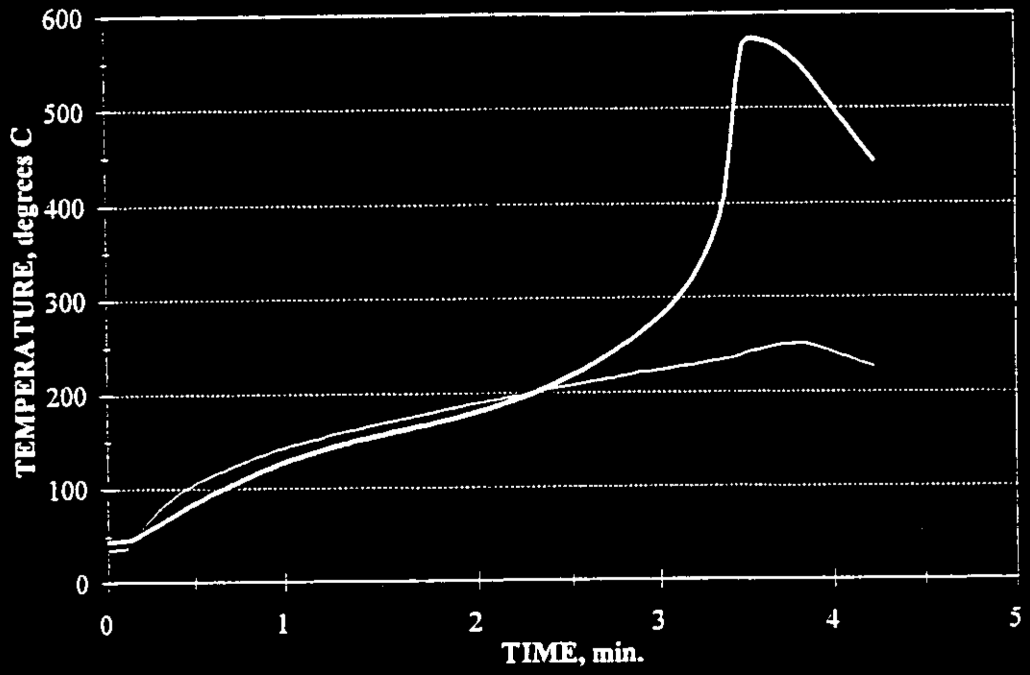


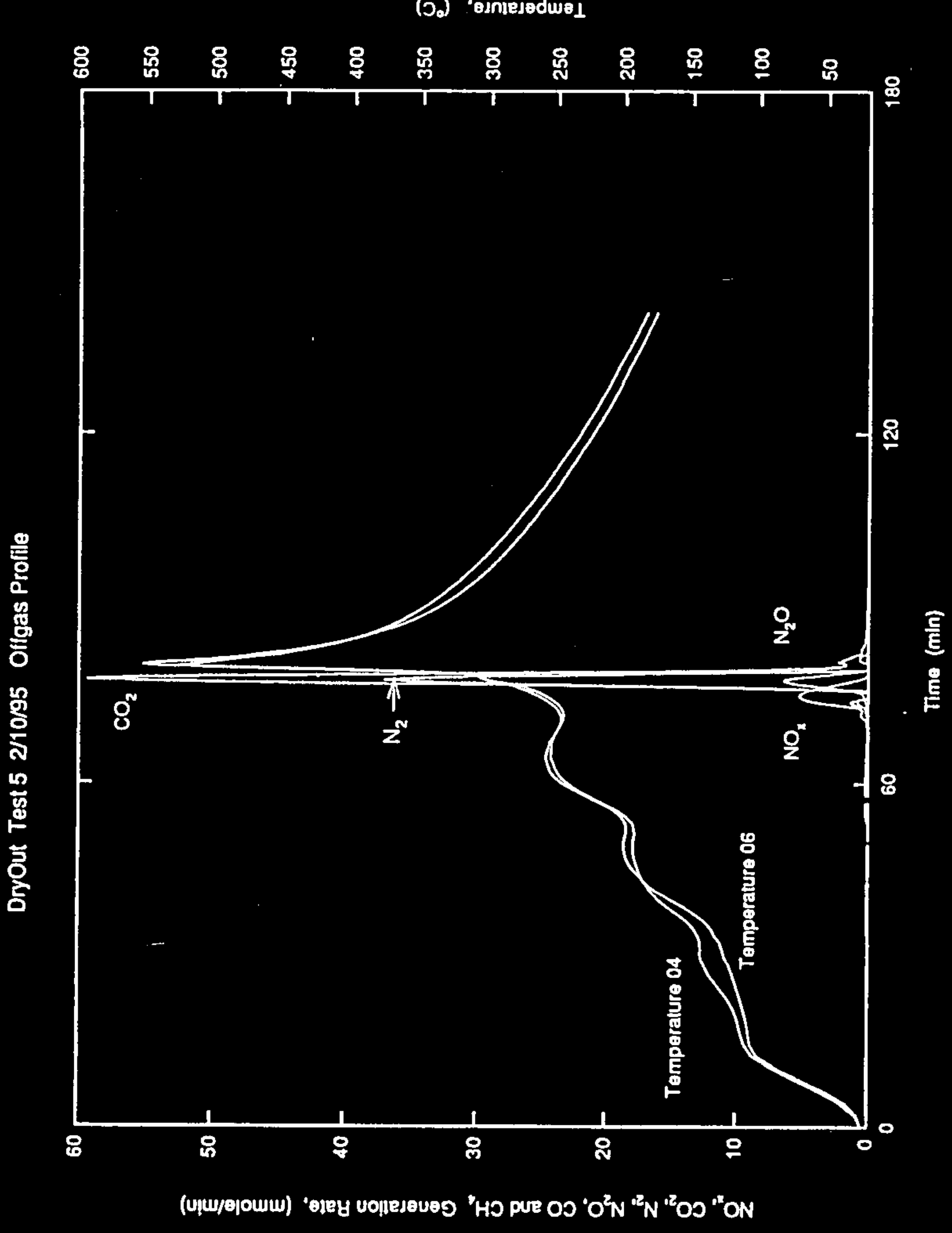
Table 2-3. Analysis of Gases Produced by Heating Partially Dry Method B Material. (DryOut Test 5 by Pacific Northwest Laboratory: Analyses on a dry basis.)

Species	mmol	vol%*	% of N liberated as
H_2	1.32	0.54	--
O_2	0.01	0.004	--
N_2	78.2	32.12	65.2
CO	NR	NR	--
CH_4	0.01	0.004	--
CO_2	122.1	50.16	--
N_2O	18.8	7.72	15.7
NO_x	23	9.45	19.2
Totals	243.44	100	100

*Preliminary value based on analyzed components.

NR = Measurement not reliable

Figure 2-2. Offgas Profile of Partially Dry Method B Material: From DryOut Test 5 by Pacific Northwest Laboratory.



2.3.2 Feed Statistics and Characteristics

Materials for Method B feed were mixed in 89 batches each weighing 227 kg (500 lb) according to Operating Procedures for Feed Preparation, Table 5, Column 1 (see Appendix A).

- Batch weight: Bayer alumina 6.36 kg (13.99 lb), boric acid 10.92 kg (24.03 lb), limestone 10.58 kg (23.28 lb), diatomite 54.18 kg (119.19 lb), -200 mesh silica 20.51 kg (45.12 lb), powdered sugar 3.43 kg (7.55 lb), NUSORB LN100-325X activated carbon 3.21 kg (7.07 lb), and LLW simulant 108.89 kg (239.55 lb).

- Additional water for pelletizing was determined by experimentation to be about 3.6 kg (8 lb)/batch.

- The total time to prepare each batch varied between 45 minutes and 2 hours with most batches prepared in <1 hour. Some variability was attributed to ambient conditions between the day and night shifts. Typically about 6 minutes were required to add dry materials to the mixer; mixing then followed for 15 to 20 minutes. Ten minutes were required to add LLW simulant and water, and about 9 minutes were required for pellet formation. A slide gate in the bottom front of the mixer was opened for about 4 minutes to deposit one-third of the contents of the mixer on the conveyor belt. At intervals of 20 minutes, the conveyor belt was moved; one-third of the contents of the mixer was deposited on the belt, and one-third of the semi-dry material on the belt was transferred to the receiving bin of the steel belt dryer. Material remained on the conveyor for about 60 minutes subject to radiant heat to remove about one-third of the contained moisture.

- Temperatures on the conveyor were considerably influenced by ambient conditions and were not determined, whereas temperatures within the steel belt dryer were recorded continuously by six thermocouples equally spaced along the length of the dryer (7.3 m [24 ft]). The temperature at the input to the dryer was below 100 °C (212 °F), but increased with distance along the belt to a maximum of 300 to 400 °C (572 to 752 °F) at about 5.5 m (18 ft) where reaction occurred. Temperature then decreased to between 200 and 280 °C (392 and 536 °F) at the output.

- Total Method B pellet production was 20,227 kg (44,500 lb), which provided 11,889 kg (26,155 lb) of dry furnace feed. Weight loss on drying and reacting, including handling losses, was 41.2%. The feed was stored in 104 barrels with an average weight of 114.3 kg (251.5 lb).

- The bulk density of Method B feed was about 0.53 g/cm^3 (33.3 lb/ft^3).

The characteristics of furnace feed prepared by Method B were similar to feed prepared by Method A with the exception of more fines resulting from incomplete reaction in some batches of Method B. Such variation is to be expected in pilot-plant operation with three crews working around the clock in an open building. Chemical analysis by the USBM and some observations of the first 11 barrels of Method B feed are listed in Table 2-4. These barrels are believed to be typical of the entire lot of B feed.

The percentage of fines was estimated but serves to indicate the physical nature of the material. Dark material remaining in the feed, which is an indication of unreacted material, ranged from 0% to 10% for barrels containing 5% to 20% fines and 25% to 60% for barrels containing 35% to 85% fines.

The calculated concentrations of C and N in dry but unreacted material, assuming complete loss of water in the LLW simulant but no decomposition of sugar or boric acid, are 4.25 and 3.07 wt%, respectively (see the following sample calculations). By similar calculations assuming complete decomposition of nitrates and nitrites, complete usage of sugar and carbon, and decomposition of organic carbon in the LLW simulant, the concentrations of residual C and N in dry and reacted furnace feed are 1.14% and 0%, respectively. The calculations clearly indicate the presence of unreacted reductant C and residual N in the furnace feed. The extent of reaction is estimated to be 64% on the basis of residual C and 80% on the basis of residual N. Barrels 6, 13, 32, and 42 of LLW simulant were analyzed by the USBM's Analytical Laboratory for total C by LECO analyzer and found to contain 1.25, 1.22, 1.34, and 1.25% C, respectively, in good agreement with the target concentration of 1.41%.

Table 2-4. Composition and Characteristics of Method B Furnace Feed (Analyses by U.S. Bureau of Mines Analytical Laboratory).

Sample	Wt%		Wt%					% fines*
	C	N	Al_2O_3	B_2O_3	CaO	Na_2O	SiO_2	
M1BPR-001	2.88	0.276	8.84	3.86	4.42	16.85	48.56	<5
M1BPR-002	3.15	0.379	8.79	3.86	4.12	15.10	46.63	<5
M1BPR-003	2.53	0.169	9.11	4.09	4.32	16.31	44.50	<5
M1BPR-004	2.61	0.234	9.05	4.28	4.38	16.31	43.21	<5
M1BPR-005	3.52	1.45	8.22	3.89	4.17	14.83	41.71	85
M1BPR-006	3.10	0.323	9.05	4.05	4.53	15.77	42.36	15
M1BPR-007	2.78	0.284	9.32	4.12	4.56	15.91	47.49	5
M1BPR-008	3.62	1.35	8.16	3.67	4.32	15.64	45.14	50
M1BPR-009	3.59	1.57	7.94	3.70	4.28	16.18	43.85	40
M1BPR-010	3.85	1.53	8.29	3.64	3.93	14.83	42.36	35
M1BPR-011	2.33	0.230	9.24	4.18	4.17	16.31	47.49	20
Mean	3.09	0.709	8.73	3.94	4.29	15.82	44.85	--

*Material likely to be entrained in the offgas during melting.

Sample calculation based on Operating Procedures for Feed Preparation, Tables 4 and 5 (see Appendix A).

	Total wt Method B raw materials:	44,500.00
C in Method B material:		
sugar	671.96 X 0.421276 =	283.08
Carbon at 87.10% C	628.87 X 0.8710 =	547.75
Subtotal C in reductants,		830.83
Limestone	2,072.21 X 0.12 =	248.67
Diatomite	10,608.05 X 0.0004 =	0.42
Subtotal C in minerals,		249.09
Org C in LLW	21,319.76 X 0.01114 =	237.50
Inorg C in LLW	21,319.76 X 0.01103 X 0.273	64.18
Subtotal C in LLW,		301.68
Total C in Method B material:	830.83 + 249.09 + 301.68 =	1,381.60
N in Method B material:		
NO_3^-	21,319.76 X 0.13526 X 0.2259 =	651.45
NO_2^-	21,319.76 X 0.05281 X 0.3045 =	342.80
NUCON at 0.552% N	628.87 X 0.00552 =	3.47
Total N in Method B material:		997.72
Weight loss on drying Method B material at 100 °C:		
Moisture at 100 °C in raw materials:		
Alumina	1,244.93 X 0.041 =	51.04
Limestone	2,072.21 X 0.003 =	6.22
Diatomite	10,608.05 X 0.0172 =	182.46
LLW	21,319.76 X 0.46348 =	9,881.29
Carbon	628.87 X 0.099 =	62.26
Water		1,799.81
Total moisture in wet, unreacted Method B material		11,983.08
Wt loss at 100 °C (%):	11,983.08/44,500.00 X 100 =	26.93
Total C in dry, unreacted B material (%):	1,381.60/32,516.92 X 100 =	4.25
Total N in dry, unreacted B material (%):	997.72/32,516.92 X 100 =	3.07
Weight loss on reacting Method B material:		
Total dry, unreacted Method B material:		32,516.92
Volatile nitrates and nitrites in LLW simulant by Equations 1-4		3,441.69
Volatile organic and inorganic C in LLW		301.68
Reductants		1,300.83
Total volatiles in dry, unreacted Method B material		5,044.20
Wt reacted B feed:		27,472.72
Wt loss on reaction (%):	5,044.20/32516.92 X 100 =	15.51
Total wt loss on drying and reacting (%):	(11,983.08 + 5,044.20)/44,500.00 =	38.26
Residual C in dry reacted Method B feed (%):		
If only reductants react:	550.77/27,472.72 X 100 =	2.00
If reductants and organic C in LLW reacts:	313.27/27,472.72 X 100 =	1.14

2.4 ANALYSIS OF FURNACE FEEDS

Samples of furnace feeds for analysis, selected to represent materials actually melted during the WHC1 campaign, were analyzed by three contract laboratories and by the USBM's Analytical Laboratory. Results by the contract laboratories are summarized and compared with the calculated composition of Method B feed in Table 2-5. For purposes of calculation it was assumed that carbonates, hydroxides, nitrates, nitrites, and organic compounds were decomposed at loss on ignition (LOI) temperature. The following observations are pertinent.

- Loss on drying (LOD) confirms effective removal of moisture during drying and reacting and also substantiates the non-hygroscopic nature of reacted furnace feed.

- Experimental LOI (mean value is 10.34% for B feed) is higher than the calculated LOI (9.33% for B feed) based on evolution of CO_2 from the limestone, H_2O from the boric acid, and CO_2 and H_2O from carbonates and hydroxides in the LLW simulant. This observation suggests retention of part of the CO_2 evolved during the denitrification reaction by reaction with hydroxides in the furnace feed.

- The halogens, except for F, appeared in the feed at target levels. Investigation of fluoride vaporization at reaction temperatures (600 °C [1112 °F]) is needed.

- In general terms, the difference in analyses between laboratories is larger than the difference between calculated and analyzed concentrations for all oxides except Na_2O, an anomaly that is explained by analysis of the LLW simulant. Four barrels of simulant used to prepare B feed were carefully sampled by withdrawing material from the well-stirred barrels, and the samples were analyzed by the USBM's Analytical Laboratory. The concentration of Na varied from 8.74 M Na to 8.96 M Na (mean value 8.85), which is a significant variation. More important is the observation that the simulant was closer to 9 M Na than 10 M Na.

An analysis of Method B feed by the USBM also indicated no significant difference among batches. Concentrations of major and minor oxides in the feed are indicated in Figures 2-3 and 2-4, respectively, as a function of feed production over the range of 2,500 to 5,680 kg (5,500 to 12,500 lb). These consistent data support the analyses by the contract laboratories listed in Table 2-5. In light of the analyses, no correlation is anticipated between product glass and batch of furnace feed.

Table 2-5. Chemical Analysis of Method A and B Furnace Feeds.

Parameter	M1APR-001C(1)	M1APR-001U(2)	M1APR-002U	BPR, calc(3)	M1BPR-022C	M1BPR-022P(4)	M1BPR-022U	M1BPR-026U	M1BPR-043U	M1BPR-050U
LOD (110C) pct	0.58	NA	NA	NA	0.08	0.03	NA	NA	NA	NA
LOI (925 C) pct	NA	15.20	8.75	9.33	NA	11.61	10.70	7.78	10.70	10.90
Component			weight percent							
Al2O3	8.08	8.560	9.150	8.97	8.810	8.020	8.970	9.190	8.940	8.970
B2O3	4.530	4.350	4.510	4.490	4.560	3.980	4.510	4.510	4.510	4.510
BaO	0.006	0.007	0.007	0.003	0.006	0.020	0.006	0.006	0.006	0.006
CaO	4.400	4.310	4.480	4.480	4.380	3.860	4.300	4.400	4.070	4.150
Cr2O3	0.009	0.014	0.016	0.004	0.008	0.000	0.011	0.012	0.012	0.012
Cs2O	0.100	0.112	0.127	0.130	0.120	0.117	0.121	0.127	0.120	0.121
Fe2O3	0.970	1.020	1.090	0.803	0.830	0.790	0.860	0.850	0.850	0.840
K2O	1.150	1.180	1.320	1.420	1.280	1.100	1.210	1.280	1.200	1.200
Li2O	NA	NA	NA	NA	NA	0.020	NA	NA	NA	NA
MgO	0.240	0.230	0.240	0.220	0.200	0.150	0.200	0.190	0.210	0.220
MnO2	0.008	0.000	0.000	0.002	0.005	0.031	0.000	0.000	0.000	0.000
MoO3	0.110	0.125	0.143	0.130	0.130	0.120	0.134	0.140	0.133	0.132
Na2O	15.300	15.500	17.600	18.370	17.400	15.700	16.500	17.400	16.400	16.400
NiO	0.005	0.001	0.001	NA	0.000	0.000	0.000	0.000	0.000	0.000
P2O5	0.095	0.130	0.190	0.183	0.860	0.540	0.110	0.120	0.120	0.110
SO3	1.380	1.260	1.490	0.200	1.640	1.350	0.137	1.460	1.370	1.370
SiO2	45.900	47.100	49.700	49.220	50.400	44.150	50.100	51.300	50.300	50.200
SrO	0.076	0.082	0.090	0.093	0.081	0.085	0.082	0.084	0.083	0.083
TiO2	0.120	0.130	0.140	0.086	0.100	0.100	0.120	0.120	0.120	0.110
ZrO2	0.006	0.005	0.005	0.004	0.000	0.019	0.004	0.004	0.004	0.004
TOC	NA	2.120	0.760	NA	NA	NA	1.300	0.990	1.260	1.300
TIC	NA	1.070	1.060	NA	NA	NA	1.610	1.360	1.620	1.650
Total C	3.310	3.190	1.820	NA	2.710	NA	2.910	2.340	2.880	2.940
Cl	0.195	0.350	0.360	0.316	0.265	0.162	0.300	0.320	0.320	0.300
F	0.030	0.050	0.060	0.258	0.030	NA	0.030	0.040	0.040	0.040
I	NA	0.109	0.121	0.115	NA	NA	0.114	0.125	0.110	0.112
NO3-	NA	5.480	2.170	NA	NA	2.810	1.770	0.510	1.870	2.210
NO2-	NA	1.230	0.050	NA	NA	0.720	0.360	0.040	0.420	0.350
Total N	2.100	NA	NA	NA	0.7	NA	NA	NA	NA	NA
PO4-3	NA	NA	NA	NA	NA	0.080	NA	NA	NA	NA
SO4-4	NA	NA	NA	NA	NA	0.980	NA	NA	NA	NA

1. Analysis by Corning; mean of four determinations.
2. Analysis by USGS; mean of two determinations.
3. Based upon experimental mean LOI (10.34 pct) and calculated glass composition in Table 4, Operating Procedures for Feed Preparation.
4. Analysis by PNL; mean of two determinations.

Figure 2-3. Concentration of Major Oxides in Method B Feed.

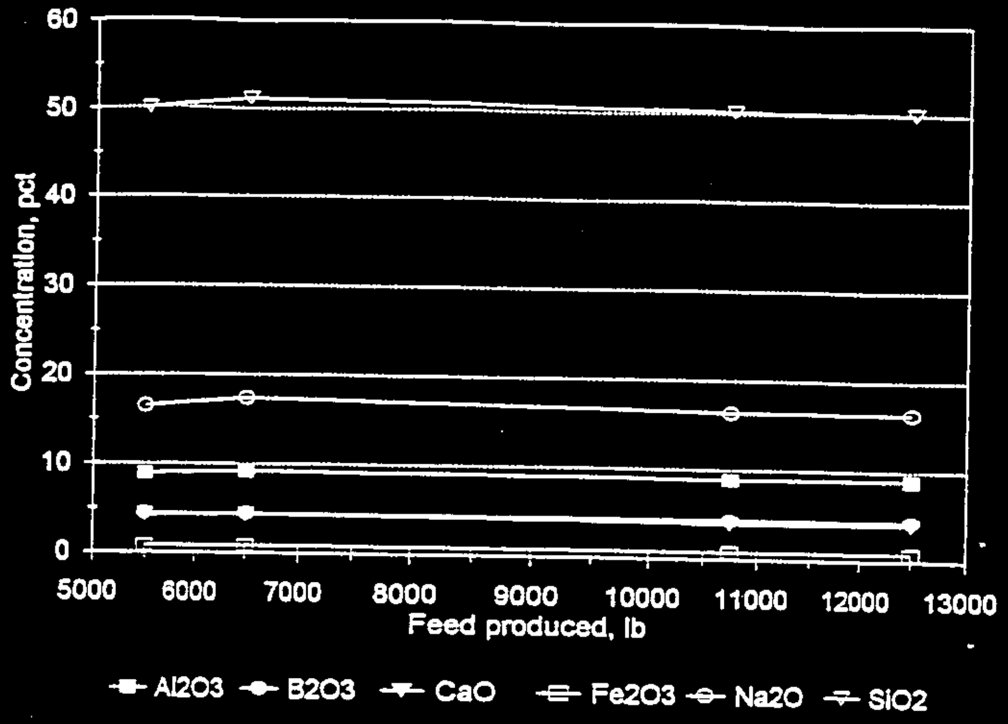
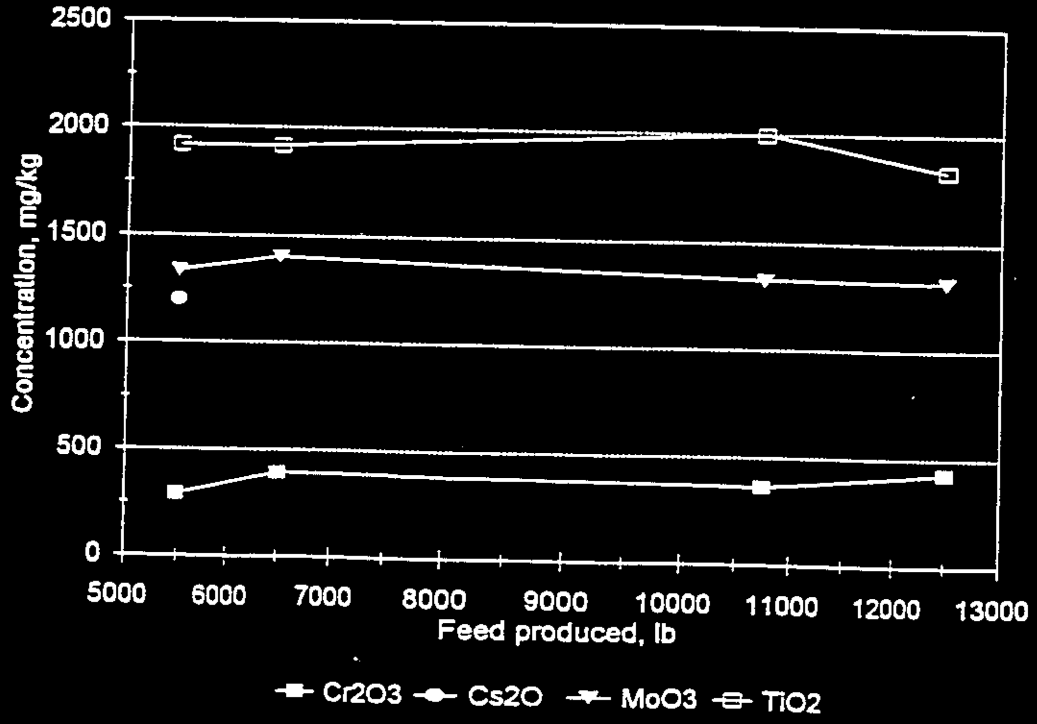


Figure 2-4. Concentration of Minor Oxides in Method B Feed.



3.0 DEMONSTRATION MELTING TEST WHC1-1995

3.1 PRETEST PREPARATIONS

All pretest conditions, as described in Section 8 of the operating procedures (see Appendix B), were implemented including expansion of the data acquisition system and reconstruction of the APCS. In addition, the feed delivery and melter systems were reconditioned as follows.

3.1.1 Feed Delivery System

1. The receiving bin was partitioned to limit access to the final 91 cm (3 ft) of the delivery screws to prevent usage of the severely worn portions of the screws.
2. The bucket elevator, rotating air lock, and feed screws were disassembled. Screws and buckets were straightened where needed, bearings were inspected and replaced if necessary, all bearings were lubricated, and each unit was reassembled with new gaskets.
3. Pressure release valves were installed on the four feed downcomers to relieve furnace pressure at positive 1.4 kPa (6 in. water column or 0.2 psi). The valves were designed to allow gases to exit the furnace but to prevent reentry.
4. All seals in the furnace roof (feed tube and electrode seals) were repacked with fiber insulation.
5. The feeder platform was enlarged to provide access to the north feed tubes and improve safety.
6. A continuous indicator for cold top height was constructed and installed on the southeast feed downcomer. The manual level indicator was reconditioned and installed on the northeast feed downcomer.

3.1.2 Melter

1. The periclase (MgO) refractory hearth of the furnace was replaced with ruby refractory ramming mix from the Harbison Walker Co. Ruby is 90% coarse alumina aggregate bonded with chromium aluminate.
2. A spacer was provided to position the entry face of the water-cooled copper glass-tapping fixture at the hot face of the wall refractory. The previous position allowed the fixture to intrude 7.6 cm (3 in.) farther into the furnace, i.e., the fixture extended 7.6 cm (3 in.) beyond the hot face of the wall refractory. The objective was to minimize cooling of the molten pool by the water-cooled fixture.

3. A type K thermocouple was installed in the metal tap hole to monitor the temperature of the hearth. The thermocouple was located approximately 10 cm (4 in.) from the interface between the hearth and the molten pool of glass.

4. A mount was constructed and attached to the inspection port on the furnace roof for a video camera to allow continuous observation of the interior of the furnace.

3.2 TEST CONDITIONS AND DETAILED CHRONOLOGY OF EVENTS

The operating procedures (see Appendix B) were followed with few variations. Reference to Figures 3-1, 3-2, 3-3, and 3-4 will assist the reader to follow the chronology of events in real time during the demonstration melting test. The figures provide continuous graphs of furnace power (Figure 3-1), feed rate (Figure 3-2), product glass temperature measured by optical pyrometer at the tap hole (Figure 3-3), and flow rate in the stack (Figure 3-4).

Figure 3-1. Furnace Power During WHC1-1995:
T-0 to T + 24-Hour Interval.

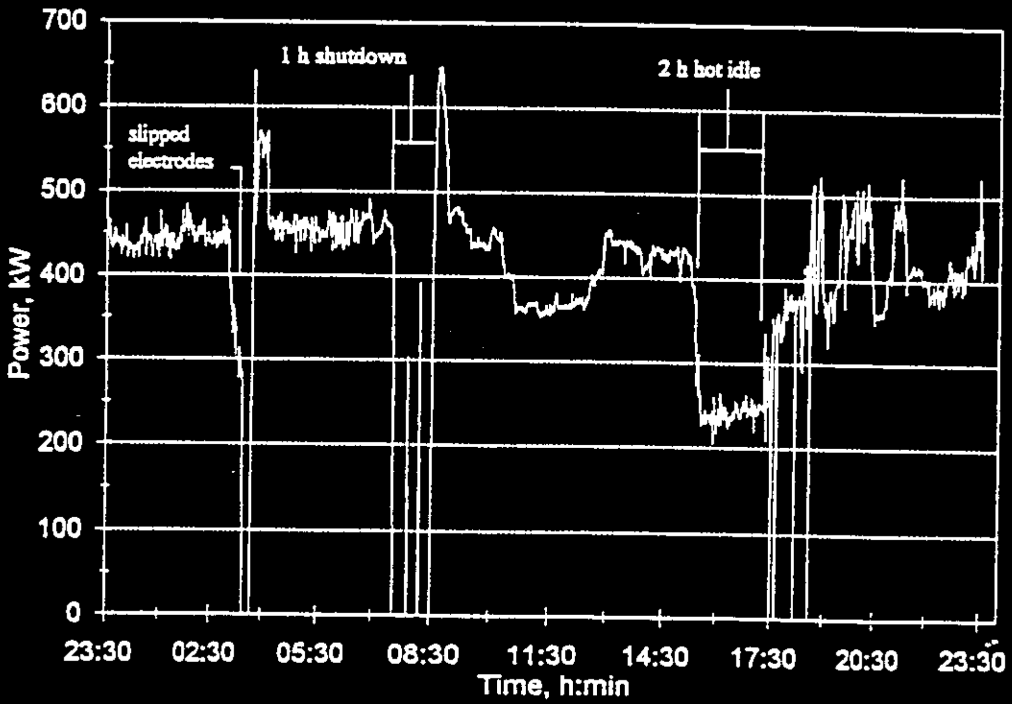


Figure 3-2. Feed Rate During WHC1-1995:
T-0 to T + 24-Hour Interval.

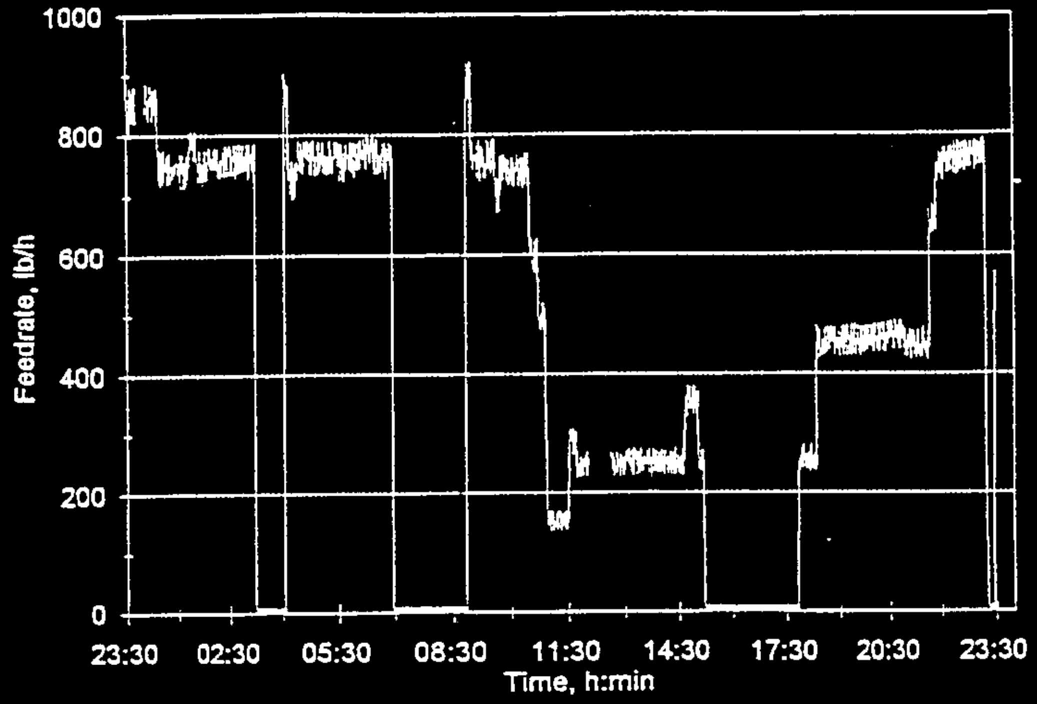


Figure 3-3. Glass Temperature by Optical Pyrometer During
WHC1-1995: T-0 to T + 24-Hour Interval.

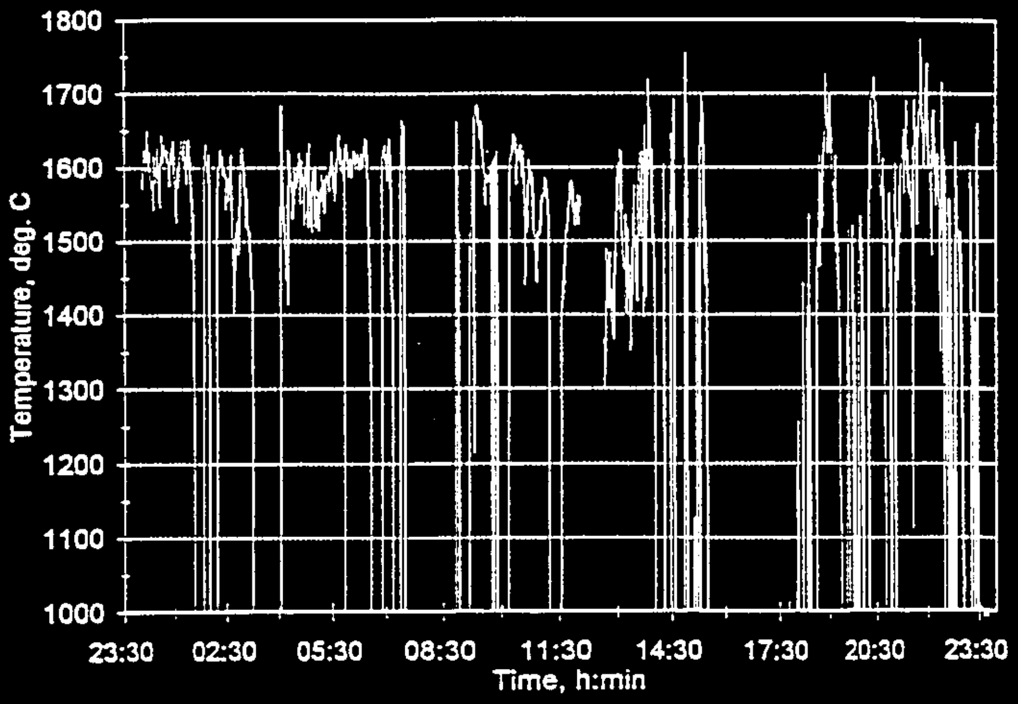
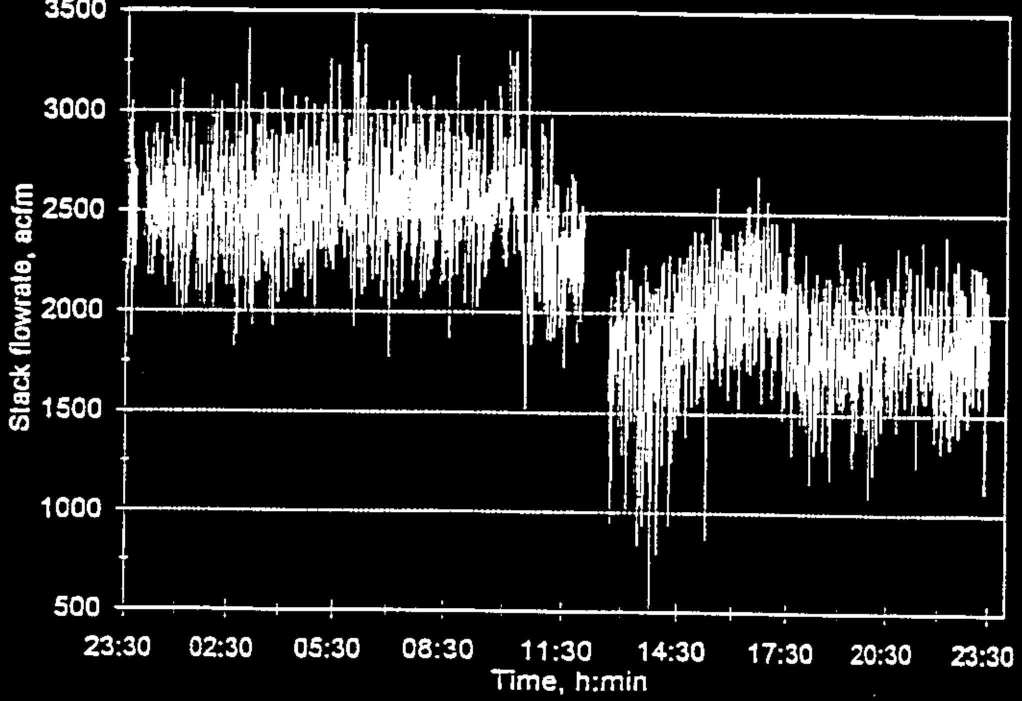


Figure 3-4. Stack Gas Flow Rate During WHC1-1995: T-0 to T + 24-Hour Interval.



03-08-95

0455 Started the electric furnace on about 227 kg (500 lb) of a mixture of finely divided limestone, Bayer alumina, silica, and rutile mineral concentrate. This material, melted for Tree Hugger Corp. (TH), after melting, quenching in water, and comminuting forms a fast-setting hydraulic cement. A conductive triangular path of crushed graphite electrode material was placed on the layer of feed materials, and the electrodes were lowered to establish electrical contact. The power supply was activated on transformer Tap D, which provided about 239 V measured phase-to-phase. The start was extraordinarily smooth, and within 5 minutes the feeder was started to deliver about 275 kg/h (600 lb/h) to the furnace.

0610 Began continuously tapping calcia alumina silicate slag and filling glass mold TH-S1.

0700 Increased feed rate to about 890 kg/h (1,960 lb/h), and plugged the tap hole to accumulate molten material for granulation. A heated ladle was placed in the pit under the glass tap hole.

0742 Opened the glass tap hole, but the material was too viscous to exit the hole. Power to the furnace was maintained from 450 to 600 kW until 1022 while feeding intermittently to maintain a thin cold top not exceeding 10 cm (4 in.). Continuous tapping of the calcium aluminum silicate could not be achieved. A total of

2,796 kg (6,152 lb) of feed materials had been placed in the receiving bin, and about 2,568 kg (5650 lb) had been fed to the furnace. About 227 kg (500 lb) remained within the feed system.

0650 Began filling glass mold TH-S2.

1000 Began filling glass mold TH-S3.

1015 Began filling glass mold TH-S4.

1012 Placed 330 kg (727 lb) of Method B feed in the receiving bin, and at 1022 about 36 kg (80 lb) of Method B feed was fed directly into the furnace thorough the rotary air lock to fluidize the calcia alumina silicate.

1030 Opened the glass tap hole, and a fluid material emerged, a tribute to the fluidizing properties of the sodium borosilicate glass. Continuous tapping continued until 1408.

1035 Began filling glass mold WHC-1.

1100 Began filling glass mold WHC-2.

1220 Began filling glass mold WHC-3.

1335 Began filling glass mold WHC1-SP1; no glass sample was collected.

1408 Stopped power to add electrode segments with a residual cold top of about 28 cm (11 in.).

1419 Resumed power, but continuous tapping could not be achieved. The cold top had increased to 36 cm (14 in.) with attendant increase in plenum temperature to about 705 °C (1300 °F).

1550 Conducted preliminary determination of temperature and velocity at the furnace outlet (M2-1). Burner 1 was off.

1601 Conducted multiple metals analysis at the furnace outlet to 1630.

1618 Conducted continuous emissions analysis (CEM-2) to 1621 with probe inside the furnace plenum.

1645 Added 68 kg (150 lb) of CaO to the furnace through the rotating air lock to fluidize the melt.

1700 Added 32 kg (70 lb) of CaO to the furnace through the rotating air lock to fluidize the melt.

1810 Added 45 kg (100 lb) of boric acid to the furnace through the rotating air lock to fluidize the melt.

1835 Added 147 kg (324 lb) of CaO to the furnace through the rotating air lock to fluidize the melt.

1908 Began filling glass mold WHC1-SP2; collected glass sample at 1935.

1945 Achieved continuous tapping, and began feeding Method B material at about 227 kg/h (500 lb/h).

1952 Began filling glass mold WHC1-SP3; collected glass sample at 2010.

2005 Power off to slip electrodes.

2018 Power on with feed rate 227 to 364 kg/h (500 to 800 lb/h) and cold top 10 to 20 cm (4 to 8 in.). Continuous tapping was attained until 2330 when the clock was started to begin the demonstration test.

2020 Conducted M2-2 at end of EGC system which is the input to the cyclone (Location 4 on Figure 2 in the Test Plan) to 2035. Test was invalidated by open ports upstream of sample location.

2025 Began filling glass mold WHC1-SP4; collected glass sample at 2035.

2040 Began filling glass mold WHC1-SP5; collected glass sample at 2050.

2125 Began filling glass mold WHC1-SP6; collected glass sample at 2145.

2225 Began filling glass mold WHC1-SP7; collected glass sample at 2305.

2240 Power off for 20 minutes to slip electrodes.

2330 Began demonstration test of steady-state operation with Method B feed. Power and feed rate were maintained constant at 450 kW and 341 kg/h (750 lb/h), respectively, with cold top nearly constant at 13 to 18 cm (5 to 7 in.). Feed rate was not sufficient for continuous tapping; therefore, the tap hole was plugged for about 15 minutes at intervals of about 45 minutes.

2330 Began filling glass mold WHC1-SP8; collected glass sample at 2400.

03-09-95

0030 Began filling glass mold WHC1-SP9; collected glass sample at 0045.

0110 Began filling glass mold WHC1-SP10; collected glass sample at 0132.

0230 Began filling glass mold WHC1-SP11; collected glass sample at 0240.

0312 Began filling glass mold WHC1-SP12; collected glass sample at 0420.

0320 Stopped the feeder to melt cold top in preparation for adding electrode segments.

0328 Stopped power for 16 minutes to add electrode segments.

0438 Began filling glass mold WHC1-SP13; collected glass sample at 0500.

0538 Began filling glass mold WHC1-SP14; collected glass sample at 0610.

0638 Began filling glass mold WHC1-SP15; collected glass sample at 0735.

0705 Stopped feeder to melt cold top in preparation for demonstrating extended stop and restart.

0735 Plugged glass tap hole, and stopped power to demonstrate ability to stop for extended time and restart. Cooling water to the upper trough was diverted to the lower plenum to decrease heat loss from the furnace.

0755 Restarted power momentarily to verify adequate conductivity.

0815 Restarted power momentarily to verify adequate conductivity.

0835 Restarted power and feed to complete demonstration of extended shutdown and restart. Cooling water was diverted to the upper trough.

0925 Began filling glass mold WHC1-SP16; collected glass sample at 0955.

1022 Conducted M2-3 at furnace outlet to 1035. Test was invalidated by closed pitot tube.

1037 Began filling glass mold WHC1-SP17; collected glass sample at 1115.

1057 Decreased power and feed rate in increments to about 350 kW and 136 kg/h (300 lb/h), respectively, attempting to establish steady-state conditions providing lower glass temperature. Cold top was decreased to about 8 cm (3 in.).

1110 Conducted CEM-2 at furnace outlet to 1138.

1225 Began filling glass mold WHC1-SP18; collected glass sample at 1330.

1253 Conducted CEM-3 at furnace outlet to 1329.

1505 Began filling glass mold WHC1-SP19; collected glass sample at 1850.

1515 T + 15 hours 45 minutes: Stopped feeding to melt cold top in preparation for demonstration of extended idle.

1530 Plugged glass tap hole, and adjusted power to minimum (Tap D with rheostats 0) to demonstrate ability to idle for extended time.

1615	Conducted M2-4 at furnace outlet with Burner 1 off to 1620. Outlet duct was nearly plugged by condensates; inside diameter estimated to be 5 cm (2 in.), originally 15 cm (6 in.).
1628	Conducted CEM-4 at furnace outlet with Burner 1 off to 1704. Pitot was plugged during traverse.
1753	T + 18 hours 23 minutes: Resumed feeding to establish cold top and complete demonstration of ability to idle for extended time and restart.
1932	Began filling glass mold WHC1-SP20; collected glass sample at 2015.
2000	Began feeding Method A feed. Cold top was maintained from 13 to 18 cm (5 to 7 in.).
2100	Began filling glass mold WHC1-SP21; collected glass sample at 2130.
2101	Conducted M2-5 and CEM-5 at furnace outlet to 2151. Pitot was plugged during traverse.
2225	Began filling glass mold WHC1-SP22; collected glass sample at 2345.
2325	Conducted M2-6 at cyclone inlet to 2340.
2350	Conducted CEM-6 at cyclone inlet to 0035.
03-10-95	
0010	Began filling glass mold WHC1-SP23; collected glass sample at 0050.
0030	Completed 24-hour demonstration test.
0050	Attempted to open center drain to empty the furnace.
0245	Added 24 kg (52 lb) CaO through the rotary air lock to maintain glass fluidity.
0330	Center drain was partially opened but flow could not be maintained; test was terminated, and furnace was left untapped.

3.3 TEST RESULTS

The test was begun at 0455 on March 8, 1995, by melting 2,660 kg (5,850 lb) of limestone, Bayer alumina, silica, and rutile mineral concentrate to preheat the furnace. At 1020, the furnace feed was switched to Method B, and 4,093 kg (9,004 lb) of Method B was melted to purge the preheat slag from the furnace. At 2330, the clock was started to begin the demonstration melting test, and a total of 4,707 kg (10,356 lb) of Method B and 1,181 kg

(2,598 lb) of Method A feeds were melted during the 24-hour period. These feeds produced 3,992 kg (8,783 lb) of glass from Method B feed and 1,002 kg (2,204 lb) of glass from Method A feed.

The hearth temperature, as measured by type K thermocouple in the metal tap hole approximately 10 cm (4-in.) beneath the glass-hearth interface, increased to about 600 °C (1112 °F) during the test. This relatively low temperature is indicative of effective heat transfer to the steel shell by the hearth refractory (ruby).

The schedule for sampling furnace products was previously referenced in Table 2-1. Samples collected during the demonstration test and later analyzed are listed in Table 3-1, which references samples to process conditions during the test. A summary of glass production during the demonstration melting test correlated with process time, tapping rate, feed rate, power, and energy input is provided in Table 3-2.

3.3.1 Gaseous Emissions and Products Collected in the APCS

- On the basis of glass production per unit weight of feed, 84.8% of feed material reported to the glass.

Gaseous emissions were analyzed by technicians from Entropy, Inc. within the furnace, in the furnace offgas exit duct, and within the stack. A summary of offgas emissions analysis by Entropy, Inc. is listed in Appendix D. The data, further summarized in Figures 3-5 and 3-6, provide for the following observations.

- Extremely low oxygen potential within the furnace is indicated by CO and CO_2 concentrations in the furnace and in the exit duct. For example, the largest CO/CO_2 ratio, 29,762, as measured March 9, 1995, in the time interval 1846 to 1850 yields by thermodynamic calculation an O_2 partial pressure ranging from 1.3E-19 atm at 527 °C (980 °F) to 3E-7 atm at 927 °C (1700 °F). The measured oxygen pressure within that interval was 0.0315 atm. Equally logical explanations are that oxygen originated by leakage of air into the furnace, or the $CO:CO_2$ equilibrium represents conditions within the reaction zone of the electrode triangle as opposed to representing global conditions within the furnace plenum.

- The NO_x concentrations within the furnace and in the furnace exit were consistently <10 ppm except during the demonstration idle when thermal NO_x formation, because of open arc conditions, increased the concentration.

- The SO_2 concentration also was highest within the furnace during the idle likely because of less Na in the plenum gases.

- Oxygen concentration in the stack was near atmospheric concentration because of extensive dilution by cooling air.

- Stack gases were within allowable concentrations, confirming the efficacy of thermal oxidizer and scrubber.

Table 3-1. Sample Reference to Process Conditions During WHC1-1995.

Product	Date	Time	Description	Analytical laboratory (1)	Sample point	Material	Test Conditions			
							Energy kW	Feed rate lb/h	Cold top in	Glass temp C
Glass										
M1G1-002	03\09\95	0215	Glass: tapping continuously prior to stopping to slip electrodes.	C, M, P, U	Glass tap	B feed	450	714	7	1620
M1G1-004	03\09\95	1030	Glass: tapping continuously after demonstrating ability to stop and restart.	C, M, P, U	Glass tap	B feed	400	714	7	1620
M1G1-005	03\09\95	1305	Glass, tapping continuously at lower power input.	C, M, P, U	Glass tap	B feed	360	277	5	1620
M1G1-008	03\09\95	1850	Glass; viscous and hot after hot idle.	C, M, P, U	Glass tap	B feed	375	277	<5	1705
M1G1-010	03\09\95	2115	Glass; tapping continuously 1.5 h after beginning A feed.	C, M, P, U	Glass tap	A feed	475	535	7	1620
M1G1-011	03\09\95	2215	Glass; tapping continuously.	C, M, P, U	Glass tap	A feed	390	714	6	1690
M1G1-012	03\09\95	2335	Glass; tapping continuously.	C, M, P, U	Glass tap	A feed	400	445	7	1720
Thermal oxidizer solids										
M1T3-001	03\15\95	1500	Representative sample of glass remaining in catch basin.	C, M, U	Basin	A and B residues	Off	0	0	Off
Cyclone solids										
M1C4-001	03\14\95	1000	Representative sample of material remaining in cyclone.	C, M, U	Cyclone	A and B residues	Off	0	12	Off
Baghouse solids										
M1B5-001	03\13\95	1600	Representative sample of material remaining in baghouse.	C, M, U	Baghouse	A and B residues	Off	0	12	Off
Scrubber solutions										
M1S6-006	03\09\95	0205	Solution; tapping glass continuously.	P	Scrubber	B feed	440	714	7	1620
M1S6-008	03\09\95	0600	Solution; tapping glass continuously.	P	Scrubber	B feed	450	720	6	1640
M1S6-011	03\09\95	1200	Solution; tapping glass continuously.	P	Scrubber	B feed	360	277	5	1580
M1S6-010	03\09\95	1330	Solution; tapping glass continuously.	P	Scrubber	B feed	410	277	5	1670
M1S6-013	03\09\95	1550	Solution, beginning hot idle test.	P	Scrubber	B feed	230	0	0	1560
M1S6-016	03\09\95	2150	Solution; tapping glass continuously.	P	Scrubber	A feed	410	625	6	1725
M1S6-017	03\10\95	0045	Solution; tapping glass continuously.	P	Scrubber	A feed	450	714	7	1705
M1S6-018	03\10\95	1300	Solution; collected 13 h after test.	P	Scrubber	A and B residues	Off	0	0	Off
Offgas(2)										
CEM-2	03\08\95	1618-1621	O2, CO2, CO, NOx, NO, and SO2.	E, Q	In furnace	B feed	600	0	-12	NA
CEM-3	03\08\95	2310-2311	O2, CO2, CO, NOx, NO, SO2, and THC.	E, Q	Furnace outlet	B feed	440	803	6	1620
CEM-4	03\08\95	2349-2400	O2, CO2, CO, NOx, NO, and SO2.	E, Q	Stack	B feed	440	803	5	1625
CEM-5	03\09\95	0642-0711	O2, CO2, CO, NOx, NO, and SO2.	E, Q	Stack	B feed	460	720	6	1640
CEM-6	03\09\95	1132-1428	O2, CO2, CO, NOx, NO, SO2, and THC.	E, Q	Stack	B feed	400	178	4	1630
CEM-7	03\09\95	1459-1540	O2, CO2, CO, NOx, NO, SO2, THC, and NH3.	E, Q	In furnace	B feed	350	357	5	1640
CEM-8	03\09\95	1758-1806	O2, CO2, CO, NOx, NO, SO2, and THC.	E, Q	In furnace	B feed	400	277	0	NA
CEM-9	03\09\95	2314-2400	O2, CO2, CO, NOx, NO, and SO2.	E, Q	In furnace	A feed	450	714	6	1700
CEM-10	03\10\95	0029-0131	O2, CO2, CO, NOx, NO, and SO2.	E, Q	Stack	A feed	450	178	8	1700
M2-1	03\08\95	1550-1600	Velocity and pressure at furnace outlet.	E, Q	Furnace outlet	B feed	550	0	13	NA
M2-2	03\08\95	2020-2025	Velocity and pressure at cyclone inlet.	E, Q	Cyclone inlet	B feed	440	446	9	1700
M2-3	03\09\95	1022-1035	Velocity and pressure at furnace outlet.	E, Q	Furnace outlet	B feed	350	714	6	1640
M2-4	03\09\95	1615-1620	Velocity and pressure at furnace outlet.	E, Q	Furnace outlet	B feed	225	0	0	NA
M2-5	03\09\95	2055-2120	Velocity and pressure at furnace outlet.	E, Q	Furnace outlet	A feed	450	625	6	1620
M2-6	03\09\95	2335-2345	Velocity and pressure at cyclone inlet.	E, Q	Cyclone inlet	A feed	450	446	6	1700
M5-1	03\08\95	1601-1630	Particulate, metals, NH3, HCl, Cl2, HF, and F2.	E, Q	Furnace outlet	B feed	600	0	12	NA
M5-2	03\09\95	1110-1138	Particulate, metals, NH3, HCl, Cl2, HF, and F2.	E, Q	Furnace outlet	B feed	350	178	5	1630
M5-3	03\09\95	1253-1329	Particulate, metals, NH3, HCl, Cl2, HF, and F2.	E, Q	Furnace outlet	B feed	450	277	5	1620
M5-4	03\09\95	1628-1708	Particulate, metals, NH3, HCl, Cl2, HF, and F2.	E, Q	Furnace outlet	B feed	230	0	0	NA
M5-5	03\09\95	2101-2151	Particulate, metals, NH3, HCl, Cl2, HF, and F2.	E, Q	Furnace outlet	A feed	450	535	7	1620
M5-6	03\09\95	2300-0035	Particulate, metals, NH3, HCl, Cl2, HF, and F2.	E, Q	Cyclone inlet	A feed	440	625	7	1700

1. Analytical laboratories:
C—Corning
M—USBM
P—PNL
U—USGS
E—Entropy Inc.
Q—Quanterra

2. Source emissions testing by Entropy Inc. using the following EPA methods:

Method	Analysis
1	Sampling point determination
2	Volumetric flow rate
3A	O2 and CO2
4	Moisture content
Mod 5	Particulate, metals, HCl, Cl2, HF, and NH3
6C	SO2
7E	NOx
10	CO
25A	THC

Table 3-2. Summary of Conditions During WHC1-1995.

Date	Time	Feed Rate lb/hr	Cumulative Feed, lb*	Cum. WHC Feed, lb	Slag Pot No.	Tap Time min	Tap Weight, lb	Tap Rate lb/hr	Cumulative Tap, lb	Cum. WHC Tap, lb	Cum. Feed -Cum. Tap	Feed Rate -Tap Rate	kWh	kWh/lb
03/08/95	06:40	1600	4000	---	TH-1	30	356	712	356	---	3644	888	1167	0.29
03/08/95	08:00	0	5402	---	---	---	---	0	356	---	5046	0	1930	0.36
03/08/95	09:15	750	6152	---	TH-2	145	356	147	712	---	5440	603	2664	0.43
03/08/95	10:15	0	6152	---	TH-3	15	840	3360	1552	---	4600	-3360	3298	0.54
03/08/95	10:35	800	6879	727	TH-4	20	892	2676	2444	---	4435	-1876	3462	0.50
03/08/95	11:00	600	7621	1469	TH-5	25	894	2146	3338	---	4283	-1546	3648	0.48
03/08/95	12:20	800	9110	2958	TH-6	80	766	575	4104	---	5006	226	4321	0.47
Commence tapping of WHC product glass														
03/08/95	13:35	750	10660	4508	WHC-0	75	844	675	4948	844	5712	75	4813	0.45
03/08/95	19:08	0	12864	6712	WHC-1	333	606	109	5554	1450	7310	-109	7008	0.54
03/08/95	19:52	750	12864	6712	WHC-2	46	592	772	6146	2042	6718	-22	7370	0.57
03/08/95	20:25	800	12864	6712	WHC-3	33	784	1425	6930	2826	5934	-625	7593	0.59
03/08/95	20:40	850	12864	6712	WHC-4	15	800	3200	7730	3626	5134	-2350	7716	0.60
03/08/95	21:25	750	13648	7496	WHC-5	45	774	1032	8504	4400	5144	-282	8048	0.59
03/08/95	22:25	800	14414	8262	WHC-6	60	760	760	9264	5160	5150	40	8491	0.59
03/08/95	23:30	825	15156	9004	WHC-7	65	788	727	10052	5948	5104	98	8935	0.59
Begin 24 hour test interval														
03/09/95	00:30	725	16624	10472	WHC-8	60	682	682	10734	6630	5890	43	9373	0.56
03/09/95	01:10	750	17416	11264	WHC-9	40	778	1167	11512	7408	5904	-417	9669	0.56
03/09/95	02:30	750	18938	12786	WHC-10	80	736	552	12248	8144	6690	198	10267	0.54
03/09/95	03:12	0	19660	13508	WHC-11	42	756	1080	13004	8900	6656	-1080	10565	0.54
03/09/95	04:38	765	19660	13508	WHC-12	86	710	495	13714	9610	5946	270	11104	0.56
03/09/95	05:38	765	21100	14948	WHC-13	60	730	730	14444	10340	6656	35	11558	0.55
03/09/95	06:38	765	21780	15628	WHC-14	60	738	738	15182	11078	6598	27	12012	0.55
03/09/95	09:25	750	22488	16336	WHC-15	167	744	267	15926	11822	6562	483	12901	0.57
03/09/95	10:37	570	23964	17812	WHC-16	72	730	608	16656	12552	7308	-38	13416	0.56
03/09/95	12:25	250	24744	18592	WHC-17	108	764	424	17420	13316	7324	-174	14073	0.57
03/09/95	15:05	0	25512	19360	WHC-18	160	804	302	18224	14120	7288	-302	15209	0.60
03/09/95	19:32	450	25512	19360	WHC-19	267	652	147	18876	14772	6636	303	16614	0.65
Start Method A feed														
03/09/95	21:00	450	26634	20482	WHC-20	88	648	442	19524	15420	7110	8	17244	0.65
03/09/95	22:25	750	27178	21026	WHC-21	85	714	504	20238	16134	6940	246	17841	0.66
03/10/95	00:10	0	28110	21958	WHC-22	105	768	439	21006	16902	7104	-439	18536	0.66
End 24 hour test interval														
03/10/95	01:10	0	28110	21958	WHC-23	60	356	356	21362	17258	6748	356	18902	0.67
03/10/95	03:24	0	28110	21958	WHC-24	---	294	---	21656	17552	6454	0	19782	0.70
03/10/95	03:24	0	28110	21958	Overflow	---	172	---	21828	17724	6282	0	19782	0.70

* feed loaded into receiving bin

Figure 3-5. Mean O_2, CO, and CO_2 Concentrations in Process Offgases During WHC1-1995.

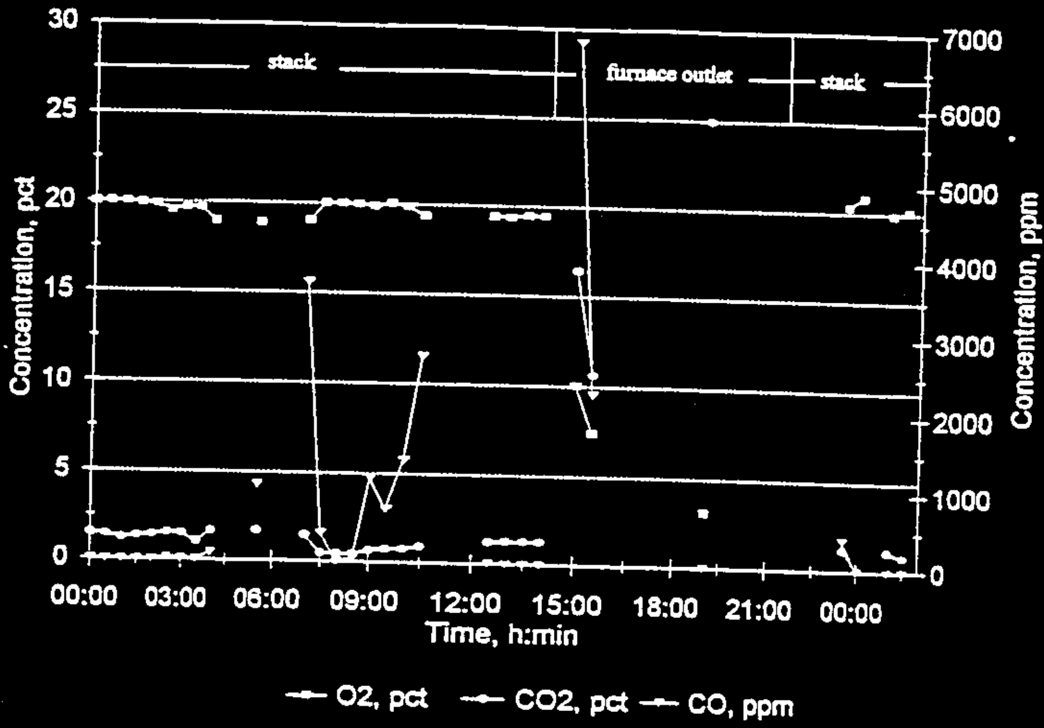
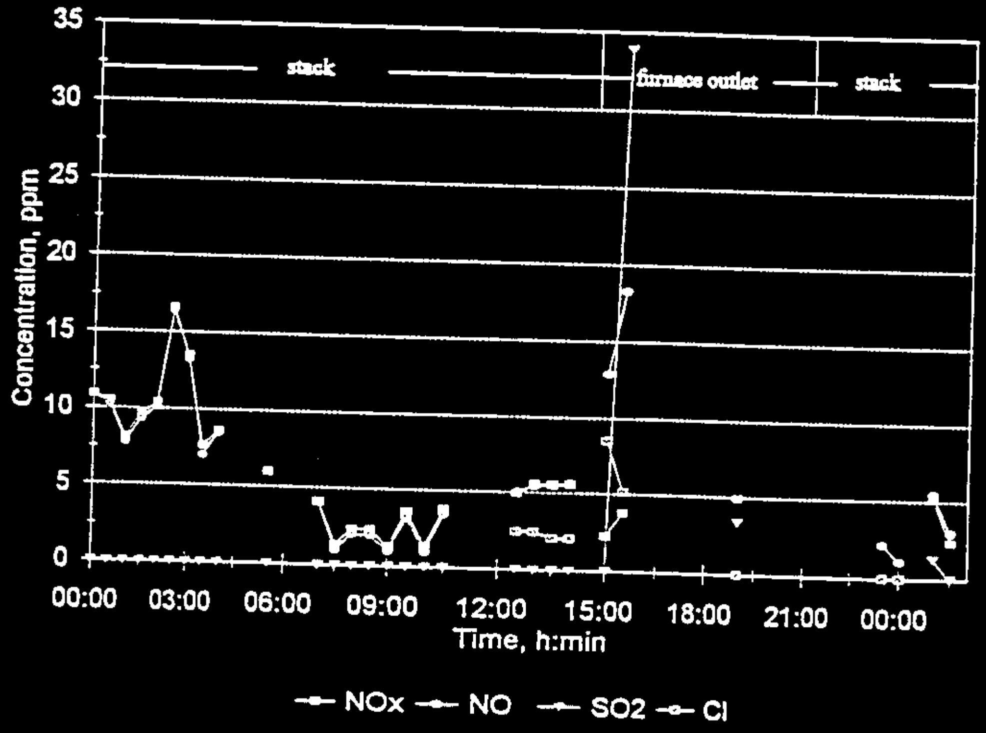


Figure 3-6. Mean NO, NO_x, and SO_2 Concentrations in Process Offgases During WHC1-1995.



- The CO level in stack gases correlates with usage of the burners, which were not properly adjusted for air:gas ratio.

- Detection of total hydrocarbons (THC) in the stack in the range to 12 ppm also confirms gas-rich adjustment of the burners.

Solid materials recovered from the APCS after the melting test included 486 kg (1,070 lb) of damp material from the baghouse (LOI 12.3%); 30 kg (66 lb) of wet material from the cyclone, EGC system, and entrance duct to the baghouse (LOI 12.7%); and 73 kg (160 lb) of glass from the base of the thermal oxidizer. Weights of materials deposited in the APCS during the 24-hour test period were calculated as the product of the total weight and the ratio of material processed during the 24-hour period to the total material processed. A small contribution to the thermal oxidizer glass was provided by the preheat material, as evidenced by TiO_2 in the glass, but this contribution was not significant.

The scrubber solution was not maintained at the optimum pH (7.5 to 8.5) during the test due to freezing of the 50% caustic solution in the supply makeup line to the scrubber liquor recirculating pump. Caustic solution of 50% concentration freezes at 14 °C (57 °F). Scrubber solution, which ranged between pH 5.6 and 6.2 during the test, was sampled regularly, and selected samples were analyzed for nitrate, nitrite, phosphate, and sulfate. The final solution, collected 13 hours after the test, was analyzed for those ions plus the major metals in the furnace feed. Table 3-3 lists the results, as determined by PNL. The concentration of anions was remarkably constant throughout the test, notwithstanding different feed rates and power input to the furnace. Therefore, it is safe to assume that the concentration of cations also was nearly constant and that the final solution is representative of solutions during the test. Cation concentrations from the final solution and the mean anion concentrations were applied to calculated mean escapement rates for species as gases or particulates passing through the baghouse. These derived data indicate that the escapement rate for each species was low, as expected for an efficient baghouse. Note that calculated escapement rates depend on the scrubber overflow rate, which was measured at the outset, but not confirmed during the test. Data logs for process water were misplaced following the test.

Baghouse and cyclone solids were analyzed by X-ray diffraction with the following results.

- Cyclone solids comprised minor NaCl and $Na_2B_4O_7{\cdot}5H_2O$ and trace $CaCO_3$ and unidentified compounds. Most of the sample was non-crystalline.

- Baghouse solids comprised minor NaCl and $Na_2B_4O_7{\cdot}5H_2O$ and trace $NaH(CO_3){\cdot}2H_2O$ and unidentified compounds. Most of the sample was non-crystalline.

- Sulfates and phosphates, although known to be present in cyclone and baghouse solids, were not detected as crystalline materials.

Gases and particulates within the furnace, in the water-cooled section of the furnace exit, in the 12-in. duct at the entrance to the cyclone, and within the stack were measured by technicians from Entropy, Inc. during the

Table 3-3. Analysis of Scrubber Solutions and Calculated Baghouse Escapement for WHC1-1995.

Species					Concentration, mole/l								
Sample no	Al	B	Ca	Fe	K	Mg	Na	Si	Cl	NO3-	NO2-	SO2	PO4-3
M1S6-006P(1)	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.63E-05	5.30E-05	3.89E-04	0.00E+00
M1S6-008P(2)	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.55E-05	0.00E+00	4.41E-04	2.35E-05
M1S6-010P(3)	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.24E-04	6.33E-05	6.77E-04	5.62E-05
M1S6-011P(4)	NA	NA	NA	NA	NA	NA	NA	NA	NA	9.72E-05	0.00E+00	IND	0.00E+00
M1S6-013P(5)	NA	NA	NA	NA	NA	NA	NA	NA	NA	8.95E-05	0.00E+00	IND	0.00E+00
M1S6-016P(6)	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.76E-05	0.00E+00	1.25E-03	2.76E-05
M1S6-017P(7)	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.21E-05	0.00E+00	IND	2.23E-05
M1S6-018P(8)	6.82E-05	3.88E-04	8.41E-05	4.08E-05	7.29E-04	1.82E-04	1.07E-01	4.73E-04	1.50E-03	7.11E-05	4.06E-05	8.13E-04	5.30E-05
Mean	6.82E-05	3.88E-04	8.41E-05	4.08E-05	7.29E-04	1.82E-04	1.07E-01	4.73E-04	1.50E-03	8.42E-05	5.23E-05	7.14E-04	3.65E-05
MW	26.980	10.820	40.080	55.850	39.100	24.320	22.991	28.090	35.457	62.008	46.008	64.008	94.975
Mean baghouse escapement(9)													
lb/h	2.31E-03	5.27E-03	4.23E-03	2.86E-03	3.58E-02	5.56E-03	3.09E+00	1.67E-02	6.68E-02	6.55E-03	3.02E-03	5.74E-02	4.36E-03

Assumptions:
Steady state scrubber solution concentration during melting test.
Solution make-up and overflow rate = 2.5 gpm = 9.5 l/min.

1. Steady state conditions, B feed, rate 750 lb/h, power 450 kW, cold top 6 in.
2. Steady state conditions after adding electrode segments, B feed, rate 750 lb/h, power 750 kW, cold top 6 in.
3. Variable conditions, B feed, rate about 600 lb/h, power about 400 kW, cold top 6 in.
4. Steady state conditions at lower operating point, B feed, rate 250 lb/h, power 360 kW, cold top 5 in.
5. During extended idle, B feed, rate 0, power 230 kW, no cold top.
6. Near steady state conditions, A feed, rate 450 lb/h, power about 400 kW, cold top 6 in.
7. End of test, A feed, rate 0, power 0, cold top 0.
8. About 13 h after end of demonstration test.
9. Mean baghouse escapement (lb/h) = make-up rate X mean concentration X MW X 0.1322.

24-hour demonstration test. Results of the analyses are presented in Appendix D as summary tables provided by Entropy. Test M5-1 was invalidated by variable feed and power to the furnace, and Test M5-4 was not accompanied by measurement of the flow rate. The volumetric flow rate was determined for Tests M5-2, -3, -5, and -6 to provide emission rates in lb/h, which are correlated with furnace energy input, glass tap temperature, feed rate, and baghouse escapement rate in Table 3-4. The following observations are pertinent.

- Furnace emissions stated in terms of percent of feed are low for Al, Ca, Fe, Mg, and Si, which are strong oxide formers.

- Emissions were extremely high for B, K, Na, Cl, S, and P, which readily form volatile species. Conditions during offgas testing were not varied over significant ranges; therefore, emission rates do not correlate strongly with process variables.

- Boron forms three oxides (B_2O, BO, and B_2O_3), and the former two have appreciable vapor pressures at processing temperatures. The total vapor pressures for B_2O and BO in mm Hg, calculated from thermodynamic data in the range of 1300 to 1700 °C (2372 to 3092 °F), are 0.017, 0.083, 0.384, 1.414, 5.174 kPa (0.13, 0.62, 2.88, 10.6, and 38.8 torr) at 1300, 1400, 1500, 1600, and 1700 °C (2372, 2552, 2732, 2912, and 3092 °F), respectively. Tapping temperatures during WHC1 were greater than 1600 °C (2912 °F) most of the time, thereby explaining the loss of B during melting.

- Ammonia was detected within the furnace during the idle demonstration at 24 ppmvd (ppm by volume on dry basis) and in the offgas in the range of 142 to 198 ppmvd. If one assumes that ethylenediaminetetraacetic acid (EDTA) in the LLW simulant was the source of NH_3 in the offgas, then from 0.12% (M5-6) to 2.02% (M5-2) of N in the EDTA was evolved as ammonia.

- Cl and S were collected quantitatively as salts, as opposed to the anticipated acid gases because of the prevalence of basic species present as particulate in the offgas.

The scrubber is an excellent collector of particulate in addition to acid gases; therefore, comparison of the mean escapement rate through the baghouse for a given element with the emission rate for that element measured at the furnace outlet provides an indication of baghouse efficiency for that element. If the element exits the furnace in the form of particulate or condensible vapor, the collection efficiency in the baghouse should be high. Conversely, the collection efficiency for elements present as gases should be low. The data clearly indicate that the metals, including P, entered the baghouse as particulates. Cl and S also reported quantitatively to the baghouse, indicating low concentration of acid species in the offgas. Chemical speciation for Na in the offgas is obscured by caustic addition to the scrubber.

Table 3-4. Furnace Emissions and Baghouse Efficiency for WHC1-1995.

Feed species/ concentration Wt pct	Entropy test no	Time	Location	Feed rate lb/h	Furnace energy kW	Glass temp C	Cold top in	Species melting rate lb/h	Furnace emissions lb/h	Furnace emissions pct of feed	Mean Baghouse Escapement lb/h	Baghouse efficiency pct
Al 4.747	M5-2	1110-1138	Furnace outlet	178	350	1630	5	8.45	0.039	0.47	0.0023	94.12
	M5-3	1253-1329	Furnace outlet	277	450	1620	5	13.15	0.035	0.26		93.36
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	25.40	0.041	0.16		94.30
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	29.43	0.045	0.15		94.90
B 1.395	M5-2	1110-1138	Furnace outlet	178	350	1630	5	2.48	2.160	86.98	0.0053	99.76
	M5-3	1253-1329	Furnace outlet	277	450	1620	5	3.86	1.500	38.81		99.65
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	7.46	1.280	17.15		99.59
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	8.65	1.340	15.49		99.61
Ca 3.202	M5-2	1110-1138	Furnace outlet	178	350	1630	5	5.70	0.026	0.45	0.0042	83.48
	M5-3	1253-1329	Furnace outlet	277	450	1620	5	8.87	0.022	0.24		80.42
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	17.13	0.019	0.11		78.20
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	19.85	0.037	0.19		88.60
Fe 0.562	M5-2	1110-1138	Furnace outlet	178	350	1630	5	1.00	0.011	1.06	0.0029	73.02
	M5-3	1253-1329	Furnace outlet	277	450	1620	5	1.56	0.010	0.62		70.52
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	3.01	0.009	0.30		67.87
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	3.48	0.015	0.43		80.81
K 1.179	M5-2	1110-1138	Furnace outlet	178	350	1630	5	2.10	1.100	52.42	0.0358	96.75
	M5-3	1253-1329	Furnace outlet	277	450	1620	5	3.27	0.923	28.27		96.12
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	6.31	0.730	11.58		95.10
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	7.31	1.210	16.56		97.04
Mg 0.133	M5-2	1110-1138	Furnace outlet	178	350	1630	5	0.24	NA	0.00	0.0056	NA
	M5-3	1253-1329	Furnace outlet	277	450	1620	5	0.37	NA	0.00		NA
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	0.71	NA	0.00		NA
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	0.82	NA	0.00		NA
Na 13.628	M5-2	1110-1138	Furnace outlet	178	350	1630	5	24.26	5.970	24.61	NA(2)	NA
	M5-3	1253-1329	Furnace outlet	277	450	1620	5	37.75	4.560	12.08		NA
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	72.91	4.270	5.86		NA
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	84.49	5.950	7.04		NA
Si 23.009	M5-2	1110-1138	Furnace outlet	178	350	1630	5	40.96	NA	0.00	0.0167	NA
	M5-3	1253-1329	Furnace outlet	277	450	1620	5	63.73	NA	0.00		NA
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	123.10	NA	0.00		NA
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	142.66	NA	0.00		NA
Cl(3) 0.316	M5-2	1110-1138	Furnace outlet	178	350	1630	5	0.56	0.764	135.83	0.0668	91.26
	M5-3	1253-1329	Furnace outlet	277	450	1620	5	0.88	0.550	62.83		87.85
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	1.69	0.480	28.39		86.06
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	1.96	1.080	55.12		93.81
NO3-(4) 1.834	M5-2	1110-1138	Furnace outlet	178	350	1630	5	3.26	NA	NA	0.0066	NA
	M5-3	1253-1329	Furnace outlet	277	450	1620	5	5.06	NA	NA		NA
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	9.81	NA	NA		NA
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	11.37	NA	NA		NA
NO2-(4) 0.378	M5-2	1110-1138	Furnace outlet	178	350	1630	5	0.67	NA	NA	0.0030	NA
	M5-3	1253-1329	Furnace outlet	277	450	1620	5	1.05	NA	NA		NA
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	2.02	NA	NA		NA
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	2.34	NA	NA		NA
SO2(5) 0.653	M5-2	1110-1138	Furnace outlet	178	350	1630	5	1.16	1.190	102.38	0.0574	95.18
	M5-3	1253-1329	Furnace outlet	277	450	1620	5	1.81	1.182	65.35		95.14
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	3.49	1.268	36.30		95.47
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	4.05	5.120	126.46		98.88
PO4-4(5)	M5-2	1110-1138	Furnace outlet	178	350	1630	5	0.14	0.159	111.52	0.0044	97.25
0.080	M5-3	1253-1329	Furnace outlet	277	450	1620	5	0.22	0.137	62.00		96.83
	M5-5	2101-2151	Furnace outlet	535	450	1620	7	0.43	0.121	28.22		96.39
	M5-6	2350-0035	Cyclone inlet	620	440	1700	7	0.50	0.252	50.87		98.27

(1) Flow rate not measured.
(2) Interference from caustic addition to scrubber.
(3) Chlorides plus chlorine.
(4) Mean by analyses by USGS and PNL.
(5) Analysis by PNL

3.3.2 Electrode Consumption

- Total electrode consumption was 130 kg (285 lb) over the entire melting campaign during which 13,094 kg (28,806 lb) of materials were melted, 10,266 kg (22,633 lb) of product glass were produced, and 19,782 kW.h of electrical energy were used. Mean electrode consumption was 9.9 kg/tonne (21.8 lb/tonne) on the basis of feed material, 12.6 kg/tonne (27.7 lb/tonne) on the basis of product glass, or 6.55 kg/MW.h) (14.4 lb/MW.h) on the basis of melting energy.

3.3.3 Power Consumption

- Mean energy consumption, 9,613 kW.h over the demonstration test, was 1.63 kW.h/kg (0.74 kW.h/lb) feed or 1.92 kW.h/kg (0.87 kW.h/lb) glass.

- During 1.5 hours of steady-state operation from 0900 to 1030, energy consumption was 1.27 kW.h/kg (0.58 kW.h/lb) feed or 1.49 kW.h/kg (0.68 kW.h/lb) glass while melting Method B feed with a power input of 429 kW, feed rate of 339 kg/h (745 lb/h), glass temperature of about 1620 °C (2948 °F), and about 2,500 acfm of stack gases. Most of the gases were derived from the burners. Following stoppage of power for 1 hour to demonstrate the ability to stop and restart, an attempt over a 40-minute period was made to establish a lower operating point with power at about 350 kW and feed rate at about 136 kg/h (300 lb/h). Glass temperature declined to about 1500 °C (2732 °F) and offgas in the stack decreased to about 2,250 acfm. However, determination of energy consumption during the attempt to establish lower tapping temperature was not accurate because of the variable feed rate. Demonstration of idle conditions for 2 hours likely resulted in extensive loss of alkali metals and B from the molten glass with attendant increased viscosity resulting in difficult tapping. Stable operating conditions were not reestablished following the idle demonstration.

3.3.4 Glass Statistics

The compositions of glasses derived from Method A and B feed were calculated based on the calculated (9.92 M Na) and analyzed (8.85 M Na) concentration of soda in the LLW simulant. Results are compared with analyzed glass compositions in Table 3-5, which also lists compositions of thermal oxidizer glass and cyclone and baghouse solids. Glass samples were collected as indicated below to represent the extremes of conditions during the demonstration test. Input energy, feed rate, cold top, and glass temperature obtained by optical pyrometer for these samples are listed in Table 3-4.

- M1G1-002: 1 hour during steady-state conditions after beginning the 24-hour test with Method B feed

- M1G1-004: 1.5 hours after demonstrating ability to stop and restart with Method B feed

Table 3-5. Composition of Furnace Products for WHC1-1995.

Saved as WHC_Feed.WB1

WHC1-1995 Product	LOI 925 C	Al2O3	B2O3	BaO	TOC	TIC	TC	CaO	Cr2O3	Cs2O	Cl	F	I	FeO	Fe2O3	K2O	Li2O	MgO	MnO2	MoO3	Na2O	NiO	P2O5	SO3	SiO2	SrO	TiO2	ZrO2
			Components as oxides or elements, wt pct																									
B glass																												
Calculated (1)	0.00	10.01	5.00	0.003	0	0	0.000	5.00	0.040	0.144	0.35	0.288	0.128	NA	0.90	1.59	NA	0.25	0.002	0.148	20.49	NA	0.204	0.223	54.90	0.104	0.096	0.002
Calculated (2)	0.00	9.92	5.17	0.003	0	0	0.000	5.17	0.036	0.130	0.32	0.259	0.115	NA	0.93	1.45	NA	0.26	0.002	0.132	18.66	NA	0.186	0.202	56.73	0.094	0.100	0.005
M1G1-002C (3)	NA	11.00	3.23	0.007	0	0	0.004	5.78	0.027	0.064	0.08	0.030	NA		1.40	1.04	NA	0.30	0.013	0.090	14.50	0.000	0.065	0.560	60.10	0.100	0.208	0.013
M1G1-002U (4)	0.00	11.10	2.93	0.009	0	0	0.000	5.82	0.034	0.064	0.10	0.040	0.012	1.38	1.40	1.03	NA	0.30	0.180	0.089	16.80	0.001	0.100	0.360	59.40	0.100	0.220	0.011
M1G1-004C		11.70	3.13	0.006	0	0	0.004	6.43	0.033	0.054	0.08	0.030	NA		1.03	1.03	NA	0.33	0.008	0.079	17.10	0.000	0.067	0.480	59.40	0.096	0.268	0.007
M1G1-004U	0.01	11.70	2.90	0.008	0	0	0.000	6.36	0.040	0.055	0.06	0.030	0.008	1.11	1.04	1.01	NA	0.31	0.012	0.080	16.50	0.000	0.090	0.310	58.50	0.096	0.280	0.006
M1G1-005C	NA	12.10	2.59	0.006	0	0	0.004	6.86	0.036	0.049	0.06	0.020	NA		1.05	0.98	NA	0.34	0.008	0.082	16.60	0.000	0.068	0.210	60.00	0.097	0.328	0.007
M1G1-005U	0.11	12.10	2.40	0.008	0	0	0.000	6.85	0.044	0.050	0.07	0.030	0.006	1.01	1.07	0.97	NA	0.33	0.012	0.083	16.10	0.001	0.100	0.000	58.80	0.096	0.340	0.006
M1G1-006C	NA	15.00	2.11	0.005	0	0	0.006	10.30	0.054	0.035	0.04	0.020	NA		1.06	0.80	NA	0.43	0.010	0.065	14.70	0.000	0.078	0.180	55.90	0.088	0.755	0.010
M1G1-006P (5)	0.37	15.20	1.84	0.050	0	0	0.021	9.57	0.090	0.029	NA	NA	NA	0.98	1.03	0.22	0.00	0.39	0.020	0.080	13.55	0.000	0.000	0.090	47.78	0.100	0.630	0.010
M1G1-006U	0.00	15.10	1.95	0.007	0	0	0.000	10.40	0.117	0.034	0.04	0.030	0.003	1.11	1.07	0.79	NA	0.39	0.012	0.065	14.10	0.001	0.100	0.120	54.60	0.088	0.770	0.009
M1G1-010C	NA	12.90	3.17	0.006	0	0	0.003	8.04	0.058	0.056	0.08	0.030	NA		1.18	1.03	NA	0.34	0.010	0.091	16.50	0.000	0.078	0.170	56.90	0.098	0.493	0.008
M1G1-010U	0.00	13.10	2.90	0.008	0	0	0.000	8.15	0.070	0.058	0.09	0.030	0.008	1.28	1.20	0.99	NA	0.31	0.012	0.097	15.90	0.001	0.110	0.000	55.70	0.095	0.510	0.007
A glass																												
Calculated (1)	0.00	10.00	5.01	0.004	0	0	0.000	5.01	0.041	0.144	0.35	0.288	0.128	NA	1.18	1.64	NA	0.40	0.002	0.146	20.47	0.001	0.216	0.240	53.91	0.104	0.124	0.007
Calculated (2)	0.00	10.28	5.17	0.004	0	0	0.000	5.17	0.037	0.130	0.32	0.260	0.115	NA	1.22	1.51	NA	0.42	0.002	0.132	18.67	0.001	0.199	0.220	55.68	0.094	0.128	0.007
M1G1-011C	NA	12.50	2.84	0.005	0	0	0.006	7.30	0.044	0.044	0.05	0.030	NA		1.21	0.98	NA	0.34	0.009	0.090	16.80	0.004	0.070	0.050	58.90	0.100	0.385	0.009
M1G1-011P	0.24	13.28	2.53	0.010	0	0	0.060	6.73	0.010	0.048	NA	NA	NA	0.98	1.13	0.00	0.00	0.28	0.018	0.080	15.38	0.000	0.015	0.000	50.21	0.100	0.300	0.000
M1G1-011U	0.03	12.60	2.67	0.009	0	0	0.000	7.34	0.055	0.046	0.06	0.040	0.000	1.28	1.21	0.96	NA	0.31	0.012	0.092	16.20	0.001	0.120	0.000	57.20	0.100	0.40	0.008
M1G1-012C	NA	11.90	2.66	0.005	0	0	0.004	6.35	0.027	0.045	0.05	0.030	NA		1.23	1.00	NA	0.32	0.009	0.088	17.30	0.005	0.081	0.030	60.70	0.103	0.270	0.008
M1G1-012U	0.00	11.90	2.50	0.009	0	0	0.000	6.33	0.038	0.049	0.08	0.040	0.005	1.20	1.24	1.00	NA	0.30	0.012	0.092	16.90	0.002	0.110	0.000	58.40	0.104	0.290	0.007
Thermal oxidizer																												
M1T3-001C		38.00	16.00	0.007	0	0	NA	8.11	0.017	0.003	0.01	0.000	NA		0.76	0.50	NA	0.14	0.000	0.097	21.70	0.000	0.385	0.004	12.20	0.031	1.215	0.105
M1T3-001U		37.20	15.90	0.008	0	0	0.000	7.87	0.026	0.008	0.00	0.020	0.000	0.08	0.78	0.61	NA	0.12	0.000	0.097	21.10	0.001	0.330	0.000	12.00	0.030	1.190	0.116
Cyclone solids																												
M1C4-001C	NA	0.69	24.00	0.000	NA	NA	NA	2.34	0.013	0.830	0.04	0.180	NA		0.26	4.70	NA	0.10	0.004	0.415	33.40	0.000	0.485	10.60	9.33	0.006	0.015	0.000
M1C4-001U	12.70	0.67	24.20	0.001	0.08	1.65	1.730	2.16	0.015	0.935	2.96	0.180	0.720	NA	0.27	4.14	NA	0.11	0.000	0.450	<30	0.001	0.510	10.10	9.52	0.006	0.000	0.001
Baghouse solids																												
M1B5-001C	NA	0.35	22.70	0.000	NA	NA	NA	0.47	0.013	0.990	0.27	0.195	NA		0.11	5.51	NA	0.03	0.000	0.456	34.20	0.000	0.466	13.20	9.50	0.000	0.000	0.000
M1B1-001U	12.30	0.37	22.50	0.000	0.045	1.51	1.560	0.54	0.016	1.053	3.71	0.190	1.035	NA	0.11	4.65	NA	0.00	0.000	0.495	<30	0.001	0.530	12.90	9.74	0.002	0.000	0.000

Concentration, moles/l

Scrubber slurry	pH	Al	B	Ba	Ca	Cr	Cs	Cl	F	NO3-	NO2-	Fe	K	Li	Mg	Mn	Mo	Na	Ni	PO4-3	SO4-2	Si	Sr	Ti	Zr
Factor		E-5	E-4	E-5	E-5	E-5		E-3		E-5	E-5	E-5	E-4	E-4	E-4	E-5	E-4	E-1	E-5	E-5	E-4	E-4	E-5	E-4	E-5
M1S6-018P	8.00	6.62	3.88	0.00	8.41	0.00	NA	1.50	NA	7.11	4.06	4.06	7.29	0.00	1.82	0.00	0.00	1.07	-0.00	0.00	8.13	4.73	0.00	0.00	0.00

1. Composition calculated from assayed starting materials and 9.82 M Na LLW simulant.
2. Composition calculated from assayed starting materials and analyzed Na concentration (8.86 M Na) in LLW simulant.
3. Analysis by Corning, mean of four determinations.
4. Analysis by USGS, mean of two determinations.
5. Analysis by PNL, mean of three determinations.

- M1G1-005: Immediately following operation for about 2.5 hours at lower power input with Method B feed
- M1G1-008: Represents the worst conditions, 20 minutes after demonstrating hot idle
- M1G1-010: 1.5 hours after beginning Method A feed during quasi steady-state operation
- M1G1-011: During lower power input and greater feed rate with Method A feed
- M1G1-012: Last sample during the demonstration test with Method A feed.

The following observations are pertinent.

- The LOI for glass products was low, ranging from nil to 0.37%, indicating low propensity for the glass to absorb moisture from the atmosphere.
- Analyses of glass samples by the U.S. Geologic Survey and Corning laboratories were consistent with few exceptions.
- Data for the principal glass components, as plotted versus time in Figure 3-7, indicate significant loss of the more volatile species Na_2O, B_2O_3, K_2O, MoO_3, P_2O_5, SO_3, Cl, and F by vaporization. These losses are quantified under Material Balance.
- The data for minor species of interest (Cr_2O_3, TiO_2, and Cs_2O) plotted in Figure 3-8 emphasize the perturbation of glass composition at about 1830, which immediately followed demonstration of extended hot idle. Heating of the furnace plenum because of loss of the cold top during extended idle apparently melted existing wall accretions, which likely were composed of material used to preheat the furnace. That material, consisting of 13% silica, 45% calcia, 33% alumina, and 5% titania derived from a rutile mineral concentrate, provided increased calcia and alumina by addition and decreased silica, soda, and boria by dilution. The rutile concentrate contained other heavy minerals including chromite, which is likely the source of increased Cr in the glass. Another obvious source of Cr that cannot be overlooked is ruby refractory from the hearth.
- Analyses of products recovered from the APCS also confirm vaporization of soda and boria, which were collected in the base of the thermal oxidizer as a molten glass and in the cyclone and baghouse as finely divided solids. The thermal oxidizer and ducts leading to the thermal oxidizer, which were lined with a castable refractory containing 80% alumina, were maintained at about 982 °C (1800 °F) by a combination of three natural gas burners. Material collected in the base of the thermal oxidizer contained more than 37% alumina, testimony to the corrosive nature of the condensates. An estimated 34 kg (75 lb) of castable refractory was dissolved by about 39 kg

Figure 3-7. Concentration of Major Species in WHC1 and WHC2 Glasses.

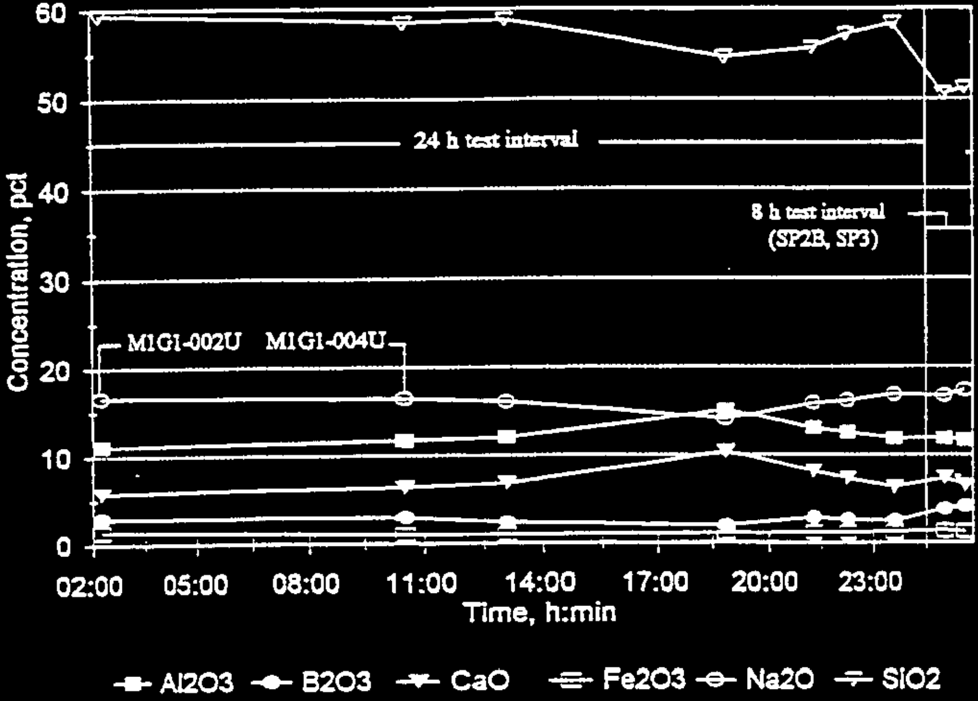
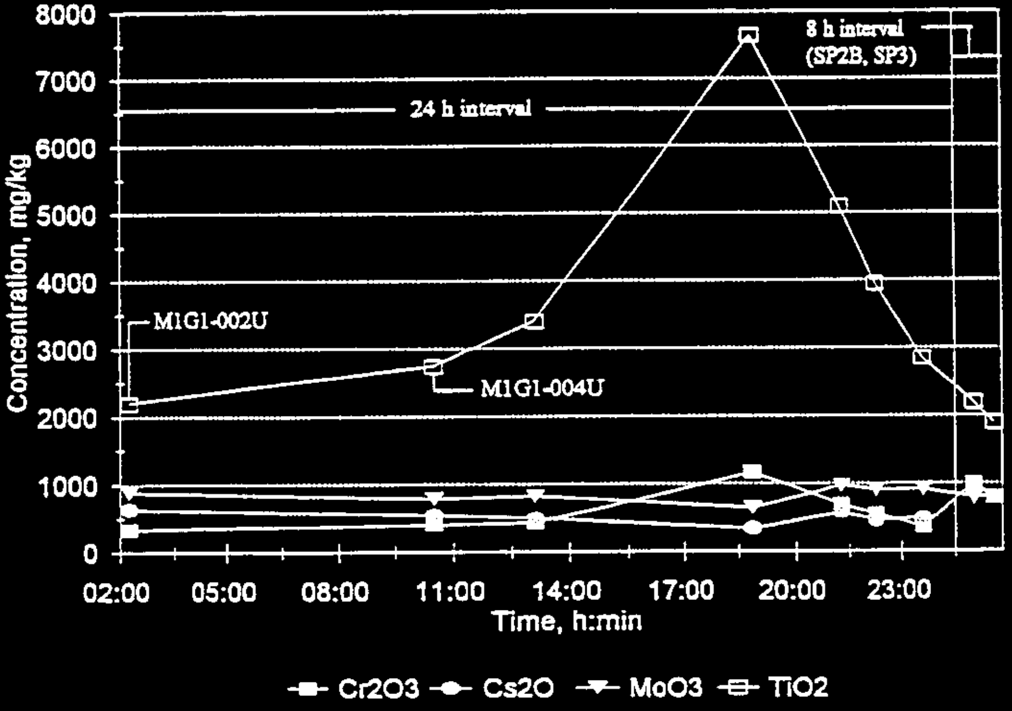


Figure 3-8. Concentration of Minor Species in WHC1 and WHC2 Glasses.



(86 lb) of condensates. These data, although not complimentary to the system as presently constructed, are important design considerations for a facility that processes radioactive wastes.

- Glass temperature varied over the narrow range of 1600 °C ± 100 °C (2912 °F ± 180 °F) which was excessive by any standard. Correlation between glass composition and tapping temperature is tenuous because of the narrow range of temperatures investigated. Vaporization of Na, B, and other volatile species correlates strongly with time indicating that mass transfer by convection of liquid glass to the superheated zone within the electrode triangle is the rate-controlling step.

3.3.5 Mass Balance

The analytical data were applied to calculate mass balances for furnace products and feed components as oxides or elements of greatest interest in the LLW simulant. The derived data listed in Table 3-6 calculated on the basis of 11.1% offgas indicate good closure for furnace products with about 85% of the feed reporting to the glass. Reasonable closure is indicated for major components soda and silica. However, closure is extremely poor for all minor components, which include the volatile materials. From 12% to 50% of the volatile components are unaccounted for in the glass and APCS solids, and no explanation is available for this important discrepancy. These components are potential problems for any melting technology, but should have been captured as solid particulate in the baghouse. Chromium was obviously an undetected or un-analyzed component of feed materials or was generated within the furnace by dissolution of ruby refractory from the hearth. The volatile components did not appear in the scrubber solution (Table 3-3) in adequate concentrations to change the material balance.

The mean concentration of volatile species in the product glass (samples M1G1-002, -004, and -005), which is the most representative concentration for each component at steady-state melting conditions using 10.16-cm (4-in.) electrodes, and the values for M1G1-008, which is the worst case glass sample, are compared in Table 3-7 with the composition for Method B glass calculated using the analyzed soda concentration in the LLW simulant (8.85 M Na). The analyses indicate near quantitative vaporization of F within the furnace and significant vaporization of the other components in the best case scenario. Vaporization losses were even greater for glass remaining after the demonstrated hot idle. These observations were the impetus for conducting an additional melting test using lower input power and lower electrode voltage.

3.3.6 Glass Quality

- Chemical analysis of glass samples M1G1-002, -004, -005, -008, -010, -011, and -012 by Corning, the U.S. Geologic Survey, and PNL failed to detect the presence of ferric iron, thereby indicating extremely reducing conditions within the electric furnace.

Table 3-6. Mass Balance Over WHC1-1995.

Saved as WHC1-MB.WB1

Mean concentration in feed and furnace products: pct (1)

	B_2O_3	Cr_2O_3	Cs_2O	K_2O	MoO_3	Na_2O
Feed	4.44	0.01	0.12	1.21	0.13	16.50
Glass	2.65	0.05	0.05	0.87	0.02	15.92
Thermal oxidizer	15.95	0.02	0.01	0.56	0.10	21.70
Cyclone	24.10	0.01	0.88	4.42	0.43	33.40
Baghouse	22.60	0.01	1.02	5.18	0.48	34.20

Component mass balance

Product mass balance			B_2O_3		Cr_2O_3		Cs_2O		K_2O		MoO_3		Na_2O	
Product	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct
Glass	10987	84.82	291.16	50.62	5.32	347.89	5.36	35.08	95.10	60.52	2.45	14.55	1749.13	81.83
Th. Ox.	97	0.75	15.47	2.69	0.02	1.36	0.01	0.03	0.54	0.34	0.09	0.56	21.05	0.98
Cyclone	40	0.31	9.64	1.68	0.01	0.37	0.35	2.31	1.77	1.13	0.17	1.03	13.36	0.63
Baghouse	645	4.98	145.77	25.34	0.09	6.12	6.59	43.10	33.41	21.26	3.07	18.25	220.59	10.32
Missing(2)	-253	-1.95	113.12	19.67	-3.91	-255.74	2.98	19.48	26.31	16.74	11.05	65.61	133.28	6.24
Offgas(3)	1438	11.10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total product	12954	100	575.16	100.00	1.53	100.00	15.29	100.00	157.13	100.00	16.84	100.00	2137.41	100.00
Total feed	12954		575.16		1.53		15.29		157.13		16.84		2137.41	

Mean concentration in feed and furnace products: pct (1)

	P_2O_5	SO_3	SiO_2	Cl	F	I
Feed	0.17	1.27	48.80	0.29	0.04	0.12
Glass	0.08	0.16	57.03	0.07	0.03	0.01
Thermal oxidizer	0.36	0.00	12.10	0.01	0.01	0.00
Cyclone	0.50	10.35	9.43	1.50	0.18	0.72
Baghouse	0.51	13.05	9.62	1.99	0.19	1.04

Component mass balance

Product mass balance			P_2O_5		SO_3		SiO_2		Cl		F		I	
Product	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct
Glass	10987	84.82	8.60	39.77	17.36	10.53	6265.89	99.12	7.37	19.90	3.37	65.10	0.66	4.42
Th. Ox.	97	0.75	0.35	1.60	0.00	0.00	11.74	0.19	0.00	0.01	0.01	0.19	0.00	0.00
Cyclone	40	0.31	0.20	0.92	4.14	2.51	3.77	0.06	0.60	1.62	0.07	1.39	0.29	1.93
Baghouse	645	4.98	3.28	15.18	84.17	51.04	62.05	0.98	12.84	34.65	1.24	23.96	6.68	44.73
Missing(2)	-253	-1.95	9.20	42.53	59.23	35.92	-21.89	-0.35	16.24	43.82	0.49	9.37	7.30	48.92
Offgas(3)	1438	11.10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total product	12954	100	21.63	100.00	164.90	100.00	6321.55	100.00	37.05	100.00	5.18	100.00	14.92	100.00
Total feed	12954		21.63		164.90		6321.55		37.05		5.18		14.92	

1. Calculated from mean concentration of furnace feeds and products by analysis.
2. Material not accounted for.
3. Calculated from best estimate for LOI of A and B furnace feeds.

Table 3-7. Loss of Glass Components by Vaporization.

Component	Calculated glass composition	Mean M1G1- -002, -004, -005	% decrease	M1G1-008	% decrease
Na_2O	18.66	16.23	13.0	14.12	24.3
B_2O_3	5.17	2.86	44.7	1.97	61.9
K_2O	1.45	1.01	30.3	0.60	58.6
MoO_3	0.13	0.084	35.4	0.06	53.8
P_2O_5	0.19	0.082	55.9	0.06	67.7
SO_3	0.20	0.320	Gain	0.13	35.0
Cl	0.32	0.078	75.6	0.04	87.5
F	0.26	0.03	88.5	0.025	90.4

- X-ray diffraction of glass samples M1G1-004, -005, -008, -010, and -012 by the USBM's Analytical Laboratory and samples M1G1-008P and -011P by PNL indicated that the samples were entirely amorphous.

- X-ray diffraction of samples M1G1-008 and -011 by PNL detected 1% maximum of metallic Mo, which was shown by scanning electron microscopy (PNL analysis) to be distributed throughout the glass as fine particles about 1 μm in diameter. Metallic Mo likely originated by reduction of the oxide which was a component of the LLW simulant.

- Petrographic analysis of glass samples M1G1-004, -005, -008, and -011 by Corning revealed <1% solid inclusions described as multi-lamellar color cords indicating inhomogeneity on a micron scale. Scanning electron microscope/energy-dispersive X-ray (SEM/EDX) analysis by the same laboratory revealed K, Na, Mo, and Cl enrichment within the cords at the expense of Si, Ca, Al, Ti, and Fe. Enrichment of the cords, which constitute the minor phase, with volatile components in the feed is consistent with the condensation of vapors on the water-cooled walls of the furnace plenum. The condensate would be expected to flow down the furnace walls onto the surface of the glass to form a thin surface layer, which would exit the tap hole with the glass to form stringers of cords in the glass.

- The product consistency test (PCT) was performed on samples listed in Table 3-8 by the indicated contract laboratories and by the USBM. The USBM's results are consistent with results of the other laboratories. The data confirm durability of the glass in excess of minimum standards, as anticipated in light of the fact that Na, B, and K concentrations in the glass were less than target levels.

Table 3-8. Mean Normalized Elemental Release Rates in Product Consistency Test Leachate (g/m^2/day).

Sample no.	pH leachate	Silicon	Boron	Sodium	Potassium
M1G1-004C	11.3	0.010	0.014	0.019	0.011
M1G1-004U	11.1	0.012	0.015	0.052	0.011
M1G1-005C	11.3	0.010	0.011	0.018	0.010
M1G1-005U	11.1	0.011	0.012	0.047	0.010
M1G1-008C	11.1	0.007	0.009	0.011	0.008
M1G1-008U	10.7	0.007	0.007	0.026	0.000
M1G1-008P	10.8	0.009	0.009	0.029	0.000
M1G1-011C	11.3	0.009	0.013	0.018	0.011
M1G1-011U	11.1	0.010	0.013	0.046	0.011
M1G1-011P	11.1	0.012	0.016	0.049	0.000

4.0 MELTING TEST WHC2-1995

4.1 PRETEST PREPARATIONS

The following problems recognized during WHC1 were investigated as described in the Operating Procedures for Melting Test WHC2-1995 (see Appendix E).

The rate of heat transfer from molten pool to feed material is the slow step determining the melt-in rate for an EAF operating in non-open arc conditions, and hence the maximum power and glass temperature commensurate with acceptable vaporization of feed components are desired operating conditions. Before the 24-hour demonstration test, the power supply was configured with 250-kVA transformers in the circuit and internal shunts of the 800-kVA transformer connected to supply electrode voltage over the range of 240 to 350 V measured phase-to-phase, which was optimum for the high-silica glasses and slags successfully melted in previous tests of INEL buried wastes. The minimum power under that configuration of the power supply proved to be excessive for the highly conductive high-Na glasses under all conditions of electrode position. The following step was taken to decrease electrode voltage, given that some superheating of molten material within the electrode triangle is essential to sustain the temperature of glass at the tap hole above that necessary to provide adequate fluidity.

- Reconfigured the power supply to remove 250-kVA transformers from the circuit, which decreased electrode voltage on Tap D from 240 V to about 100 V phase-to-phase and decreased minimum power to the furnace on transformer Tap D from 425 to 100 kW.

Temperature in the APCS duct downstream of the wind box should exceed 120 °C (250 °F) to avoid condensation of acid gases within the baghouse. Such was not the case during WHC1 because of the high moisture level introduced into the furnace offgases by the natural gas burners and the EGC system.

- Installed natural gas-fired heater with heat exchanger in the cooling air duct downstream of the cooling air valve to preheat the baghouse and maintain gas temperatures to at least 120 °C (250 °F).

4.2 TEST CONDITIONS AND DETAILED CHRONOLOGY OF EVENTS

Operating Procedures for WHC2 were followed without significant exception. The furnace was started on a hearth full of glass from WHC1, and the hearth was not tapped at the end to improve heat retention in preparation for INEL and IWPF melts to follow. To estimate material balance, the quantity and composition of glass initially within the furnace was assumed to be identical to glass left in the furnace at the end of the test.

Figures 4-1 (furnace power), 4-2 (feed rate), 4-3 (product glass temperature by optical pyrometer), and 4-4 (stack gas flow rate) will assist the reader to follow events during WHC2.

Figure 4-1. Furnace Power During WHC2-1995.

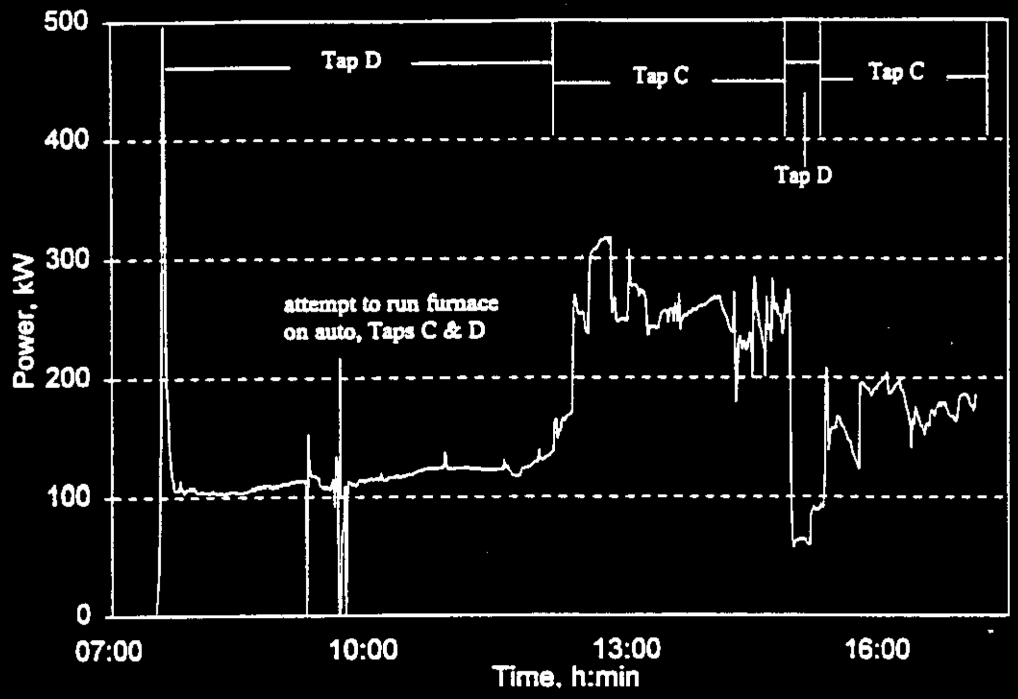


Figure 4-2. Feed Rate During WHC2-1995.

Figure 4-3. Glass Temperature by Optical Pyrometer During WHC2-1995.

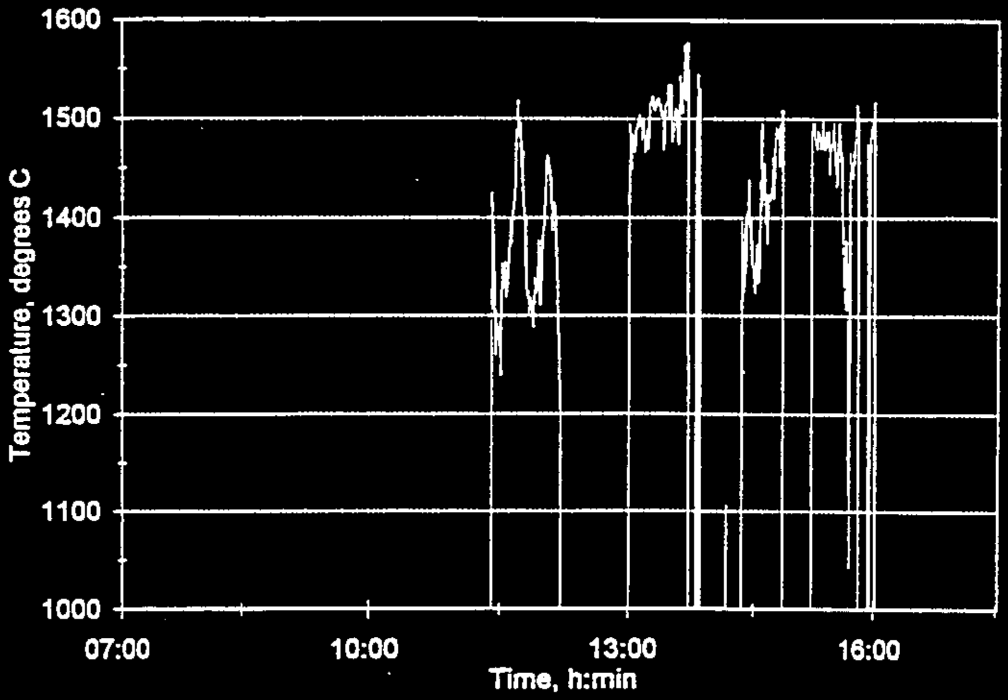
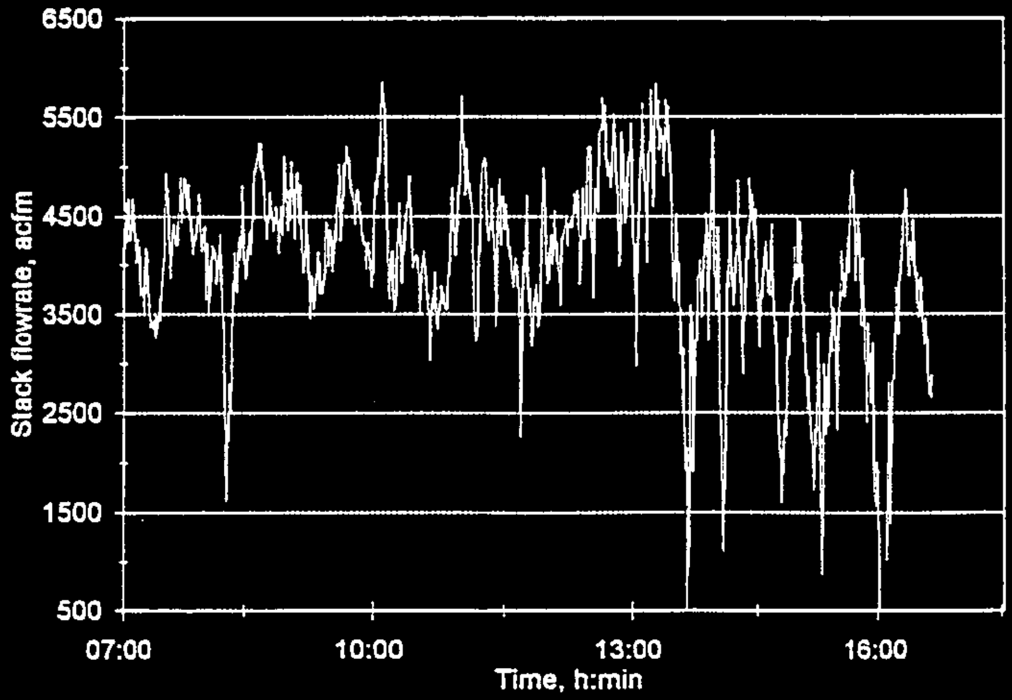


Figure 4-4. Stack Gas Flow Rate During WHC2-1995.



04-10-95

0400 Started induced draft blower, cooling air blower, and baghouse heater with 150 °C (300 °F) set point to preheat ducting, cyclone, and baghouse above the dew point of acid gases. Prepared furnace with thermocouples in metal tap hole and graphite glass-tapping fixture, carbon circuit connecting electrodes on existing glass remaining in the furnace, and video camera in place on inspection port.

0735 Started furnace on transformer Tap D (60 V phase-to-neutral or 100 V phase-to-phase) with manual control. Power input on Tap D ranged from 100 to 130 kW.

0940 Attempted unsuccessfully to operate furnace with automatic control.

0946 Resumed manual control. Operator was instructed to maintain equal power in each phase, which is equivalent to automatic control.

1130 Contents of the furnace were molten to the hearth.

1135 Began feeding and melting Method B feed.

1223 Changed to Tap C for remainder of test. Power input on Tap C ranged from 150 to 250 kW with a short excursion to 318 kW.

1230 Began filling glass mold WHC2-SP1, glass temperature by optical pyrometer 1375 °C (2507 °F); collected glass sample at 1420.

1435 Began filling glass mold WHC2-SP2; collected glass sample WHC2-SP2A at 1535 and WHC2-SP2B at 1555.

1445 APCS plugged in water-cooled section of exhaust duct immediately below analysis port because of presence of analytical probe. Probe was removed and the plug was partially removed by steel rod through burner port. Increased output of burner 1 to 90%, but plug reformed quickly. Offgas exit duct remained impaired or plugged for the remainder of the test.

1555 Began filling glass mold WHC2-SP3; collected glass sample at 1630.

1724 Terminated test without draining the furnace to improve heat retention in preparation for INEL and IWPF melting tests the following day.

4.3 TEST RESULTS

Sampling was conducted as specified in the Operating Procedures, and samples listed in Table 4-1 were analyzed by the indicated laboratories.

Table 4-1. Sample Log for WHC2-1995.

Sample number	Date	Time sampled	Sample matrix	Sample point	Analytical Laboratory
WHC2-SP1	04-10-95	1420	Product glass	Furnace glass tap	USBM
WHC2-SP2A	04-10-95	1535	Product glass	Furnace glass tap	USBM
WHC2-SP2B	04-10-95	1555	Product glass	Furnace glass tap	USBM and PNL
WHC2-SP3	04-10-95	1630	Product glass	Furnace glass tap	USBM and PNL

PNL = Pacific Northwest Laboratory
USBM = U.S. Bureau of Mines

Significant improvements were obtained by melting at lower electrode voltage, as indicated by the glass analyses in Table 4-2 and mass balance over furnace products in Table 4-3.

- On the basis of glass production, 88.3% of materials in the feed reported to the glass, a modest improvement over WHC1.

- Comparison of the data in Table 4-2 with analyses for WHC1 glass samples in Table 3-5 indicates significant improvement in retention of volatile species in the glass with lower electrode voltage. Boria increased from 2.65% to 3.80% and soda increased from 15.92% to 17.54% where values are averages over the analyses. More detailed comparison of results is provided in Section 6.0.

- Vaporization losses in terms of condensible solids collected in the cyclone and baghouse decreased from about 6% of feed for WHC1 to 0.6% for WHC2. This number is not consistent with vaporization losses based on Na and B concentrations in product glasses. On the latter basis, 24.4% of the boria and 6.1% of the soda were not accounted for in product glass.

- Product glass was tapped at temperatures ranging from 1350 °C (2462 °F) to about 1525 °C (2777 °F), which is more than 100 °C (212 °F) lower than experienced for WHC1 (compare Figures 3-3 and 4-3).

- Energy consumption during 1.5 hours of steady-state operation was 0.98 kW.h/kg (0.45 kW.h/lb) feed, and mean energy consumption during WHC2 was 1.05 kw.h/kg (0.48 kW.h/lb) feed or 1.15 kW.h/kg (0.52 kW.h/lb) glass, which indicates significant improvement of electrical efficiency at lower electrode voltage.

- Electrode consumption was determined over the entire melting campaign during which 4,670 kW.h of electrical energy was used and 9,202 kg (20,287 lb) of material was melted including 455 kg (1,000 lb) of LD6-5510 glass remaining in the furnace, 1,088 kg (2,394 lb) of Method B, 2,013 kg (4,428 lb) of calcia alumina silicate, and 5,666 kg (12,465 lb) of INEL and IWPF materials. Consumption was extremely high, 25 kg/tonne (55 lb/tonne) feed or 49.3 kg/MW.h (109 lb/MW.h) because of feed chemistry and one overnight hold with a hot furnace. The INEL and IWPF materials contained up to 90% combustibles and up to 26% chlorine.
- Offgases (noncondensible species) were determined experimentally in WHC2 to be 11.1% of furnace feed, in good agreement with the value estimated from laboratory investigations.

These data were sufficiently encouraging to justify an additional melting test with further refinement of the furnace and operating procedures.

Table 4-2. Composition of Product Glass for WHC2-1995.

Saved as WHC2&3.WB1

	Components as oxides and elements										
	Al2O3	B2O3	BaO	Cl	CaO	Cr2O3	Cs2O	F	FeO	Fe2O3	K2O
WHC2-SP1M(1)	NA	3.19	NA	NA	NA	NA	NA	NA	NA	NA	NA
WHC2-SP2AM(1)	NA	3.48	NA	NA	NA	NA	NA	NA	NA	NA	NA
WHC2-SP2BM(1)	NA	3.80	NA	NA	NA	NA	NA	NA	NA	NA	NA
WHC2-SP2BP(2)	11.89	3.85	0.01	NA	7.370	0.10	NA	NA	0.926	0.000	3.620
WHC2-SP3M(1)	NA	4.34	NA	NA	NA	NA	NA	NA	NA	NA	NA
WHC2-SP3P(2)	11.71	4.16	0.01	NA	6.530	0.08	NA	NA	0.848	0.000	4.250
Mean	11.8	3.80	0.01	NA	6.95	0.09	NA	NA	0.887	0	3.935

	Components as oxides and elements									
	MgO	MnO2	MoO3	Na2O	P2O5	SO3	SiO2	SrO	TiO2	ZrO2
WHC2-SP1M(1)	NA	NA	NA	16.85	NA	NA	NA	NA	NA	NA
WHC2-SP2AM(1)	NA	NA	NA	17.93	NA	NA	NA	NA	NA	NA
WHC2-SP2BM(1)	NA	NA	NA	18.20	NA	NA	NA	NA	NA	NA
WHC2-SP2BP(2)	0.41	0.02	0.08	16.66	0.270	0.90	50.49	0.12	0.22	0.05
WHC2-SP3M(1)	NA	NA	NA	18.20	NA	NA	NA	NA	NA	NA
WHC2-SP3P(2)	0.39	0.02	0.08	17.40	0.320	1.01	51.22	0.12	0.19	0.01
Mean	0.40	0.02	0.08	17.54	0.295	0.96	50.86	0.12	0.21	0.03

1. Analysis by USBM, single determination.
2. Analysis by PNL, mean of two determinations: KOH fusion in Ni crucible (no analysis for K) and Na2O2 fusion in Zr crucible (no analysis for Na).

Table 4-3. Product Mass Balance Over WHC2-1995.

Product	Wt (lb)	%
Glass	2,114	88.3
Thermal oxidizer	0	0
Cyclone	0.6	0.03
Baghouse	12.9	0.54
Offgas	266	11.1
Total furnace feed	2,394	100

5.0 MELTING TEST WHC3-1995

5.1 PRETEST PREPARATIONS

High glass temperature, low melt-in rate for a given power input, and excessive vaporization of volatile components are deficiencies related to electrode power density, which is proportional to the inverse square of the electrode diameter. The present furnace cannot accept electrodes larger than 10.16 cm (4 in.) through the roof, but there is adequate space in the plenum for larger working ends on the electrodes. To this end, graphite stubs 20.32 cm (8 in.) in diameter by 30.48 cm (12 in.) long were installed on the working end of each 10.16-cm (4-in.) electrode to decrease the energy density by one-fourth for a given current and voltage. The top of each stub was drilled and tapped 10.16 cm (2 in.) off center to accept male threads (3-in. UNC threads, four threads per inch) on the 10.16-cm (4-in.) electrode so that the surfaces of 10.16-cm (4-in.) electrode and 20.32-cm (8-in.) stub were coincident at one point on the circumference. Orientation of each electrode so that a radius from the center of the electrode triangle passed through the center of each 20.32-cm (8-in.) stub decreased electrode spacing the minimum distance: 18.41 cm (7.25 in.) with 10.16-cm (4-in.) electrodes to 17.14 cm (6.75 in.) with 20.32-cm (8-in.) electrodes.

Injection of air or oxygen beneath the surface of the molten glass is a potentially useful means to increase the oxygen potential of the glass. Oxidation of metal within the furnace also has important application if the feed contains metals and tapping of metal is undesirable. These applications were investigated by injecting oxygen through a lance and porous plug during the preheat portion of the test. An air-cooled stainless steel lance was prepared and cemented into the center drain of the furnace, and a 15.2-cm (6-in.) long porous plug of coarse alumina aggregate was placed in the drain hole between lance and hearth to prevent glass or metal from contacting the lance.

Graphite inserts with central holes 1.27, 1.59, and 1.91 cm (0.50, 0.62, and 0.75 in.) were prepared to investigate throttling of the tapping rate as a means to obtain continuous tapping at low melting rates.

The heated exhaust ducts, thermal oxidizer, and EGC system were essential for processing INEL materials because of the combustible and corrosive nature of the exhaust gases and fumes but unnecessary and even a disadvantage for the present materials. Therefore, the natural gas burners were removed from the APCS; slide gates were installed in burner ports 2 and 3; and a removable plate was installed in burner port 1. The slide gates were adjusted to allow cooling air to enter the APCS, and provided access to the exit duct to remove condensate should the duct become plugged during operation. These and other problems recognized during WHC2 were investigated as described in Operating Procedures for Melting Test WHC3-1995 (see Appendix F).

5.2 TEST CONDITIONS AND DETAILED CHRONOLOGY OF EVENTS

Operating procedures were followed without significant alteration. Figures 5-1 (furnace power), 5-2 (feed rate), and 5-3 (product glass temperature by optical pyrometer) will assist the reader to follow the chronology.

05-03-95

0500 Energized APCS console and performed startup procedures as stated in the Operating Procedures, Section 2.3. Loaded furnace with 45 kg (98 lb) of carbon steel punchings and about 455 kg (1,000 lb) of crushed glass from the previous melt of INEL soil and waste mixtures, and prepared a triangular path of crushed graphite connecting the electrodes.

0730 Started 0.31 L/s (40 cfh) argon flow through lance to maintain porosity of ceramic plug.

0735 Started furnace on transformer Tap D (60 V phase-to-neutral or 100 V phase-to-phase) with manual control. Power input on Tap D ranged from 100 to 130 kW.

0737 Increased transformer tap to C to increase power to about 250 kW.

1028 Initiated tapping of glass, and began filling preheat glass mold PH-SP1.

1035 Replaced argon with 0.14 L/s (17.4 cfh) oxygen to oxidize 2.4 kg/h (5.2 lb/h) Fe to FeO.

1051 Converted flow back to argon.

1102 Added 91 kg (200 lb) of carbon steel punchings through the rotary air lock.

1105 Reestablished continuous tapping; glass temperature 1485 °C (2705 °F).

1114 Replaced argon flow with oxygen at flow rate 0.31 L/s (39 cfh) to oxidize 5.4 kg/h (11.8 lb/h) Fe.

1223 Increased oxygen flow to 0.62 L/s (79 cfh) to oxidize 10.9 kg/h (24.0 lb/h) Fe.

1230 Began filling glass mold PH-SP2.

1245 Began filling glass mold PH-SP3.

1324 Increased oxygen flow to 0.99 L/s (126 cfh) to oxidize 17.4 kg/h (38.3 lb/h) Fe.

1350 Interrupted PH-SP3 to begin filling instrumented 55-gal barrel to determine cooling rate.

1353 Increased oxygen flow to 1.44 L/s (183 cfh) to oxidize 25.2 kg/h (55.5 lb/h) Fe.

1409 Oxygen lance failed by burning; oxygen injection test was terminated.

1448 Completed filling of barrel instruments to determine cooling rate; glass flow was diverted to PH-SP3.

1530 Began filling glass mold PH-SP4.

1637 Opened bottom drain to empty furnace; glass molds PH-MT 1 and PH-MT 2 were filled. Glass and metal remaining in the center drain were adequate to seal the hole.

1646 Began feeding Method B pellets to the hot furnace with transformer energized on Tap C.

1651 Established electrical contact with the molten pool; maintained 250 kW.

1833 Molten glass level to tap hole, but no tap; removed 1.27-cm (0.5-in.) graphite insert from tapping fixture. The other graphite inserts were not investigated.

1842 Established continuous tapping of glass at 1400 °C (2552 °F), and began filling glass mold WHC3-SP1.

1853 Collected glass sample WHC3-SP1A.

1905 Increased power to range 325 to 375 kW; maintained 30-cm (12-in.) cold top of unmelted charge.

1955 Collected glass sample WHC3-SP1B.

2015 Collected glass sample WHC3-SP1C.

2017 Realized that cold top had become semi-molten and electrically conductive; only intermittent tapping was possible.

2020 Added 45 kg (100 lb) of CaO through rotary air lock to fluidized glass and increase depth of molten pool.

2042 Collected glass sample WHC3-SP1D.

2119 Collected glass sample WHC3-SP1E.

2122 Added 38 kg (83 lb) of CaO through rotary air lock.

2145 Began filling glass mold WHC3-SP2; collected glass sample WHC3-SP2 at 2155.

2148 Added 55 kg (120 lb) of CaO through rotary air lock.

2148	Started continuous tapping; glass temperature about 1500 °C (2732 °F).
2200	Began filling glass mold WHC-SP3; collected glass sample at 2215.
2210	Attempted 250 kW steady state with cold top <5 cm (2 in.); feed rate 211 kg/h (464 lb/h).
2220	Began filling glass mold WHC3-SP4.
2230	Collected glass sample WHC3-SP4A.
2255	Collected glass sample WHC3-SP4B.
2308	Began filling glass mold WHC3-SP5; collected glass sample at 2334.
2349	Established 15 cm (6 in.) cold top; feed rate about 364 kg/h (800 lb/h).
05-04-95	
0021	Began filling glass mold WHC3-SP6.
0040	Power off for 13 minutes to clear exit duct.
0042	Collected glass sample WHC3-SP6A.
0130	Collected glass sample WHC3-SP6B. All Method B and A feed in furnace; cold top completely melted.
0145	Opened bottom drain to empty furnace; glass temperature 1445 to 1490 °C (2633 to 2714 °F). Filled glass molds WHC3-MT1 and WHC3-MT2.
0152	Terminated test.

5.3 TEST RESULTS

Experiments to oxidize iron within the furnace were conducted during the melt of INEL product glass. Oxygen was injected in 20-minute intervals at rates equivalent to oxidize 2.4, 5.4, 10.9, 17.4, and 25.2 kg/h (5.2, 11.8, 24.0, 38.3, and 55.5 lb/h) of iron to the ferrous state. The experiment successfully demonstrated that oxygen can be injected into the molten pool without perturbing the furnace. Further development of the lance is needed as indicated by failure of the stainless steel model during the attempt to oxidize 25.2 kg/h (55.5 lb/h) of iron.

Sampling of furnace products during WHC3 was conducted as specified in the Operating Procedures. Samples listed in Table 5-1 were analyzed by the USBM's Analytical Laboratory. The results, listed in Table 5-2, provide the best description of process conditions to date.

Figure 5-1. Furnace Power During WHC3-1995.

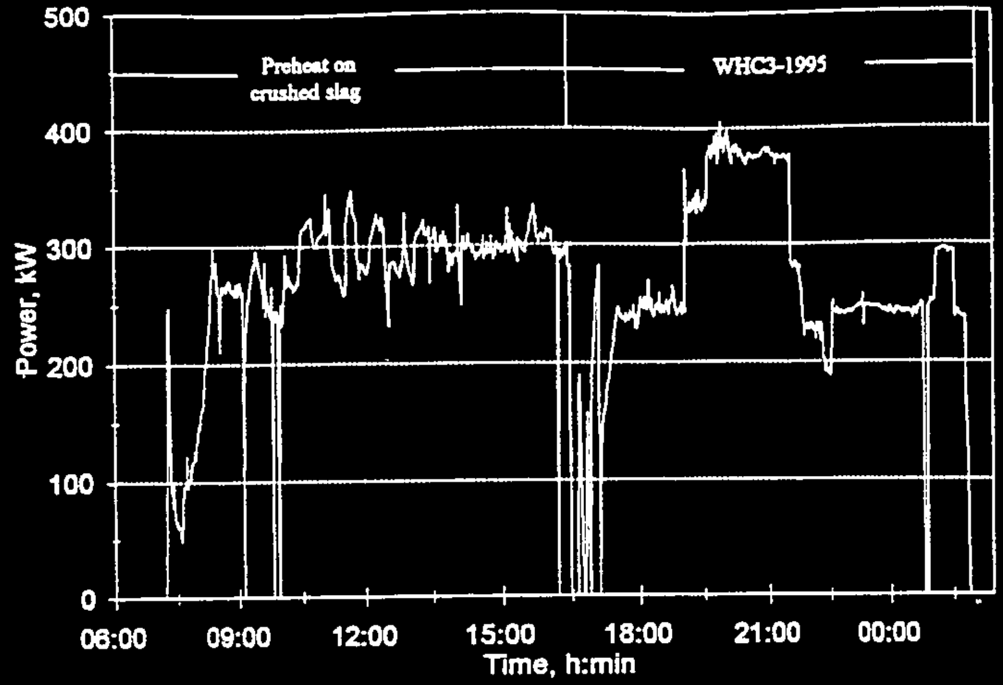


Figure 5-2. Feed Rate During WHC3-1995.

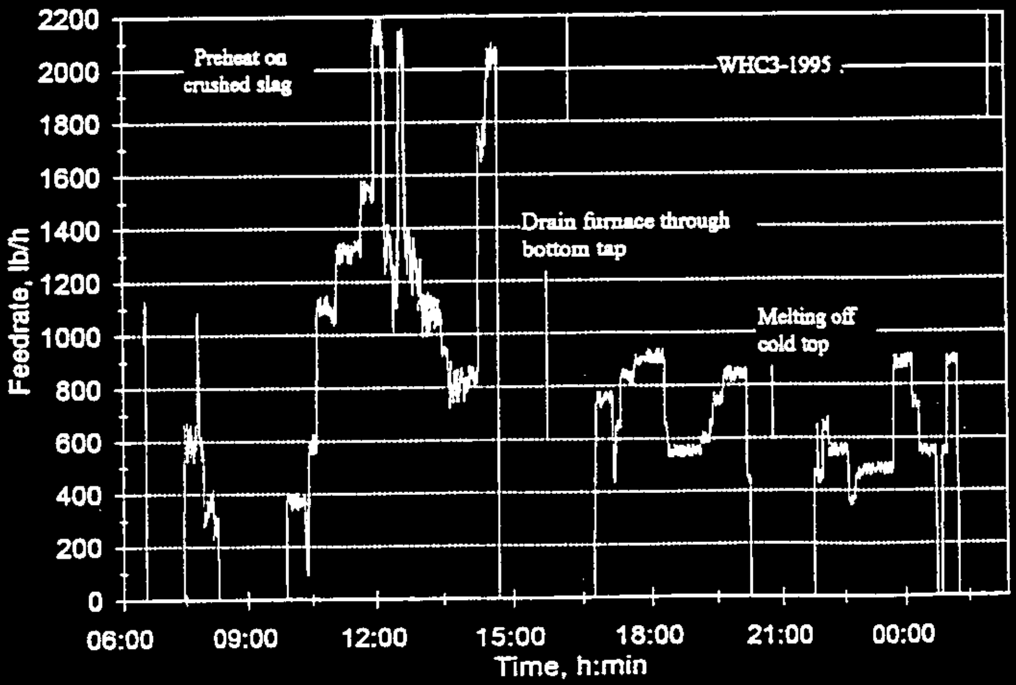


Figure 5-3. Glass Temperature by Optical Pyrometer During WHC3-1995.

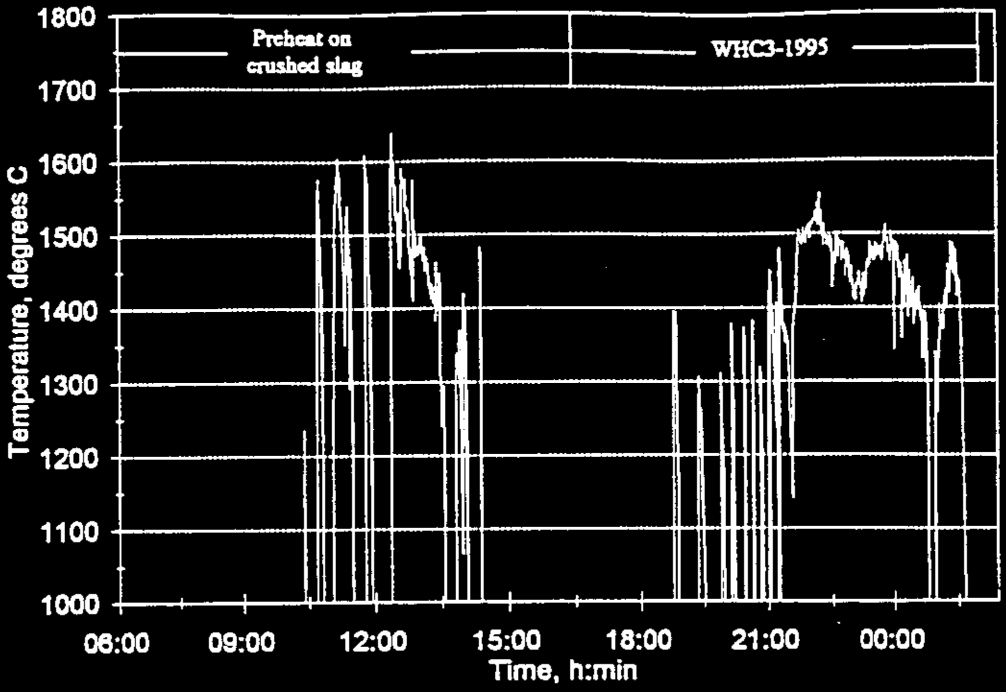


Table 5-1. Sample Log for WHC3-1995.

Sample number	Date	Time sampled	Sample matrix	Sample point	Analytical Laboratory
WHC3-SP1B	05-03-95	1955	Product glass	Furnace glass tap	USBM
WHC3-SP1D	05-03-95	2045	Product glass	Furnace glass tap	USBM
WHC3-SP1E	05-03-95	2144	Product glass	Furnace glass tap	USBM
WHC3-SP6A	05-04-95	0042	Product glass	Furnace glass tap	USBM
WHC3-C7	05-03-95	2350	Cyclone solids	Cyclone	USBM
WHC3-B7	05-03-95	2350	Baghouse solids	Baghouse	USBM

USBM = U.S. Bureau of Mines

Table 5-2. Composition of Furnace Products for WHC3-1995.

	Components as oxides and elements										
	Al_2O_3	B_2O_3	BaO	Cl	CaO	Cr_2O_3	Cs_2O	F	FeO	Fe_2O_3	K_2O
WHC3-SP1BM(1)	10.22	4.02	0.01	0.013	7.25	0.08	0.099	0.001	1.40	0.00	1.25
WHC3-SP1DM(1)	10.05	4.25	0.01	0.010	7.81	0.06	0.096	0.001	1.38	0.00	1.27
WHC3-SP1EM(1)	9.79	3.73	0.01	0.005	13.43	0.07	0.082	0.002	1.42	0.00	1.19
WHC3-SP6AM(1)	9.67	4.02	0.01	0.010	12.34	0.07	0.097	0.002	1.13	0.00	1.25
Mean	9.93	4.01	0.01	0.010	10.21	0.07	0.094	0.002	1.33	0.00	1.24
WHC3-C7M(1)	3.95	11.46	0.01	2.81	8.33	0.02	0.937	0.025	1.36	0.00	3.05
WHC3-B7M(1)	0.46	8.14	0.01	15.80	4.76	0.02	1.993	0.120	0.62	0.00	9.19

	Components as oxides and elements									
	MgO	MnO_2	MoO_3	Na_2O	P_2O_5	SO_3	SiO_2	SrO	TiO_2	ZrO_2
WHC3-SP1BM(1)	0.42	0.020	0.077	18.20	0.12	0.02	54.55	NA	0.19	0.04
WHC3-SP1DM(1)	0.39	0.020	0.078	18.74	0.10	0.02	55.62	NA	0.19	0.03
WHC3-SP1EM(1)	0.47	0.024	0.076	15.91	0.09	0.01	52.41	NA	0.21	0.04
WHC3-SP6AM(1)	0.41	0.019	0.106	19.55	0.09	0.01	51.77	NA	0.17	0.03
Mean	0.42	0.021	0.084	18.10	0.10	0.02	53.59	NA	0.19	0.04
WHC3-C7M(1)	0.34	0.017	0.219	17.39	0.27	8.67	41.07	NA	0.10	0.01
WHC3-B7M(1)	0.68	0.049	0.312	23.45	0.23	19.00	11.36	NA	0.01	0.00

1. Analysis by USBM, single determination.

- Comparison of analyses for WHC2 glass samples in Table 4-2 with WHC3 glass samples in Table 5-2 indicates significant improvement in retention of volatile species in the glass with larger electrodes, with 92.7% of materials in the feed reporting to product glass (7.34% loss). This value is likely incorrect and indicates carryover of material from the melt of INEL glass that preceded WHC3 to preheat the furnace. Based on an estimated 11.1% loss, carryover was 96 kg (211 lb).

- Boria in product glass increased from 3.8% to 4.0% and soda increased from 17.54% to 18.10%, where analyses are mean values over four samples analyzed.

- Volatile species including B, Cs, Mo, K, P, the halogens, and S that were depleted in the glass appeared as particulate in cyclone and baghouse solids. Accountability for those components in glass and APCS solids is B 90.5%, Cs 85.1%, Mo 60.1%, P 54.9%, S 15.0%, Cl 50.9%, F 5.7%, and I 0%.

- Species carried from the furnace as entrained particulate, including Al and Si, appeared in larger proportion in cyclone solids than in baghouse solids. Boron, known to form volatile suboxides, also was more concentrated in cyclone solids, indicating that B exited the furnace as a complex species likely chemically associated with alumina or silica, or condensed from the vapor on those particles.

- Iron was observed in all furnace products in the ferrous state, indicating reducing conditions in the furnace.

X-ray diffraction analysis of product glass failed to detect the presence of crystalline phases.

Process conditions during the test provided the following additional observations:

- Product glass was tapped at temperatures ranging from 1480 °C (2696 °C) to about 1320 °C (2408 °F), which is more than 100 °C (180 °F) lower than experienced for WHC2.

- Energy consumption during 3 hours of steady-state operation was 0.95 kW.h/kg (0.43 kW.h/lb) feed, and mean energy consumption during WHC3 was 0.92 kW.h/kg (0.42 kW.h/lb) feed or 1.00 kW.h/kg (0.45 kW.h/lb) glass, a significant improvement over WHC2.

- Decreasing the diameter of the glass tap hole with graphite inserts was ineffective in achieving continuous tapping at the desired temperature. Heat loss with attendant increase in viscosity of the glass near the water-cooled tapping fixture is a problem better addressed by heating the tap hole or heating the glass at the entrance to the tap hole. The latter method is preferred to allow continued use of the copper tapping fixture.

- Electrode consumption was determined over the melt to preheat the furnace and WHC3. Total material melted (4,761 kg or 10,475 lb) comprised 2,073 kg (4,560 lb) INEL glass, 2,415 kg (5,312 lb) Method B and A feed, 138 kg (303 lb) lime, and 136 kg (300 lb) iron. Mean electrode consumption based on 4,915 kW.h of electrical energy used and 25.1 kg (55.3 lb) C loss from the 20.32-cm (8-in.) stubs was 5.28 kg/tonne (11.6 lb/tonne) feed or 5.40 kg/tonne (11.9 lb/tonne) based on glass and metal products. Total carbon loss including air burn from the 10.16-cm (4-in.) diameter supporting electrodes was 48.9 kg (107.5 lb).

Mass balance for furnace products and for important species in the LLW simulant using the percentage offgas determined experimentally for WHC2 (11.1%) is listed in Table 5-3.

- The calculations over furnace products, assuming 11.1% offgas, provide good closure and indicate about 89.3% of the feed reporting to the product glass and about 1% reporting to the cyclone and baghouse.
- About 1.4 kg (3 lb) of Cr was present in glass and APCS solids in excess of feed indicating corrosion of hearth refractory. The rate of refractory corrosion is estimated to be 0.22 mm/h on the basis of 10% chromium oxide in ruby, 16-hour exposure, and 1.1 m^2 exposed refractory surface.
- Soda, potacia, and silica also were present in glass in excess of feed, but the small disparities are explained by uncertainties in the analyses.
- 88.4% of the B and 70.8% of the Cs were accounted for in the glass. The latter observation is especially important to the design of a radioactive facility.
- 85.0% of the S and 50% of the Cl in the feed were unaccounted for in glass and APCS products indicating the existence of gaseous species passing through the baghouse.
- F and I were similarly unaccounted for in glass and APCS solids.
- Vaporization of Mo remained a problem, with 39.9% of the Mo in the feed unaccounted for in glass and APCS solids. Mo, if a good surrogate for Tc, indicates an impending challenge to retain Tc in the glass for all melting technologies.

These data derived from WHC3 confirm the advantage of large electrodes and low electrode current density. Additional improvements in glass-tapping temperature and retention of volatile species are anticipated with auxiliary heating at the entrance to the glass tap hole.

Table 5-3. Mass Balance Over WHC3-1995.

Saved as WHC3-MB.WB1

Mean concentration in feed and furnace products: pct (1)

	B2O3	Cr2O3	Cs2O	K2O	MoO3	Na2O
Feed	4.05	0.01	0.12	1.13	0.13	15.04
Glass	4.01	0.07	0.09	1.24	0.08	18.10
Cyclone	11.46	0.02	0.94	3.05	0.22	17.39
Baghouse	8.14	0.02	1.99	9.19	0.31	23.45

Product mass balance			Component mass balance											
			B2O3		Cr2O3		Cs2O		K2O		MoO3		Na2O	
Product	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct
Glass	5203	89.31	208.64	88.42	3.64	529.78	4.86	70.76	64.52	98.00	4.39	57.91	941.74	107.45
Cyclone	14	0.24	1.60	0.68	0.00	0.41	0.13	1.91	0.43	0.65	0.03	0.40	2.43	0.28
Baghouse	43	0.74	3.50	1.48	0.01	1.25	0.86	12.47	3.95	6.00	0.13	1.77	10.08	1.15
Missing(2)	-81	-1.38	22.21	9.41	-2.97	-431.44	1.02	14.86	-3.06	-4.65	3.02	39.91	-77.80	-8.88
Offgas(3)	647	11.10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total products	5826	100	235.95	100.00	0.69	100.00	6.87	100.00	65.83	100.00	7.57	100.00	876.46	100.00
Total feed(4)	5826		235.95		0.69		6.87		65.83		7.57		876.46	

Mean concentration in feed and furnace products: pct (1)

	P2O5	SO3	SiO2	Cl	F	I
Feed	0.17	1.16	46.20	0.26	0.04	0.12
Glass	0.10	0.02	53.59	0.01	0.00	NA
Cyclone	0.27	8.67	41.07	2.81	0.03	NA
Baghouse	0.23	19.00	11.36	15.88	0.12	NA

Product mass balance			Component mass balance											
			P2O5		SO3		SiO2		Cl		F		I	
Product	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct	Wt, lb	Pct
Glass	5203	89.31	5.20	53.48	0.78	1.15	2788.29	103.59	0.49	3.26	0.08	3.35	0.00	0.00
Cyclone	14	0.24	0.04	0.39	1.21	1.80	5.75	0.21	0.39	2.60	0.00	0.15	0.00	0.00
Baghouse	43	0.74	0.10	1.02	8.17	12.09	4.88	0.18	6.83	45.08	0.05	2.21	0.00	0.00
Missing(2)	-81	-1.38	4.39	45.12	57.42	84.96	-107.31	-3.99	7.43	49.06	2.20	94.29	6.71	100.00
Offgas(3)	647	11.10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total products	5826	100	9.73	100.00	67.58	100.00	2691.61	100.00	15.15	100.00	2.33	100.00	6.71	100.00
Total feed(4)	5826		9.73		67.58		2691.61		15.15		2.33		6.71	

1. Calculated from mean concentration of furnace feeds and products by analysis.
2. Material not accounted for.
3. Calculated from best estimate for LOI of furnace feeds.
4. Includes 5,312 lb A and B feed, 303 lb CaO added to fluidize the melt, and 211 lb carry over of INEL glass.

6.0 SUMMARY AND DISCUSSION

Liquid, low-level, high-Na LLW simulant was converted into dry denitrified furnace feed by mixing with readily available industrial minerals and common carbonaceous reductants in a straightforward series of operations. The resulting pelletized material constitutes ideal furnace feed for melting technologies that function optimally with dry feed. The material is homogeneous and free flowing with a melting temperature of about 950 °C (1742 °F). Two versions of the procedure were demonstrated.

The electric furnace is a versatile instrument, but the present furnace tends to be cumbersome because of its age. In retrospect, it would have been advantageous to stop the demonstration melting test and reconfigure the power supply to provide lower voltage, but scheduling requirements dictated that the test be continued. This test must be recognized not only as a demonstration of the 3-phase electric arc melting furnace, but also as a shakedown evaluation of a newly constructed APCS. A shorter test (WHC2-1995) of about 10-hour duration was conducted April 10, 1995, without cost to the vender to evaluate the effects of decreased electrode voltage and revised operating procedures. That test demonstrated more effective retention of volatile materials in the glass and continuous tapping of glass at about 100 °C (180 °F) lower temperature. Further increased performance was observed in a nominal 9-hour melting test conducted in April 1995 (WHC3-1995) during which 20.32-cm (8-in.) electrodes were evaluated. Current density over the larger electrodes was decreased by a factor of 4 for a given energy input, which decreased the value to the level successfully demonstrated in small-scale, 23-kg (50-lb), single-phase furnace tests. Retention of volatile species in the glass improved over the previous test, and glass temperature decreased an additional 100 °C (180 °F).

Injection of oxygen into the furnace through an orifice in the bottom center of the hearth was successfully demonstrated during the preheat stage of the last test, and oxidation of iron at rates to 25 kg/h (55 lb/h) was achieved. Oxidation of metal within the furnace by air or oxygen injection would eliminate the need to open the central tap hole to remove metal from the furnace if metals were present in the feed. Oxygen injection also could provide a more highly oxidized glass, with commensurate greater durability and resistance to leaching. Oxygen injection was done to fulfill an opportunity and was not required.

Table 6-1 provides a comparison of melting parameters and glass composition under steady-state conditions and a comparison of mean melting parameters for tests WHC1, WHC2, and WHC3-1995. The data conclusively indicate the continuing improvement of glass chemistry accomplished by decreasing electrode voltage and electrode current density through the use of larger electrodes. Retention of important volatile species in product glass also increased with improved processing conditions. Some species, principally S and the halogens, were not retained within the product glass or accounted for in APCS solids and were assumed to be present largely as gases.

Table 6-1. Comparison of Process Conditions and Test Results for WHC1, WHC2, and WHC3-1995.

Saved as WHCSS.wb1

Melting parameters under steady-state conditions								Mean melting parameters over test					
Test	Sample number	Time Begin/end	Power kW	Melt-in rate kg/m^2/h lb/ft^2/h	Glass temp, C	Electrode power(1) kW/cm^2 kW/in^2	Melting energy kW.h/kg kW.h/lb	Duration h	Melt-in rate kg/m^2/h lb/ft^2/h	Energy consumption kW.h/kg kW.h/lb		Electrode consumption(2)	
										Feed	Glass	kg/tonne lb/tonne	kg/MW.h lb/MW.h
WHC1-1995	M1G1-004(3)	0900-1030	429	304	1620	1.76	1.27	24	252(4)	1.63	1.92	9.9	6.55
				62		11.4	0.58		51(4)	0.74	0.87	21.8	14.4
WHC2-1995	WHC2-SP2B(5)	1530-1700	178	163	1480	0.73	0.98	9.75	142	1.05	1.61	25(6)	49(6)
				33		4.7	0.45		29	0.48	0.73	55(6)	109(6)
WHC3-1995	WHC3-SP6A(7)	2140-0040	241	228	1480 to	0.25	0.95	8.5	269	0.92	1.00	5.3	5.4
				47	1320	1.6	0.43		55	0.42	0.45	11.6	11.9

		Glass Composition, wt pct											
Test	Sample number	Al2O3	B2O3	CaO	Cl	Cs2O	F	FeO	K2O	MoO3	Na2O	P2O5	SO3
WHC1-1995	M1G1-004	11.70	3.02	6.41	0.08	0.055	0.03	1.11	1.02	0.08	16.8	0.08	0.40
WHC2-1995	WHC2-SP2B	11.89	3.83	7.37	NA	NA	NA	0.93	3.62	0.08	16.7	0.27	0.90
WHC3-1995	WHC3-SP6A	9.67	4.02	12.34	0.01	0.097	0.002	1.13	1.25	0.106	19.6	0.09	0.01

1. Assumes electrodes were submerged to depth of diameter/2.
2. Mean electrode consumption over entire melting campaign.
3. Best steady state feed rate and power input; B feed with cold top steady at 15 to 18 cm (6 to 7 in); continuous tapping of glass.
4. Omits 3 h to demonstrate stop/restart and extended idle.
5. Best steady state but APCS severely impared or plugged; B feed with cold top steady at 13 cm (5 in); continuous tapping of glass.
6. Includes one overnight hold.
7. Best steady state, B feed, tapping rate declined with time indicating inadequate power for given feed rate.

Melting parameters also improved with larger electrodes and lower electrode voltage. The melt-in rate obtained with 20.32-cm (8-in.) electrodes and 241 kW power input was 228 kg/m^2/h (47 lb/ft^2/h), which is 75% of the rate obtained with 10.16-cm (4-in.) electrodes and nearly twice the power input. Melting energy and electrode consumption also decreased significantly with lower electrode voltage and current density.

The objective of the USBM at the outset was to demonstrate EAF technology for vitrifying the subject radioactive waste, because the electric furnace historically has been the technology of choice in industrial applications where versatile, rugged, low-maintenance equipment was needed. The USBM has the only functioning research furnace and facility of its size in the northern hemisphere and has experience in melting materials of vastly different chemistry and physical properties. The investigation was extended beyond initial funding, and two additional tests were conducted within fiscal constraints imposed by in-house resources.

Some questions remain unanswered regarding the attainable minimum glass temperature and optimum processing parameters, and these will be researched in a test designated WHC4-1995. This test will be conducted following installation of auxiliary electrodes to supply additional heat at the entrance to the glass tap hole and preparation of additional Method B furnace feed.

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8.0 GLOSSARY

ABBREVIATIONS AND ACRONYMS

ac	alternating current
acfm	actual cubic feet per minute
ALRC	Albany Research Center
APCS	air pollution control system
ASME	American Society of Mechanical Engineers
atm	atmosphere
CEM	continuous emissions analysis
CFB	circulating fluidized bed
cfh	cubic feed per hour
EAF	electric arc furnace
EDTA	ethylenediaminetetraacetic acid
EGC	evaporative gas cooling
FTIR	Fourier transform infrared
GC	gas chromatograph
HEPA	high-efficiency particulate air
ID	inside diameter
IR	infrared
INEL	Idaho National Engineering Laboratory
IWPF	Idaho Waste Processing Facility
kVA	kilo volt ampere
kW	kilowatt
LOD	loss on drying
LOI	loss on ignition
LLW	low-level waste
MMT	multiple metals train
MW	megawatt
OD	outside diameter
PCT	product consistency test
PNL	Pacific Northwest Laboratory
QA	quality assurance
QC	quality control
RDF	refuse derived fuel
RWMC	Radioactive Waste Management Complex
SEM/EDX	scanning electron microscope/energy-dispersive X-ray
TCLP	toxicity characteristic leaching procedure
TH	Tree Hugger Corp.
THC	total hydrocarbons
UNC	unified national coarse
USBM	U.S. Bureau of Mines
USGS	U.S. Geologic Survey
WHC	Westinghouse Hanford Company
WTE	waste to energy

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APPENDIX A

OPERATING PROCEDURE FOR FEED PREPARATION

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OPERATING PROCEDURE FOR FEED PREPARATION

PHASE 1 DEMONSTRATION OF 3-PHASE ELECTRIC ARC MELTING FURNACE TECHNOLOGY FOR VITRIFYING HIGH-SODIUM CONTENT LOW-LEVEL RADIOACTIVE LIQUID WASTES

Prepared by the U.S. Bureau of Mines, Department of the Interior, Albany Research Center, Albany, Oregon

Date prepared: January 23, 1995

OPERATING PROCEDURE FOR FEED PREPARATION

PHASE 1 DEMONSTRATION OF 3-PHASE ELECTRIC ARC MELTING FURNACE TECHNOLOGY FOR VITRIFYING HIGH-SODIUM CONTENT LOW-LEVEL RADIOACTIVE LIQUID WASTES

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PHASE 1 DEMONSTRATION OF 3-PHASE ELECTRIC ARC MELTING FURNACE TECHNOLOGY FOR VITRIFYING HIGH-SODIUM CONTENT LOW-LEVEL RADIOACTIVE LIQUID WASTES

(1) INTRODUCTION

1.1. Objective:

Prepare pelletized dry furnace feed by two methods, designated A and B, for the ALRC arc melter and which also is appropriate to other dry-feed melting technologies using 10 M LLW simulant, sucrose and carbon reductants, and readily available industrial minerals.

(2) SAMPLE COLLECTION, LABELING, AND STORAGE

Persons responsible for sampling and the samples to be collected are identified in table 1. All samples shall be placed in prelabeled containers and stored on a single pallet.

Table 1.- Required Samples

Sample	Description and frequency	Number	Responsible person
Starting materials	1 at beginning of feed preparation	1 (400 g each) for each material	Weigher
A Feed	Wet pellets w/o LLW	2 (400 g each)	Disc assistant
A Feed	Dry pellets w/o LLW	2 (400 g each)	Disc assistant
A Feed	Wet pellets w LLW	2 (400 g each)	Disc assistant
A Feed	Dry pellets w LLW	2 (400 g each)	Disc assistant
A Feed	Reacted pellets	2 (400 g each)	Disc assistant
A Feed	Reacted pellets	1 (1000 g)	Disc assistant
B Feed	Wet pellets	2 (400 g each)	Receiver
B Feed	Reacted pellets	48 (1 every other barrel, each 400 g)	Receiver

(3) RECORD KEEPING

The following records shall be kept during mixing of dry materials for Method A pellets and pelletizing of Method B feed.

Record	Responsible person
1. NO_x Concentration Log	QA person
2. NO_x Monitor Service Log	QA person
3. Batch Weight Log	QA person
4. Mixer Log	Mixer operator
5. Sample Log	Receiver and disc assistant
6. Belt Dryer Log	Receiver

(4) DUTIES OF OPERATORS

Five operators are needed at all times during feed preparation involving operation of the double ribbon mixer. Two additional persons are needed to operate the disc pelletizer.

1. Weigher: Responsible for collecting 1 each 400-g sample of each feed material, for accurately formulating each batch of material by carefully weighing each component and managing materials to avoid confusion.

2. Mixer: Manages the mixer to prepare pellets, and enters appropriate information on the Mixer Log; operates the conveyor to efficiently dry and transfer pellets to the belt dryer, and rabbles material on the conveyor to encourage removal of moisture.

3. Lift operator: Operates fork and barrel lifts to transfer materials between the weighing and mixing stations, maintains an inventory of materials at the weigh station, and assists to rabble the conveyor as needed.

4. Receiver: Receives material from the belt dryer, assures that material issuing from the belt dryer cleanly reports to barrels, checks alignment of the belt at 15 min intervals, numbers barrels of Method B feed as filled, and collects samples as follows:
   B Feed: 1 each 400 g sample of wet Method B pellets near the beginning and end of Method B feed preparation.
   B Feed: 1 each 400 g sample from every other barrel of reacted Method B feed.

5. Quality assurance person: Responsible for assuring safe conditions in the work place. Changes and recharges battery and downloads information in each NO_x monitor at beginning of each shift. Checks the NO_x monitors at 15 min intervals and records the concentration on the NO_x Log. Responsible for assuring accurate weighing of feed components. Records the total weight of dry material and 10 M LLW for each batch on the Batch Weight Log.

6. Pelletizer: Operates the disc to prepare dense pellets with uniform size and shape.

7. Disc assistant: Operates fork and barrel lifts as needed to transfer mixed materials to the pelletizer station, transfers wet pellets to the dryer, transfers dry pellets to barrels containing polyethylene liners, and collects samples as follows:

A Feed: 1 each 400 g sample of wet pellets near the beginning and end of pellet preparation.

A Feed: 1 each 400 g sample of dry pellets near the beginning and end of drying of Method A pellets.

A Feed: 1 each 400 g sample of wet pellets containing LLW near the beginning and end of loading of Method A pellets.

A Feed: 1 each 400 g sample of dry pellets containing LLW near the beginning and end of drying of loaded Method A pellets.

A Feed: 1 each 400 g sample of reacted pellets containing LLW near the beginning and end of reaction of loaded Method A pellets.

A Feed: 1 each 1,000 g sample of reacted Method A pellets near the midpoint of reaction of loaded Method A pellets.

(5) PREPARATION OF FURNACE FEED

The glass composition designated LD6-5510 (from Kim 5/16/94) was selected for investigation. Furnace feed prepared by Methods A and B differ in terms of components, but result in very similar glass compositions. Approximately 4,000 lb of Method A feed and 24,000 lb of Method B feed will be prepared.

Reductants comprising 25 pct of stoichiometric sucrose, as powdered sugar, and 50 pct of stoichiometric carbon, as activated wood-derived carbon, will be incorporated in pellets prepared by both Methods A and B. The stoichiometry is based upon equations 1 through 4, which were the basis for experimentation but may not represent the actual chemical reactions.

Sucrose reductant:

Equation 1. $C_{12}H_{22}O_{11} + 8\ NaNO_3 \rightarrow 4\ Na_2O + 4\ N_2 + 8\ CO_2 + 4\ CO + 11\ H_2O$

Equation 2. $C_{12}H_{22}O_{11} + 12\ NaNO_2 \rightarrow 6\ Na_2O + 6\ N_2 + 6\ CO_2 + 6\ CO + 11\ H_2O$

Carbon reductant:

Equation 3. $3\ C + 2\ NaNO_3 \rightarrow Na_2O + N_2 + 2\ CO_2 + CO$

Equation 4. $2\ C + 2\ NaNO_2 \rightarrow Na_2O + N_2 + CO_2 + CO$.

5.1. Method A:

Method A, termed the Bureau of Mines Dry Feed Process, requires six steps:

1. Mixing of dry materials including glass formers, binders, and reductants,
2. Pelletizing mixed dry materials with water using a disc pelletizer to form spherical pellets,
3. Drying pellets to remove moisture and develop physical strength to withstand normal handling and absorptive capacity to assimilate the appropriate quantity of LLW simulant,
4. Contacting dry pellets with LLW simulant as appropriate to provide 25 pct waste loading in the product glass.
5. Drying loaded pellets to remove moisture, and
6. Heating dry loaded pellets to initiate reaction between reductants and nitrates and nitrites.

Reacted pellets constitute dry denitrified furnace feed. Method A is preferred for application to actual LLW in that the exposure, effort, and expense of processing radioactive materials are significantly decreased.

5.1.1 Pellet Preparation:

Pellet preparation must be preceded by competent mixing of all dry materials. Water to decrease dust formation during pellet formation is advantageously added to the dry materials in the mixer. Table 2 provides the recipe for Method A pellets and table 3 lists the weights of materials needed to prepare 4,000 lb in batches ranging from 500 to 1,000 lb. Actual batch weight will be determined by experiment, beginning with 500 lb. The weigher will highlight the batch weight determined to be appropriate to prevent errors in subsequent batches. The following sequence of operations assures reliable and consistent batches. Begin with labeled containers each marked with the tare weight.

1. Collect 400 g of each material for analysis excluding water and LLW simulant.
2. Weigh Bayer alumina, boric acid, and S bentonite into labeled 5 gal buckets.
3. Weigh diatomite into labeled barrel.
4. Transfer alumina, boric acid, and S bentonite into barrel containing diatomite, and record weight on Batch Weight Log. Remove barrel from scale.
5. Weigh -200 silica, powdered sugar, and carbon in labeled 5 gal buckets (two buckets may be required for carbon).
6. Weigh Micro-Cel into labeled barrel.
7. Transfer silica, powdered sugar, and carbon into barrel containing Micro-Cel, and record weight on Batch Weight Log.
8. Weigh the required water into a labeled barrel.
9. Place barrels on pallet and transport pallet to the mixer station.
10. Transfer the dry materials to the mixer with the barrel lift, and mix for 5 minutes. Determine optimum mixer speed to prevent excessive dust formation. Record mixing time and mixer speed on the Mixer Log.

Table 2.- Composition of Industrial Minerals, Resultant Pellets,10 M LLW Simulant, and Product Glass for Method A

Date prepared: 12-16-94 0.25 pct waste loading Saved as HAN25Q

Update new compositions: 1-19-95

Component	Bayer alumina	Boric acid	Southern Bentonite	Diatomite	Micro Cell	Glass makers sand		Pellet as dried	10 M LLW solution		Glass after melting
Pct	5.550	10.820	3.646	51.384	18.600	10.000					
Total all components:		100									
			Pct volatile material in components:			8.9395			Pct of	Pct of	
Component			Analysis					Weight	sol'n	solids	Pct
Ag2O							Ag2O	0.000	0.000	0.000	0.000
Al2O3	95.427		14.303	4.289	1.568	0.060	Al2O3	8.319	3.544	12.595	10.001
B2O3		56.183					B2O3	6.079	0.000	0.000	5.007
BaO			0.015	0.006	0.007		BaO	0.005	0.000	0.000	0.004
CaO			4.060	0.588	30.240		CaO	6.075	0.003	0.010	5.006
CdO							CdO	0.000	0.000	0.000	0.000
CeO2			0.026	0.002	0.008		CeO2	0.003	0.000	0.000	0.003
Cr2O3			0.001	0.002	0.006		Cr2O3	0.002	0.045	0.159	0.041
Cs2O				0.001			Cs2O	0.001	0.162	0.575	0.144
CuO				0.002	0.002		CuO	0.001	0.000	0.000	0.001
FeO							FeO	0.000	0.000	0.000	0.000
Fe2O3	0.009		4.405	2.016	1.229	0.010	Fe2O3	1.427	0.003	0.010	1.178
HgO							HgO	0.000	0.000	0.000	0.000
K2O	0.012	0.008	0.675	0.349	0.253		K2O	0.252	1.610	5.722	1.638
MgO			2.783	0.464	0.783		MgO	0.486	0.003	0.010	0.403
MnO2							MnO2	0.000	0.003	0.010	0.002
MoO3							MoO3	0.000	0.165	0.585	0.146
Cl			0.002	0.018	0.002		Cl	0.010	0.388	1.378	0.352
F							F	0.000	0.324	1.153	0.288
I							I	0.000	0.144	0.512	0.128
Na2O	0.263	0.023	0.337	3.734	0.310		Na2O	2.005	21.181	75.278	20.471
NiO			0.001	0.001	0.006		NiO	0.002	0.000	0.000	0.001
P2O5			0.085	0.041	0.066		P2O5	0.037	0.209	0.744	0.216
PbO			0.001	0.0008			PbO	0.000	0.000	0.000	0.000
SO3			0.216	0.027	0.074		SO3	0.035	0.237	0.843	0.240
SeO2							SeO2	0.000	0.000	0.000	0.000
SiO2	0.090		51.643	86.357	49.500	99.910	SiO2	65.460	0.000	0.000	53.914
SrO							SrO	0.000	0.117	0.417	0.104
TiO2			0.615	0.218	0.088		TiO2	0.151	0.000	0.000	0.124
ZnO			0.016	0.005	0.006		ZnO	0.004	0.000	0.000	0.003
ZrO2			0.063	0.010	0.001		ZrO2	0.008	0.000	0.000	0.007
Other*	0.100	0.001	0.002	0.146	3.323	0.000	Other	0.699	0.000	0.000	0.576
Subtotal	95.900	56.214	79.250	98.276	87.473	99.980	Subtotal	91.060	28.14	100.00	100.000
CO2			1.650	0.004	2.277		CO2	0.486	1.103		
H2O	4.100	43.786	19.100	1.720	10.250	0.020	H2O	8.454	46.348		
NO3-							NO3-	0.000	13.526		
NO2-							NO2-	0.000	5.281		
OH-							OH-	0.000	4.491		
Org C							Org C	0.000	1.114		
								Subtotal	71.863		
Total	100.000	100.00	100.00	100.00	100.00	100.00		100.00	100.00		

* Other comprises unanalyzed components in the industrial minerals.

Table 3.- Material for 4 Hour Demonstration Test of Method A Furnace Feed

Date: 1-19-95

Saved as HANA.wb1

Components are scaled to provide 4000 lb of reacted pellets.

Composition is based upon spread sheet HAN 25 Q as revised 1-19-95.

Reductants provide 25 pct of stoichiometric sugar and 50 pct of stoichiometric carbon as Nucon NUSORB LN100-325X. The carbon contains 4 pct ash and 6 pct moisture.

Components	Fraction of minerals	Wt, lb
Bayer alumina	0.0555	170.31
Boric acid	0.1082	332.02
S bentonite	0.0365	111.88
Diatomite	0.5138	1576.76
Micro Cel	0.1860	570.76
-200 silica	0.1000	306.86
Total minerals	1.0000	3068.58
	Fraction of total	
Minerals	0.6936	3068.58
Sugar	0.0236	104.32
Carbon	0.0221	97.63
Water	0.2608	1153.60
Total to pelletize	1.0000	4424.14
10 M LLW		3309.95

					Batch weight, lb						
Components	500.00	550.00	600.00	650.00	700.00	750.00	800.00	850.00	900.00	950.00	1000.00
Bayer alumina	19.25	21.17	23.10	25.02	26.95	28.87	30.80	32.72	34.65	36.57	38.49
Boric acid	37.52	41.28	45.03	48.78	52.53	56.29	60.04	63.79	67.54	71.30	75.05
S bentonite	12.64	13.91	15.17	16.44	17.70	18.97	20.23	21.50	22.76	24.02	25.29
Diatomite	178.20	196.02	213.84	231.66	249.48	267.30	285.12	302.94	320.76	338.58	356.40
Subtotal	247.61	272.38	297.14	321.90	346.66	371.42	396.18	420.95	445.71	470.47	495.23
Micro Cel	64.50	70.96	77.41	83.86	90.31	96.76	103.21	109.66	116.11	122.56	129.01
-200 silica	34.68	38.15	41.62	45.08	48.55	52.02	55.49	58.96	62.42	65.89	69.36
Sugar	11.79	12.97	14.15	15.33	16.51	17.69	18.86	20.04	21.22	22.40	23.58
Carbon	11.03	12.14	13.24	14.34	15.45	16.55	17.65	18.76	19.86	20.97	22.07
Subtotal	122.01	134.21	146.41	158.61	170.81	183.01	195.21	207.42	219.62	231.82	244.02
Total all solids	369.6242	406.5866	443.5490	480.5114	517.4739	554.4363	591.3987	628.3611	665.3235	702.2860	739.2484
Water	130.38	143.41	156.45	169.49	182.53	195.56	208.60	221.64	234.68	247.71	260.75
Batch total	500	550	600	650	700	750	800	850	900	950	1000

11. Add water by pumping from the container into the mixer using the dedicated pump at the mixer station. Mixer is designed to provide water uniformly along its length.
12. Continue mixing for 10 minutes to uniformly distribute water within the materials. Record mixing time and mixer speed on the Mixer Log. From this point mixing time need only be recorded if different.
13. Open slide gate as needed in bottom of mixer with the mixer running to transfer materials to 55 gal barrels. Record slide gate position on the Mixer Log.
14. Cover each barrel, and transport to the disc pelletizer station.
15. Pelletize materials on 48 in disc with additional water as needed to prepare spherical pellets in the range 1/4 to 3/4 in diameter.
16. Place green pellets in stainless steel trays and transfer to drying oven with set point 100 C. Collect 400 g of wet pellets near the beginning and near the end of pellet production as per table 1. Collect about 1 lb of wet pellets, weigh carefully, place in a tray, and dry along with wet pellets to determine weight loss on drying. Allow green pellets to dry overnight. The integrity of the dried pellets is such that no additional heating is required.

5.1.2. Loading Pellets with 10 M LLW simulant:

17. Weigh dry pellets into screen baskets in lots of 25 lb.
18. Dip baskets into well stirred vat of 10 M LLW. Determine residence time or number of dips needed to absorb the appropriate weight of 10 M LLW, as determined by calculation. Document calculations and procedure for reference. Collect 400 g of pellets containing LLW at the beginning and end of loading, as per table 1.
19. Transfer wet pellets to stainless steel trays and place in drying oven with 100 C set point. Collect about 1 lb of wet loaded pellets, weigh carefully, place in a tray, and dry along with loaded pellets to determine weight loss. Allow loaded pellets to dry overnight.
20. Collect 400 g of dry loaded pellets at the beginning and end of loading campaign.
21. Transfer dry loaded pellets to barrels and transport to belt dryer.

5.1.3. Reaction of Dry Loaded Pellets:

22. Preheat belt dryer with set point 250 C and belt speed 2 ft/min. Start exhaust fan to ventilate belt dryer and surrounding area.
23. Transfer dry loaded pellets to input hopper of the belt dryer by motorized barrel lift, and pass pellets through dryer. Collect 400 g of reacted pellets near the beginning and end of pellet reaction as per table 1. Collect 1,000 g of reacted pellets near the midpoint, as per table 1. Collect about 1 lb of wet loaded pellets, weigh carefully, place in a tray, and pass through belt dryer to determine weight loss on reaction. Note that the tray must be placed on the belt and removed by hand.
24. Collect reacted pellets in barrels, and number each barrel.
25. The following day transfer pellets to barrels containing a polyethylene liner, and secure the liner with a tie to exclude moisture to complete feed preparation by Method A.

5.2. Method B:

The process for Method B relies upon pellet formation by mixing the dry ingredients including glass formers and reductants in a double ribber mixer, adding the LLW simulant with continued mixing, and finally adding water until pellet formation is complete. Method B is more cost effective for preparing small lots of furnace feed in a batch process. Table 4 provides the recipe for Method B pellets, and table 5 lists the weights of materials needed to prepare 24,000 of furnace feed in batches ranging from 500 to 1,000 lb. Actual batch size will be determined by experiment, beginning with 500 lb. The weigher will highlight the batch weight determined to be appropriate to prevent errors in subsequent batches.

5.2.1. Preparation of Loaded Pellets:

1. Collect 400 g of limestone to complete sampling of minerals.
2. Weigh Bayer alumina, boric acid, limestone, -200 silica, powdered sugar, and carbon into labeled 5 gal buckets (carbon may require 2 buckets).
3. Weigh diatomite into labeled barrel.
4. Transfer contents of 5 gal buckets containing dry materials into barrel containing diatomite, and record weight on Batch Weight Log. Remove barrel from scale.
5. Weigh the required water into a labeled 5 gal bucket.
6. Transfer the required weight of 10 M LLW from a well-stirred barrel using the dedicated pump at the mixer station into a labeled barrel fixed to a pallet with mixer and pipe to withdraw liquid.
7. Place bucket of water and barrel containing dry materials on a pallet and transport pallet and pallet with the barrel containing LLW to the mixer station.
8. Transfer dry materials to the mixer with the barrel lift, and mix for 5 min at moderate speed to limit dust formation. Record mixing time and speed on the Mixer Log. From this point mixing conditions need only be recorded if different.
9. Connect the dedicated pump at the mixer station to the transfer pipe on the barrel containing LLW, and transfer LLW to the mixer with continued mixing.
10. Increase mixing speed to maximum, and continue mixing for 10 minutes to uniformly distribute LLW within the dry materials. Record mixing time on the Mixer Log. From this point mixing time need only be recorded if different.
11. Pour water from bucket into LLW barrel, and transfer water slowly into the mixer with continued mixing at maximum speed to ascertain conditions for pellet formation. Record water and mixing conditions on the Mixer Log. From this point conditions need only be recorded if different. Note that pellet formation is a function of mixing and liquid content. The objective is to minimize water use. Stop mixer immediately upon pellet formation. Excessive mixing will result in very wet and sticky pellets and ultimately in a thick soup.
12. Return empty containers to the weigh station.
13. Start conveyor, and set speed control at 5 ft/min.
14. Start heaters over the conveyor.

Table 4.- Composition of Industrial Minerals, 10 M LLW Simulant, and Product Glass for Method B
Date prepared: 12-16-94 0.25 pct waste loading Saved as HAN25L
Update new compositions: 1-19-95

Component	Bayer alumina	Boric acid	Ag lime	Diatomite	Micro Cell	Glass makers sand		10 M LLW solution		Glass after melting
Pct	6.200	10.650	10.320	52.830	0.000	20.000				
Total all components:		100								
			Pct volatile material in		components:	10.3660		Pct of	Pct of	
Component				Analysis				sol'n	solids	Pct
Ag2O							Ag2O	0.000	0.000	0.000
Al2O3	95.427			4.289	1.568	0.060	Al2O3	3.544	12.595	10.005
B2O3		56.183					B2O3	0.000	0.000	5.007
BaO				0.006	0.007		BaO	0.000	0.000	0.003
CaO			54.880	0.588	30.240		CaO	0.003	0.010	5.001
CdO							CdO	0.000	0.000	0.000
CeO2				0.002	0.008		CeO2	0.000	0.000	0.001
Cr2O3				0.002	0.006		Cr2O3	0.045	0.159	0.040
Cs2O				0.001			Cs2O	0.162	0.575	0.144
CuO				0.002	0.002		CuO	0.000	0.000	0.001
FeO							FeO	0.000	0.000	0.000
Fe2O3	0.009			2.016	1.229	0.010	Fe2O3	0.003	0.010	0.896
HgO							HgO	0.000	0.000	0.000
K2O	0.012	0.008		0.349	0.253		K2O	1.610	5.722	1.586
MgO			0.483	0.464	0.783		MgO	0.003	0.010	0.249
MnO2							MnO2	0.003	0.010	0.002
MoO3							MoO3	0.165	0.585	0.146
Cl				0.018	0.002		Cl	0.388	1.378	0.352
F							F	0.324	1.153	0.288
I							I	0.144	0.512	0.128
Na2O	0.263	0.023		3.734	0.310		Na2O	21.181	75.278	20.486
NiO				0.001	0.006		NiO	0.000	0.000	0.000
P2O5				0.041	0.066		P2O5	0.209	0.744	0.204
PbO				0.0008			PbO	0.000	0.000	0.000
SO3				0.027	0.074		SO3	0.237	0.843	0.223
SeO2							SeO2	0.000	0.000	0.000
SiO2	0.090			86.357	49.500	99.910	SiO2	0.000	0.000	54.898
SrO							SrO	0.117	0.417	0.104
TiO2				0.218	0.088		TiO2	0.000	0.000	0.096
ZnO				0.005	0.006		ZnO	0.000	0.000	0.002
ZrO2				0.010	0.001		ZrO2	0.000	0.000	0.005
Other*	0.100	0.001	0.703	0.146	3.323	0.000	Other	0.000	0.000	0.130
Subtotal	95.900	56.214	56.067	98.276	87.473	99.980	Subtotal	28.14	100.00	100.000
CO2			43.633	0.004	2.277		CO2	1.103		
H2O	4.100	43.786	0.3	1.720	10.250	0.020	H2O	46.348		
NO3-							NO3-	13.526		
NO2-							NO2-	5.281		
OH-							OH-	4.491		
Org C							Org C	1.114		
								71.863		
Total	100.000	100.00	100.00	100.00	100.00	100.00		100.00		

* Other comprises unanalyzed components in the industrial minerals.

Table 5.- Material for 24 Hour Demonstration Test of Method B Furnace Feed

Date: 1-19-95

Saved as HANB.wb1

Components	Fraction of minerals	Wt, lb
Bayer alumina	0.0620	1244.93
Boric acid	0.1065	2138.48
Limestone	0.1032	2072.21
Diatomite	0.5283	10608.05
-200 silica	0.2000	4015.92
Total minerals	1.0000	20079.59
	Fraction of total	
Minerals	0.4512	20079.59
Sugar	0.0151	671.96
Carbon	0.0141	628.87
10 M LLW	0.4791	21319.76
Water	0.0404	1799.81
Total	1.0000	44500.00

Components are scaled to provide 44,500 lb of loaded wet pellets. Anticipated weight loss on drying is 30 pct, and additional weight loss on reaction is 16 pct. Total weight loss is 46 pct. To prepare 24,000 lb of reacted pellets requires 44,500 lb of loaded wet pellets.

Composition is based upon spread sheet HAN 25 L as revised 1-18-95. Reductants provide 25 pct of stoichiometric sugar and 50 pct of stoichiometric carbon as Nucon NUSORB LN100-325X. The carbon contains 4 pct ash and 6 pct moisture.

	Batch weight, lb										
Components	500.00	550.00	600.00	650.00	700.00	750.00	800.00	850.00	900.00	950.00	1000.00
Bayer alumina	13.99	15.39	16.79	18.18	19.58	20.98	22.38	23.78	25.18	26.58	27.98
Boric acid	24.03	26.43	28.83	31.24	33.64	36.04	38.44	40.85	43.25	45.65	48.06
Limestone	23.28	25.61	27.94	30.27	32.60	34.92	37.25	39.58	41.91	44.24	46.57
Diatomite	119.19	131.11	143.03	154.95	166.87	178.79	190.71	202.63	214.54	226.46	238.38
-200 silica	45.12	49.63	54.15	58.66	63.17	67.68	72.20	76.71	81.22	85.73	90.25
Total minerals	225.61	248.17	270.74	293.30	315.86	338.42	360.98	383.54	406.10	428.67	451.23
Sugar	7.55	8.31	9.06	9.82	10.57	11.33	12.08	12.84	13.59	14.35	15.10
Carbon	7.07	7.77	8.48	9.19	9.89	10.60	11.31	12.01	12.72	13.43	14.13
Total dry materials	240.23	264.25	288.28	312.30	336.32	360.34	384.37	408.39	432.41	456.44	480.46
10 M LLW	239.55	263.50	287.46	311.41	335.37	359.32	383.28	407.23	431.19	455.14	479.10
Water	20.22	22.24	24.27	26.29	28.31	30.33	32.36	34.38	36.40	38.42	40.45
Total weight	500	550	600	650	700	750	800	850	900	950	1000

15. Start mixer and immediately adjust mixer speed to minimum. Open slide gate on bottom of mixer to deposit material on the conveyor so that the entire batch in the mixer is distributed along the length of the conveyor. Record speed control position, conveyor speed, and slide gate position on the Mixer log. Stop conveyor before material exits to the receiving bin of the belt dryer. The correct opening will be determined by experiment. Mark slide gate to indicate position.
16. Begin preparation of new batch of pellets in the mixer.
17. Start belt dryer with 250 C set point and 2 ft/min belt speed. Record belt speed, set point, and indicated temperature on the Mixer Log.
18. Start exhaust fan to ventilate belt dryer and surrounding area.

5.2.2. Predrying of loaded pellets:

19. Rabble pellets on conveyor at intervals of 10 min to expose fresh surface to the heaters. Start conveyor after 1 h, and transfer 1/3 of material to the receiving bin of the belt dryer. Transfer 1/3 of material on the conveyor to the receiving bin at intervals of 20 min or sooner depending upon capacity of belt dryer. Note that a new batch will be started every hour beginning with the second batch, and the contents of the mixer will be transferred to the conveyor at intervals of 20 min in increments of 1/3 of its contents. The conveyor remains full at all times to obtain maximum output drying efficiency.

5.2.3. Reaction of Partially Dried Loaded Pellets:

20. Belt speed and temperature set point will be adjusted by experiment to maximize the output. Record data as appropriate to allow inference of optimum conditions on the Mixer Log.
21. Collect reacted pellets in barrels, and number each barrel. Collect 400 g of reacted material from every other barrel of reacted Method B pellets.
22. The following day transfer pellets to barrels containing a polyethylene liner, and secure the liner with a tie to exclude moisture to complete feed preparation by Method B.

(6) SAFETY NOTES

6.1. Potential Hazards

All personnel on the feed preparation crew are required to wear hard hats, safety shoes, and safety glasses (when not wearing goggles) as part of their normal safety equipment to prevent injuries typical to working with moving and overhead equipment and hazards. In addition, the feed preparation operation can be broken down into three potential hazards:

6.1.1. 10 M LLW Simulant:

Ten molar (10 M) LLW simulant is caustic, and extreme care must be taken to guard against contact with the skin and eyes. Goggles or full face respirator shall be worn by all personnel handling LLW or in the vicinity of LLW simulant or any material containing LLW simulant including the Method B batches. In addition to goggles, caustic resistant gloves and apron are also to be worn by those handling this material. Emergency procedures for LLW simulant in the eyes, or suspected exposure to the eyes, are to immediately wash the eyes for at least 10 minutes followed by examination by a physician. Contact lenses are to be avoided if alternative eye is available. Exposure to the skin requires immediate washing with water. If any skin irritation develops, examination by a physician is required.

6.1.2. Respirable Dust:

The glass formers contain some very fine, respirable dusts. It is required that all personnel in areas where dusty conditions are present wear cartridge type respirators with three-way canisters. In addition, all personnel are encouraged to wear coveralls.

6.1.3. Potential NO_x Exposure:

The denitrification reaction that occurs on the belt drier produces a small amount of NO_x either in the form of NO or NO_2. Care has been taken in calculating potential NO_x evolution, and the exhaust system has been designed such that NO_x levels will be less than one-fifth the allowable limit. Even so, five NO_x detectors will be employed to assure personnel safety. The Mixer and Receiver shall each wear a personal detector. Area detectors will be located in the belt drier room, the weighing area, and north of building 25 downwind from the stack. Two of these detectors are equipped with loud emergency horns that sound when NO_x reach threshold limits. All detectors will be monitored on a 15 minute basis by the QA person. In case of an alarm, a designated individual will don self-contained breathing apparatus (SCBA), enter the belt drier room, stop the belt, and turn off the heating elements on the belt drier. All other personnel will exit the process area to the north and assemble at the east end of building 28. After NO_x reaches a safe level (as monitored by the person wearing the SCBA), personnel will return to the feed preparation area and decrease the feed input to the drier to ensure safe NO_x levels.

6.2. Required Personal Safety Equipment:

1. Weigher: Coveralls, safety shoes, hard hat, respirator with 3-way canisters, goggles, caustic resistant gloves and apron, and NO_x detector.

2. Mixer: Coveralls, safety shoes, hard hat, respirator with 3-way canisters, goggles, caustic resistant gloves and apron, and NO_x detector.

3. Lift operator: Coveralls, safety shoes, hard hat, respirator with 3-way canisters, and goggles.

4. Receiver: Coveralls, safety shoes, hard hat, respirator with 3-way canisters, goggles, and caustic resistant gloves and apron.

5. Quality assurance person: Coveralls, safety shoes, hard hat, respirator with 3-way canisters, and safety glasses (maintain goggles on person).

6. Pelletizer: Coveralls, safety shoes, hard hat, respirator with 3-way canisters, and safety glasses.

7. Disc assistant: Coveralls, safety shoes, hard hat, respirator with 3-way canisters, and safety glasses.

6.3. Personnel Safety Responsibilities:

All personnel, both supervisory and non-supervisory are required to inform non-pelletizing personnel of the hazards in the work area and to keep any personnel not wearing appropriate safety equipment out of the work area. All personnel are expected to wear appropriate safety equipment at all times. Please remember that safety equipment is being required, not to discomfort or to encumber personnel, but for their safety.

NO_x CONCENTRATION LOG

A record of NO_x concentrations within the work area during preparation of Westinghouse Hanford Co furnace feeds by Methods A and B

Date	Time	Position			Remarks	Initials
		1	2	3		

NO$_X$ MONITOR LOG

Gas Monitor Exotox 75	Time of data download	Time Battery replaced	Time Battery in charger	Initial and date
#06416116				
#05416049				
#06416116				
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#06416116				

BATCH WEIGHT LOG

A record of dry materials batch weights for Westinghouse Hanford C furnace feeds prepared by Methods A and B

	Batch Weight			
Batch number	Subtotal 1*	Subtotal 2**	Remarks	Initials
Method A-				

	Batch Weight			
Batch number	Dry materials	10 M LLW	Remarks	Initials
Method B-				

	Batch Weight			
Batch number	Dry materials	10 M LLW	Remarks	Initials
Method B-				

MIXER LOG

A record of mixing conditions for Westinghouse Hanford Co furnace feeds prepared by Methods A and B

Batch number	Date	Time	LLW addition		Water addition		Initials	Remarks
			Time	Speed	Time	Speed		

SAMPLE LOG

KEY
A--Method A
B--Method B
D--Dry
F--Feed
L--Contains LLW simulant
P--Pellets
R--Reacted
W--Wet

Date	Time	Description	ID number	Initials	Remarks
		Feed: Bayer alumina	F-1 (400g)		
		Feed: Boric acid	F-2		
		Feed: S bentonite	F-3		
		Feed: Diatomite	F-4		
		Feed: Micro Cel	F-5		
		Feed: -200 silica	F-6		
		Feed: Limestone	F-7		
		Feed: Powdered sugar	F-8		
		Feed: Nucon carbon	F-9		
		A pellets, wet, no LLW	APW-1		
		A pellets, wet, no LLW	APW-2		
		A pellets, dry, no LLW	APD-1		
		A pellets, dry, no LLW	APD-2		
		A pellets, wet, with LLW	APW-1		
		A pellets, wet, with LLW	APW-2		
		A pellets, dry, with LLW	APD-1		
		A pellets, dry, with LLW	APD-2		
		A pellets with LLW, reacted	APLR-1		
		A pellets with LLW, reacted	APLR-2		
		A pellets with LLW, reacted	APLR-3 (1000 g)		
		B pellets, wet	BPW-1 (400 g)		
		B pellets, wet	BPW-2 (400 g)		
		B pellets, reacted	BPR-3 (400 g)		
		B pellets, reacted	BPR-4 (400 g)		
		B pellets, reacted	BPR-5 (400 g)		
		B pellets, reacted	BPR-6 (400 g)		
		B pellets, reacted	BPR-7 (400 g)		
		B pellets, reacted	BPR-8 (400 g)		
		B pellets, reacted	BPR-9 (400 g)		
		B pellets, reacted	BPR-10 (400 g)		

KEY

A--Method A
B--Method B
D--Dry
F--Feed
L--Contains LLW simulant
P--Pellets
R--Reacted
W--Wet

		B pellets, reacted	BPR-11 (400 g)		
		B pellets, reacted	BPR-12 (400 g)		
		B pellets, reacted	BPR-13 (400 g)		
		B pellets, reacted	BPR-14 (400 g)		
		B pellets, reacted	BPR-15 (400 g)		
		B pellets, reacted	BPR-16 (400 g)		
		B pellets, reacted	BPR-17 (400 g)		
		B pellets, reacted	BPR-18 (400 g)		
		B pellets, reacted	BPR-19 (400 g)		
		B pellets, reacted	BPR-20 (400 g)		
		B pellets, reacted	BPR-21 (400 g)		
		B pellets, reacted	BPR-22 (400 g)		
		B pellets, reacted	BPR-23 (400 g)		
		B pellets, reacted	BPR-24 (400 g)		
		B pellets, reacted	BPR-25 (400 g)		
		B pellets, reacted	BPR-26 (400 g)		
		B pellets, reacted	BPR-27 (400 g)		
		B pellets, reacted	BPR-28 (400 g)		
		B pellets, reacted	BPR-29 (400 g)		
		B pellets, reacted	BPR-30 (400 g)		
		B pellets, reacted	BPR-31 (400 g)		
		B pellets, reacted	BPR-32 (400 g)		
		B pellets, reacted	BPR-33 (400 g)		
		B pellets, reacted	BPR-34 (400 g)		
		B pellets, reacted	BPR-35 (400 g)		
		B pellets, reacted	BPR-36 (400 g)		
		B pellets, reacted	BPR-37 (400 g)		
		B pellets, reacted	BPR-38 (400 g)		
		B pellets, reacted	BPR-39 (400 g)		
		B pellets, reacted	BPR-40 (400 g)		
		B pellets, reacted	BPR-41 (400 g)		
		B pellets, reacted	BPR-42 (400 g)		
		B pellets, reacted	BPR-43 (400 g)		
		B pellets, reacted	BPR-44 (400 g)		
		B pellets, reacted	BPR-45 (400 g)		
		B pellets, reacted	BPR-46 (400 g)		

A--Method A
B--Method B
D--Dry
F--Feed
L--Contains LLW simulant
P--Pellets
R--Reacted
W--Wet

		B pellets, reacted	BPR-47 (400 g)		
		B pellets, reacted	BPR-48 (400 g)		
		B pellets, reacted	BPR-49 (400 g)		
		B pellets, reacted	BPR-50 (400 g)		
		B pellets, reacted	BPR-51 (400 g)		
		B pellets, reacted	BPR-52 (400 g)		
		B pellets, reacted	BPR-53 (400 g)		
		B pellets, reacted	BPR-54 (400 g)		
		B pellets, reacted	BPR-55 (400 g)		
		B pellets, reacted	BPR-56 (400 g)		
		B pellets, reacted	BPR-57 (400 g)		

BELT DRYER LOG

Date	Time	Belt speed	Process temp, T_1	Process temp, T_2	Initials

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APPENDIX B

PROCEDURES FOR OPERATING BUREAU OF MINES THERMAL WASTE TREATMENT FACILITY AND OPERATING PROCEDURES FOR MELTING TEST WHC1-1995

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PROCEDURES FOR OPERATING
BUREAU OF MINES THERMAL WASTE TREATMENT FACILITY
and
OPERATING PROCEDURES FOR MELTING TEST WHC1-1995

Prepared by the U.S. Bureau of Mines, Department of the Interior,
Albany Research Center, Albany, Oregon

Date prepared: March 3, 1995 Saved as WHC1-95

PROCEDURES FOR OPERATING
BUREAU OF MINES THERMAL WASTE TREATMENT FACILITY
and
OPERATING PROCEDURES FOR MELTING TEST WHC1-1995

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ILLUSTRATIONS

(1) INTRODUCTION

The Bureau of Mines' thermal waste treatment facility at the Albany Research Center in Albany, Oregon consists of an 800 kilowatt 3-phase electric arc melting furnace with supporting systems for cooling and recycling process water, feeding material to the furnace, treating offgases to remove particulates and acidic components, and recording pertinent process data. The air pollution control system (APCS) is operated by a central control console. Figures 1.1 and 1.2 are plan and elevation views of the system. Figure 1.2 provides the positions of sensors in the furnace and APCS numbered from 1 to 21. Sensors include thermocouples (T), pressure sensors (P), oxygen sensor (O), and flow measuring devices for gases (F) and water (W). Additional ports to access the system for analysis are indicated by (A) and (G). Rotary air locks (R) for sampling of particulates in the APCS are provided on the baghouse and cyclone exits. Process data as millivolt or 4 to 20 milliamp signals are sent to a data logger, which applies a linear scaler if needed and transmits the data to a PC for storage and display.

1.1. Objectives:

(1) Demonstrate 3-phase electric furnace melting technology in a 24-h continuous demonstration melting test of dry denitrified feed material prepared by two methods A and B to produce glass of the LD6-5510 composition. Both furnace feeds are compounded from simulated Hanford Site low-level tank waste (LLW simulant), readily available industrial minerals, and reductants selected to decompose nitrates and nitrites in the LLW simulant to elemental nitrogen.

(2) Demonstrate steady state operation including continuous feeding of Method B feed and continuous tapping of glass.

(3) Demonstrate ability to stop for an extended time and restart with Method B feed.

(4) Demonstrate ability to idle for an extended time with Method B feed.

(5) Demonstrate steady state operation including continuous feeding of Method A feed and continuous tapping of glass.

(6) Demonstrate that the 3-phase electric arc furnace can be operated in a practical and acceptable manner to minimize reduction of metal oxides.

(7) Demonstrate the inherent reliability, versatility, and maintainability of the 3-phase electric arc melting furnace.

(8) Demonstrate the capability of the 3-phase electric arc melting furnace to vitrify feed materials containing NaOH, $NaNO_3$, $NaNO_2$, and $NaAlO_2$ as significant constituents, PO_4^{-3}, SO_4^{-2}, Cl, and F as minor constituents, and regulated components including Ba, Cd, Cr, and Pb.

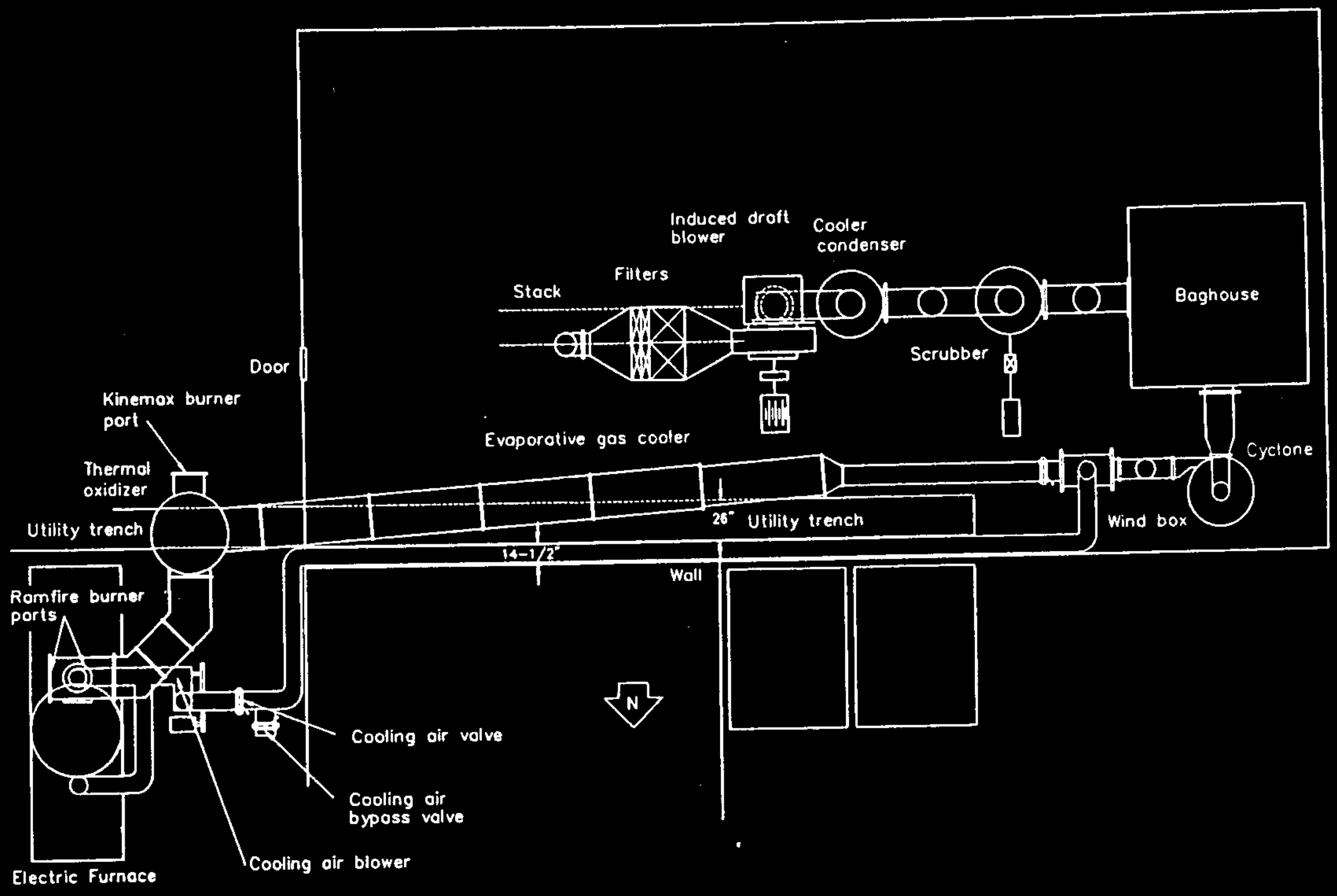

Figure 1.1 Plan view of thermal waste treatment facility.

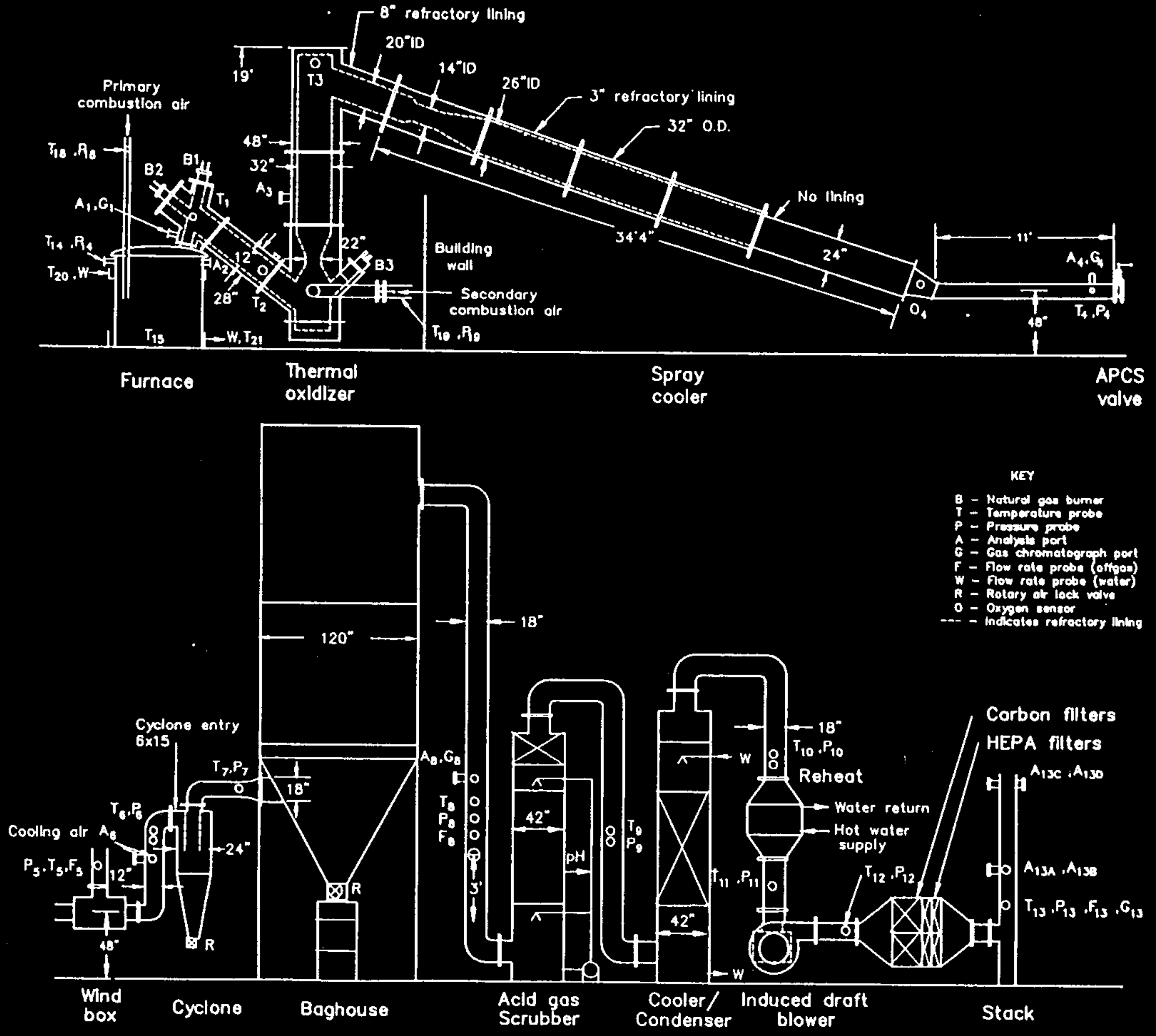

Figure 1.2 Elevation view of thermal waste treatment facility.

(9) Demonstrate the capability of the electric arc melting furnace to produce a durable, consistent, and homogeneous glass containing minimum 25 pct waste loading.
(10) Demonstrate the capability of the electric arc melting furnace to process the LLW simulant in compliance with applicable NO_x and SO_x requirements.
(11) Determine the distribution of LLW components among glass, fume solids, and offgas products.
(12) Determine composition and flow rate of offgas and quantities and composition of entrained particulates as related to feed chemistry.
(13) Collect and compile experimental electrical and process data that can be scaled to the requisite 200 metric tons/day LLW vitrification plant to support engineering studies, technology evaluation, life-cycle cost analysis, and to evaluate life expectancy, reliability, and maintenance requirements.

(2) SAMPLE COLLECTION, LABELING, AND STORAGE

Samples described in table 2.1 will be collected by the Sample Manager, as identified in Section 4. All samples shall be placed in 1 gal prelabeled steel cans and stored on a single pallet.

Table 2.1.- Sample Description and Schedule

Sample	Description	Number
Offgas	Offgas/particulate	2 sets during demonstration test of B feed.
Offgas	Offgas/particulate	1 set during demonstration test of A feed
Offgas	Offgas/particulate	1 set during hot idle
Offgas	Cyclone solids	1 during each offgas set
Offgas	Cyclone solids	Every 2 h, except as above
Offgas	Baghouse	1 during each offgas set
Offgas	Baghouse	Every 2 h, except as above
Offgas	Scrubber solution	1 during each offgas set
Offgas	Scrubber solution	Every 2 h, except as above
Offgas	Cooler/condenser	1 during each offgas set
Offgas	Cooler/condenser	Every 2 h, except as above
Offgas	Thermal oxidizer	1 at end
Glass	Collect on steel plate	1 at T = 0, B feed
Glass	Collect on steel plate	1 each offgas set and 3 others during B feed
Glass	Collect on steel rod	1 during hot idle with B feed
Glass	Collect on steel plate	1 after hot idle with B feed
Glass	Collect on steel plate	1 during A feed
Metal	Collect from metal tap	1 at end of test

(3) RECORD KEEPING

The following records shall be kept during the melting demonstration test.

Record	Responsible person
1. Electrode Log	Sample Manager
2. Receiving Bin Log	Sample Manager
3. Feeder Log	Feeder Operator
4. Furnace Log	Furnace Operator
5. APCS Solids Log	Sample Manager
6. Glass and Metal Product Log	Sample Manager

3.1. Traceability:

All samples to be analyzed or archived will be assigned an identifying designation, entered on the appropriate log, and stored in clean labeled plastic containers.

Samples of product glass and metal collected as described in table 2.1. will be provided to the WHC-designated analytical laboratory, and the others will be archived in clean labeled plastic containers.

All data shall be clearly traceable from a final report back through the analytical records and worksheets to the date of analysis, the individual who performed the analysis, and to the measuring and test equipment used to collect the data.

All analytical test conditions, specimen preparation information, and related data for conducting the analyses shall be documented as a part of the laboratory records, and shall be clearly traceable to the final report of analytical results.

3.2. Records Disposition:

The final disposition of project records (data files, logs, report formats, records storage and disposition) shall be determined by the WHC Project Manager and the subcontractor.

(4) DUTIES OF OPERATORS

Seven operators, a supervisor, and an electrician are needed at all times during furnace operation.

Assignment	Responsibilities
1. Feeder operator	Operating the feeder and primary air system and keeping the Feeder Log.

2. Furnace operator	Operating the electric arc furnace and keeping the Furnace Log.
3. APCS operator	Operating the APCS.
4. Sample manager	Collects or supervises the collection of all samples and keeps the Electrode Log, Receiving Bin Log, APCS Solids Log, and Glass and Metal Products Log.
5. Gas chromatograph operator	Operates the gas chromatograph
6. Lift operator	Operates fork and barrel lifts to transfer feed materials to the receiving bin and glass and metal products to the storage area.
7. Crane and tapping crew	Operates the overhead crane and taps furnace to remove glass and metal.
8. Supervisor	Responsible for assuring safe operating conditions in the work place. Spot checks the NO_x monitors. Spot checks feed and product weights to assure accurate weighing of feed and products.
9. Electrician	On call for possible electrical problems.

(5) SAFETY AND ENVIRONMENTAL ISSUES

5.1. Safety:

All personnel attending the furnace are required to wear protective clothing, respirators (when needed), gloves, boots, safety glasses, and hard hats. Face shields and reflective heat-resistant clothing are required of the tapping crew. Additional common sense measures are required including remaining out of harm's way when not actually conducting a task.

5.2 Environmental:

5.2.1. Air quality in the work place:

Contamination of air within the building including the control room will be assured by the following preventative and control measures.

1. Emissions of gases and fumes into the building will be significantly decreased during furnace operation by withdrawing air through hoods over the tap holes for injection into the APCS as cooling air. The hood over the metal tap hole will be closed while tapping glass to

maximize fume collection over the glass tap hole. Similarly, the hood over the glass tap hole will be closed while tapping of the metal side.

2. Air within the building housing the thermal waste treatment facility will be changed at intervals of 2 min by a combination of 3 blowers that remove air from ducts in the roof.

3. The control room will be pressurized with filtered air to preclude ingress of air from the furnace room.

4. Air within the building will be sampled by stationary air monitoring devices located above the glass (North) and metal (South) tap holes. A reference (R) monitor is installed in the control room. The monitors will be operated for 8 h during the demonstration test.

5.2.2. Air quality in the neighborhood:

Contamination of air outside of the building will be well within State guide lines as assured by oxidation of CO and volatile hydrocarbons and destruction of chlorinated hydrocarbons in the thermal oxidizer, collection of particulate and condensed fume solids by baghouse, removal of acid gases by caustic scrubber, and final polishing of exhaust gases by activated carbon and HEPA filters prior to the stack.

5.2.3. Disposal of unused feed and test products:

All feed will be melted to eliminate potential disposal problems. Product glass, cyclone solids, and baghouse solids will be disposed of in a municipal landfill if shown to be benign by analysis. All materials failing the TCLP test will be interred in a hazardous waste landfill. Scrubber solution will satisfy the City's requirement for sanitary sewer disposal (pH between 6 and 10 and no undissolved solids) and will be drained continuously into the city sewer as an overflow from the scrubber. Water for the cooler/condenser is provided by the cooling tower. The contents of the cooling water system will be vented after the test to the City sewer following analysis and pH adjustment, if needed. Solutions not acceptable for sewer disposal will be evaporated to dryness, and the solids will be placed in a hazardous waste landfill.

(6) DESCRIPTION OF SYSTEMS

6.1. Cooling Water and City Water Backup:

Water for cooling the various water cooled devices within the thermal waste treatment facility is recycled through an evaporative cooling tower as a water and cost-saving measure. City water is available as a cooling fail safe and as make up for evaporation losses.

6.2. Feed and Fugitive Dust Collection:

Feed materials are delivered continuously to the furnace with conventional screw conveyors and a bucket elevator. A dedicated fan exhausting through a baghouse collects dusts generated by the feed system. Materials enter the furnace through four ports in the roof to provide a uniform layer of unmelted material over the molten glass (cold top).

6.3. Air Pollution Control:

The air pollution control system (APCS) incorporates state-of-the-art gas cleaning and particulate control technology deployed to recover particulate matter before removing the acid gases. The APCS includes the following unit operations, beginning at the furnace exit:

(1) Heated refractory-lined ducts to preclude the formation of solid accretions.
(2) Thermal oxidizer providing minimum 1 sec residence time at 1,600 F to destroy carbon-chlorine bonds.
(3) Evaporative gas cooler assisted by injection of room air to rapidly cool process gases to 300 F to minimize the formation of dioxins and furans.
(4) Cyclone for removal of large particulate and baghouse rated to remove 99.8 pct of particulate greater than 3 micrometer.
(5) Acid gas scrubber rated to remove 99 pct of HCL, SO_x, and NO_2.
(6) Cooler/condenser and tube-in-shell heat exchanger to condition the gases prior to the induced draft (ID) blower.
(7) Activated carbon and high energy particulate air (HEPA) filters to remove residual metal vapors (Hg), chlorinated hydrocarbons, and 99.8 pct of particulates greater that 3 micrometers.
(8) Stack venting to atmosphere 40 feet above ground level to assure dispersion of exhaust gases.

The APCS is assisted by ten automatic single loop controllers, two passive systems, and three fail safe devices.

6.3.1. Automatic control loops:

(1) Furnace pressure:

Pressure within the furnace can be regulated within the range 0 to -2 in WC by the induced draft (ID) blower acting through the ID blower damper and the APCS valve. The speed of the ID blower is constant, thereby allowing the blower to provide its rated static pressure (30 in WC) at volumetric flow rates in the range 2400 to 4800 cubic feed per minute (cfm). The automatic control loop is comprised of a pressure transducer that senses pressure within the plenum of the furnace at position 14 (see figure 1.2), a controller in the console, and the APCS valve. Draft to the APCS valve is determined by the position of the ID blower damper, which is positioned manually by means of a controller in the console to maintain the APCS valve at the 70 pct open position, the position for optimum regulation. The positions of the APCS valve and the ID blower damper are indicated at the console. It is the responsibility of the APCS operator to maintain the APCS valve at about 70 pct open by adjusting the ID blower damper.

(2) Temperature within the refractory-lined furnace exit duct:

Burner 1, an 800,000 Btu/h Ramfire*natural gas burner by Maxon Corp, fires a narrow cylindrical flame through the center of the water-cooled furnace exit duct into the furnace plenum. The flame heats the surface of the duct to operating temperature (1,600 F) and provides a pilot light within the furnace to preclude the formation of explosive conditions. The burner can be controlled automatically by the thermocouple at position 1 to maintain the desired temperature within the duct, or controlled manually, as required during a cold start to heat the refractory-lined ducting at the desired rate to operating temperature. The air:gas ratio is preset to provide for stoichiometric combustion of the fuel gas.

(3) Temperature within the crossover duct that connects the furnace exit duct to the thermal oxidizer:

Burner 2, which is identical to Burner 1, fires down the center of the crossover duct. The burner can be controlled automatically by the thermocouple at position 2 to maintain the desired temperature in the duct, or manually, as required during a cold start. The air:gas ratio in burner 2 is preset to provide for stoichiometric combustion of the fuel gas.

(4) Temperature within the thermal oxidizer:

Burner 3, a 3 million Btu/h Kinemax*natural gas burner, fires into the base of the thermal oxidizer. Control is either automatic by the thermocouple at position 3, or manual, as required to heat the thermal oxidizer to operating temperature during a cold start. The air:gas ratio in burner 3 is preset to provide for stoichiometric combustion of the fuel gas.

(5) Secondary air:

Gases generated within the furnace by partial combustion of organic matter in the furnace feed are oxidized by air (secondary air) that is injected through two 2-in ports in the venturi section of the thermal oxidizer. The volume of secondary air is metered by the 3-in secondary air valve, which is controlled by the Oxygen sensor at position 4 to provide 5.5 pct oxygen in the output of the Evaporative Gas Cooler. Secondary air is provided by the cooling air blower.

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*Ramfire and Kinemax are trademarks of Maxon Corporation

(6) Evaporative Gas Cooler (EGC):

Injection of water as a fine mist by air atomization to cool the combined furnace exhaust and combustion gases is controlled by the thermocouple at position 4 at the outlet of the EGC. The desired temperature at position 4 is 500 F.

(7) Cooling air:

Cooling of exhaust gases from 500 F to 300 F is accomplished by injecting cool (room temperature) air into the APCS at the wind box. Cooling air, regulated by the cooling air valve, is obtained from hoods over the tap holes of the electric furnace by the action of the cooling air blower. The speed of the cooling air blower is manually adjusted by the variable frequency control (VFC) located to the left of the console. The volume of cooling air injected into the APCS is determined by the position of the cooling air valve, which is controlled by the thermocouple at position 6. The position of the cooling air valve and the speed of the cooling air blower are indicated at the console. It is the responsibility of the APCS operator to maintain the cooling air valve at about 70 pct open by adjusting the VFC for the cooling air blower.

(8) pH control of acid gas scrubber solution:

Fifty (50) pct caustic solution is metered into the output side of the scrubber solution recycle pump by a caustic metering pump to maintain pH of the solution in the range 8.0 to 8.5. pH of the recycle solution is sensed by a pH transmitter, which signals a controller to operate the caustic metering pump as needed. Makeup water for the scrubber is obtained from the cooling tower supply. An overflow of 2 to 5 gpm is maintained to prevent excessive accumulation of dissolved solids in the scrubber solution. Clean gases exit the scrubber saturated with water at 153 F.

(9) Cooler/condenser:

Water from the cooling tower is passed once through the cooler/condenser to cool the flue gases from 153 F to 90 F. Water flow is regulated by a motorized 3 inch ball valve, which is controlled by thermocouple T10 located in APCS duct after the cooler/condenser.

(10) Supertrol.*

The Supertrol provides hot water to the exhaust gas reheat heat exchanger, which increases the temperature of saturated gases from the cooler/condenser to preclude condensation in the ID blower and the filters. Reheat is optimally in the range 5 to 10 degrees F.

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*Super-Trol is a trademark of The Lees-Bradner Company.

6.3.2. Systems under manual control:

Three subsystems are strictly under manual control).

(1) Primary air to the furnace.

Primary air for partial combustion of organic materials in the feed will vary with the composition of the feed and the feed rate. Primary air is regulated by the constant-speed primary air blower and the primary air valve. Controls for both devices are located at the feed control station.

(2) Baghouse pulsator.

The rate at which the bags are pulsed to dislodge particulate is regulated by the baghouse timer, which is adjusted manually.

(3) Cooling air to bottom of furnace shell.

6.3.3. Fail safe devices:

Three fail safe devices in the APCS assist the operator to avoid conditions which could damage the system or endanger personnel.

(1) High temperature burner fail safe.

If the temperature at the outlet of the thermal oxidizer (T3) exceeds a preset maximum (200 F higher than the operating temperature of the thermal oxidizer), the fail safe signals with a flashing light on the console and stops the burners. Manual reset is required to restart the burners.

(2) High temperature baghouse and scrubber protection.

If the temperature at the outlet of the wind box (T6) exceeds the low set point (315 F), the fail safe signals with a buzzer and a flashing light on the console. If no action is taken to correct the temperature, and the temperature at T6 increases to exceed the high set point (335 F), the fail safe stops all burners and closes the APCS valve. The bags are rated for continuous duty at 350 F exposed to gases containing less than 15 pct oxygen, but the scrubber is rated for 300 F gas inlet temperature.

(3) Low pressure baghouse, scrubber, and cooler/condenser protection.

If the pressure at the inlet to the baghouse (P7) becomes less than a preset minimum, the fail safe signals with a buzzer and a flashing light on the console. If the condition is not corrected within a preset time (30 sec), the fail safe opens the cooling air valve to increase the pressure. Manual reset of the pressure sensor is required to regain control of the cooling air valve. The baghouse, scrubber, and cooler/condenser are rated at negative 20 in WC working pressure.

6.4. Data Acquisition:

Basic information to evaluate the performance of the feed system, electric arc melting furnace, and the APCS are recorded electronically and/or manually throughout a melting campaign. Sampling of offgas will be done by Entropy Inc., a qualified air quality laboratory using EPA methods described in 40 CFR part 60 Appendix A. Particulate matter will be further analyzed with the protocols of SW 846 for all feed components to assess entrainment.

6.4.1. Electrical Parameters:

Electrical parameters for analyzing demand and consumption of the electric furnace are continuously monitored by a True RMS Power and Demand Analyzer Model 3950, which records rms voltage (V), rms current (A), apparent power (VA), active power (W), reactive power (var), power factor, and total energy (kW·h). These data are integrated over 1 min interval, and the integral values are stored by the instrument. Four channels (V, A, kW, and kW·h) are transmitted to a data logger, which receives up to 38 additional inputs from sensors in the feed system, electric furnace, and APCS, applies a linear scaling factor to each input as needed, and transmits the calculated values to a personal computer at intervals of 1 min for display and storage. A hard copy is printed at 5-min intervals.

6.4.2. Continuous Monitoring Locations:

Monitoring locations in the furnace and the APCS are indicated on figure 1.2. The following data derived from both the furnace, APCS, and feeder will be recorded continuously during the vitrification demonstration test by the data acquisition system:

Thermocouple sensor and type:	Monitoring point
Furnace exit after gas burner 1, Type R.	1.
Crossover duct exit after burner 2, Type R.	2.
Thermal oxidizer exit, Type R.	3.
Evaporative gas cooler exit, Type J.	4.
Cooling air supply duct, Type J.	5.
Wind box exit (cyclone entrance), Type J.	6.
Cyclone exit (baghouse entrance), Type J.	7.
Baghouse exit, Type J.	8.
Scrubber exit, Type J.	9.
Cooler/condenser exit, Type J.	10.
Reheater exit (ID blower entrance), Type J.	11.
ID blower exit (filter entrance), Type J.	12.
Filter exit (stack), Type J.	13.

Furnace upper plenum, Type K.	14.
Furnace shell bottom, Type J.	15.
Metal tap hole, Type R.	16.
Product glass, continuous indicating pyrometer.	17.
Primary combustion air, Type J.	18.
Secondary combustion air, Type J.	19.
Cooling water to furnace, Type J.	20.
Warm water return, Type J.	21.

Gas pressure transducer:	Monitoring point
Evaporative Gas Cooler exit.	4.
Cooling air.	5.
Wind box exit.	6.
Cyclone exit.	7.
Baghouse exit.	8.
Scrubber exit.	9.
Cooler/condenser exit.	10.
Reheat exit.	11.
ID blower exit.	12.
Filter exit or stack.	13.
Furnace upper plenum (air draft X-mitter).	14.
Primary combustion air.	18.
Secondary combustion air.	19.

Gas flow sensor and type:	Monitoring point
Atomization air for EGC, flow X-mitter.	EGC air supply
Evaporative gas cooler exit, He tracer.	4.
Cooling air duct, S-type pitot with P X-ducer.	5.
Baghouse exit, He tracer.	8.
Baghouse exit, S-type pitot with P X-ducer.	8.
Stack, S-type pitot with P X-ducer.	13.
Primary combustion air, flow X-mitter.	18.
Secondary combustion air, S-type pitot with P X-ducer	19.

Water flow sensor and type:	Monitoring point
EGC water, flow X-mitter.	EGC water supply
Cooling water to furnace, totalizing flow meter.	20.
Warm water return, totalizing flow meter.	21.

Miscellaneous sensor and type	Monitoring point
Feed rate	Metering bin
Cold top depth (continuous)	Under SE feed tube

Cold top depth (manual)	Under NE feed tube

6.4.3. Additional Logs:

Manual logs will be kept to record the following:

(1) Date, time installed, and weight of graphite electrode segments placed in service, (Electrode Log).
(2) Date, time, and weight of all materials entering the receiving bin of the feed system, (Receiving bin Log).
(3) Depth of cold top at irregular intervals to verify continuous indicating sensor, (Feeder Log).
(4) Feed rate at irregular intervals to verify continuous indicating sensor, (Feeder Log).
(5) Furnace parameters: transformer tap, electrode voltage, electrode current, power, energy, and rheostat settings, (Furnace Log).
(6) Date and time collected and the weight of all APCS products, (APCS Solids Log).
(7) Date and time collected and the weight of product glass ingots and samples for analysis, (Glass and Metal Product Log).

6.4.4. Offgas Analysis:

Furnace exhaust gases will be analyzed by contractor for CO, CO_2, N_2, H_2, O_2, SO_x, and NO_x as minimum requirements, with speciation of NO_x, Cl, F, PO_4^-, B, NH_3, and CH_4 desired. An on-line dual-column gas chromatograph also will be available to determine concentrations of CO, CO_2, O_2, N_2, SO_2, NO_x, and He at 1-min intervals. He, the tracer gas, will be continuously injected at a measured rate into the plenum of the furnace to allow calculation of gas flow rate at any point downstream. The output of the chromatograph is displayed on a video monitor and also saved to disk.

6.5. Electric Arc Melting Furnace and Power Supply:

The furnace is a sealed 3-phase electric arc furnace with three 4-in (10.2 cm) diameter graphite electrodes. The furnace proper is a refractory-lined carbon steel shell 65 in (1.65 m) high tapering from 56-in (142.2 cm) ID at the top to 60-in (152.4 cm) ID at the bottom. The roof and sidewalls of the furnace are water cooled and the bottom of the furnace shell is air cooled to minimize refractory erosion. The initial 18 in (46 cm) of the exhaust gas exit port also is water cooled. Metal is tapped from the furnace and the hearth is drained as needed by manually opening a 1-1/2-in (3.81 cm) diameter hole in the bottom center of the hearth. Glass is tapped continuously or upon demand from the furnace at rates up to 2,200 lb/h (1 mt/h) through a water-cooled copper tapping fixture, which is a welded, double-walled, structure. A graphite tapping fixture with central hole up to 4 in diameter (10.2 cm) is available if the water cooled fixture interferes with tapping of glass.

The bottom and sidewall of the furnace shell are lined with chromic oxide-alumina bonded 90 pct alumina super duty firebrick. Additional protection of the sidewall refractory is provided by water cooling of the exterior of the metal walls. The upper sidewall is lined with 70 pct alumina insulating arch firebrick. The finished inside diameter of the furnace is about 46 in (1.17 m). The hemispherical hearth with 5 ft^3 capacity below the glass tap hole was finish formed with chromic oxide-alumina bonded alumina ramming mix.

The roof of the furnace is lined with 4 in (10.2 cm) of 85 pct alumina plastic refractory.

The furnace is powered by a 3-phase 800 KVA transformer and three 250 KVA single-phase transformers configured to provide phase-to-phase voltage in the range 239 to 352 volts, which is satisfactory for melting high-resistance materials such as the LD6-5510 glass composition. The power supply can be reconfigured to accommodate most metallic and nonmetallic feed materials.

Voltage regulation of 3 to 5 pct of the mean from open circuit to full load is provided by the power supply with 2,080 ampere maximum output current measured at the furnace. Power can be increased for a given transformer tap position by increasing the electrode positioning rheostats. A rheostat for each phase, working through the electrode positioning circuit for that phase, adjusts the electrode position to decrease the arc length, or even submerge the electrode in the melt, thereby providing increased current. Power to the furnace is a function of the voltage (transformer tap), current (electrode position as determined by rheostat setting), and the resistivity of the slag. A rheostat controls each electrode thereby providing a means to balance the power.

(7) PROCEDURES FOR APCS AND COOLING WATER SYSTEMS

7.1. Cooling Water Supply and City Water Backup:

(1) Turn on city water supply valves (two blue handles) in trench outside building and red handle near red switch in trench near furnace.

(2) Close drain valves (on bottom) of 15 hp water supply pump, 5 hp tower circulating pump, and Supertrol pump. Also close drain valves on Supertrol hot water supply lines and tower water supply line in trench.

(3) Open tower water supply valve to Supertrol (yellow handle on line leading to Supertrol).

(4) Turn on power conditioner (in vault) to city water fail safe valve.

(5) Verify that city water fail safe valve is closed by opening water supply valve to any feed tube. Momentarily turn power off to the power conditioner; fail safe valve should open, and water should flow in the open supply line.

(6) Press start button (left button) on W wall to activate cooling tower circulating pump. Allow a few minutes for city water to make up the water held in the cooling tower. Verify that the tower circulating pump has not lost its prime.

(7) Press start button (right button) to activate tower water supply pump, and close fan start switch on electrical box to start the cooling tower fan. The supply pump must not operate for more than a few minutes without flow.

(8) Verify that all drain valves are closed by opening the trench cover outside the building and making a complete inspection of the water supply system.

(9) Open manual water valves near the east side of the furnace to supply 20 gpm to the feed tubes, glass tap hole fixture, and exhaust gas duct (six valves). Shunt all cooling water to the lower water trough by arranging the valves in the exit lines. Open the single manual valve on the W wall to supply 30 gpm to the transformer and electrode clamps and arms (verify flow by observing flows in the four exit circuits).

7.2. Operation of UDC Controllers:

Upper display:	Indicates process variable (temperature, pressure, pct, other):
Lower display:	Indicates one of the following (Set point, Output, Deviation).
Push buttons:	The following keys are operational: Lower display, Up arrow, Down arrow, Auto/Manual and Tuning (function and set up).

For normal operation the keys to be used are: Lower display, Up arrow, Down arrow, and Auto/Manual.

Use the Lower Display key to change the lower display to the desired function.

Use the Arrow keys to change the value.

Change the set point by having Set Point in the lower display and using the arrow keys.

To change the output: 1. Place controller in Manual mode, 2. Change lower display to Out, 3. Use the arrow keys to change the value.

7.3. Operation of Console, APCS, and Data Acquisition Systems:

(10) UPS on.

(11) Turn on power switch to computers and data loggers (near monitor), and verify that all sensors are reporting to the data logger.

(12) Synchronize all watches and clocks.

(13) Move control power selector switch to the on position.
Power on indicator light will glow.

Note that controllers reset to manual mode when the console power is turned off. Controllers return to a preset condition when power is resumed. Default conditions are the following:
APCS valve controller, 10 pct = 10 pct open,
Cooling air valve controller, 100 pct = 100 pct open,
ID blower damper controller, 10 pct = 10 pct open,
EGC controller, 100 pct = minimum water flow. Note that EGC controller is opposite to all others.

(14) Push start buttons for circuits A, B, C, D, and E on the furnace console to supply power to the Supertrol, feed system, and low water pressure alarm for the electrode clamps and support arms. Then push Supertrol power on button; green verification light will glow. Set temperature at controller outside of building to 150 F. Verify that tower water supply valve to Supertrol is open and that Supertrol is receiving water.

(15) Set high temperature limit controller 200 F higher than the desired operating temperature for the thermal oxidizer (T3). The operating temperature for the WHC test is 1,600 F, and the high temperature limit is 1,800 F. If the high temperature limit is exceeded, the controller signals with a flashing red light and stops all burners. Manual reset is required before restarting the burners.

(16) Verify that low and high temperature set points on the baghouse/scrubber temperature fail safe are 315 F and 335 F, respectively. If the temperature at the outlet of the wind box (T6) exceeds the low set point (315 F), the fail safe signals with a buzzer and a flashing light on the console. If no action is taken to correct the temperature, and the temperature at T6 increases to exceed the high set point (335 F), the fail safe stops all burners and closes the APCS valve.

(17) Verify that the low pressure set point on the baghouse pressure fail safe is -21 in WC. If the pressure at the inlet to the baghouse (P7) becomes less than the preset minimum, the fail safe activates a timer and signals with a buzzer and a flashing light on the console. If the condition is not corrected within a preset time (30 sec), the fail safe opens the cooling air valve to increase the pressure. Manual reset of the pressure

sensor is required to regain control of the cooling air valve. The baghouse, scrubber, and cooler/condenser are rated at negative 20 in WC working pressure.

(18) Open cooling air bypass valve. This is a manual valve and must be opened by hand. A limit switch in the cooling air bypass valve will close, and a green verification light on the console will glow.

(19) Open furnace inspection port. Note that the furnace, the refractory lined ducts, and the EGC will not be purged unless the furnace inspection port is open.

(20) Verify the default condition for the secondary air controller: manual mode with zero output. The blue verification light will glow confirming that the secondary air valve is closed.

(21) Verify default condition for the ID blower damper controller: manual mode with 10 pct output (damper is 10 pct open). The ID blower damper controller remains in the manual position while the system is operating.

(22) Verify default condition for the APCS valve controller: manual mode with 10 pct output (valve is 10 pct open).

(23) Verify default condition for the cooling air valve controller: manual mode with 100 pct output (cooling air valve is 100 pct open). A green verification light will glow confirming the open status of the cooling air valve. The cooling air valve must be controlled manually until T6 exceeds 300 F. Premature automatic operation will result in closing of the cooling air valve, which could activate the low pressure baghouse fail safe.

(24) Press the ID blower start button and hold until green light glows. If air pressure switch fails to close within 3 sec, failure light glows. A purge timer is automatically energized, and a purge light will glow when the purge cycle is complete (5 min unless otherwise adjusted). Note that the purge cycle timer is adjustable on the instrumentation panel. At the end of purge cycle, purge complete light glows. Do not light burners until Purge Complete Light is on, but note that the purge timer does not prevent lighting of the burners.

(25) Adjust variable frequency control (VFC) knob for the cooling air blower to full CCW position. The VFC is the green box on the left side of the console.

(26) Start the cooling air blower by holding the start button down while moving the start control switch on the VFC to reset (down) and then to run (up). A limit switch will make, and a green verification indicator light will glow confirming operation of the blower.

(27) Manually close the furnace inspection door.

(28) Observe the pressure profile over the APCS. Static pressure (SP) across the ID blower should be in the range 26 to 31 in WC. The motor will draw excessive current if the SP is less than 26 in WC. To correct, close the APCS valve in small increments while observing SP over the ID blower and pressure in the cooler/condenser. If pressure in the cooler decreases to negative 20 in WC before the desired SP is obtained, reopen the APCS valve to 10 pct, adjust the ID damper to 15 pct, and then close the APCS valve in increments until SP is within range. The APCS valve must be operated in manual mode during heating of the APCS to maintain SP in the range 26 to 31 in WC and pressure in the cooler greater than negative 20 in WC.

(29) Manually open the air line (two valves) to the baghouse.

(30) Turn on baghouse pulsator. Baghouse pulsator lights will glow proving power and air pressure.

(31) Turn on manual water valve to acid gas scrubber (tower water), and allow scrubber reservoir to fill. Adjust manual valve to provide about 5 gpm overflow.

(32) Turn on manual water valve one complete turn to cooler/condenser (tower water).

Note that the scrubber and cooler/condenser should not be activated until the temperature in the baghouse exit equals 180 F.

7.4. Operation of Burners:

The following applies to burners 1, 2, and 3. Burner 1 is the example.

(33) Open manual gas valves, and check incoming pressure. Each burner has a separate inlet valve and a pilot valve and a separate outlet valve. Each of the nine valves must be opened.

(34) Place burner #1 controller in the manual mode, and press down arrow until display indicates 0 pct. Burner #1 control valves (air and gas) are in low fire position (not completely closed).

(35) Press burner #1 blower start button and hold until green pressure verification light glows.

(36) Turn burner #1 switch to on position.
  a. Burner will purge for 60 sec.
  b. After 10 sec ignition transformer will operate and pilot gas valve will open.
  c. Ignition transformer turns off.
  d. Main gas valve opens 10 sec later and pilot gas valve closes. Burner #1 green verification light glows.

Flame failure light glows if flame is not present by end of b, or main flame is not sensed. Press reset button, and try again. If burner fails to light after third attempt, check incoming gas valves and other sources of error.

(37) Start burners 2 and 3.

(38) Monitor temperatures at T_1, T_2, and T_3; press up arrow as needed on the controllers to provide heating rate of 50 F per hour (heating to the previous operating temperature can be 100 F/h; therefore, heating to 600 F can be 100 F/h).

(39) Monitor temperature at T_4 (between the EGC and windbox) and T_6 (after the wind box). Note that the gas temperature at T_6 will carry through the baghouse to the scrubber and the cooler condenser, which should not be exposed to temperatures greater than 180 F without water flow.

(40) When T_6 reaches 180 F, turn acid gas scrubber switch to on position to activate scrubber recycle pump. A green light on the console will glow proving that power is on and recycle line is pressurized. Monitor liquid level in the scrubber, and adjust makeup water valve to provide 2 to 3 gpm overflow.

(41) With cooler/condenser controller in manual mode, press up arrow until display indicates 10 pct (3 in ball valve in supply line is 10 pct open).

(42) Place cooler/condenser switch in on position. A green light on the console will glow proving that power is on and water line is pressurized.

Note that the cooling air bypass valve is open, the APCS valve controller is in manual mode, the cooling air blower controller is in manual mode, and the cooling air blower is operating at maximum output.

(43) Turn on manual valves to provide water and air to the EGC system.

(44) Place the H/O/A switch for the EGC system in the "A" position. Note that the H position is for set up and adjustment of the spray lance. Spray lance then can be operated outside the system. The EGC controller operates independently of the H/O/A switch.

(45) Continue to monitor T_4 and T_6 as the output of the burners is increased. When T_6 indicates 300 F, cooling in addition to air supplied by the open cooling air bypass valve is required. Therefore, move the EGC system power switch to the on position. EGC system power green lights will glow if air pressure and water switches are made. If EGC system power lights do not glow, check air and water valves. EGC will automatically maintain T_4 at 500 F. The temperature at T_6 then will decrease to below 300 F.

(46) Close the cooling air bypass valve in increments until T_6 indicates 300 F.

(47) Continue to advance the burners to provide the desired heating rate, and continue to adjust the APCS valve, the ID blower damper, and the cooling air bypass valve to maintain SP over the ID blower in the range 26 to 31 in WC, T_6 near 300 F, and furnace pressure, P_{14}, at negative value (0.5 in WC is desired). Negative pressure in the furnace assures the correct direction of flow of combustion gases.

(48) Monitor P_{14}. When furnace pressure can be maintained manually at negative 0.5 in WC, attempt automatic control of the APCS valve. If successful, attempt automatic control of the cooling air valve. If successful, slowly close the cooling air bypass valve in increments. A limit switch in the cooling air bypass valve will close and blue verification light will glow confirming closure of the valve.

(49) Carefully adjust the ID blower damper to position the APCS valve at the 70 pct open position, the position for optimum control. Note that the ID blower damper must be adjusted manually as the burners are increased to maintain the 70 pct open position.

(50) Carefully adjust the speed of the cooling air blower to position the cooling air valve at the 70 pct open position, the position for optimum control. Note that the cooling air blower speed must be monitored and adjusted manually as needed while the APCS is heating to maintain the cooling air valve at 70 pct open.

(51) When T_1 reaches 1,600 F, turn controllers for burners 1, 2, and 3 to auto which starts the respective control loops.

Air pollution control and water cooling systems are now operational.

7.5. Scheduled Shutdown of APCS and Water Cooling Systems:

(1) Place burner 1 controller in the manual mode, and press down arrow to zero pct. Place burner 1 switch in the off position. Note that burner 1 blower remains on to provide air to cool the burner.

(2) Monitor position of APCS and cooling air valves, and allow valves to compensate for decreased gas flow in the APCS. Adjust ID blower damper and VFC for cooling air blower as needed to maintain APCS and cooling air valves 70 pct open.

(3) Repeat steps 1 and 2 for burners 2 and 3.

(4) When temperature at location T_4 reaches 600 F, place cooling air valve controller in manual mode, press up arrow to 100 pct, and maintain that position until the system is entirely cold and purged of moisture and acidic remanents.

(5) Open cooling air bypass valve.

(6) The EGC will automatically turn off when the temperature run permissive at position T_4 comes out of the circuit at 500 F.

(7) When T_4 reaches 300 F push the burner blower stop buttons.

(8) Turn off the EGC system.

(9) Place the EGC H/O/A in the Off position.

(10) Manually open the furnace inspection door to assist purge of acidic remnants.

(11) Monitor pressure drop across the ID blower. Position APCS valve and ID blower damper during cooling to maintain pressure drop over ID blower in the range 26 to 31 in WC.

(12) Press down arrow on Supertrol controller to 100 F to prevent overheating of carbon filters, which will begin to liberate adsorbed materials at 120 F.

(13) Place cooler/condenser controller in manual mode, and press down arrow to zero. Close manual water valve to cooler/condenser.

(23) Continue to operate baghouse, scrubber, ID blower, and cooling air blower for 12 to 24 h to purge moisture and acidic remnants from the system.

(24) After purge is complete turn off baghouse pulsator.

(25) Push cooling air blower and ID blower stop buttons to complete shutdown of APCS.

(26) Turn off cooling water supply pump, cooling water circulating pump, cooling tower fan, and all manual water valves. Open all drain valves.

7.6. Emergency Shutdown of APCS:

The following actions should be taken in a matter of seconds.

(1) Turn all burner controls to off position. Burner blowers will automatically decrease to minimum flow.

(2) Place APCS controller in manual mode, press down arrow to drive output to zero, which closes the APCS valve. These actions will isolate the heat sensitive components of the APCS.

(3) Place cooling air controller in manual mode, and drive cooling air valve 100 pct open. Adjust cooling air blower VFC to maximum.

(4) Monitor pressure P_{10}. Adjust ID damper controller to prevent excessive negative pressure in the cooler/condenser, scrubber, and baghouse.

(5) EGC system will stop automatically when temperature at T_4 decreases to 500 F.

(6) Open manual cooling air bypass valve.

(7) Stop burner blowers if pressure in the furnace becomes excessive, but monitor temperature of burners to prevent damage from overheating. Carefully open the APCS valve to 5 pct open and restart burner blowers if burners become overheated.

(8) Monitor T_6. Air provided by the open cooling air bypass valve should maintain T_6 below 300 F.

7.7. Restarting APCS after Emergency Shutdown:

Conditions: Burner controllers in manual mode with zero output.
Cooling air bypass valve open.
Cooling air controller in manual mode with 100 pct output.
Cooling air blower VFC at maximum.
APCS valve controller in manual mode with 5 pct output.
ID blower damper controller output at 10 pct.

(1) Restart burner 1.

(2) Monitor T_4 and T_6. EGC system should restart when T_4 reaches 500 F. Do not allow T_6 to exceed 315 F.

(3) Slowly increase burner 1 output to condition prior to emergency shutdown. Adjust APCS valve and ID blower damper to maintain static pressure across the ID blower in the range 26 to 31 in WC.

(4) Repeat steps 1, 2, and 3 for burner 2.

(5) Monitor P_{14}. When furnace pressure can be maintained manually at negative 0.5 in WC, attempt automatic control of the APCS valve. If successful, attempt automatic control of the cooling air valve. If successful, slowly close the cooling air bypass valve in increments. A limit switch in the cooling air bypass valve will close and blue verification light will glow confirming closure of the valve.

(6) Carefully adjust the ID blower damper to position the APCS valve at the 70 pct open position, the position for optimum control. Note that the ID blower damper must be adjusted manually as the burners are increased to maintain the 70 pct open position.

(7) Carefully adjust the speed of the cooling air blower to position the cooling air valve at the 70 pct open position, the position for optimum control. Note that the cooling air blower speed must be monitored and adjusted manually as needed while the APCS is heating to maintain the cooling air valve at 70 pct open.

(8) Reheat APCS to desired temperature to complete restart of system.

(8) WHC DEMONSTRATION MELTING TEST

8.1. Pretest Conditions:

(1) At least 32,000 lb of pelletized, denitrified, LD6-5510 feed material consisting of 4,000 lb of feed prepared by Method A and 28,000 lb prepared by Method B is available.
(2) The feed system, furnace, power supply, APCS, and data acquisition systems are functioning.
(3) Metal tap hole cleaned and plugged with 8 in of Permanente 165. An alumina-sheathed Type B thermocouple will be installed in the metal tap hole during repair.
(4) Two lengths carbon electrode in each electrode arm with clamps tightened. Note initial weight and length of each electrode and record additional electrode weights and lengths along with date and time installed in the Electrode Log.
(5) Emergency furnace cooling hoses in place.
(6) Electric drill and masonry bits available to open the metal tap hole.
(7) Steel rods available for closing glass tap hole.
(8) Two conical glass molds in position in north pit. All conical molds are coated with graphite or carbon wash and contain about 4 inches of sand in the bottom.
(9) Immersion thermocouple instrument checked out and 5 ft thermocouple tips available.
(10) Spoon for metal sample and rod for slag sample available.

(11) Steel rod for sounding furnace available.
(12) The thermal oxidizer catch basin is clean and the cyclone and baghouse are clean.
(13) The scrubber solution concentration is known and the solution has adequate capacity.
(14) He tracer inlet valve and gas chromatograph are functioning.
(15) All manual logs are available, and pertinent starting data are entered including water and gas totalizers.
(16) All personnel attending the furnace shall wear protective clothing, gloves, boots, and hard hats. Face shields and silver suits are required for the tapping crew. Respirators are required if appreciable fume escapes the fume collection hoods.
(17) Demonstration test procedures have been discussed and are understood by crew members.
(18) Sound cold furnace to measure depth from the thermocouple port to the true bottom of the furnace; record measurement in the Test Log.
(19) Feed materials in barrels are conveniently accessible to the barrel lift.
(20) Air monitors are installed to determine air quality within the building.
(21) Charge hopper is available to transfer charge materials to the receiving bin.
(22) Bags and dump hopper on small baghouse are clean.

8.2. <u>Melting Schedule:</u> Starting time for the demonstration test will be denoted T = 0.

8.2.1. Preheating of Furnace Refractories:

T minus 16 h:

Start furnace and begin feeding and melting mixture of limestone, silica, and alumina to heat furnace refractories to operating temperature. Begin He tracer injection into the furnace plenum, and verify operation of the chromatograph at the baghouse exit. Confirm veracity of thermocouples, pressure and velocity probes, and totalizing water and natural gas meters

8.2.2. Purging of Preheat Slag from Furnace:

T minus 4 h:

Begin feeding denitrified pellets of Method B Feed at 500 lb/h. Balance the feed rate, cold top depth, power input, and furnace pressure to melt 1,000 lb/h with continuous tapping of glass. Continue fine tuning of system while melting at 1,000 lb/h for 4 h to purge the furnace of residual calcium aluminum silicate. Obtain glass samples at one-half h intervals to document steady state melting conditions.

T minus 15 min:

Clean cyclone and baghouse, sample scrubber solution, and collect glass samples (2 kg in a conical steel mold and 2 kg on a cold steel plate).

8.2.3. Demonstrate steady state operation with Method B feed:

T = 0: Maintain steady state test conditions. Collect, identify, and package samples of glass, cyclone and baghouse solids, and scrubber solution at 2-h intervals.

8.2.4. Demonstrate Ability to Stop for an Extended Time and Restart:

T plus 8 h:

Stop feed, allow cold top to melt, plug glass tap hole with iron bar, stop power with electrodes in place, and stop cooling water to furnace shell. Maintain cooling water in all other circuits.

T plus 8 h 20 min:

Restart power supply on transformer tap D. If power starts readily, stop power to continue the stop test.

T plus 8 h 40 min:

Restart power supply on transformer tap D. If power starts readily, stop power to continue the stop test.

T plus 9 h:

Restart power supply on transformer tap D. If power supply is slow to start, increase tap to C, then B, and then A until current flow is established. Decrease transformer tap to C, restart water flow to the furnace sidewalls, and begin feeding to increase cold top to previous level. After 30 min, remove iron bar from slag tap hole to initiate continuous tapping. Establishment of continuous tapping completes the demonstration to stop for extended period and restart the furnace.

8.2.5. Demonstrate ability to idle for extended time (2 h) and restart:

T plus 16 h:

Stop feed, melt cold top, decrease power to minimum (transformer tap D with rheostats 0), and plug glass tap hole with iron bar.

T plus 18 h:

Increase power to previous value, and begin feeding at previous rate. After 30 min remove iron bar to initiate continuous tapping. Establishment of continuous tapping completes the demonstration to idle for an extended period.

8.2.6. Demonstrate steady state operation with Method A feed:

T = 20 h:

Switch to Method A feed, and maintain steady state test conditions while feeding and melting 1000 lb/h. Collect, identify, and package samples of glass, cyclone and baghouse solids, and scrubber solution at 2-h intervals.

T plus 24 h:

Cease feeding and allow cold top to melt. Plug glass tap hole with iron bar. Open metal tap hole to drain furnace contents into preheated ladle. Sample stream immediately using cast iron cup to capture metal if present. Sample glass as it exits the furnace using steel crucible and steel plate. Operate power supply as needed to maintain flow of material from the metal tap hole in order to completely drain the hearth. Completion of tapping stops the clock and ends the 24-h demonstration test. Remove ladle from the pit and transfer contents to cast iron molds. Conduct scheduled shutdown procedure for APCS, and allow furnace to cool. Remove electrodes from cool furnace. Record weight, length, and appearance on the electrode log. Collect residues from cyclone and baghouse, and sample scrubber and cooler/condenser solutions. Observe interior of furnace through inspection port in roof, and describe appearance of refractory.

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APPENDIX C

SAMPLE LOG FOR FURNACE FEEDS AND WHC1-1995 FURNACE PRODUCTS

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USBM

No.	Sample Number	Sample Date	Time Sampled	Sampler Initials	Sample Matrix	Sample Point
48	M1BPR-029M	01/27/95	21:30	FJ	Method B reacted pellets	Belt dryer exit
49	M1BPR-030M	01/27/95	23:40	FJ	Method B reacted pellets	Belt dryer exit
50	M1BPR-031M	01/30/95	12:25	FJ	Method B reacted pellets	Belt dryer exit
51	M1BPR-032M	01/30/95	13:45	FJ	Method B reacted pellets	Belt dryer exit
52	M1BPR-033M	01/30/95	15:20	FJ	Method B reacted pellets	Belt dryer exit
53	M1BPR-034M	01/30/95	17:00	JR	Method B reacted pellets	Belt dryer exit
54	M1BPR-035M	01/30/95	19:10	JR	Method B reacted pellets	Belt dryer exit
55	M1BPR-036M	01/30/95	21:10	JR	Method B reacted pellets	Belt dryer exit
56	M1BPR-037M	01/30/95	22:55	JR	Method B reacted pellets	Belt dryer exit
57	M1BPR-038M	01/31/95	02:20	JR	Method B reacted pellets	Belt dryer exit
58	M1BPR-039M	01/31/95	03:15	JR	Method B reacted pellets	Belt dryer exit
59	M1BPR-040M	01/31/95	05:25	RW	Method B reacted pellets	Belt dryer exit
60	M1BPR-041M	01/31/95	07:40	RW	Method B reacted pellets	Belt dryer exit
61	M1BPR-042M	01/31/95	09:25	FJ	Method B reacted pellets	Belt dryer exit
62	M1BPR-043M	01/31/95	11:20	FJ	Method B reacted pellets	Belt dryer exit
63	M1BPR-044M	01/31/95	13:20	FJ	Method B reacted pellets	Belt dryer exit
64	M1BPR-045M	01/31/95	14:45	FJ	Method B reacted pellets	Belt dryer exit
65	M1BPR-046M	01/31/95	16:40	JR	Method B reacted pellets	Belt dryer exit
66	M1BPR-047M	01/31/95	18:30	JR	Method B reacted pellets	Belt dryer exit
67	M1BPR-048M	01/31/95	20:00	JR	Method B reacted pellets	Belt dryer exit
68	M1BPR-049M	01/31/95	22:45	JR	Method B reacted pellets	Belt dryer exit
69	M1BPR-050M	02/01/95	00:15	JR	Method B reacted pellets	Belt dryer exit
70	M1BPR-051M	02/01/95	02:15	JR	Method B reacted pellets	Belt dryer exit
71	M1BPR-052M	02/01/95	04:00	JR	Method B reacted pellets	Belt dryer exit
72	M1BPR-053M	02/01/95	06:05	DP	Method B reacted pellets	Belt dryer exit
73	M1BPR-054M	02/01/95	07:45	DP	Method B reacted pellets	Belt dryer exit
74	M1BPR-055M	02/01/95	09:25	FJ	Method B reacted pellets	Belt dryer exit
75	M1BPR-056M	02/01/95	11:00	FJ	Method B reacted pellets	Belt dryer exit
76	M1BPR-057M	02/01/95	12:55	FJ	Method B reacted pellets	Belt dryer exit
77	M1BPR-058M	02/01/95	14:50	FJ	Method B reacted pellets	Belt dryer exit
78	M1BPR-059M	02/01/95	16:10	JR	Method B reacted pellets	Belt dryer exit
79	M1BPR-060M	02/01/95	17:50	JR	Method B reacted pellets	Belt dryer exit
80	M1BPR-061M	02/01/95	20:00	JR	Method B reacted pellets	Belt dryer exit
81	M1BPR-062M	02/01/95	22:30	JR	Method B reacted pellets	Belt dryer exit
82	M1BPR-063M	02/02/95	00:25	KJ	Method B reacted pellets	Belt dryer exit
83	M1BPR-064M	02/02/95	01:50	KJ	Method B reacted pellets	Belt dryer exit
84	M1BPR-065M	02/02/95	03:30	KJ	Method B reacted pellets	Belt dryer exit
85	M1BPR-066M	02/02/95	05:50	RW	Method B reacted pellets	Belt dryer exit
86	M1BPR-067M	02/02/95	07:35	RW	Method B reacted pellets	Belt dryer exit
87	M1BPR-068M	02/02/95	09:05	FJ	Method B reacted pellets	Belt dryer exit
88	M1BPR-069M	02/02/95	11:20	FJ	Method B reacted pellets	Belt dryer exit
89	M1BPR-070M	02/02/95	12:50	FJ	Method B reacted pellets	Belt dryer exit
90	M1BPR-071M	02/02/95	15:05	FJ	Method B reacted pellets	Belt dryer exit
91	M1BPR-072M	02/02/95	17:15	JR	Method B reacted pellets	Belt dryer exit
92	M1BPR-073M	02/02/95	19:15	JR	Method B reacted pellets	Belt dryer exit
93	M1BPR-074M	02/02/95	20:45	JR	Method B reacted pellets	Belt dryer exit
94	M1BPR-075M	02/02/95	22:30	JR	Method B reacted pellets	Belt dryer exit
95	M1BPR-076M	02/03/95	01:00	JR	Method B reacted pellets	Belt dryer exit
96	M1BPR-077M	02/03/95	02:30	JR	Method B reacted pellets	Belt dryer exit

USBM

No.	Sample Number	Sample Date	Time Sampled	Sampler Initials	Sample Matrix	Sample Point
97	M1BPR-078M	02/03/95	04:35	RW	Method B reacted pellets	Belt dryer exit
98	M1BPR-079M	02/03/95	07:40	RW	Method B reacted pellets	Belt dryer exit
99	M1BPR-080M	02/03/95	09:25	RW	Method B reacted pellets	Belt dryer exit
100	M1BPR-081M	02/03/95	11:30	RW	Method B reacted pellets	Belt dryer exit
101	M1BPR-082M	02/03/95	13:15	RW	Method B reacted pellets	Belt dryer exit
102	M1BPR-083M	02/03/95	14:55	RW	Method B reacted pellets	Belt dryer exit
103	M1BPR-084M	02/03/95	16:40	JR	Method B reacted pellets	Belt dryer exit
104	M1BPR-085M	02/03/95	17:30	JR	Method B reacted pellets	Belt dryer exit
105	M1BPR-086M	02/03/95	18:45	JR	Method B reacted pellets	Belt dryer exit
106	M1BPR-087M	02/03/95	20:40	JR	Method B reacted pellets	Belt dryer exit
107	M1BPR-088M	02/03/95	22:45	JR	Method B reacted pellets	Belt dryer exit
108	M1BPR-089M	02/04/95	02:00	JR	Method B reacted pellets	Belt dryer exit
109	M1G1-000M	03/08/95	14:56	SG	Glass from method B feed	Furnace slag tap
110	M1G1-001M	03/08/95	21:44	SG	Glass from method B feed	Furnace slag tap
111	M1G1-002M	03/09/95	02:15	BOC	Glass from method B feed	Furnace slag tap
112	M1G1-003M	03/09/95	05:40	BOC	Glass from method B feed	Furnace slag tap
113	M1G1-004M	03/09/95	10:30	BOC	Glass from method B feed	Furnace slag tap
114	M1G1-005M	03/09/95	13:05	SG	Glass from method B feed	Furnace slag tap
115	M1G1-006M	03/09/95	14:36	SG	Glass from method B feed	Furnace slag tap
116	M1G1-007M	03/09/95	15:30	SG	Glass from method B feed	Furnace slag tap
117	M1G1-008M	03/09/95	18:50	SG	Glass from method B feed	Furnace slag tap
118	M1G1-009M	03/09/95	20:15	SG	Glass from method B feed	Furnace slag tap
119	M1G1-010M	03/09/95	21:15	SG	Glass from method A feed	Furnace slag tap
120	M1G1-011M	03/09/95	22:15	SG	Glass from method A feed	Furnace slag tap
121	M1G1-012M	03/09/95	23:35	SG	Glass from method A feed	Furnace slag tap
122	M1MT2-001M	03/10/95	02:46	SG	Glass from method A feed	Metal tap
123	M1T3-001M	03/15/95	15:00	BOC	Glass from entire test interval	Thermal oxidizer base
124	M1C4-001M	03/14/95	10:00	BOC	Residues from entire test interval	Cyclone catch
125	M1B5-001M	03/13/95	16:00	BOC	Residues from entire test interval	Baghouse catch
126	M1S6-000M	03/08/95	14:20	SG	Scrubber solution	Scrubber
127	M1S6-001M	03/08/95	17:05	SG	Scrubber solution	Scrubber
128	M1S6-002M	03/08/95	18:10	SG	Scrubber solution	Scrubber
129	M1S6-003M	03/08/95	20:15	SG	Scrubber solution	Scrubber
130	M1S6-004M	03/08/95	22:15	SG	Scrubber solution	Scrubber
131	M1S6-005M	03/09/95	00:10	SG	Scrubber solution	Scrubber
132	M1S6-006M	03/09/95	02:05	BOC	Scrubber solution	Scrubber
133	M1S6-007M	03/09/95	04:00	BOC	Scrubber solution	Scrubber
134	M1S6-008M	03/09/95	06:00	BOC	Scrubber solution	Scrubber
135	M1S6-009M	03/09/95	08:15	BOC	Scrubber solution	Scrubber
136	M1S6-010M	03/09/95	10:30	BOC	Scrubber solution	Scrubber
137	M1S6-011M	03/09/95	12:00	SG	Scrubber solution	Scrubber
138	M1S6-012M	03/09/95	13:50	SG	Scrubber solution	Scrubber
139	M1S6-013M	03/09/95	15:50	SG	Scrubber solution	Scrubber
140	M1S6-014M	03/09/95	17:55	SG	Scrubber solution	Scrubber

USBM

No.	Sample Number	Sample Date	Time Sampled	Sampler Initials	Sample Matrix	Sample Point
141	M1S6-015M	03/09/95	19:50	SG	Scrubber solution	Scrubber
142	M1S6-016M	03/09/95	21:50	SG	Scrubber solution	Scrubber
143	M1S6-017M	03/10/95	00:45	SG	Scrubber solution	Scrubber
144	M1S6-018M	03/10/95	13:00	BOC	Scrubber solution	Scrubber

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APPENDIX D

SUMMARY OF OFFGAS EMISSIONS ANALYSIS BY ENTROPY, INC.

NOTE: Appendix D contains only the first part of the melter offgas report as prepared by Entropy Inc. The full report including field data and calculations is issued as a separate document "U. S. Bureau of Mines, Phase 1 Hanford Low-Level Waste Melter Tests: Melter Offgas Report" (WHC-SD-WM-VI-032).

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ENTROPY, INC.

Specialists in Air Emissions Technology

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(714) 373-0998 • (800) 899-3687 • Fax (714) 895-1915

SOURCE EMISSIONS TEST REPORT

HANFORD FEED

ELECTRIC ARC MELTER

Source Location:

US Bureau of Mines
Albany Research Center
1450 Queen Avenue, SW
Albany, Oregon 97321

Test Date: March 8 through 10, 1995
Issue Date: May 31, 1995
Revision: 1

Prepared for:

Lockheed Idaho Technologies Company
1955 Fremont Avenue
Idaho Falls, Idaho 83415

Prepared by:

Entropy, Inc.
EI No.: 13911 A

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Prepared by:

Entropy, Inc.
EI No.: 13911 A

Prepared By: Sakhalin Finnie — Sakhalin Finnie, Report Writer

Reviewed By: ______ Shawn Graham, Project Manager

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(continued)

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1.0 SUMMARY

1.1 Source Information

Plant Name and Address:
U.S. Bureau of Mines
Albany Research Center
1450 Queen Avenue, SW
Albany, Oregon 97321

Source Tested: Electric Arc Melter

Plant Contact: Larry Oden

Phone Number: (503) 967 - 5862

1.2 Testing Firm Information

Firm Name and Address:
Entropy, Inc.
5932 Bolsa Avenue, Suite 105
Huntington Beach, CA 92649

Firm Contact: Shawn Graham

Phone Number: (714) 373-0998 Ext. 27

Subcontractor: Quanterra Environmental Services

1.3 Test Information

Test Requested By: Lockheed Idaho Technologies Company (LITCO)

Firm Contact: Nick Soelberg

Phone Number: (208) 526 - 6923

Test Objective: To obtain emissions measurements to evaluate and understand melter system performance on surrogate waste materials.

Test Methods:

EPA 3A	O_2 and CO_2
EPA 5 Type	Particulate, Metals, NH_3, HCl, Cl_2, HF and F_2
EPA 6C	SO_2
EPA 7E	NO_x
EPA 10	CO
EPA 25A	Total Hydrocarbons (THC)

Test Date: March 8 through 10, 1995

1.4 Test Personnel

Test Coordinator: Nick Soelberg

Test Observers:	Larry Oden, USBM Bill O'Conner, USBM Paul Turner, USBM Lynn Ball, LITCO
Entropy Test Personnel:	Shawn Graham, Project Manager Hung Duong, Project Supervisor Eric Swope, Team Leader

2.0 TEST RESULTS AND DATA PRESENTATION

The result of the ammonia test run from the continuous emissions monitoring (CEM) conditioning system is presented in Table 2-1. The results of the particulate, metals, NH_3, HCl, Cl_2, HF and F_2 emissions testing are summarized in Table 2-2. The results of the O_2, CO_2, SO_2, NO_x, CO and THC testing are summarized in Table 2-3. The temperature and pressure measurements obtained from the EPA Method 2 sample traverses are presented in Tables 2-4 and 2-5, respectively.

Detailed field data and results tabulations are presented in Appendix A. Example calculations are given in Appendix B. Field data are given in Appendix C. Analytical data are provided in Appendix D. Calibration data are presented in Appendix E. Sampling train schematics are presented in Appendix F. Process schematics are presented in Appendix G.

TABLE 2-1
AMMONIA TEST RESULTS
(FROM CEM CONDITIONING SYSTEM)

PARAMETER	DATE	RUN TIME	TEST LOCATION	FEED	CATCH WEIGHT (mg)	VOLUME SAMPLED (acf)	CONCENTRATION (ppmvd)
Ammonia	March 9, 1995	1454-1622	In-Furnace	B & Idle	15.9	33.2	23.9

TABLE 2-2

EMISSIONS TEST RESULTS

PARAMETER	UNITS	TEST RUN 2 HANFORD B FURNACE OUTLET	TEST RUN 3 HANFORD B FURNACE OUTLET	TEST RUN 4 IDLE FURNACE OUTLET	TEST RUN 5 HANFORD A FURNACE OUTLET	TEST RUN 6 HANFORD A CYCLONE INLET
Run Time	minutes	1110-1138	1253-1329	1628-1708	2101-2151	2350-0035
Temperature	°F	981	981	▨	1670	645
Velocity	ft/s	14.5	14.5	▨	4.7	12.5
Volumetric Flow Rate	scfm	104.8	104.4	▨	14.9	223
Particulate	gr/dscf	28.4	23.5	0.0178	147	16.9
	lb/hr	25.5	21.0	▨	18.8	32.4
Aluminum	mg/dscf	2.84	2.52	0.00849	20.5	1.53
	lb/hr	0.0393	0.0348	▨	0.0405	0.0453
Boron	mg/dscf	156	109	0.175	648	45.5
	lb/hr	2.16	1.50	▨	1.28	1.34
Calcium	mg/dscf	1.85	1.57	0.0231	9.84	1.26
	lb/hr	0.0256	0.0216	▨	0.0194	0.0371
Cesium	mg/dscf	14.3	12.8	0.0212	64.8	9.71
	lb/hr	0.198	0.176	▨	0.128	0.286
Iron	mg/dscf	0.765	0.699	0.00311	4.50	0.505
	lb/hr	0.0106	0.00966	▨	0.0089	0.0149
Molybdenum	mg/dscf	7.92	5.09	0.00755	26.3	3.79
	lb/hr	0.110	0.0703	▨	0.052	0.112
Phosphorus	mg/dscf	3.74	3.24	0.00410	20.0	2.79
	lb/hr	0.0518	0.0448	▨	0.0394	0.0823
Potassium	mg/dscf	80.1	66.9	0.108	373	40.9
	lb/hr	1.11	0.923	▨	0.73	1.21
Sodium	mg/dscf	431	330	0.561	2168	202
	lb/hr	5.97	4.56	▨	4.27	5.95
Strontium	mg/dscf	0.0428	.0308	0.000104	0.178	0.0227
	lb/hr	0.000593	0.000425	▨	0.000351	0.000668
Sulfur	mg/dscf	42.9	42.8	0.0660	321	86.8
	lb/hr	0.595	0.591	▨	0.634	2.56

TABLE 2-2 (CONTINUED)

EMISSIONS TEST RESULTS

PARAMETER	UNITS	TEST RUN 2 HANFORD B FURNACE OUTLET	TEST RUN 3 HANFORD B FURNACE OUTLET	TEST RUN 4 IDLE FURNACE OUTLET	TEST RUN 5 HANFORD A FURNACE OUTLET	TEST RUN 6 HANFORD A CYCLONE INLET
Run Time	minutes	1110-1138	1253-1329	1628-1708	2101-2151	2350-0035
Temperature	°F	981	981		1670	645
Velocity	ft/s	14.5	14.5		4.7	12.5
Volumetric Flow Rate	scfm	104.8	104.4		14.9	223
Ammonia	ppmvd	157	142	54.1	198	0.287
	lb/hr	0.0437	0.0394		0.0078	0.000170
Chloride	ppmvd	1277	952	3.72	5830	876
	lb/hr	0.740	0.550		0.480	1.08
Hydrogen Chloride	ppmvd	< 10.2	< 4.36	< 0.889	< 19.7	< 2.01
	lb/hr	< 0.00605	< 0.00259		< 0.00167	< 0.00255
Chlorine	ppmvd	20.5	< 4.69	< 2.43	< 20.0	< 1.97
	lb/hr	0.0237	< 0.00541		< 0.0030	< 0.00486
Fluoride	ppmvd	< 90.5	93.8	0.295	< 20.0	83.3
	lb/hr	< 0.0281	0.0290		< 0.0444	0.0550
Hydrogen Fluoride	ppmvd	< 18.9	8.20	< 1.66	< 36.9	< 3.81
	lb/hr	< 0.00618	0.00267		< 0.00171	< 0.00264
Fluorine	ppmvd	< 11.1	8.75	< 1.58	< 37.5	< 3.68
	lb/hr	< 0.00686	0.00541		< 0.0030	< 0.00486

TABLE 2-3

O_2, CO_2, SO_2, NO_X, CO AND THC TEST RESULTS

DATE	TIME	LOCATION	FEED	O_2 (%)	CO_2 (%	CO (ppm)	NO_x (ppm)	NO (ppm)	SO_2 (ppm)	THC (ppm)	COMMENTS
March 8, 1995	0308-0316	Stack	Thermal Oxidizer Only	19.6	0.89	3.80	4.40	5.4			
	1619-1621	In-Furnace	B	2.91	13.5	3916	30.8	43.4	14.7		Four minutes of testing. The first minute of testing was discarded, because, the probe to close to the inlet wall.
	1827-2121	Stack		20.0	0.93	1.43	6.77	6.33	0.0		Sample line clogged after 3 minutes of sampling.
	2310-2311	Furnace Outlet		2.23	25.01	16.15	6.6	152.2	0.2	1.81	CO_2 over range. Sampling halted due to plugging.
	2349-0048	Stack		20.02	1.45	2.3	10.7	10.3	0.0		
March 9, 1995	0049-0148			20.0	1.28	0.9	8.9	8.5	0.0		
	0149-0248			19.7	1.5	16.5	13.5	13.3	0.0		
	0248-0348			19.7	1.27	8.8	10.5	10.2	0.0		
	0417-0502			18.9	1.66	> 100	12.5	12.5	0.0		All CO readings were over instrument span.
	0527-0602			18.9	1.7	> 1000	6.0	6.1	0.0		

TABLE 2-3 (CONTINUED)

O_2, CO_2, SO_2, NO_X, CO AND THC TEST RESULTS

DATE	TIME	LOCATION	FEED	O_2 (%)	CO_2 (%	CO (ppm)	NO_x (ppm)	NO (ppm)	SO_2 (ppm)	THC (ppm)	COMMENTS
March 9, 1995	0641-0741	Stack	B	19.52	0.98	2005	2.7	2.6	0.0		
	0749-0848			20.01	0.45	26.1	2.4	2.0	0.0		
	0848-0948			19.6	0.72	906.2	2.5	2.1	0.0		
	0948-1048			19.64	0.85	2701	3.8	3.5	0.0	3.2	Problem with post test system bias because sample line to the sample pump had a cut in it.
	1132-1146			19.4	1.09	290.4	4.0	4.0	0.0	12.2	The THC analyzer range was lowered to 0-100 ppm.
	1202-1301			19.39	1.27	10.1	5.3	5.3	0.0	2.5	
	1302-1401			19.47	1.28	0.5	5.6	5.6	0.0	2.2	
	1402-1428			19.52	1.30	6.3	6.6	6.8	0.0	1.9	

TABLE 2-3 (CONTINUED)

O_2, CO_2, SO_2, NO_X, CO AND THC TEST RESULTS

DATE	TIME	LOCATION	FEED	O_2 (%)	CO_2 (%	CO (ppm)	NO_x (ppm)	NO (ppm)	SO_2 (ppm)	THC (ppm)	COMMENTS
March 9, 1995	1459-1529	In-Furnace	B	10.1	16.5	6831	2.3	12.9	0.0	8.5	For all remaining CEM testing at the In-Furnace/Furnace Outlet the coil drain down condenser was replaced with a 2 impinger 0.1 N H_2SO_4 system. Data for the SO_2 and NO_x biased low due to wet impinger conditioning system. The NO_x was over range for 12 minutes. The CO was over range for 6 minutes.
	1530-1558		Idle	7.3	10.3	1822	12.4	26.4	50.4	5.0	Data for the SO_2 and NO_x biased low due to wet impinger conditioning system.

TABLE 2-3 (CONTINUED)

O_2, CO_2, SO_2, NO_X, CO AND THC TEST RESULTS

DATE	TIME	LOCATION	FEED	O_2 (%)	CO_2 (%	CO (ppm)	NO_x (ppm)	NO (ppm)	SO_2 (ppm)	THC (ppm)	COMMENTS
March 9, 1995	1758-1806	In-Furnace	A	4.42	14.7	175.9	0.0	23.7	0.98	8.0	The condenser system plugged after 9 minutes of sampling. The CO_2 was over range for 5 minutes. Data for the SO_2 and NO_x biased low due to wet impinger conditioning system.
	1846-1850			3.15	> 25.0	8.4	4.9	193.1	3.4	0.0	The sample line plugged after 6 minutes of testing. The CO_2 was over range during this time. Data for the SO_2 and NO_x biased low due to wet impinger conditioning system.

TABLE 2-3 (CONTINUED)

O_2, CO_2, SO_2, NO_X, CO AND THC TEST RESULTS

DATE	TIME	LOCATION	FEED	O_2 (%)	CO_2 (%	CO (ppm)	NO_x (ppm)	NO (ppm)	SO_2 (ppm)	THC (ppm)	COMMENTS
March 9, 1995	2035-2037	In-Furnace	A	20.35	1.09	2577	3.1	4.6	3.0	0.0	The THC not analyzed due to water in the system after four minutes of testing. Data for the SO_2 and NO_x biased low due to wet impinger conditioning system.
	2314-2343			20.35	1.23	400	0.0	4.3	0.0	0.0	CO over range for 1 minute. Data for the SO_2 and NO_x biased low due to wet impinger conditioning system.
	2344-2400			20.9	0.11	2.4	0.0	1.1	0.0	0.0	▨
March 10, 1995	0029-0131	Stack		20.01	1.0	2.5	3.8	4.3	0.6	▨	▨
	0136-0204			19.9	0.98	2.7	5.9	5.5	5.6	6.8	▨

TABLE 2-4

TEMPERATURE TEST RESULTS

RUN NUMBER	RUN TIME	TEST LOCATION	TEST DATE	AVERAGE TEMPERATURE (°F)	MAXIMUM TEMPERATURE (°F)	MINIMUM TEMPERATURE (°F)	COMMENTS
M2-1	1550-1600	Furnace Outlet	March 8, 1995	1743.5	1770	1701	Preliminary Data
M2-2	2020-2035	Cyclone Inlet		232	256	198	Preliminary Data
M2-3	1022-1035	Furnace Outlet	March 9, 1995	981	1536	86	
M2-4	1615-1625			Not Measured			The duct plugged with particulate, therefore the traverse was not completed.
M2-5	2055-2120			1670	1670	1670	Single Point
M2-6	2335-2345	Cyclone Inlet		645	645	645	Single Point

TABLE 2-5

PRESSURE TEST RESULTS

RUN NUMBER	RUN TIME	TEST LOCATION	TEST DATE	AVERAGE VELOCITY (ft/s)	AVERAGE PRESSURE (in H_20)	MAXIMUM PRESSURE (in H_20)	MINIMUM PRESSURE (in H_20)	COMMENTS
M2-1	1550-1600	Furnace Outlet	March 8, 1995	▨	0.0061	0.007	0.006	Preliminary Data
M2-2	2020-2035	Cyclone Inlet		▨	0.017	0.022	0.011	Preliminary Data
M2-3	1022-1035	Furnace Outlet	March 9, 1995	14.5	0.0233	0.070	0.012	▨
M2-4	1615-1625			▨	0.046	0.21	0.007	The duct plugged with particulate, therefore the traverse was not completed.
M2-5	2055-2120			4.7	0.001	0.20	0.0005	Pitot tube plugged.
M2-6	2335-2345	Cyclone Inlet		▨	0.0227	0.013	0.029	The last four points on the vertical axes were not measured due to particulate buildup in the duct.

3.0 INTRODUCTION

On March 8 through 10, 1995 Entropy, Inc. conducted source emissions testing for LITCO at the U.S. Bureau of Mines in Albany, Oregon. The testing was conducted on the Electric Arc Melter. The methods used during this test program were EPA Method 1 for sampling point determination, EPA Method 2 for volumetric flow rate, EPA Method 3A for O_2 and CO_2. EPA Method 4 for moisture content, an EPA Method 5 type for particulate, metals, HCl, Cl_2, HF, F_2 and NH_3, EPA Method 6C for SO_2, EPA Method 7E for NO_x, EPA Method 10 for CO and EPA Method 25A for THC.

Below is a time log which shows the source tested, sampling methods, sampling objectives, and run numbers for the test program.

TIME LOG

DATE	TIME	FEED	ACTIVITY	COMMENTS
March 8, 1995	0308-0316	Thermal Oxidizer Only	Preliminary CEM test run at the furnace stack for O_2, CO_2, CO, NO_x, and NO	
	1550-1600	Hanford B	Preliminary test run M2-1 conducted for velocity and temperature at the furnace outlet.	
	1601-1630		Test run M5-1 conducted for Particulate, metals, NH_3, HCl, Cl_2, HF and F_2 at the furnace outlet.	Test run aborted due to plant load not established.
	1618-1621 1827-2121		CEM test run at the In-furnace for O_2, CO_2, CO, NO_x, NO and SO_2.	
	2020-2025		Preliminary test run M2-2 conducted for velocity and temperature at the cyclone inlet.	
	2310-2311		CEM test run at the furnace outlet for O_2, CO_2, CO, NO_x, NO and SO_2 and THC.	
	2349-2400		CEM test run at the stack for O_2, CO_2, CO, NO_x, NO and SO_2.	
March 9, 1995	0001-0239 0240-0250 0251-0348 0417-0502 0527-0602			

TIME LOG (CONTINUED)

DATE	TIME	FEED	ACTIVITY	COMMENTS
March 9, 1995	0642-0711 0712-0741 0749-0933 0934-1048	Hanford B	CEM test run at the stack for O_2, CO_2, CO, NO_x, NO and SO_2.	
	1022-1035		Test run M2-3 conducted for velocity and temperature at the furnace outlet.	
	1110-1138		Test run M5-2 conducted for particulate, metals, NH_3, HCl, Cl_2, HF and F_2 at the furnace outlet.	
	1132-1428		CEM test run at the stack for O_2, CO_2, CO, NO_x, NO and SO_2 and THC.	
	1253-1329		Test run M5-3 conducted for particulate, metals, NH_3, HCl, Cl_2, HF and F_2 at the furnace outlet.	
	1459-1540		CEM test run in the furnace for O_2, CO_2, CO, NO_x, NO and SO_2 and THC. The condenser system was replaced with impingers to avoid plugging. The impinger contents were analyzed for NH_3.	Data for SO_2 and NO_x biased low due to wet impingement conditioning system.
	1615-1620	Idle	Test run M2-4 conducted for velocity and temperature at the furnace outlet.	Test aborted due to plugging in sampling duct.
	1628-1708		Test run M5-4 conducted for particulate, metals, NH_3, HCl, Cl_2, HF and F_2 at the furnace outlet.	
	1758-1806 1846-1850 2035-2037	Hanford A	CEM test run in the furnace for O_2, CO_2, CO, NO_x, NO and SO_2 and THC.	Data for SO_2 and NO_x biased low due to wet impingement conditioning system.
	2055-2120		Test run M2-5 conducted for velocity and temperature at the furnace outlet.	Test aborted due to plugging in pitot tube.

TIME LOG (CONTINUED)

DATE	TIME	FEED	ACTIVITY	COMMENTS
March 9, 1995	2101-2151	Hanford A	Test run M5-5 conducted for particulate, metals, NH_3, HCl, Cl_2, HF and F_2 at the furnace outlet.	▨
	2314-2400		CEM test run in the furnace for O_2, CO_2, CO, NO_x, NO and SO_2.	Data for SO_2 and NO_x biased low due to wet impingement conditioning system.
	2335-2345		Test run M2-6 conducted for velocity and temperature at the cyclone inlet.	▨
	2300-0035		Test run M5-6 conducted for particulate, metals, NH_3, HCl, Cl_2, HF and F_2 at the cyclone inlet.	▨
March 10, 1995	0029-0131 0136-0204		CEM test run at the stack for O_2, CO_2, CO, NO_x, NO and SO_2.	Data for SO_2 and NO_x biased low due to wet impingement conditioning system.

4.0 SOURCE PROCESS AND EQUIPMENT DESCRIPTION

4.1 Process Description

The three phase 800 kVA Arc Melter furnace uses three graphite electrodes for melting materials and maintaining furnace temperature. Gases from the furnace are passed through a series of three afterburners before passing through a cyclone for initial particulate removal. Gases from the cyclone are directed through a baghouse for final particulate removal. Flue gases then pass through an acid gas scrubber, a condenser and reheat exchanger. An induced draft next blower directs the gas through a series of carbon and HEPA filters before exhausting out of the stack.

4.2 Location Description

4.2.1 In-Furnace

The furnace is approximately four (4) feet in diameter at the location tested. The test port available was 2 inch pipe thread reduced to 0.75 inch pipe.

4.2.2 Furnace Outlet

The furnace outlet test port location was contained within an eight (8) inch duct seven (7) inches above the furnace outer wall. The test port was seven (7) inches upstream of the next flow disturbance, afterburner 2. The test port was 1.5 inch pipe reduced to 0.75 inch pipe. The total length of the test port, including the reduction was 17 inches.

4.2.3 Cyclone Inlet

The cyclone inlet duct was a horizontal 11.25 inch diameter duct. The distances to the nearest upstream and downstream disturbance were 28.5 and 32 inches, respectively. Two three inch test ports are available for sampling.

4.2.4 Furnace Stack

The stack is 13.625 inches in diameter. Two three inch test ports were available for sampling.

5.0 SAMPLING AND ANALYTICAL PROCEDURES

Following are brief descriptions of the sampling and analytical procedures employed during this test program.

5.1 Sampling Point Determination - EPA Method 1

The number and locations of the sampling and/or traverse points were determined according to the procedures outlined in EPA Method 1. Verification of absence of cyclonic flow was conducted prior to testing.

5.2 Flue Gas Velocity and Flow Rate - EPA Method 2

The flue gas velocity and volumetric flow rate were determined according to the procedures outlined in EPA Method 2. Velocity measurements were made using Type S Pitot tubes conforming to the geometric specifications in the test method. Accordingly, each has been assigned a coefficient of 0.84. Differential pressures were measured with Magnehelic gauges of appropriate range or with fluid manometers. Effluent gas temperatures were measured with Type K (chromel-alumel) thermocouples equipped with hand-held digital readouts.

5.3 Flue Gas Moisture Content - EPA Method 4

The flue gas moisture content was determined in conjunction with each EPA Method 4 type train and according to the sampling and analytical procedures outlined in EPA Method 4. The impingers were connected in series and contained reagents as listed in the following method descriptions. The impingers were contained in an ice bath to assure condensation of the flue gas stream moisture. Any moisture that was not condensed in the impingers was captured in the silica gel; therefore, all moisture was weighed and entered into moisture content calculations.

5.4 Particulate, Metals, NH_3, HCl, Cl_2, HF and F_2 - EPA Method 5 Type

The concentrations of particulate, metals, NH_3, HCl, Cl_2, HF, and F_2 were determined using the procedures and equipment described in EPA Method 5, in combination with Methods 1 through 4 described above. Particulate matter was withdrawn from the source and collected on a quartz filter maintained at a temperature in the range of 248 ± 25°F.

Sampling Train Description. The sampling train consisted of quartz or glass probe, a heated quartz fiber filter, four chilled impingers in series, a pump, a dry gas meter and a calibrated orifice. The filter was housed in a glass filter holder and supported on a glass frit. The first and second impingers each contained 100 mL of 0.1N sulfuric acid water, the third contained 100 ml of 0.1N sodium hydroxide, and the fourth contained preweighed silica gel. The probe and filter housing were further cleaned for metals by soaking in 1:1 nitric acid. All glassware was precleaned using soap, tap water and deionized (DI) water. A diagram of the sampling train used by Entropy for the testing is presented in Appendix G.

A stainless steel nozzle was used for sampling conducted at the cyclone inlet. An unheated 5 foot transfer line between the probe and filter was used for testing conducted at the furnace outlet.

Sample Train Operation. The sample train was operated according to EPA Method 5 at the cyclone inlet. Sampling at the furnace outlet was conducted at a single point and constant rate. Sampling trains were leak tested to ensure that leakage did not exceed 0.02 cfm. The filter compartment was maintained at 248°F ± 25°F during sampling.

Sample Recovery. The filter was removed and placed in a jar. The nozzle (if applicable), transfer line (if applicable), probe and filter front half were rinsed with acetone into a jar, followed by a 0.1N nitric acid rinse into a separate jar. The contents of the impingers were returned to the original jar, weighed, the weight recorded and the liquid level marked. The impingers were then rinsed with DI into the jar containing the impingers' reagent. The silica gel was returned to the original tared jar, weighed and the weight recorded.

Sample Analysis. The particulate mass, which included any material that condensed at or above the filtration temperature, was determined gravimetrically after removal of uncombined water.

Analyses for metals were conducted after completion of particulate analyses. The filter was leached with DI water. Half of the leached material was analyzed for metals while the other half was analyzed for particulate, metals, NH_3, HCl, Cl_2, HF, and F_2. The filter catch residue was digested with HNO_3/HCl to a volume of 100 mls. 50 mls was archived and 50 mls was combined with the leached fraction and 50 % of the 0.1N HNO3 front half rinse. The combined fraction was analyzed for metals by ICP and ICP/MS.

Half of both the DI leached filter and the 0.1N HNO_3 probe rinse were analyzed for fluoride and chloride by EPA Method 300.0. The impinger contents were analyzed for NH_3, HCl, Cl_2, HF, and F_2 by EPA Method 350.2.

5.5 O_2, CO_2, SO_2, NO_x, CO and THC - EPA Methods 3A, 6C, 7E, 10 and 25A

The sampling and analytical procedures outlined in EPA Methods 3A, 6C, 7E, 10 and 25A were used to measure the concentrations of gaseous species in the flue gas stream using Entropy's CEM Mobile Laboratory. The EPA Methods were followed to quantify dry basis flue gas concentrations of CO, SO_2, NO_x, THC, CO_2, and O_2. Calibration gases were selected to meet the criteria of the method. All calibration gas concentrations were certified by EPA Protocol 1 analysis.

At the beginning of each test day, a calibration error test was conducted by flowing zero, mid and high range calibration gases directly to the analyzers. Before and after each test run, system calibration bias tests were conducted by flowing zero and upscale calibration gases through the sampling system. A description of the analyzers used for the test program is presented in Table 5-1.

TABLE 5-1

ANALYZERS USED FOR EPA METHODS 3A, 6C, 7E, 10 AND 25A

Monitor Type	Manufacturer	Model Number	Detection Principle	Range - Cyclone Inlet	Range - Stack Locations
O_2	Teledyne	320P-4	Fuel Cell	0-25 %	0-25 %
CO_2	ACS (Fuji)	3300	Non-Dispersive	0-20 %	0-20 %
NO_x	Thermo Environmental	10	Chemilumin - escence	0-10,000 ppm	0-250 ppm
NO	Thermo Environmental	10	Chemilumin - escence	0-5,000 ppm	0-250 ppm
SO_2	Western Research	721 A	Non-Dispersive Ultraviolet	0-5,000 ppm	0-1,000 ppm
CO	Thermo Environmental	48	Gas Filter Correlation	0-10,000 ppm	0-100 ppm

Sample gas was withdrawn from the source using a quartz or stainless steel probe. Teflon* sample line was used to transport the sample gas to the sample conditioner where the moisture was separated from the gas. At the stack a peristaltic pump was used to continuously remove the liquid from the sample conditioner. The sample gas was then passed through a post-pump condenser for further moisture removal before entering the sample manifold. At the In-Furnace test location, the sample conditioner was replaced with two impingers containing 0.1N H_2SO_4 for particulate and moisture removal. Flow to each instrument was controlled by flow control valves and meters downstream of the sample manifold. Instrument outputs were permanently recorded by a PC-based data acquisition system (DAS) developed by Entropy. The DAS consisted of a Toshiba Model

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*Teflon is a trademark of E.I. du Pont de Nemours & Company.

3200SX portable computer, Data Translation, Inc. interface hardware, and software written by Entropy. The DAS polled analyzer signals once each second and printed one-minute and other selectable averages. It also was used to record calibration results. A layout of the sampling system used by Entropy is provided in Appendix G.

6.0 TEST CRITIQUE

6.1 Volumetric Flow Rate - EPA Method 2

6.1.1 Furnace Outlet

Run number M2-5 is considered unreliable due to low flow and particulate buildup on the pitot. Run number M2-4 could not be completed due to particulate buildup blocking the furnace outlet duct.

6.1.2 Cyclone Inlet

The sampling and leak check procedures described in EPA Method 2 were strictly followed. For run number M2-6 the last four points on the vertical axes were not measured due to particulate buildup in the duct.

6.2 Particulate, Metals, NH_3, HCl, Cl_2, HF, and F_2 - EPA Method 5 Type

6.2.1 Furnace Outlet

The leak check criteria of EPA Method 5 were met. The sampling trains were not operated isokinetically. The sample trains were operated at low flow rates to avoid clogging filters and sample lines. Samples were collected at a single point near the center of the duct. Quartz probes with an angled end were used for sampling. Samples were directed to the heated quartz filter using unheated Teflon jumpers approximately 5 feet long. Since the jumpers were unheated much of the particulate plugging occurred in the Teflon jumper section.

During run number M5-1 the plant was not operating at steady state, therefore, the run was aborted. The velocity during idle corresponding to Run number M5-4 could not be determined due to particulate buildup blocking the furnace outlet duct. The flow rate determined from M2-3 was used to calculate emissions for runs M5-2, M5-3 and M5-5.

6.2.2 Cyclone Inlet

Sampling at the cyclone inlet was conducted within 10% of 100% isokinetic. The leak check criteria of EPA Method 5 were met. Sampling for run number M5-6 was aborted at the port change due to pending loss of feed at the furnace.

6.3 O_2, CO_2, SO_2, NO_x, CO and THC - EPA Methods 3A, 6C, 7E, 10 and 25A

6.3.1 In-Furnace/Furnace Outlet

All calibrations met EPA bias and drift requirements; the data was not drift corrected. Due to frequent clogging of sample lines and filters during testing at the furnace, sample run times were shortened. To increase run time the coil condenser conditioning system was replaced with an impinger system. The impinger conditioning system consisted of three impingers in series with each of the first two impingers containing 100 ml of 0.1N H_2SO_4. The impinger system allowed longer sampling time but NO_2 and SO_2 were scrubbed out in the process. The impinger reagent from testing at the furnace during Hanford B feed was analyzed for NH_3. Approximately 23.9 ppmvd of NH_3 were determined to exist in the furnace.

During CEM testing at the stack on March 9, 1995 the sample pump sample line had a cut in it, therefore causing problems with the post test system bias.

CO and CO_2 concentrations sometimes spiked above their calibrated range. Data collected outside the calibrated range is flagged with an asterisk (*).

With the high ammonia concentration present in the flue gas stream, the NO_x analyzer equipped with the Moly-Converter was occasionally biased low.

The CEM time recorded throughout the entire test period was 10 minutes ahead of plant time.

7.0 CALIBRATION AND QUALITY ASSURANCE PROCEDURES

7.1 Equipment Inspection and Maintenance

Each item of field test equipment purchased by Entropy was assigned a unique, permanent identification number. An effective preventive maintenance program is necessary to ensure data quality. Each item of equipment returning from the field was inspected before it is returned to storage. During the course of these inspections, items were cleaned, repaired, reconditioned, and recalibrated as necessary.

Each item of equipment transported to the field was inspected before being packed to detect equipment problems which may originate during periods of storage. Occasional equipment failure in the field is unavoidable despite the most rigorous inspection and maintenance procedures. For this reason, Entropy transported to the job site replacement equipment for all critical sampling train components.

7.2 Equipment Calibration

New items which require calibration were calibrated before initial field use. Equipment whose calibration status may have changed with use or time was inspected in the field before testing and again upon return from field use. When an item failed to meet the required calibration specifications, it was repaired and recalibrated or retired from service. All equipment was periodically recalibrated in full, regardless of the outcome of these regular inspections.

Calibrations were conducted in a manner, and at a frequency, which met or exceeded U. S. EPA specifications. Entropy followed the calibration procedures outlined in the applicable EPA Methods and those recommended in the Quality Assurance Handbook for Air Pollution Measurement Systems: Volume III (EPA-600/4-77-027b, August, 1977). When these methods were inapplicable, Entropy used methods prescribed by the American Society for Testing and Materials (ASTM). Emissions sampling equipment requiring calibration include Pitot tubes, pressure gauges, thermometers, dry gas meters, orifices and barometers.

Calibration data were recorded on standardized forms which are checked for completeness and accuracy. Data reduction and subsequent calculations were performed using Entropy's computer facilities.

7.3 Sample Custody Procedures

Sample custody procedures were based on procedures recommended by the EPA. All samples were given a unique alphanumeric identification code. Because the samples were transported to the analytical laboratory for analysis, the custody procedures emphasize careful documentation of the sampling and analytical data and use of the chain of custody records. All sampling data, including information regarding sampling times, locations, and any specific considerations associated with sample acquisition were recorded on preformatted data sheets. All samples were inspected upon arrival at the analytical laboratory to insure sample integrity was not compromised

7.4 Sampling QA/QC Procedures

All sampling was performed in accordance with the specified test methods. Adherence to prescribed QC procedures ensured data of consistent and measurable quality. The following general QC procedures were incorporated into the sampling effort:

7.4.1 General QC Procedures

The following general QC checks were conducted:

- All sampling equipment was thoroughly checked to ensure clean and operable components.
- Equipment was inspected for possible damage from shipment.
- The number and location of the sampling traverse points were checked before taking measurements.
- The temperature measurement system was visually checked for damage and operability by measuring the ambient temperature prior to each traverse.
- All sampling data and calculations were recorded on preformatted data sheets.

7.4.2 Flue Gas Velocity

The data required to determine the flue gas velocity was collected using the methodology specified in EPA Method 2. Quality control procedures were as follows:

- Visually inspected the Type S pitot tube before and after sampling.
- Leak checked both legs of the pitot tube before and after sampling.
- The number and location of the sampling traverse points were verified before taking measurements.

7.4.3 Particulate

The particulate in the flue gas was determined using EPA Method 5 type sampling train. The following on-site QC checks were performed:

- The complete sampling train was leak checked before every run.
- Ice was maintained in the ice bath throughout each run.
- Probe and filter were heated and maintained at 248 ± °F.
- The filter and catch were visually inspected after each run.
- Run isokinetics were calculated on-site.

7.4.4 Continuous Emission Monitoring

The extensive quality assurance procedures included in the EPA Methods 3A, 6C, 7E, 10 and 25A were followed for this test program. Calibration error tests were conducted by introducing zero, mid-, and high-range calibration gases directly to the analyzers before each test set. Calibration bias tests were conducted before and after each test run by injecting zero and upscale calibration gases at the probe outlet. The results of all calibration error and sampling system bias tests were within the limits specified by the applicable methods. All calibration gases used were certified by the vendor using EPA Protocol 1 analysis (±1% tolerance).

Sampling system leak tests were conducted before and after each test by blocking the tip of the sample probe and observing the flow from the sample pump. During the leak check, flow to the analyzer manifold board was shut off and all flow from the sample pump must exit through the post-pump condensate trap. The presence of bubbling in the post pump condensate trap indicated a leak in the sampling system.

APPENDIX E

PROCEDURES FOR OPERATING BUREAU OF MINES THERMAL WASTE TREATMENT FACILITY AND OPERATING PROCEDURES FOR MELTING TEST WHC2-1995

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PROCEDURES FOR OPERATING BUREAU OF MINES THERMAL WASTE TREATMENT FACILITY

OPERATING PROCEDURES FOR MELTING TEST WHC2-1995

Prepared by the U.S. Bureau of Mines, Department of the Interior,
Albany Research Center, Albany, Oregon

Date prepared: March 28, 1995
Updated:April 7, 1995

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NOTES

(1) INTRODUCTION

The demonstration test of dry furnace feed prepared from low-level high-sodium liquid waste from the Hanford site conducted March 7, 1995 suffered from operational and procedural deficiencies. These deficiencies, probable cause, and corrective actions taken or planned during the present test are the following:

1. Excessive glass temperature (1575 to 1700 C) resulting in excessive vaporization of sodium and boron.
   Probable cause:
      a. Electrode voltage too high, electrode configuration and/or arc length not optimum (rheostat positions), and/or excessive cooling of glass in the furnace by the water-cooled tapping fixture.
   Corrective action:
      a. Remove 250 kVA transformers from the circuit to provide decreased voltage for a given tap setting. Optimum voltage phase-to-phase, as calculated by Howard Davis, is 80 to 100 V with 1/6 reactance (the previous voltage was 240 V with the same reactance).
      b. Optimize arc length. Howard advises that the optimum electrode position is that depth at which no corona around the electrode tips is visible. Note that automatic operation likely will not be possible owing to decreased phase voltage. This means manual operation throughout the test of WHC material. In the manual mode the rheostats do not function.
      c. Replace water cooled tapping fixture with a graphite fixture. The temperature of the graphite fixture will be monitored continuously by thermocouple.

2. Condensation of water vapor in the cyclone and baghouse.
   Probable cause:
      a. Temperature of cyclone and baghouse below the dew point of natural gas combustion products (120 F).
   Corrective action:
      a. Preheat the cyclone and baghouse before starting the gas burners using an indirect fired heater in the cooling air duct,
      b. Provide heaters for rotary air locks on cyclone and baghouse,
      c. Condition the cooling air by heating to maintain 300 to 325 F at the entrance to the cyclone (position 6).
      d. Move the cooling air bypass valve to position 9 (between scrubber and cooler/condenser) to eliminate input of cold air into the APCS prior to the baghouse.

3. Inability to provide secondary combustion air to the thermal oxidizer.
   Probable cause:
   a. Inadequate pressure differential between secondary air supply (cooling air duct) and thermal oxidizer.
   Corrective action:
   a. Redesign the secondary air circuit to obtain air from the blower for burner #3.

4. Excessive draft capacity by the ID blower.
   Probable cause:
   a. The blower was designed for melting the INEL materials which evolve copious volumes of gas, and as such is over designed for WHC materials.
   Corrective action:
   a. Install a variable frequency speed control for the blower motor.
   b. Move the cooling air bypass valve to position 9 between the scrubber and the cooler. The valve can provide air as needed to maintain the output of the fan at the design volume (4900 cfm).

5. Failure to demonstrate tapping from the metal tap hole.
   Probable cause:
   a. Inadequate tools.
   Corrective action:
   a. Purchase star drills and fabricate chisels from tool steel to allow drilling of the metal tap hole.
   b. Modify procedures to include percussion drilling using star drills and sharpened tool steel bits with periodic cooling of the bits and drills by immersion in water. Final entry into the molten pool will be by punching.

6. Inability to control pH in the acid gas scrubber, thereby forcing manual operation.
   Probable cause.
   a. pH meter was not calibrated and set points for starting and stopping the caustic metering pump were not adjusted.
   Corrective action:
   b. Calibrate pH meter and adjust set points (pH 7.5 starts the pump and pH 8.5 stops the pump.

7. Failure of the EGC system to operate properly.
   Probable cause.
   a. Improper set-up of EGC controller, likely the result of the power interruption.
   Corrective action:
   b. Reprogram the EGC controller(proper operation was demonstrated prior to test).

8. Failure of the primary combustion air system to provide data to the Hydra and for the control valve to operate properly.
   Probable cause:
   - a. Failure to provide card in the controller for 2_{nd} output to the Hydra.
   - b. Improper stroking of the control valve.

   Corrective action:
   - a. Install card for 4-20 ma output.
   - b. Adjust valve to correlate position with controller output.

The present test of 12 h duration will be conducted at no cost to Westinghouse Hanford Co beginning 0400 h April 10, 1995 to address the above deficiencies.

1.1. Objectives:

(1) Correct the recognized deficiencies from the test March 7, 1995.

(2) Demonstrate successful operation of the waste treatment facility including steady state operation with continuous feeding and tapping of glass.

(3) Demonstrate operation of the 3-phase electric arc furnace in a practical and acceptable manner to minimize reduction of metal oxides.

(4) Demonstrate the capability of the electric arc melting furnace to produce a durable, consistent, and homogeneous glass containing minimum 25 pct waste loading.

(5) Demonstrate the capability of the electric arc melting furnace to process the LLW simulant in compliance with applicable NO_x and SO_x requirements.

(6) Determine the distribution of LLW components among glass, fume solids, and offgas products.

(7) Determine composition and flow rate of offgas and quantities and composition of entrained particulates as related to feed chemistry.

(8) Collect and compile experimental electrical and process data that can be scaled to the requisite 200 metric tons/day LLW vitrification plant to support engineering studies, technology evaluation, life-cycle cost analysis, and to evaluate life expectancy, reliability, and maintenance requirements.

(2) SAMPLE COLLECTION, LABELING, AND STORAGE

Samples described in table 2.1 will be collected by the Sample Manager, as identified in Section 4. All samples shall be placed in 1 gal prelabeled steel cans and stored on a single pallet.

Table 2.1.- Sample Description and Schedule

Sample	Description	Number
Offgas	Offgas	Semi-continuous analysis by gas chromatograph at the baghouse outlet
Offgas	Cyclone solids	Every 2 h
Offgas	Baghouse	Every 2 h
Offgas	Scrubber solution	Every 2 h
Offgas	Cooler/condenser	Every 2 h
Offgas	Thermal oxidizer	1 at end
Glass	Collect on steel plate	Every 2 h
Metal	Collect from metal tap	1 at end of test

(3) RECORD KEEPING

The following records shall be kept during the melting demonstration test.

Record	Responsible person
1. Electrode Log	Sample Manager
2. Receiving Bin Log	Weigher
3. Feeder Log	Feeder Operator
4. Furnace Log	Furnace Operator
5. APCS Solids Log	Sample Manager
6. Glass and Metal Product Log	Sample Manager
7. Test Log	Sample Manager
8. Melter Inventory Log	Sample Manager

3.1. <u>Traceability:</u>

All samples to be analyzed or archived will be assigned an identifying designation, entered on the appropriate log, and stored in clean labeled plastic or metal containers.

Samples of solutions, product glass, and metal collected as described in table 2.1. will be submitted for analysis by the Bureau's Analytical Laboratory. The remaining materials will be archived in clean labeled plastic or metal containers.

All data shall be clearly traceable from a final report back through the analytical records and worksheets to the date of analysis, the individual who performed the analysis, and to the measuring and test equipment used to collect the data.

All analytical test conditions, specimen preparation information, and related data for conducting the analyses shall be documented as a part of the laboratory records, and shall be clearly traceable to the final report of analytical results.

3.2. Records Disposition:

The final disposition of project records (data files, logs, report formats, records storage and disposition) shall be determined by Bureau of Mines Project Supervisor in cooperation with the WHC Project Manager.

(4) DUTIES OF OPERATORS

All operators and an electrician are needed during furnace operation.

Assignment	Responsibilities
1. Weigher	Weighs and delivers materials to receiving bin. Keeps the Receiving Bin Log.
2. Feeder operator	Operates the feeder and primary combustion air system and keeps the Feeder Log.
2. Furnace operator	Operates the electric arc furnace and keeps the Furnace Log.
3. APCS operator	Operates the APCS.
4. Sample manager	Collects or supervises the collection of all samples and keeps the Electrode Log, APCS Solids Log, Glass and Metal Products Log, Test Log and Melter Inventory Log.

5. Gas chromatograph operator	Operates the gas chromatograph
6. Lift operator	Operates fork and barrel lifts to transfer feed materials to the receiving bin and glass and metal products to the storage area.
7. Crane and tapping crew	Operates the overhead crane and taps furnace to remove glass and metal. Keeps the Glass and Metal Products Log.
8. Quality assurance person	Responsible for assuring safe operating conditions in the work place. Spot checks the NO_x monitors. Spot checks feed and product weights to assure accuracy.

(5) SAFETY AND ENVIRONMENTAL ISSUES

5.1. Safety:

All personnel attending the furnace are required to wear protective clothing, respirators (when needed), gloves, boots, safety glasses, and hard hats. Face shields and reflective heat-resistant clothing are required of the tapping crew. Additional common sense measures are required including remaining out of harm's way when not actually conducting a task.

5.2 Environmental:

5.2.1. Air quality in the work place:

Contamination of air within the building including the control room will be mitigated by the following preventative and control measures.

1. Emissions of gases and fumes into the building will be significantly decreased during furnace operation by withdrawing air through hoods over the tap holes for injection into the APCS as cooling air. The hood over the metal tap hole will be closed while tapping glass to maximize fume collection over the glass tap hole. Similarly, the hood over the glass tap hole will be closed while tapping of the metal side.

2. Air within the building housing the thermal waste treatment facility will be changed at intervals of 2 min by a combination of 3 blowers that remove air from ducts in the roof.

3. The control room will be pressurized with filtered air to preclude ingress of air from the furnace room.

4. Air within the building will be sampled by stationary air monitoring devices located above the glass (North) and metal (South) tap holes. A reference (R) monitor is installed in the control room. The monitors will be operated for 8 h during the demonstration test.

5.2.2. Air quality in the neighborhood:

Contamination of air outside of the building will be well within State guide lines as assured by oxidation of CO and volatile hydrocarbons and destruction of chlorinated hydrocarbons in the thermal oxidizer, collection of particulate and condensed fume solids by baghouse, removal of acid gases by caustic scrubber, and final polishing of exhaust gases by activated carbon and HEPA filters prior to the stack.

5.3. Disposal of unused feed and test products:

All feed will be melted to eliminate potential disposal problems. Product glass, cyclone solids, and baghouse solids will be disposed of in a municipal landfill if shown to be benign by analysis. All materials failing the TCLP test will be interred in a hazardous waste landfill. Scrubber solution will satisfy the City's requirement for sanitary sewer disposal (pH between 6 and 10 and no undissolved solids) and will be drained continuously into the city sewer as an overflow from the scrubber. Water for the cooler/condenser is provided by the cooling tower. The contents of the cooling water system will be vented after the test to the City sewer following analysis and pH adjustment, if needed. Solutions not acceptable for sewer disposal will be evaporated to dryness, and the solids will be placed in a hazardous waste landfill.

(6) DATA ACQUISITION:

Basic information to evaluate the performance of the feed system, electric arc melting furnace, and the APCS are recorded electronically and/or manually throughout a melting campaign. Sampling of offgas will be done by gas chromatograph.

6.1. Electrical Parameters:

Electrical parameters for analyzing demand and consumption of the electric furnace are continuously monitored by a True RMS Power and Demand Analyzer Model 3950, which records rms voltage (V), rms current (A), apparent power (VA), active power (W), reactive power (var), power factor, and total energy (Kw.h). These data are integrated over 1 min interval, and the integral values are stored by the instrument. A data logger receives up to 48 additional inputs from sensors in the feed system, electric furnace, and APCS, applies a linear scaling factor to each input as needed, and transmits the calculated values to a personal computer at intervals of 30 sec for display and storage. A hard copy is printed at 5-min intervals.

6.2. Continuous Monitoring Locations:

The following data derived from both the furnace, APCS, and feeder will be recorded continuously during the vitrification demonstration test by the data acquisition system:

Thermocouple sensor and type:	Monitoring point
Furnace exit after gas burner 1, Type R.	1.
Crossover duct exit after burner 2, Type R.	2.
Thermal oxidizer exit, Type R.	3.
Evaporative gas cooler exit, Type J.	4.
Cooling air supply duct, Type J.	5.
Wind box exit (cyclone entrance), Type J.	6.
Cyclone exit (baghouse entrance), Type J.	7.
Baghouse exit, Type J.	8.
Scrubber exit, Type J.	9.
Cooler/condenser exit, Type J.	10.
Reheater exit (ID blower entrance), Type J.	11.
ID blower exit (filter entrance), Type J.	12.
Filter exit (stack), Type J.	13.
Furnace upper plenum, Type K.	14.
Furnace shell bottom, Type J.	15.
Metal tap hole, Type K.	16.
Product glass, continuous indicating pyrometer.	17.
Primary combustion air, Type J.	18.
Secondary combustion air, Type J.	19.
Cooling water to furnace, Type J.	20.
Warm water return, Type J.	21.
Graphite glass tapping fixture, Type R.	22.

Gas pressure transducer:	Monitoring point
Evaporative Gas Cooler exit.	4.
Cooling air.	5.
Wind box exit.	6.
Cyclone exit.	7.
Baghouse exit.	8.
Scrubber exit.	9.
Cooler/condenser exit.	10.
Reheat exit.	11.
ID blower exit.	12.
Filter exit or stack.	13.
Furnace upper plenum (air draft X-mitter).	14.
Primary combustion air.	18.
Secondary combustion air.	19.

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Gas flow sensor and type:	Monitoring point
Atomization air for EGC, flow X-mitter.	EGC air supply
Evaporative gas cooler exit, He tracer.	4.
Cooling air duct, S-type pitot with P X-ducer.	5.
Baghouse exit, He tracer.	8.
Baghouse exit, S-type pitot with P X-ducer.	8.
Stack, S-type pitot with P X-ducer.	13.
Primary combustion air, flow X-mitter.	18.
Secondary combustion air, S-type pitot with P X-ducer	19.

Water flow sensor and type:	Monitoring point
EGC water, flow X-mitter.	EGC water supply
Cooling water to furnace, totalizing flow meter.	20.
Warm water return, totalizing flow meter.	21.

Miscellaneous sensor and type	Monitoring point
Feed rate	Metering bin
Cold top depth (continuous)	Under SE feed tube
Cold top depth (manual)	Under NE feed tube

6.3. Additional Logs:

Manual logs will be kept to record the following:

(1) **ELECTRODE LOG**:
a. Date, time installed, and weight of graphite electrode segments placed in service.

(2) **RECEIVING BIN LOG**:
a. Date, time, and weight of all materials entering the receiving bin of the feed system.

(3) **FEEDER LOG**:
a. Feed rate when feed rate is changed and at irregular intervals,
b. Depth of cold top when feed rate is changed and at irregular intervals as appropriate.

(4) **FURNACE LOG**:
a. Furnace operating parameters including transformer tap, electrode voltage (V), electrode current (A), power (kW), energy (kW.h), rheostat settings, and glass temp.

(5) **APCS SOLIDS LOG**:
a. Date and time collected and the weight of all solids recovered from the APCS.

(6) **GLASS AND METAL PRODUCTS LOG:**
a. Date and time collected and the weight of product glass ingots and samples for analysis.

(7) **TEST LOG:**
a. Depth to bottom of hearth and thermal oxidizer.
b. Totalizing flowmeters: EGC water, scrubber water, cooler/condenser water, and natural gas.

(8) **MELTER INVENTORY LOG:**
a. Feed and glass tapping rates; cumulative total feed and glass, power, and energy consumption.

6.4. Offgas Analysis:

An on-line dual-column gas chromatograph also will be available to determine concentrations of CO, CO_2, O_2, N_2, SO_2, NO_x, and He at 1-min intervals. He, the tracer gas, will be continuously injected at a measured rate into the plenum of the furnace to allow calculation of gas flow rate at any point downstream. The output of the chromatograph is displayed on a video monitor and also saved to disk.

(7) PROCEDURES FOR APCS AND COOLING WATER SYSTEMS

7.1. Cooling Water Supply and City Water Backup:

(1) Turn on city water supply valves (two blue handles) in trench outside building and red handle near red switch in trench near furnace. Turn on cooling water supply (handle in trench near red handle on city water valve).

(2) Close drain valves on bottom of 15 hp water supply pump, 5 hp tower circulating pump, and Supertrol pump. Also close drain valves on Supertrol hot water supply lines and tower water supply line in trench.

(3) Open tower water supply valve to Supertrol (yellow handle on line leading to Supertrol).

(4) Turn on power conditioner (in vault) to city water fail safe valve.

(5) Verify that city water fail safe valve is closed by opening water supply valve to any feed tube. Momentarily turn power off to the power conditioner; fail safe valve should open, and water should flow in the open supply line.

(6) Press start button (left button) on W wall to activate cooling tower circulating pump. Allow a few minutes for city water to make up the water held in the cooling tower. Verify that the tower circulating pump has not lost its prime.

(7) Press start button (right button) to activate tower water supply pump (the supply pump must not operate for more than a few minutes without flow). Close fan start switch on electrical box and set fan switch to desired hi or low position to start the cooling tower fan.

(8) Verify that all drain valves are closed by opening the trench cover outside the building and making a complete inspection of the water supply system.

(9) Open manual water valves as follows:
a. Open valve on west wall over the utility trench to supply continuous flows in the exit lines from the transformer and the electrode arms and clamps (four exit pipes).
b. Open valves near the east side of the furnace to supply 20 gpm to the feed tubes, glass tap hole fixture (water is not required if the graphite fixture is in place), and exhaust gas duct (five or six valves). Shunt cooling water to the upper water trough by arranging the valves provided in two of the exit lines. Verify continuous coverage of the furnace wall. Remove blockage in drain holes as required.

7.2. Operation of UDC Controllers:

Upper display:	Indicates process variable (temperature, pressure, pct, other).
Lower display:	Indicates one of the following (Set point, Output, Deviation).
Push buttons:	The following keys are operational: Lower display, Up arrow, Down arrow, Auto/Manual and Tuning (function and set up).

For normal operation the keys to be used are: Lower display, Up arrow, Down arrow, and Auto/Manual.

Use the Lower Display key to change the lower display to the desired function.

Use the Arrow keys to change the value.

Change the set point by having Set Point in the lower display and using the arrow keys.

To change the output: 1. Place controller in Manual mode, 2. Change lower display to Out, 3. Use the arrow keys to change the value.

7.3. <u>Operation of Console, APCS, and Data Acquisition Systems:</u>

(10) UPS on.

(11) Turn on power switch to computers and data loggers (near monitor), and verify that all sensors are reporting to the data logger.

(12) Synchronize all watches and clocks.

(13) Move control power selector switch to the on position. Power on indicator light will glow.

Note that controllers reset to manual mode when the console power is turned off. Controllers return to a preset condition when power is resumed. Default conditions are the following:

a. APCS valve controller, 10 pct = 10 pct open,
b. Cooling air valve controller, 100 pct = 100 pct open,
c. ID blower damper controller, 10 pct = 10 pct open,
d. EGC controller, 100 pct = minimum water flow. Note that EGC controller is opposite to all others.

(14) Push start buttons for circuits A, B, C, D, and E on the furnace console to supply power to the Supertrol, feed system, and low water pressure alarm for the electrode clamps and support arms. Then push Supertrol power on button; green verification light will glow. Set temperature at controller outside of building to 125 F. Verify that tower water supply valve to Supertrol is open and that Supertrol is receiving water.

(15) Set high temperature limit controller 200 F higher than the desired operating temperature for the thermal oxidizer (T3). The operating temperature for the WHC test is 1,600 F, and the high temperature limit is 1,800 F. If the high temperature limit is exceeded, the controller signals with a flashing red light and stops all burners. Manual reset is required before restarting the burners.

(16) Verify that low and high temperature set points on the baghouse/scrubber temperature fail safe are 315 F and 335 F, respectively. If the temperature at the outlet of the wind box (T6) exceeds the low set point (315 F), the fail safe signals with a flashing light on the console. If no action is taken to correct the temperature, and the temperature at T6 increases to exceed the high set point (335 F), the fail safe stops all burners and closes the APCS valve.

(17) Verify that the low pressure set point on the baghouse pressure fail safe is -21 in WC. If the pressure at the inlet to the baghouse (P7) becomes less than the preset minimum, the fail safe activates a timer and signals with a flashing light on the console. If the condition is not corrected within a preset time (30 sec), the fail safe opens the cooling air valve to increase the pressure. Manual reset of the pressure sensor is required to regain control of the cooling air valve. The baghouse, scrubber, and cooler/condenser are rated at negative 20 in WC working pressure.

(18) Open cooling air bypass valve to 20 pct open (2nd notch). This is a manual valve and must be opened by hand.

(19) Open furnace inspection port. Note that the furnace, the refractory lined ducts, and the EGC will not be purged unless the furnace inspection port is open.

(20) Verify the default condition for the secondary air controller: manual mode with zero output. The blue verification light will glow confirming that the secondary air valve is closed.

(21) Verify default condition for the ID blower damper controller: manual mode with 10 pct output (damper is 10 pct open). The ID blower damper controller remains in the manual position while the system is operating.

(22) Verify default condition for the APCS valve controller: manual mode with 10 pct output (valve is 10 pct open).

(23) Verify default condition for the cooling air valve controller: manual mode with 50 pct output (cooling air valve is 50 pct open). The cooling air valve must be controlled manually until T6 exceeds 300 F. Premature automatic operation will result in closing of the cooling air valve, which could activate the low pressure baghouse fail safe.

(24) Start the cooling air blower by holding the start button down. A pressure-activated limit switch will make, and a green verification indicator light will glow confirming operation of the blower.

(25) Press the ID blower start button to supply power to the variable frequency speed control (VFC), which is in the caustic shed.

(26) Press the ID blower start button to supply power to the variable frequency speed control (VFC), which is outside in the caustic shed.

(27) Adjust VFC for the induced draft blower to 45 hertz and press the run pad to start the fan. The speed of the blower will be 45/60*3550 = 2662 rpm which will provide 3650 cfm at 17.7 in static pressure, and the motor will draw 15.5 hp. If the air pressure permissive switch fails to close within 3 sec, the failure light will glow. A purge timer is automatically energized, and a purge light will glow when the purge cycle is complete (5 min unless otherwise adjusted). Note that the purge cycle timer is adjustable on the instrumentation panel. At the end of purge cycle, purge complete light glows. Do not light burners until Purge Complete Light is on, but note that the purge timer does not prevent lighting of the burners. Note that the VFC must be adjusted in increments of 1 (for example 45 to 46 or 55 to 54) to prevent loss of power to the ID blower.

Note that the VFC must be adjusted in increments of 1 (for example 45 to 46 or 55 to 54) to prevent loss of power to the ID blower.

7.3.1. Preheating cyclone and baghouse:

(27) Open gas valve to baghouse heater, and manually light the pilot.

(28) Start the baghouse heater as follows:
Observe the process variable (PV) on the baghouse heater controller. The PV is the temperature at T_5 in the cooling air duct immediately following the heater.
Change display to output.
Press the up or down arrow as appropriate to adjust the output to 20 degrees higher than the PV.

Note that the baghouse heater controller (UDC 2000) operates only in the manual mode. Also note that the butterfly of the cooling air valve has been drilled to provide two 1-in holes so that air flow through the heat exchanger to the thermocouple is assured even if the valve is closed.

Monitor temperature at T_5 to verify operation of the burner.
Increase PV in increments of 20 to 50 F to increase the temperature of the baghouse to 300 F.

(29) Start heaters to rotary airlocks on cyclone and baghouse. Monitor the temperature and adjust heaters as needed to provide 300 F.

7.3.2. Operation after heating baghouse.

(30) Turn on manual water valve to acid gas scrubber (tower water), and allow scrubber reservoir to fill. Adjust manual valve to provide about 2.5 gpm overflow. Open manual valves in the scrubber recycle line before and after the pump.

(31) Turn on manual water valve 1.5 turns to cooler/condenser (tower water).
Note: Observe the flow of water returning from the cool water tank to the warm water tank (open the lids to observe flows). The quantity returning is available for cooling. The quantity returning must not be allowed to decrease to zero.

(32) When T_6 reaches 180 F, turn acid gas scrubber switch to on position to activate scrubber recycle pump and pH controller. A green light on the console will glow proving that power is on and recycle line is pressurized. Monitor liquid level in the scrubber, and adjust makeup water valve to provide 2 to 3 gpm overflow.

(33) Open manual vent valve to caustic barrel and valves in caustic supply line. Place caustic metering pump switch in auto position.

(34) With cooler/condenser controller in manual mode, press up arrow until display indicates 5 pct (3 in ball valve in supply line is 5 pct open).

(35) Place cooler/condenser switch in on position. A green light on the console will glow proving that power is on and water line is pressurized.
Note that water flow to the scrubber and cooler/condenser must be established before the input temperature to the scrubber reaches 180 F. Excessive temperature will damage the fiberglass vessels.

(36) Adjust controller and cooling air valve as needed to heat the baghouse to 300 F. Do not proceed until baghouse is hot. Record working conditions for future use.

7.3.3 Heating of refractory-lined ducts:

(37) Manually close the furnace inspection door.

(38) Observe the pressure profile over the APCS. Static pressure (SP) across the ID blower should be in the range 20 to 30 in WC. The motor will draw excessive current if SP is less than 20 in WC. To correct, adjust the ID blower VFC, the cooling air bypass valve, the APCS valve, and the ID blower damper in small increments while observing SP over the ID blower and pressure in the cooler/condenser. Record conditions providing acceptable operating pressures in the APCS for future reference.

Note that the cooling air valve and the baghouse heater must also be coordinated to maintain baghouse temperature at 300 F. This balancing act will take some experimentation to optimize. APCS valve and cooling air valve must be operated in manual mode during heating of the APCS to maintain SP in the range 20 to 30 in WC and pressure in the cooler greater than negative 20 in WC.

(39) Manually open the air line (two valves) to the baghouse.

(40) Turn on baghouse pulsator. Baghouse pulsator lights will glow proving power and air pressure.

7.4. Operation of Burners:

Verify that APCS is fully purged. The following applies to burners 1, 2, and 3. Burner 1 is the example.

(41) Open manual gas valves, and check incoming pressure. Each burner has a separate inlet valve, pilot valve, and outlet valve. Each of the nine valves must be opened.

(42) Place burner #1 controller in the manual mode, and press down arrow until display indicates 0 pct. Burner #1 control valves (air and gas) are in low fire position (not completely closed).

(43) Press burner #1 blower start button and hold until green pressure verification light glows.

(44) Turn burner #1 switch to on position.
   a. Burner will purge for 60 sec.
   b. After 10 sec ignition transformer will operate and pilot gas valve will open.
   c. Ignition transformer turns off.
   d. Main gas valve opens 10 sec later and pilot gas valve closes. Burner #1 green verification light glows.

Flame failure light glows if flame is not present by end of b, or main flame is not sensed. Press reset button, and try again. If burner fails to light after third attempt, check incoming gas valves and other sources of error.

(45) Start burners 2 and 3.

(46) Monitor temperatures at T_1, T_2, and T_3; press up arrow as needed on the controllers to provide heating rate of 100 F per hour (heating to the previous operating temperature can be faster, up to 200 F/h.

(47) Monitor temperature at T_4 (between the EGC and windbox) and T_6 (after the wind box).
Note that the gas temperature at T_6 will carry through the baghouse to the scrubber and the cooler condenser, which should not be exposed to temperatures greater than 180 F without water flow.

(48) Turn on manual valves to provide water and air to the EGC system.

(49) Place the H/O/A switch for the EGC system in the "A" position.
Note that the H position is for set up and adjustment of the spray lance. Spray lance then can be operated outside the system. The EGC controller operates independently of the H/O/A switch.

(50) Continue to monitor T_4 and T_6 as the output of the burners is increased. When T_6 indicates 300 F, cooling in addition to air supplied by the cooling air is required. Therefore, move the EGC system power switch to the on position. EGC system power green lights will glow if air pressure and water switches are made. If EGC system power lights do not glow, check air and water valves. EGC will automatically maintain T_4 at 500 F. The temperature at T_6 then will be maintained at 300 F by the cooling air valve.

(51) Close the cooling air bypass valve in increments until T_6 indicates 300 F.

(52) Continue to advance the burners to provide the desired heating rate, and continue to adjust the APCS valve, cooling air bypass valve, VFC for the ID blower, and ID blower damper to maintain SP over the ID blower in the appropriate range, T_6 near 300 F, and furnace pressure, P_{14}, at negative value (0.5 in WC is desired). Negative pressure in the furnace assures the correct direction of flow of combustion gases.

(53) Monitor P_{14}. When furnace pressure can be maintained manually at negative 0.5 in WC, attempt automatic control of the APCS valve. If successful, attempt automatic control of the cooling air valve. If successful, slowly close the cooling air bypass valve in increments. A limit switch in the cooling air bypass valve will close and blue verification light will glow confirming closure of the valve.

(54) Carefully adjust the VFC for the ID blower and the ID blower damper to position the APCS valve at the 70 pct open position, the position for optimum control. Note that the ID blower damper must be adjusted manually as the burners are increased to maintain the 70 pct open position.

(55) When T_1 reaches 1,600 F, turn controllers for burners 1, 2, and 3 to auto which starts the respective control loops.

Air pollution control and water cooling systems are now operational.

7.5. Scheduled Shutdown of APCS and Water Cooling Systems:

(1) Place burner 1 controller in the manual mode, and press down arrow to zero pct. Place burner 1 switch in the off position. Note that burner 1 blower remains on to provide air to cool the burner.

(2) Monitor position of APCS and cooling air valves, and allow valves to compensate for decreased gas flow in the APCS. Adjust VFC for ID blower and ID blower damper as needed to maintain APCS valve 70 pct open.

(3) Repeat steps 1 and 2 for burners 2 and 3.

(4) When temperature at location T_4 reaches 500 F, place cooling air valve controller in manual mode. Adjust baghouse heater controller and cooling air valve to maintain baghouse at 300 F (T_6) until the system is purged of moisture and acidic remanents (allow minimum 12 h to purge acids from the system).

(5) The EGC will automatically turn off when the temperature run permissive at position T_4 comes out of the circuit at 500 F.

(6) When T_4 reaches 300 F push the burner blower stop buttons.

(7) Turn off the EGC system.

(8) Place the EGC H/O/A in the Off position.

(9) Manually open the furnace inspection door to assist purge of acidic remnants.

(10) Monitor pressure drop across the ID blower. Position APCS valve, VFC control for ID blower, and ID blower damper during cooling to maintain pressure drop over ID blower in the appropriate range in table 6.

(11) Press down arrow on Supertrol controller to 100 F to prevent overheating of carbon filters, which will begin to liberate adsorbed materials at 120 F.

(12) Place cooler/condenser controller in manual mode, and press down arrow to zero. Close manual water valve to cooler/condenser.

(13) Continue to operate baghouse, scrubber, ID blower, and cooling air blower for 12 to 24 h to purge moisture and acidic remnants from the system. Maintain baghouse temperature at 300 F during purge to prevent condensation of acids.

(14) After purge is complete turn off baghouse pulsator.

(15) Open cooling air bypass valve to notch 5.

(16) Push cooling air blower stop button.

(17) Push stop button on ID blower VFC.

(18) Push ID blower stop button on console to complete shutdown of APCS.

(19) Turn off cooling water supply pump, cooling water circulating pump, cooling tower fan, and all manual water valves. Open all drain valves.

7.6. Emergency Shutdown of APCS:

The following actions should be taken in a matter of seconds.

(1) Turn all burner controls to off position. Burner blowers will automatically decrease to minimum flow.

(2) Push ID blower stop button.

(3) Push cooling air blower stop button.

(4) Place APCS controller in manual mode, press down arrow to drive output to zero, which closes the APCS valve.

(5) Open manual cooling air bypass valve to notch 5.

(6) Stop baghouse heater by pressing down arrow to zero output.

These actions will isolate the heat sensitive components of the APCS, prevent pressurization of the APCS by the cooling air blower, and prevent overheating of the baghouse heater.

(7) EGC system will stop automatically when temperature at T_4 decreases to 500 F.

(8) Stop burner blowers if pressure in the furnace becomes excessive, but monitor temperature of burners to prevent damage from overheating.

7.7. Restarting APCS after Emergency Shutdown:

Conditions:
- a. Burner controllers in manual mode with zero output.
- b. Cooling air bypass valve 50 pct open (5th notch).
- c. ID blower off.
- d. Cooling air blower off.
- e. APCS valve closed; controller in manual mode with 0 pct output.

(1) Proceed with instructions in Section 7.4.

(8) WHC DEMONSTRATION MELTING TEST WHC2-95

8.1. Pretest Conditions:

(1) About 8,000 lb of pelletized, denitrified, LD6-5510 feed material is available.
(2) The feed system, furnace, power supply, APCS, and data acquisition systems are functioning.
(3) Metal tap hole cleaned and plugged with 8 in of Permanente 165. An alumina-sheathed Type K thermocouple is installed in the metal tap hole.
(4) Two lengths carbon electrode in each electrode arm with clamps tightened. Note initial weight and length of each electrode and record additional electrode weights and lengths along with date and time installed in the **Electrode Log**.
(5) Emergency furnace cooling hoses in place.
(6) Electric drill, masonry bits, and tools are available to open the metal tap hole.
(7) Tools for opening the glass tap hole are available. Steel rods available for closing glass tap hole.
(8) Two conical glass molds in position in north pit. All conical molds are coated with graphite or carbon wash and contain about 4 inches of sand in the bottom.
(9) Immersion thermocouple instrument checked out and 5 ft thermocouple tips available.
(10) Spoon for metal sample and rod for slag sample available.
(11) Steel rod for sounding furnace available.
(12) The thermal oxidizer catch basin is clean and the cyclone and baghouse are clean.
(13) The scrubber solution concentration is known and the solution has adequate capacity.
(14) He tracer inlet valve and gas chromatograph are functioning.
(15) All manual logs are available, and pertinent starting data are entered including water and gas totalizers.
(16) All personnel attending the furnace shall wear protective clothing, gloves, boots, and hard hats. Face shields and silver suits are required for the tapping crew. Respirators are required if appreciable fume escapes the fume collection hoods.

(17) Demonstration test procedures have been discussed and are understood by crew members.
(18) Sound cold furnace to measure depth from the thermocouple port to the true bottom of the furnace; record measurement in the **Test Log**.
(19) Feed materials in barrels are conveniently accessible to the barrel lift.
(20) Air monitors are installed to determine air quality within the building.
(21) Charge hopper is available to transfer charge materials to the receiving bin.
(22) Bags and dump hopper on small baghouse are clean.

8.2. Melting Schedule:

Note that approximately 1000 lb of LD6-5510 glass remains in the furnace and that the level of the glass is about 2 in above the glass tap hole.

8.2.1. Preheating of Furnace Refractories:

4-10-95:

0400 Start baghouse heater, and heat baghouse to 300 F.

Start APCS and burners, and heat refractory lined ducts at 200 F/h.

Feed about 100 lb of WHC feed to the furnace. Additional lime may be needed if viscosity of material in the furnace is too high.

Prepare furnace with graphite triangle for starting.

Instal Video camera mount and connect air line.

0600 Plug graphite cinder monkey with iron bar.

Start furnace power supply in manual mode on transformer tap D. If furnace will not start increase tap position as needed.

Note that power supply likely will require manual operation during the test.

Begin He tracer injection into the furnace plenum, and verify operation of the chromatograph at the baghouse exit.

Confirm veracity of thermocouples, pressure and velocity probes, totalizing water and natural gas meters, and Hydras.

Continue heating refractory lined ducts to 1,600 F.

Periodically remove iron bar in graphite cinder monkey. Begin tapping when glass is fluid.

Begin feeding Method B Feed at 250 lb/h after tapping is demonstrated. Avoid cold top in excess of 4 in until it is clear that tapping is possible. Coordinate power and feed rate to establish steady state conditions.

Adjust and evaluate transformer configuration if needed to provide steady state operation with glass temperature as low as possible.

Collect samples for analysis as specified.

Demonstrate minimum 2 h steady state operation with continuous feeding and tapping of glass. If time permits explore influence of cold top.

1400 Cease feeding and allow cold top to melt.

Plug glass tap hole with iron bar before tap ceases.

Open metal tap hole to drain furnace contents into preheated ladle. Sample stream immediately using cast iron cup to capture metal if present. Sample glass as it exits the furnace using steel crucible and steel plate.

Operate power supply as needed to maintain flow of material from the metal tap hole in order to completely drain the hearth.

Remove ladle from the pit and transfer contents to cast iron molds.

Adjust water valves to shunt water to lower trough. Allow cooling water and APCS systems to operate overnight.

4-11-95

0500 Remove electrodes from cool furnace. Record weight, length, and appearance on the Electrode Log.

Observe interior of furnace through inspection port in roof, and describe appearance of refractory. This completes test WHC2-1995.

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APPENDIX F

PROCEDURES FOR OPERATING BUREAU OF MINES THERMAL WASTE TREATMENT FACILITY AND OPERATING PROCEDURES FOR MELTING TEST WHC3-1995

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TEST PLAN WHC3-1995

PROCEDURES FOR OPERATING BUREAU OF MINES THERMAL WASTE TREATMENT FACILITY

Prepared by the U.S. Bureau of Mines, Department of the Interior, Albany Research Center, Albany, Oregon

Date prepared: May 1, 1995

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NOTES

(1) INTRODUCTION

The demonstration test of dry furnace feed prepared from low-level high-sodium liquid waste from the Hanford site conducted March 7, 1995 suffered from operational and procedural deficiencies. These deficiencies, probable causes, and corrective actions taken were addressed in a follow-up melting test of 8-h duration conducted April 10, 1995. Some issues remained unresolved, and it is the objective of this test to resolve those issues, which are the following:

1. Glass tapping temperature, melting rate, and vaporization of sodium and boron were improved in the follow-up test, but further improvement is needed.
   Probable cause:
   a. These deficiencies are related to electrode diameter. Low electrode voltage is essential to minimize arcing, but inadequate current is transferred to the molten pool by the 4-in electrodes for a given voltage.
   Corrective action:
   a. Provide 8-in diameter electrodes as stubs on the working ends of the 4-in electrodes, as practiced so successfully with the W furnace.

2. Redox conditions in the furnace were too reducing, as indicted by excessive reduction of sodium and boron (vaporization) and the very high ratio of ferrous to ferric iron in product glass.
   Probable cause:
   a. Excessive energy density at the electrode-molten glass interface. The resulting high temperature within the electrode vicinity provides a very reducing atmosphere owing to carbon vaporization.
   Corrective action:
   a. Larger electrodes will decrease energy density and decrease localized temperature.
   b. Provide for oxygen injection into the hearth through a porous plug and an orifice (pressure drop is over the orifice).
   Oxidation of metals by oxygen injection also will be investigated. Successful oxidation of metals will eliminate the need to tap metal, which will greatly simplify processing of the INEL materials.

3. Plugging of the offgas exit duct.
   Probable cause:
      a. Plugging occurred at two general locations: 1. In the 6 in ID duct between burner 1 and the water-cooled section (some buildup of material also occurred below the water-cooled section), and 2. In the 12-in ID duct downstream from burner 2 within the region of the large thermal gradient provided by the burner. Plugging was most troublesome as per 1 for the Hanford melt and as per 2 for the INEL melts. The present theory is that burner 1 failed to maintain the temperature of the duct above the melting range of the condensible fumes. It was not proven by observation that burner 1 could fire into the furnace.

         The INEL materials contained lime and soil which produced fine particles (dust) having high melting temperatures. Plugging following burner 2 likely was caused by heating of the dust by burner 2 to the semi-liquid sticky stage.

   Corrective action:
      a. Remove burners 1, 2, and 3, and close burner 1 hole with a steel plate. Provide slide gates in place of burners 2 and 3, and introduce cooling air at those latter locations. About 2,000 cfm of cooling air is needed at location 2 to provide 2500 ft/min gas velocity in the 12-in duct. The ID blower does not have the capacity to move the volume needed to carry all of the dust through the thermal oxidizer. A compromise is to inject an additional 3,000 cfm at burner 3 location. The remaining 1,000 cfm ID blower capacity will be provided as heated air through the cooling air duct. The ID blower should move 6,000 cfm continuously with 40 hp to the motor see fan curve, page 22). We will monitor the pressure profile in the APCS and current to the motor to determine satisfactory operating conditions (see fan curve page 19).

4. Failure to provide continuous tapping of glass at low feed/melting rates.
   Probable cause:
      a. Tap hole too large.
   Corrective action:
      b. Provide graphite inserts in the copper water-cooled tapping fixture to decrease the effective area of the tap hole. Graphite inserts with 1/2, 5/8/, and 3/4 in diameter center holes will be prepared.

1.1. Objectives:

(1) Investigate melting characteristics using 8-in diameter stubs on the electrodes, and demonstrate tapping of glass in the range 1,300 to 1,350 C.

(2) Demonstrate successful operation of the waste treatment facility including steady state operation with continuous feeding and tapping of glass at melting rates in the range 500 to 1,000 lb/h.

(3) Demonstrate oxidation of metal in the furnace by injecting oxygen through the metal tap hole.

(4) Demonstrate operation of the 3-phase electric arc furnace in a practical and acceptable manner to minimize reduction of metal oxides.

(5) Demonstrate the capability of the electric arc melting furnace to produce a durable, consistent, and homogeneous glass containing minimum 25 pct waste loading.

(6) Demonstrate the capability of the electric arc melting furnace to process the LLW simulant in compliance with applicable NO_x and SO_x requirements.

(7) Determine the distribution of LLW components among glass, fume solids, and offgas products.

(8) Determine composition and flow rate of offgas and quantities and composition of entrained particulates as related to feed chemistry.

(9) Collect and compile experimental electrical and process data that can be scaled to the requisite 200 metric tons/day LLW vitrification plant to support engineering studies, technology evaluation, life-cycle cost analysis, and to evaluate life expectancy, reliability, and maintenance requirements.

(2) WHC3-1995 DEMONSTRATION MELTING TEST

2.1. Furnace Feed:

The furnace will be started and operated for 4 to 8 h on calcium silicate slag to preheat furnace refractories and to investigate oxidation of metal in the furnace. About 5000 lb of dry furnace feed including both A and B materials are available for the demonstration test melt.

2.2. Pretest Conditions:

1. The power supply is configured as per test WHC1-1995, that is, to provide the following conditions:

Tap	Voltage	Current	Fraction of Reactance
A	182	2540	1/2
B	137	2540	1/2
C	124	2150	1/6
D	95	2540	1/6

2. The furnace is modified to provide a 12 in long by 8 in diameter graphite stub on each electrode. Each stub is connected to a 16-in long by 4-in diameter electrode segment by 3-in diameter threaded connection drilled 2-in off-center in the 8-in stub. The electrodes are oriented so that a radius from the center of the electrode triangle intersects the coincident surface of the 4-in diameter and 8-in diameter pieces. The electrode spacing is decreased from 7.25 in to 6.75 in.
   a. Note initial weight and length of each electrode and record additional electrode weights and lengths along with date and time installed in the **Electrode Log**.

3. The water-cooled feed tubes were removed and replaced with short (12 in long) non-cooled segments that only penetrate the furnace roof. Feed materials will thereby fall about 50 in to the molten pool. Distribution of feed over the area of the hearth will be improved, but dust formation and particulate entrainment may be worsened.

4. Burners 1, 2, and 3 were removed. Burner 1 was replaced by a steel plate, and burners 2 and 3 were replace with slide gates.

5. The tap hole was plugged with 6 in of dry coarse aggregate screened from Permanente 165 (periclase). This plug of porous material will transmit gases into the bottom of the hearth.

6. A 1-in OD by 42-in long injection lance was constructed from stainless steel and placed in the metal tap hole such that the end of the lance is 3 in from the porous periclase plug. The lance has a central 1/4-in nominal injection tube with 0.053-in diameter orifice and a 1/4-in nominal tube that extends to within 1/2 in of the end for cooling air injection. Cooling air will traverse the lance and exit near the point of entry. The orifice will provide 175 cfh oxygen at about 8 psi, which should oxidize 50 lb/h of iron to the ferrous state. Air will be injected continuously to cool the lance except when measuring the temperature by thermocouple inserted in the exit hole.

7. The copper glass tapping fixture will be used without a graphite insert during the preheat. An insert (1/2 in) will be installed after tapping out the preheat slag.

8. About 8000 lb of calcium silicate slag and slag from melting INEL feeds NOM 90, NOM 80, and NOM 70 were crushed and screened to -1/2 in + 12 mesh to minimize dust entrainment during melting to preheat the furnace.

9. The furnace was preloaded with 95 lb of steel punchings and 300 lb of calcium silicate slag. A triangular path of crushed electrode graphite was placed in a shallow trench to connect the electrode positions, and the electrodes were carefully lowered to contact the graphite.

10. Emergency furnace cooling hoses are in place.

11. Electric drill, masonry bits, and tools are available to open the metal tap hole.

12. Tools for opening the glass tap hole are available. Steel rods are available for closing glass tap hole.

13. Two conical glass molds are in position in north pit. All conical molds are coated with graphite or carbon wash and contain about 4 inches of sand in the bottom.

14. Spoon for metal sample and rod for slag sample are available.

15. Steel rod for sounding furnace is available.

16. The thermal oxidizer catch basin is clean and the cyclone and baghouse are clean.

17. The scrubber solution concentration is known and the solution has adequate capacity.

18. All manual logs are available, and pertinent starting data are entered including water and gas totalizers.

19. All personnel attending the furnace shall wear protective clothing, gloves, boots, and hard hats. Face shields and silver suits are required for the tapping crew. Respirators are required if appreciable fume escapes the fume collection hoods.

20. Demonstration test procedures have been discussed and are understood by crew members.

21. Sound cold furnace to measure depth from the thermocouple port to the true bottom of the furnace; record measurement in the **TEST LOG**. The steel bar may contact the electrode stubs!

22. Feed materials in barrels is conveniently accessible to the barrel lift.

23. Air monitors are installed to determine air quality within the building.

24. Charge hopper is available to transfer charge materials to the receiving bin.

25. Bags and dump hopper on small baghouse are clean.

26. Oxygen and argon cylinders are in place. The initial weigh of the oxygen bottle is recorded on the **Test Log** Oxygen usage will be determined by weight change of the oxygen cylinder.

2.3. Scheduled Chronology of Events:

The planned schedule calls for 4 to 6 h of melting calcium silicate slag to preheat refractories, at least 2 h of steady-state operation to demonstrate oxidation of metal while feeding metal and calcium silicate, and 5 to 10 h of melting Methods A and B feeds.

Explicit instructions for operation of the APCS were provided in the test plans for WHC1-1995 and WHC2-1995.

5-3-95

0500 (Partial crew reports)

1. Provide power to APCS console.

2. Open cooling air bypass valve to the fifth notch (50 pct open).

3. Start ID blower at 45 hz.

4. Start cooling air blower, and adjust cooling air valve to 20 pct open, which should provide 1000 cfm flow through the cooling air duct.

5. Start baghouse heater, and adjust set point to 300 F.

6. Start cooling tower fan and water circulating pumps.

7. Start flow of cooling water to transformer and furnace cooling circuits.

8. Open manual valve to scrubber to fill reservoir and provide 2.5 gpm overflow.

9. Open manual valves on caustic supply system.

10. Start scrubber pump, which also starts pH controller.

11. Provide water to cooler/condenser by opening manual valve 1.5 turns. Operate cooler/condenser controller in manual mode with 20 pct setpoint.

12. Start Supertrol.

13. Open slide gate to 50 pct open at position 2.

14. Open slide gate to 50 pct open at position 3.

15. Slowly close cooling air bypass valve.

16. Monitor pressure profile in APCS while adjusting ID blower speed, APCS valve, cooling air valve, and slide gates at positions 1 and 3 to obtain 1000 cfm in the cooling air line, 2000 cfm in the 12 crossover duct, and 5000 cfm in the thermal oxidizer. Total flow at the stack should be about 6,000 cfm.

0600 (Full crew reports)

1. Start furnace on tap D, manual operation. <u>DO NOT ATTEMPT AUTOMATIC OPERATION. ELECTRODES WILL BE DRIVEN INTO THE HEARTH AND BROKEN!</u>
    a. Melt calcium silicate for 4 to 6 h to preheat the furnace with feed rate as needed to protect the plenum with a thin layer of cool top.
    b. Increase electrode voltage as needed to provide the needed temperature.
    c. Adjust APCS parameters as needed to maintain 1000 cfm in the cooling air duct, 2000 cfm in the crossover duct, and 6000 cfm in the stack.

2. Stop cooling air to the lance at intervals of 30 min to determine temperature of the hearth. Record the temperature in the **TEST LOG**.

3. Operate the lance with air cooling and argon injection during preheat until the slag is molten and fluid to the depth of the metal layer on the hearth. Argon injection at about 1 cfm during preheat is necessary to prevent plugging of the porous periclase plug. Establish argon flow as follows with reference to the nomograph on page 20:
    a. Determine pressure drop across the flow meter (this is the new metering pressure).
    b. Determine the correction factor by reference to the nomograph using the line for 15 psi as the original design pressure). Multiply the correction factor by the meter reading to determine the corrected flow rate.

4. Replace the flow of argon with oxygen when the slag is molten to the metal layer on the hearth, as determined by sounding with an iron bar. Iron will burn in oxygen at temperatures much lower than its melting point. If the slag is entirely molten, then the oxide produced by burning iron will be assimilated into the slag. Establish steady state operating conditions for 20 min each condition to oxidize 10, 20, 30, 40, and 50 lb/h iron. Use the corrected flow rate for oxygen as determined for argon. Maintain oxygen flow rate to oxidize 50 lb/h for an additional hour to burn the remaining iron in the furnace. Note that it will not be necessary to add iron the furnace. Add additional iron through the rotating air lock if needed owing to changes in the test plan.

Iron oxidation rate (lb/h)	Oxygen injection rate (scfh)	Time min	Iron oxidized	Iron remaining in furnace (lb)
10	35.09	20	3.33	91.67
20	70.19	20	6.67	85.00
30	105.3	20	10.00	75.00
40	140.4	20	13.33	61.67
50	175.5	20	16.67	45.00

1600

1. Feed all remaining calcium silicate to the furnace,and tap slag to decrease the slag height to the level of the tap hole.

2. Add 2 barrels of Method B feed to the receiving bin and fill the metering bin.

3. Determine the position of each electrode by raising the electrodes individually until contact is broken, then lower electrode until contact is re-established. Stop power to the furnace and mark the position of the electrode arms on its mast. Raise the electrode arms and mark each mast 4 in above the existing mark. These marks indicate the positions of the arms when the electrodes are repositioned for restarting the furnace. Note this is the only way, except by visual observation, to determine the position of the electrodes.

4. Lower electrodes to contact the molten pool and increase power to superheat the glass to prepare for tapping the hearth.

5. Stop oxygen and air flow to the lance, and remove lance from the hearth using the slide hammer provided.

6. Tap the hearth to drain the furnace.

7. Clear the glass tap hole and install the 1/2 in graphite insert.

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8. Clear the metal tap hole and plug with 6 to 8 of dry Permanente 165.

9. Lower electrodes carefully to the marks on the masts. The electrodes should be within 2 in of the hearth.

10. Begin feeding Method B feed at maximum rate. Current should begin to flow when the level of the molten pool reaches the electrodes.

11. Continue melting B feed to establish continuous tapping.

12. Balance power input and feed rate to define steady state operating conditions for at least two hours at 200, 250, and 300 kW input.

13. Stop power, open metal tap hole, and drain furnace into glass mold when feed is exhausted to complete the test.

14. Sample stream immediately using cast iron cup to capture metal if present. Sample glass as it exits the furnace using steel crucible and steel plate.

15. Adjust water valves to shunt water to lower trough. Allow cooling water and APCS systems to operate overnight.

5-4-95

0800

1. Remove electrodes from cool furnace. Record weight, length, and appearance on the Electrode Log.

2. Observe interior of furnace through inspection-port in roof, and describe appearance of refractory. This completes test WHC3-1995.

(3) SAMPLE COLLECTION, LABELING, AND STORAGE

Sampling is necessary during processing of Methods A and B feeds. The following samples, described in table 3.1, will be collected by the Sample Manager, as identified in Section 4. All samples shall be placed in 1 gal prelabeled steel cans and stored on a single pallet.

Table 3.1.- Sample Description and Schedule

Sample	Description	Number
Offgas	Cyclone solids	Every 1 h
Offgas	Baghouse	Every 1 h
Offgas	Scrubber solution	Every 1 h
Offgas	Cooler/condenser	Every 1 h
Offgas	Thermal oxidizer	1 at end
Glass	Collect on steel plate	Every 1 h
Metal	Collect from metal tap	1 at end of test

(4) RECORD KEEPING

The following records shall be kept during the melting demonstration test.

Record	Responsible person
1. Electrode Log	Sample Manager
2. Receiving Bin Log	Weigher
3. Feeder Log	Feeder Operator
4. Furnace Log	Furnace Operator
5. APCS Solids Log	Sample Manager
6. Glass and Metal Product Log	Sample Manager
7. Test Log	Sample Manager
8. Melter Inventory Log	Sample Manager

4.1. Traceability:

All samples to be analyzed or archived will be assigned an identifying designation, entered on the appropriate log, and stored in clean labeled plastic or metal containers.

Samples of solutions, product glass, and metal collected as described in table 3.1. will be submitted for analysis by the Bureau's Analytical Laboratory. The remaining materials will be archived in clean labeled plastic or metal containers.

All data shall be clearly traceable from a final report back through the analytical records and worksheets to the date of analysis, the individual who performed the analysis, and to the measuring and test equipment used to collect the data.

All analytical test conditions, specimen preparation information, and related data for conducting the analyses shall be documented as a part of the laboratory records, and shall be clearly traceable to the final report of analytical results.

4.2. Records Disposition:

The final disposition of project records (data files, logs, report formats, records storage and disposition) shall be determined by Bureau of Mines Project Supervisor in cooperation with the WHC Project Manager.

(5) DUTIES OF OPERATORS

All operators and an electrician are needed during furnace operation.

	Assignment	Responsibilities
1.	Weigher	Weighs and delivers materials to receiving bin. Keeps the Receiving Bin Log.
2.	Feeder operator	Operates the feeder and primary combustion air system and keeps the Feeder Log.
2.	Furnace operator	Operates the electric arc furnace and keeps the Furnace Log.
3.	APCS operator	Operates the APCS.
4.	Sample manager	Collects all samples and keeps the Electrode Log, APCS Solids Log, Glass and Metal Products Log, Test Log and Melter Inventory Log.
5.	Lift operator	Operates fork and barrel lifts to transfer feed materials to the receiving bin and glass and metal products to storage area.
6.	Crane and tapping crew	Operates the overhead crane and taps furnace to remove glass and metal. Keeps the Glass and Metal Products Log.
7.	Quality assurance person	Responsible for assuring safe operating conditions in the work place. Spot checks the NO_x monitors. Spot checks feed and product weights to assure accuracy.

(6) SAFETY AND ENVIRONMENTAL ISSUES

6.1. Safety:

All personnel attending the furnace are required to wear protective clothing, respirators (when needed), gloves, boots, safety glasses, and hard hats. Face shields and reflective heat-resistant clothing are required of the tapping crew. Additional common sense measures are required including remaining out of harm's way when not actually conducting a task.

6.2 Environmental:

6.2.1. Air quality in the work place:

Contamination of air within the building including the control room will be mitigated by the following preventative and control measures.

1. Emissions of gases and fumes into the building will be significantly decreased during furnace operation by withdrawing air through hoods over the tap holes for injection into the APCS as cooling air. The hood over the metal tap hole will be closed while tapping glass to maximize fume collection over the glass tap hole. Similarly, the hood over the glass tap hole will be closed while tapping of the metal side.

2. Air within the building housing the thermal waste treatment facility will be changed at intervals of 2 min by a combination of 3 blowers that remove air from ducts in the roof.

3. The control room will be pressurized with filtered air to preclude ingress of air from the furnace room.

4. Air within the building will be sampled by stationary air monitoring devices located above the glass (North) and metal (South) tap holes. A reference (R) monitor is installed in the control room. The monitors will be operated for 8 h during the demonstration test.

6.2.2. Air quality in the neighborhood:

Contamination of air outside of the building will be well within State guide lines as assured by oxidation of CO and volatile hydrocarbons and destruction of chlorinated hydrocarbons in the thermal oxidizer, collection of particulate and condensed fume solids by baghouse, removal of acid gases by caustic scrubber, and final polishing of exhaust gases by activated carbon and HEPA filters prior to the stack.

6.3. Disposal of Unused Feed and Test Products:

All feed will be melted to eliminate potential disposal problems. Product glass, cyclone solids, and baghouse solids will be disposed of in a municipal landfill if shown to be benign by analysis. All materials failing the TCLP test will be interred in a hazardous waste landfill. Scrubber solution will satisfy the City's requirement for sanitary sewer disposal (pH between 6 and 10 and no undissolved solids) and will be drained continuously into the city sewer as an overflow from the scrubber. Water for the cooler/condenser is provided by the cooling tower. The contents of the cooling water system will be vented after the test to the City sewer following analysis and pH adjustment, if needed. Solutions not acceptable for sewer disposal will be evaporated to dryness, and the solids will be placed in a hazardous waste landfill.

(7) DATA ACQUISITION:

Basic information to evaluate the performance of the feed system, electric arc melting furnace, and the APCS are recorded electronically and/or manually throughout a melting campaign. Sampling of offgas will be done by gas chromatograph.

7.1. Electrical Parameters:

Electrical parameters for analyzing demand and consumption of the electric furnace are continuously monitored by a True RMS Power and Demand Analyzer Model 3950, which records rms voltage (V), rms current (A), apparent power (VA), active power (W), reactive power (var), power factor, and total energy (Kw.h). These data are integrated over 1 min interval, and the integral values are stored by the instrument. A data logger receives up to 48 additional inputs from sensors in the feed system, electric furnace, and APCS, applies a linear scaling factor to each input as needed, and transmits the calculated values to a personal computer at intervals of 30 sec for display and storage. A hard copy is printed at 5-min intervals.

7.2. Continuous Monitoring Locations:

The following data derived from both the furnace, APCS, and feeder will be recorded continuously during the vitrification demonstration test by the data acquisition system:

Thermocouple sensor and type:	Monitoring point
Furnace exit after gas burner 1, Type R.	1.
Crossover duct exit after burner 2, Type R.	2.
Thermal oxidizer exit, Type R.	3.
Evaporative gas cooler exit, Type J.	4.
Cooling air supply duct, Type J.	5.
Wind box exit (cyclone entrance), Type J.	6.
Cyclone exit (baghouse entrance), Type J.	7.

Baghouse exit, Type J.	8.
Scrubber exit, Type J.	9.
Cooler/condenser exit, Type J.	10.
Reheater exit (ID blower entrance), Type J.	11.
ID blower exit (filter entrance), Type J.	12.
Filter exit (stack), Type J.	13.
Furnace upper plenum, Type K.	14.
Furnace shell bottom, Type J.	15.
Metal tap hole, Type K.	16.
Product glass, continuous indicating pyrometer.	17.
Primary combustion air, Type J.	18.
Secondary combustion air, Type J.	19.
Cooling water to furnace, Type J.	20.
Warm water return, Type J.	21.

Gas pressure transducer:	Monitoring point
Evaporative Gas Cooler exit.	4.
Cooling air.	5.
Wind box exit.	6.
Cyclone exit.	7.
Baghouse exit.	8.
Scrubber exit.	9.
Cooler/condenser exit.	10.
Reheat exit.	11.
ID blower exit.	12.
Filter exit or stack.	13.
Furnace upper plenum (air draft X-mitter).	14.
Primary combustion air.	18.
Secondary combustion air.	19.

Gas flow sensor and type:	Monitoring point
Atomization air for EGC, flow X-mitter.	EGC air supply
Evaporative gas cooler exit, He tracer.	4.
Cooling air duct, S-type pitot with P X-ducer.	5.
Baghouse exit, He tracer.	8.
Baghouse exit, S-type pitot with P X-ducer.	8.
Stack, S-type pitot with P X-ducer.	13.
Primary combustion air, flow X-mitter.	18.
Secondary combustion air, S-type pitot with P X-ducer	19.

Water flow sensor and type:	Monitoring point
EGC water, flow X-mitter.	EGC water supply
Cooling water to furnace, totalizing flow meter.	20.
Warm water return, totalizing flow meter.	21.

Miscellaneous sensor and type	Monitoring point
Feed rate	Metering bin
Cold top depth (continuous)	Under SE tube
Cold top depth (manual)	Under NE tube

7.3. Additional Logs:

Manual logs will be kept to record the following:

(1) **ELECTRODE LOG:**
a. Date, time installed, and weight of graphite electrode segments placed in service.

(2) **RECEIVING BIN LOG:**
a. Date, time, and weight of all materials entering the receiving bin of the feed system.

(3) **FEEDER LOG:**
a. Feed rate when feed rate is changed and at irregular intervals,
b. Depth of cold top when feed rate is changed and at irregular intervals as appropriate.

(4) **FURNACE LOG:**
a. Furnace operating parameters including transformer tap, electrode voltage (V), electrode current (A), power (kW), energy (kW.h), rheostat settings, and glass temp.

(5) **APCS SOLIDS LOG:**
a. Date and time collected and the weight of all solids recovered from the APCS.

(6) **GLASS AND METAL PRODUCTS LOG:**
a. Date and time collected and the weight of product glass ingots and samples for analysis.

(7) **TEST LOG:**
a. Depth to bottom of hearth and thermal oxidizer.
b. Totalizing flowmeters: EGC water, scrubber water, cooler/condenser water, and natural gas.

(8) **MELTER INVENTORY LOG:**
a. Feed and glass tapping rates; cumulative total feed and glass, power, and energy consumption.

nyb The New York Blower Company
7660 Quincy Street
Willowbrook, IL. 60521

Revision 0

PERFORMANCE CURVE

To determine Performance
at another RPM multiply
CFM x K
SP x K^2
BHP x K^3
where K is new RPM divided
by RPM shown at right.

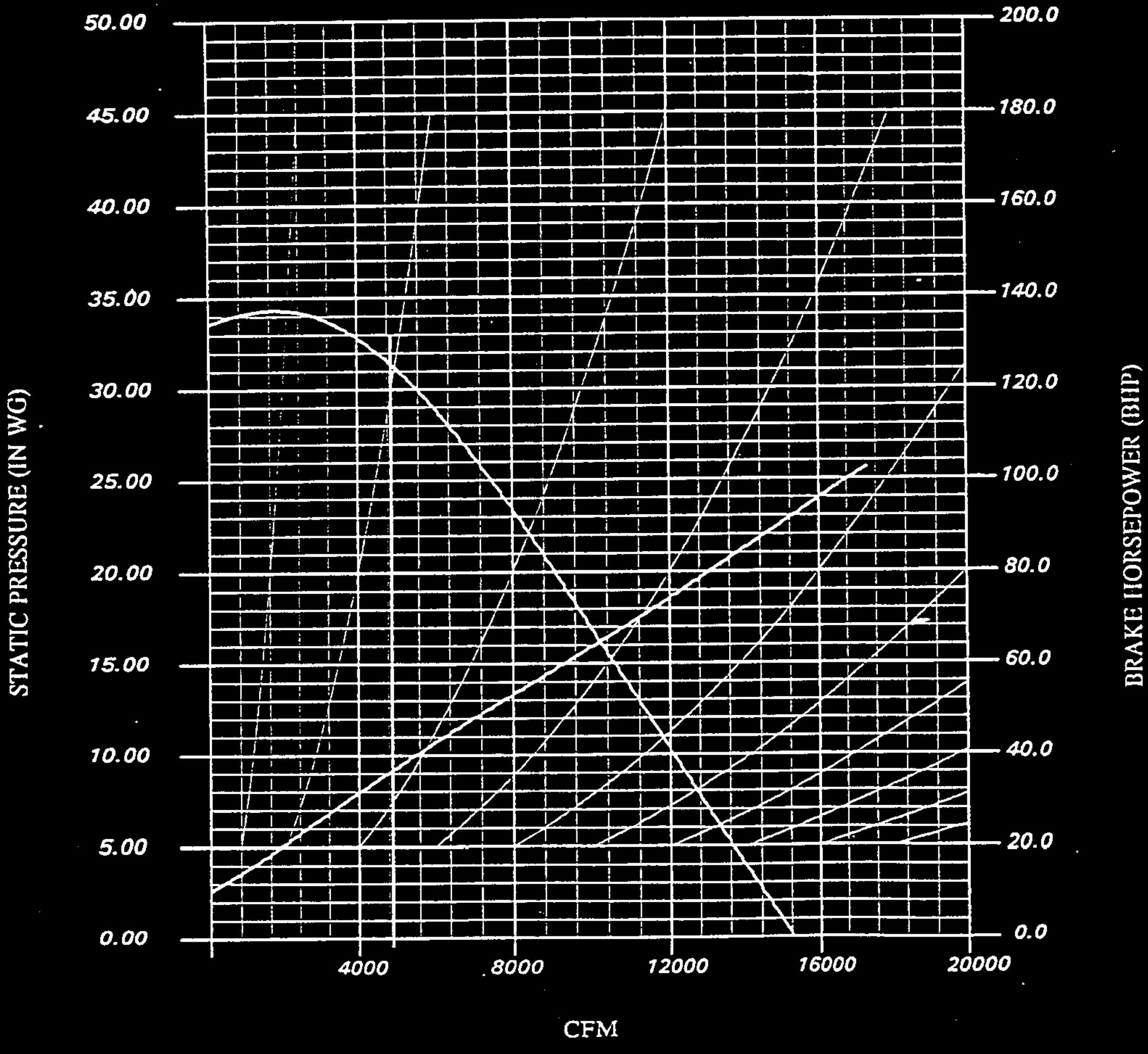
DATE : *Aug 27 1994*

CUST. NO : *C94K45072*
CUSTOMER : *USBM*
TAGGING :
FAN TYPE : *Series 45 - DH*
FAN SIZE : *224*
CFM : *4900*
SP : *31.4*
RPM : *3550*
BHP : *36.75*

TEMP : *100* deg F
DENS : *0.070* LB/FT³

FILE : *K09987/100* *GDB*

PERFORMANCE OPTIONS : *Inlet Box, Inlet Box Damper*



GENERAL CORRECTION FACTOR CURVE FOR GAS PRESSURES

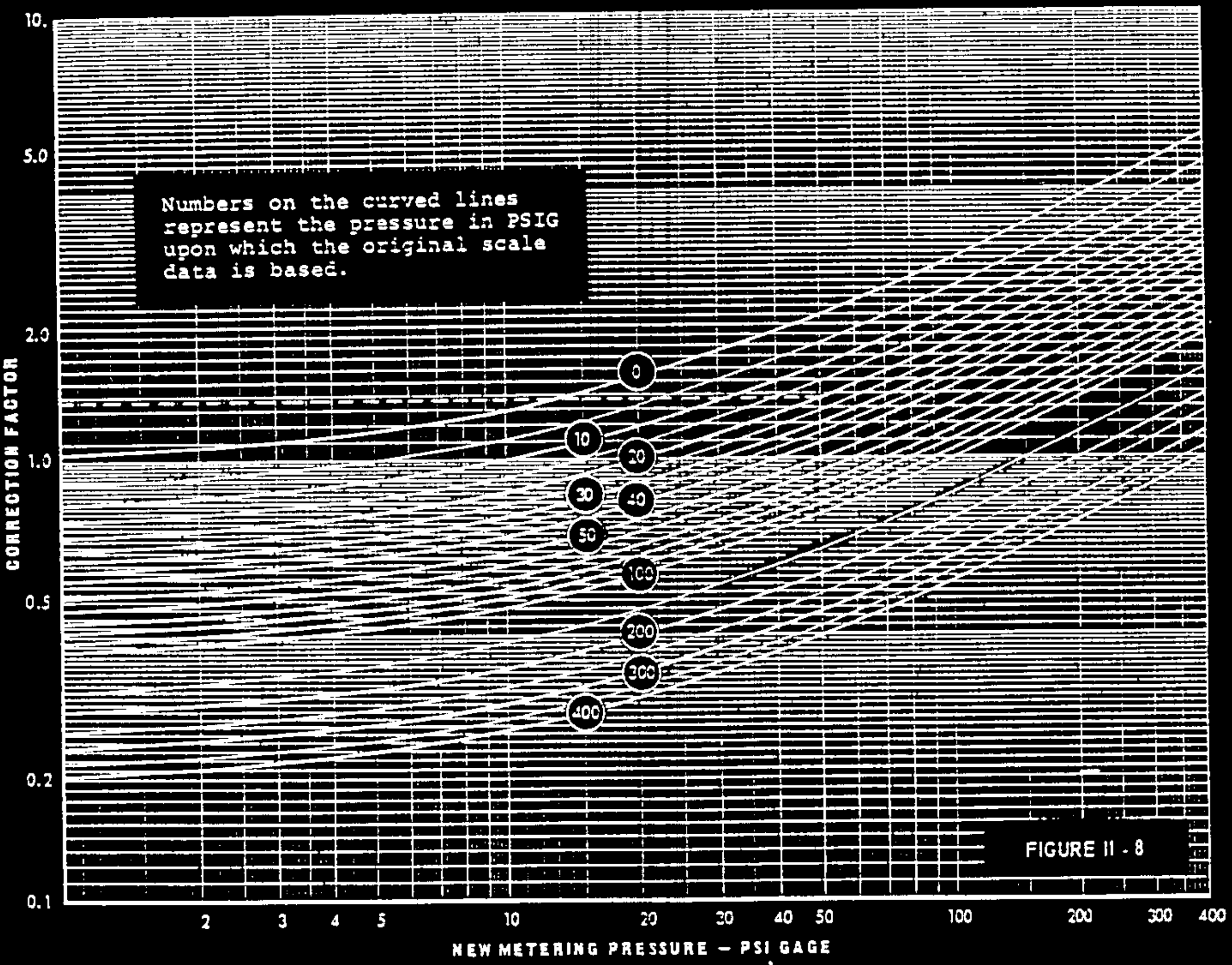
(PERFECT GASES ONLY)

FOR CORRECTING STANDARD VOLUME UNITS (SCFM or SLPM) or GRAVIMETRIC UNITS (PPH or kg/HR)

Indicated Flow Rate × Correction Factor = Corrected Flow Rate

FOR CORRECTING ACTUAL VOLUME UNITS (ACFM or OCFM)-

Indicated Flow Rate ÷ Correction Factor = Corrected Flow Rate



Numbers on the curved lines represent the pressure in PSIG upon which the original scale data is based.

FIGURE II - 8

EXAMPLE

What is correct flow rate of air metered at 50 PSIG when scale reads 24 SCFM in meter whose scale is based on air at 20 PSIG?

Step #1 Locate 50 on bottom scale

#2 Go vertically upward on 50 PSIG line until intersecting curved line representing 20 PSIG

#3 At intersection go horizontally to left and read Correction Factor = 1.37

#4 New Flow = (1.37)24 = 32.8 SCFM air