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Baseline Tests for Arc Melter Vitrification of INEL Buried Wastes

Volume I: Facility Description and Summary Data Report

L. L. Oden
W. K. O'Connor
P. C. Turner
N. R. Soelberg
G. L . Anderson

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Idaho National Engineering Laboratory
EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

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Prepared by:

N. R. Soelberg
Principal Investigator

23 Nov 93
Date

Reviewed by:

G. L. Anderson
Principal Investigator and Project Manager

24 Nov. 93
Date

Approved by:

K. M. Kostelnik
Coordinator, Buried Waste Integrated Demonstration

11/30/93
Date

ABSTRACT

This report presents field results and raw data from the Buried Waste Integrated Demonstration (BWID) Arc Melter Vitrification Project Phase 1 baseline test series conducted by the Idaho National Engineering Laboratory (INEL) in cooperation with the U.S. Bureau of Mines (USBM). The baseline test series was conducted using the electric arc melter facility at the USBM Albany Research Center in Albany, Oregon. Five different surrogate waste feed mixtures were tested that simulated thermally-oxidized, buried, TRU-contaminated, mixed wastes and soils present at the INEL. Additional waste application and system modification tests are planned for later phases.

The USBM Arc Furnace Integrated Waste Processing Test Facility includes a continuous feed system, the arc melting furnace, an offgas control system, and utilities. The melter is a sealed, 3-phase alternating current (ac) furnace approximately 2 m high and 1.3 m wide. The furnace has a capacity of 1 metric ton of steel. With a power input rate of up to 800 kW, the melter can process as much as 1,500 lb/h of soil-type waste materials.

The surrogate feed materials included five mixtures designed to simulate incinerated TRU-contaminated buried waste materials mixed with INEL soil. The waste types that were simulated included (a) cemented sludges with absorbed organic oils and solvents, (b) solidified evaporator salts containing potassium and sodium nitrates and (c) contaminated metals. Mixtures of surrogate waste materials (a) and (b) were processed both with and without small additions of zirconium oxide and titanium oxide to investigate processing properties of a tailored glass ceramic final waste form material. In order to reduce molten slag viscosities to facilitate continuous slag tapping, some of the surrogate feed mixtures were further modified with additions of calcium oxide, calcium carbonate, and non-oxides during the baseline tests. Cerium oxide was included as a surrogate for plutonium oxide to investigate behavior and partitioning of TRU elements in the melting furnace.

Process samples, melter system operations data and offgas composition data were obtained during the baseline tests to evaluate the melter performance and meet test objectives. Samples and data gathered during this program included (a) automatically and manually logged melter systems operations data, (b) process samples of slag, metal and fume solids, and (c) offgas composition, temperature, velocity, flowrate, moisture content, particulate loading and metals content. Sample analyses have been completed to plan for the process slag, metal and fume samples, and the offgas samples. Analytical results will be used with the process and offgas measurements to (a) characterize melter operation, (b) evaluate the composition and leachability of the fume, slag and metal phases, (c) evaluate the fate and partitioning of key elements in the feed mixtures, and (d) perform mass balances.

This report consists of 2 volumes: Volume I summarizes the baseline test operations. It includes an executive summary, system and facility description, review of the surrogate waste mixtures, and a description of the baseline test activities, measurements, and sample collection. Volume II contains the raw test data and sample analyses from samples collected during the baseline tests.

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ACRONYMS

APCS	Air Pollution Control System
BWID	Buried Waste Integrated Demonstration
CEMS	Continuous Emissions Monitoring System
DAS	Data Acquisition System
DOE	Department of Energy
EPA	Environmental Protection Agency
HEPA	High Efficiency Particulate Air (filter)
ID	Induced Draft
ID	inside diameter
IEB	Iron Enriched Basalt
INEL	Idaho National Engineering Laboratory
LOI	Loss on Ignition
MMT	Multiple Metals Train
OD	outside diameter
RWMC	Radioactive Waste Management Complex
SDA	Subsurface Disposal Area
TCLP	Toxicity Characteristic Leaching Procedure
THC	total hydrocarbons
TRU	transuranic
USBM	United States Bureau of Mines

Baseline Tests for Arc Melter Vitrification of INEL Buried Wastes

Volume I: Facility Description and Summary Data Report

1. EXECUTIVE SUMMARY

The U.S. Bureau of Mines (USBM) conducted arc melter vitrification baseline tests at the Albany Research Center arc melter test facility in Albany, Oregon. This melter is located at the USBM Albany Research Center. The tests were conducted using surrogate waste materials and soils prepared to simulate thermally-oxidized, buried, TRU-contaminated wastes at the Idaho National Engineering Laboratory (INEL). These Phase 1 baseline tests are part of the Buried Waste Integrated Demonstration (BWID) Arc Melter Vitrification Project[1] being performed by INEL in cooperation with the USBM during Fiscal Year 1993 (FY93).

The Phase 1 objectives include evaluating and demonstrating existing industrial arc melter technology for the thermal treatment of mixed transuranic (TRU) contaminated wastes and soils. Baseline design and operating conditions will be evaluated using soil and additive mixtures designed to simulate thermally-oxidized radioactive wastes presently buried at the Idaho National Engineering Laboratory Subsurface Disposal Area (SDA) at the Radioactive Waste Management Complex (RWMC). The objectives of the baseline tests are further described in the test plan document.[2] Subsequent studies are planned to more specifically evaluate and optimize the arc melter design, operation, process control, and containment parameters to enable safe and effective vitrification of mixed, TRU-contaminated wastes and soils.

The USBM electric arc melter system includes a continuous feed system, the 3-phase, electric arc melting furnace, an offgas control system, and utilities. The melting furnace is approximately 2 m high and 1.3 m wide. The furnace has a capacity of 1 metric ton of steel. With a power input rate of up to 800 kW, the melter can process as much as 1,500 lb/h of soil-type waste materials. The melter is refractory-lined with a water-cooled roof, sidewall, feed tubes and slag tapping fixture. Melt temperatures can exceed 1,800°C. Slag tapping can be continuous. Four feed tubes penetrated the roof of the furnace. Three 4-in. diameter graphite electrodes also penetrated the furnace roof.

A shakedown test was performed on June 3, 1993, about six weeks before the baseline tests. INEL soil was melted in the shakedown test to evaluate the operability of all of the melter systems and to provide preliminary test data for designing the baseline tests. The baseline tests were conducted on July 19–23, 1993. The melter was preheated on July 18, just before the baseline tests, using a feed mixture of calcium and silicon oxides to clean out soil residues from the shakedown test.

1.1 Shakedown Test Overview

The shakedown test was conducted on June 3, 1993, primarily to determine the melting characteristics of the soil and to identify potential problems with the facility and procedures prior

to the planned baseline tests. The shakedown test demonstrated very effective performance of the feed system, the furnace and the recently modified air pollution control system (APCS). A cold top was established that maintained low melter headspace and offgas temperatures. Slag was continuously tapped after adjusting slag viscosity, and offgas measurements and samples were collected.

Approximately 6,000 lb of RWMC soil was processed during the 12-hour shakedown test. The unadulterated soil produced a very acidic slag (basicity ratio 0.28) that proved to be very viscous at temperatures to 1550°C and very corrosive to furnace refractories at higher temperatures. Basicity ratio is the molar ratio of basic oxides (such as CaO, MgO, FeO, Na_2O, and K_2O) to acidic oxides (SiO_2, Al_2O_3, and Fe_2O_3) in the slag. Additions of mill scale (Fe_3O_4) in the ratio of 20 lb mill scale (basicity ratio 0.37) to 100 lb soil provided only marginally satisfactory fluidity at 1550°C. Similar problems were anticipated with the surrogate waste feed mixtures prepared for the baseline tests because of their low basicity ratio. Additives including additional mill scale, limestone ($CaCO_3$), and pebble lime (CaO) were purchased for modifying the baseline test feed compositions when needed.

As a result of the shakedown tests, a number of modifications to the test procedures were made before the baseline tests. The most important of these included (a) development of a strategy for slag viscosity control for easier tapping at lower temperatures, (b) development of strategies/ procedures for reducing feed classification and obtaining the most representative offgas, slag, metal, and fume[a] samples as reasonably possible, and (c) additional and improved diagnostics and instrumentation including better slag temperature determination, hearth temperature measurements, and cooling water flowmeters.

A number of offgas measurements were made during the shakedown test. Since soil without surrogate waste additives was tested only during the shakedown test, the offgas, particulate and slag measurements from the shakedown test are the only measurements obtained for the soil feed. There were three offgas particulate sampling test runs during the shakedown test. These tests were performed to get preliminary information for the upcoming baseline tests, and to characterize the offgas conditions and emissions for the shakedown tests. Because results of these tests were not considered as critical as results from the baseline tests, several deviations were made to streamline and reduce costs of sample collection. However, the objectives of the shakedown testing were accomplished. The results should be usable and comparable to particulate results from the baseline tests, with the caveat that these shakedown test results are not as rigorous in depicting the offgas conditions.

Other measurements performed during the shakedown test included offgas velocity, temperature, CO, and NO_x measurements. Process samples that were collected during the shakedown tests included several slag samples and the fume collected in fume trap 1 and the baghouse. Roughly one lb of fume was collected in the fume trap, and about 20–30 lb was collected in the baghouse hopper.

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a. Fume is material that volatilized in the furnace and condensed in cooler regions of the furnace and offgas system. Entrained particulate is solid feed material (dust) that is physically entrained in the offgas. Fume can condense on the surfaces of entrained particulate or form very fine particles.

1.2 Baseline Test Overview

The baseline tests were conducted on July 19–23, 1993. The furnace was operated for 12 hours on July 18, prior to the baseline tests, to heat the furnace refractories and clean out melted soil residues from the shakedown test. For this preheat and cleanout run, 4,300 lb of calcium oxide and silica sand (basicity ratio of 1.0) were processed in the melter.

During the baseline tests, the five surrogate waste mixtures were melted in as many consecutive daily 16-h campaigns. Waste mixtures S60 and S60-IV with basicity ratios of 0.52 and 0.51, respectively, were successfully melted without modifying the compositions. Continuous tapping of slag was achieved at temperatures ranging from 1,450 to 1,650°C. The N80 and N80-IV waste mixtures with basicity ratios of 0.48 and 0.44, respectively, were more viscous and required higher tapping temperatures, up to 1,850°C. These waste materials were processed for about four hours each while process and offgas data and samples were collected. Following a full set of sample and data collection (except for metal samples) the melts were modified by adding limestone ($CaCO_3$) or pebble lime (CaO) and mill scale to the feed mixture to increase the basicity ratio to one. Another full set of sample and data collection (except for metal samples) was obtained while operating with the modified mixtures.

The M60 surrogate waste was a mixture of 60% soil and metal powders, flakes and small shot. The soil was exceedingly acidic with a basicity ratio of 0.28. About 3,260 lb of M60 was melted in four hours at feedrates up to 1,500 lb/h, while process and offgas data and samples (except for metal samples) were collected. During this time the slag could not be successfully tapped without severely overheating the furnace and potentially damaging the furnace refractory, feed tubes or other components. Because the slag could not be tapped for this condition, samples could not be obtained from the slag tap. A slag sample was collected using a steel probe inserted through a port in the furnace. Following the sample and data collection, the melt was modified by feeding 3,006 lb of N80-IV-Mod plus an additional 400 lb of pebble lime over the following 4 hours. After decreasing the melt viscosity, continuous slag tapping was successfully initiated. Another set of process data and sample collection was performed at this operating condition.

For the five baseline test days, a total of 39,419 lb of the surrogate waste mixtures and 4,194 lb of additives were melted at feedrates up to 1,500 lb/h with continuous slag tapping. Product slag accounted for 85.92% of the total charge material, 2.05% reported to the fume solids, and 2.83% was recovered as metal. The observed approximate 10% loss on ignition (primarily moisture loss and evolution of CO_2 gas from carbonates) of the feed materials results in essentially 100% mass balance closure.

During extended periods of continuous operation, the energy input ranged from 0.37 to 0.57 kWh/lb of feed material. The mean value over the 5-day baseline test series was 0.52 kWh/lb. Electrode consumption averaged over the six days of melting (five baseline test days plus the preheat day), was 12.15 lb/st (short ton); or stated in terms of energy usage, 11.38 lb/MWh. A total of 47,914 lb of material was melted in those six days.

1.2.1 Baseline Feed Mixtures

The surrogate waste feed materials processed during the baseline tests were five base mixtures designed to simulate soil mixed with thermally oxidized TRU-contaminated wastes. The waste types that were simulated include (a) cemented calcium silicate sludge with absorbed organic oils and solvents, (b) solidified evaporator salts containing potassium and sodium nitrates

and (c) contaminated scrap metals, each mixed with soil. In order to achieve sufficiently low molten slag viscosities to enable continuous slag tapping, some of these mixtures were further modified during the baseline tests. The tests that were performed and the feed mixtures are summarized as follows:

Test day	Feed type designation	Description
July 19	S60	60 wt% RWMC soil and 40% additives that simulate thermally oxidized, cemented calcium silicate sludge with absorbed organic oils and solvents.
July 20	S60-IV	S60 mixture with zircon and ilmenite additives to provide zirconium and titanium, representative elements from Group IV of the Periodic Table, at levels of about 3% ZrO_2 and 6% TiO_2 in the resultant slag. The added Zr and Ti make the slag chemistry similar to Iron-Enriched Basalt (IEB-4).
July 21	N80	80% RWMC soil and 20% additives that simulate evaporator salts from solar drying liquid wastes. The additives include sodium and potassium carbonates as substitutes for the more reactive sodium and potassium nitrates.
July 21	N80-Mod	N80 modified to reduce slag viscosity by adding 37.5 lb limestone and 20.7 lb mill scale per 100 lb N80 mixture.
July 22	N80-IV	N80 mixture with zirconia and ilmenite additives to provide zirconium and titanium, at levels of about 4% ZrO_2 and 8% TiO_2 in the resultant slag. The added Zr and Ti make the slag chemistry more similar to Iron-Enriched Basalt (IEB-4).
July 22	N80-IV-Mod	N80 modified to reduce slag viscosity by adding 22.4 lb CaO as pebble lime and 20.7 lb mill scale per 100 lb N80-IV mixture.
July 23	M60	60% RWMC soil and 40% metal additives to simulate TRU-contaminated metal wastes.
July 23	N80-IV-Mod	N80 modified to reduce slag viscosity by adding 22.4 lb CaO as pebble lime and 20.7 lb mill scale per 100 lb N80-IV mixture. This feed mixture was added to dilute the M60 melt and enable continuous tapping.

The feed compositions were calculated from sample analysis of the INEL soil and the compositions of the individual additives. The compositions were calculated rather than determined from sample collection and analysis to prevent analysis inaccuracies from incompletely mixed materials.

1.2.2 Baseline Test Data and Sample Collection

Process samples and system operations data were collected during the field tests for (a) monitoring process conditions during operation and (b) subsequent laboratory analysis and data interpretation for evaluating the melter system performance according to the test objectives.[2] Process samples and operating data gathered during this program included:

- Melter system process data, including process instrumentation data automatically logged in the continuous data acquisition system and data recorded by hand on data logs.
- Process samples of (a) slag from the slag tap and from slag adhering to a steel probe dipped into the melt (the M60 test only), (b) metal samples (from the metal heel removed from the hearth following the test program), and (c) fume solids samples from fume trap 1, fume trap 2, and the baghouse.
- Offgas measurements including (a) gas composition from continuous monitoring at selected sample locations in the APCS, (b) velocity and flowrate, (c) swirl angle, and (d) moisture content.
- Samples from the offgas particulate/metals sampling train (Draft EPA Method 29).

The process data logged automatically and manually were obtained during the entire operation period for each test. Process samples were collected at selected times for each test. One slag sample was collected for each slag pot filled, resulting in around 5–10 slag samples per test. Since the slag could not be tapped (because of high slag viscosity) during the M60 test, a slag sample was collected by freezing it onto a steel probe dipped into the melt. Fume samples from the fume traps and the baghouse were collected after each test condition for each feed mixture.

At least one complete set of offgas measurements was collected for each of the above listed feed mixtures. Two complete sets of offgas measurements were obtained for the S60, S60-IV mixtures. Two sets of offgas measurements were also obtained for the N80-IV-Mod mixture, although the second set of offgas measurements was obtained on July 23 while the M60 melt was being diluted with the N80-IV-Mod mixture.

The offgas measurements included velocity, flowrate, temperature, gas composition (oxygen, carbon dioxide, carbon monoxide, nitrogen oxides and sulfur dioxide), and sample collection for subsequent total particulate and metals analysis. These measurements were performed in accordance with applicable U.S. Environmental Protection Agency (EPA) sampling procedures. Deviations from these procedures were limited to a few that (a) did not impair the data quality for the purposes of the baseline tests, and (b) were deemed necessary in order to effectively perform the measurements and data collection.

Laboratory and data analyses are presently underway for the process and offgas samples. Analytical results will be used with the process and offgas data to (a) characterize melter operations performance, (b) evaluate the composition and leachability of the fume, slag and metal phases, (c) evaluate the fate and partitioning of key elements in the feed mixtures, and (d) perform mass balances.

1.2.3 Electronic, Photographic, and Video Records

Electronic records of the baseline tests include the following:

- Facility continuous data acquisition system files—Saved in ASCII format, these files contain 1-minute instantaneous values for the automatically logged process parameters for each test. These files fit on one 3.5-in. 1.44 MB computer diskette.

- Offgas continuous emissions monitoring system gas composition files—Saved in Lotus 123 spreadsheets, these files contain 1-minute average values for the offgas composition. These files fit on one 3.5-in. 1.44 MB computer diskette.

- Spreadsheets for the metals/particulate test runs—Saved in Lotus 123 format, these files contain the sampling parameters including sample time, sample volume, velocity, and isokinetic sampling rate. These spreadsheets will also be used to calculate the particulate and metals concentrations and mass emission rates in the offgas. These files fit on one 3.5-in. 1.44 MB computer diskette.

Photographs were taken of key or interesting operations at various times during the shakedown test and the baseline tests. At different times, photographs were taken using a Polaroid and a 35-mm camera. A number of video stills were also obtained of the furnace interior during startup, before dust evolution in the furnace chamber. These were stored in the facility data acquisition system computer.

Video taping of key features and activities also was performed during the shakedown and baseline tests. Approximately 20 minutes of video footage was obtained of the shakedown tests. The primary feature of this footage is the unit-by-unit overview of the entire melter system. About 60 minutes of footage was obtained of the baseline tests. The primary features of this footage include a sequence showing slag tapping from the slag tap hole and tapping the metals tap hole at the end of a test run. About 15 minutes of this video footage was obtained by a professional photographer. Footage taken by the professional photographer includes slag tapping, inspection of the solidified slag molds, and an overview of the facility and various operations.

1.3 Report Organization

This report consists of two volumes that contain the field summary of the baseline tests and the presently available test data: Volume I contains a field summary report that includes an executive summary, introduction, facility description, review of the surrogate waste mixtures, and overview of the baseline test activities. Volume II contains raw data from the shakedown and baseline tests, including manually and automatically recorded system operations data, offgas monitoring and sampling data, and sample analyses.

2. INTRODUCTION

The Bureau of Mines, Albany Research Center, and the Department of Energy (DOE) through its contractor EG&G Idaho, Inc. have collaborated on a research project to evaluate the applicability of 3-phase electric arc furnace melting technology to vitrify materials simulating buried mixed wastes. Part of this project has been to conduct a series of baseline melting tests at the Albany Research Center arc melter facility. The primary objective of the melting tests was to demonstrate the applicability of 3-phase electric arc melting technology to vitrify thermally oxidized simulated mixed wastes. A description of the surrogate waste feed mixtures is provided in Section 3.

Performance of this test program required several modifications to the arc melter facility. These modifications included the addition of water-cooled feed tubes to the existing, sealed, 3-phase, electric arc melting furnace. The APCS was also modified. An air-dilution temperature quench system was added to cool the melter offgas at the outlet of the melter. A High Efficiency Particulate-Air (HEPA) filter unit was added downstream of the baghouse and upstream of the induced draft (ID) fan. A thorough description of the arc melter facility is provided in Section 4. Section 5 describes safety and personnel practices. Section 6 describes the facility and process data collection methods. Section 7 describes the offgas monitoring and sampling data collected. Section 8 describes the baseline test series operations including the initial soil only shakedown test and summarizes operations and post test data. Section 9 describes samples taken and analyses being conducted, some preliminary conclusions are provided in Section 10. Volume II presents the test data in a series of appendices.

3. DESCRIPTION OF SURROGATE WASTE MIXTURES

The surrogate waste mixtures were prepared by mixing soil from the Radioactive Waste Management Complex (RWMC) with selected additives. The additives were selected to simulate buried wastes that have been incinerated. The mixture proportions of the soil and additives were calculated so that the resultant vitrified slag product from the vitrification process would be chemically similar to iron-enriched basalt (IEB) or IEB-4, which is IEB that is enriched in Group IV elements (Ti and Zr). IEB-4 potentially provides longer duration immobilization of TRU elements and better leach resistance.[2,3] Moisture content and carbon were limited in all waste forms to 3 and 1.5%, respectively. Sulfur and chlorine were limited to 1.5% in the surrogate waste mixtures (S60 and S60-IV) designed to simulate soil and incinerated organic solvents.

Some of the waste types were suspected to produce very viscous slags; therefore, additional materials were obtained before the melting test to fluidize the melts (if needed). These additional materials comprised limestone ($CaCO_3$), pebble lime (CaO), and magnetite (Fe_3O_4) as mill scale obtained from a local steel mill. Surrogate waste types N80, N80-IV, and M60 were modified during the melting tests, as described below. The waste types S60 and S60-IV did not require modification to reduce viscosity.

Surrogate waste type	Description
S60	The S-0 series of wastes describes organic oils and solvents immobilized by mixing with Micro-Cell E ($CaSiO_3$) and Oil-Dri. These wastes were generated at EG&G's Rocky Flats Plant, and include Organic Setups (prefix 743, also identified as INEL Content Code 3).[4,b] Waste mixture S60 is 60% RWMC soil (A-100) and 40% simulated thermally oxidized S-0. Gypsum ($CaSO_4 \cdot 2H_2O$) and NaCl were added to provide the desired sulfur and chlorine concentrations, respectively.
S60-IV	This waste mixture is the S60 mixture with additions of zircon and ilmenite to provide around 3% ZrO_2 and 6% TiO_2 in the slag.
N80	The N-0 series of wastes contains evaporator salts from solar drying liquid wastes and consists mostly of sodium and potassium nitrates with limited amounts of other wastes and small amounts of Oil-Dri. These wastes were generated at EG&G Rocky Flats Plant, and include prefix 745 (Content Code 5) evaporator salts. The surrogate waste mixture N80 is 80% RWMC soil and 20% simulated thermally oxidized N-0. Sodium and potassium nitrates in the buried N-0 wastes were replaced by sodium and potassium carbonates to avoid potential problems with chemical reaction of the nitrates during melting.
N80-Mod	The N80 waste mixture was modified during the melting test with limestone and mill scale in the ratio 100 lb N-80: 37.5 lb limestone: 20.7 lb mill scale.

b. W. S. Roesener, H. R. Soelberg, and A. L. Ayers, "Identification of a Treatment Process for the Idaho Waste Processing Facility Project—A Preconceptual Design Study," unpublished report, September 1992.

Surrogate waste type	Description
N-80-IV	This waste mixture is the N80 mixture with additions of zirconia and ilmenite to provide around 4% ZrO_2 and 8% TiO_2 in the molten product.
N80-IV-Mod	The N80-IV waste mixture was modified during the melting test with pebble lime and mill scale in the ratio 22.4 lb CaO and 20.7 lb mill scale for every 100 lb N80-IV.
M60	The M-0 waste (from EG&G Rocky Flats Plant, Content Code 480) is a variety of unleached scrap metals (some bagged in plastic) and loaded into boxes and drums. Surrogate waste mixture M60 is 60% RWMC soil and 40% simulated thermally oxidized M-0 waste.

3.1 Feed Mixture Analysis

The elemental compositions (Table 3-1) of the feed mixtures were calculated from the compositions and amount of each additive in the feed mixtures (Tables 3-2 through 3-8). The compositions of the INEL soil and each additive are shown in Tables 3-9(a), (b), and (c). The compositions of the feed mixtures were not determined by analysis of feed mixture samples because of the potential for segregation of the different additives during sampling. Such segregation is common when, as in this case, mixtures of materials of different particle sizes, shapes, and densities are handled. Therefore, calculated mixture compositions for these types of mixtures are considered more accurate than measured compositions.

Soil for preparing the surrogate waste mixtures was spread on a concrete floor and dried in a heated building at the INEL. The moisture content of the dried soil, as determined by heating numerous samples at 110°C for 24 h, ranged from 2 to 3.5%. The mean loss on ignition (LOI) for numerous samples, as obtained by heating for 4 h at 1,000°C, was approximately 10%. The combined moisture content and LOI weight loss averaged around 12%. Soil samples for chemical and instrumental analysis were obtained by conventional cone-and-quartering procedures from 200 lb of thoroughly mixed soil.

The chemical composition of the INEL soil was determined by the USBM using appropriate chemical and instrumental analytical methods. Analyses of the various additives were obtained from the additive suppliers.

Table 3-1. Calculated elemental composition of the surrogate waste mixtures.

Element	Surrogate Waste Mixture Elemental Composition (as received wt. %)						
	S60	S60-IV	N80	N80-Mod	N80-IV	N80-IV-Mod	M60
Ag	4.52e-04	3.97e-04	5.95e-04	4.90e-04	5.24e-04	4.47e-04	5.14e-04
Al	3.99	3.58	4.35	3.59	3.79	3.25	5.85
As	6.21e-04	5.46e-04	8.24e-04	6.79e-04	7.27e-04	6.36e-04	6.94e-04
Ba	0.05	0.05	0.03	0.03	0.03	0.03	0.03
Bi	-	-	-	-	-	-	2.21e-07
C	0.88	0.78	2.91	3.74	2.77	2.38	0.99
Ca	6.47	6.22	3.99	7.73	3.50	8.09	4.20
Cd	2.82e-05	2.48e-05	3.72e-05	3.06e-05	3.27e-05	2.80e-05	3.15e-05
Ce	0.34	0.35	0.34	0.28	0.34	0.29	0.38
Cl	1.24	1.27	8.31e-03	6.85e-03	7.95e-03	6.79e-03	2.52e-03
Cr	0.04	0.04	0.03	0.03	0.03	0.03	1.72
Cs	0.40	0.41	3.72e-03	3.06e-03	3.27e-03	2.80e-03	3.15e-03
Cu	2.54e-03	2.24e-03	3.34e-03	0.02	2.95e-03	0.02	0.74
F	0.06	0.06	0.06	0.05	0.06	0.05	0.06
Fe	11.63	11.66	6.68	9.99	6.33	10.44	26.80
H	0.75	0.69	0.84	0.70	0.76	0.68	0.71
Hf	-	1.36	-	-	0.05	0.05	-
Hg	5.65e-06	4.97e-06	7.68e-06	6.33e-06	6.80e-06	5.80e-06	6.30e-06
K	1.17	1.03	5.04	4.16	4.86	4.15	1.28
Li	4.13e-03	4.24e-03	-	-	-	-	-
Mg	1.48	1.41	1.08	0.92	0.94	0.82	0.87
Mn	0.03	0.08	0.01	0.04	0.09	0.12	2.15e-03
N	-	-	-	-	-	-	1.75e-03
Na	1.36	1.32	5.34	4.40	5.25	4.48	0.60
Ni	1.92e-03	1.69e-03	2.53e-03	0.01	2.23e-03	0.01	0.96
O	47.73	45.61	49.97	48.35	48.36	45.63	35.97
P	0.06	0.05	0.07	0.06	0.07	0.06	0.06
Pb	1.30e-03	1.14e-03	1.77e-03	1.46e-03	1.56e-03	1.37e-03	0.74
Rb	9.90e-03	0.01	-	-	-	-	-
S	1.35	1.38	0.04	0.04	0.03	0.03	0.02
Sb	-	-	-	-	-	-	1.47e-06
Se	6.31e-05	5.55e-05	8.31e-05	6.85e-05	7.32e-05	6.25e-05	7.12e-05
Si	20.78	18.51	20.26	16.70	17.84	15.26	17.86
Sn	-	-	-	-	-	-	2.95e-06
Sr	0.04	0.04	0.02	0.01	0.02	0.01	0.02
Te	-	-	-	-	-	-	7.37e-07
Th	1.44e-03	1.48e-03	1.46e-03	1.20e-03	2.02e-03	1.73e-03	1.61e-03
Ti	1.27	3.04	0.70	0.57	3.92	3.35	0.17
U	-	-	-	-	8.44e-04	7.21e-04	-
V	0.08	0.08	0.04	0.03	0.03	0.03	-
Y	-	-	-	-	4.15e-03	3.55e-03	-
Zn	6.21e-03	5.46e-03	8.18e-03	6.74e-03	7.20e-03	6.15e-03	1.47
Zr	5.65e-03	0.70	7.43e-03	6.12e-03	2.49	2.12	6.30e-03
Other	-1.24e+00	0.24	-1.82e+00	-1.47e+00	-1.60e+00	-1.43e+00	-1.53e+00
Total	99.97	99.97	100.01	100.01	100.01	100.00	99.99

Table 3-2. S60 surrogate waste mixture additives and composition.

Species	Amount of each species provided by the listed additives (lb)									Tot. amt. of ea. species (lb)	Tot. wt. % of ea. species
	Cerium Oxide Conc.	Gypsum	Magnetite	Pollucite	Salt	Silica	Soil	Talc	Wollastonite		
Al2O3	-	-	137.42	37.80	-	22.41	748.02	9.02	5.40	960.06	7.54
Ag2O	-	-	-	-	-	-	0.06	-	-	0.06	4.85e-04
As2O	-	-	-	-	-	-	0.09	-	-	0.09	6.87e-04
BaO	-	-	-	-	-	-	0.80	-	-	0.80	6.30e-03
CaCO3	-	-	-	-	-	3.18	934.00	-	1.08	938.26	7.37
CaO	3.05	-	16.03	-	-	0.24	8.05	55.45	253.71	336.52	2.64
CaSO4	-	7.33	-	-	-	-	-	-	-	7.33	0.06
CaSO4*2H2O	-	876.32	-	-	-	-	-	-	-	876.32	6.89
CdO	-	-	-	-	-	-	4.10e-03	-	-	4.10e-03	3.22e-05
CeO2	52.50	-	-	-	-	-	0.40	-	-	52.90	0.42
Cr2O3	-	-	4.58	-	-	-	2.10	-	-	6.68	0.05
Cs2O	-	-	-	-	-	-	0.38	-	-	0.38	2.99e-03
CuO	-	-	-	-	-	-	0.40	-	-	0.40	3.18e-03
Fe2O3	-	-	-	-	-	0.48	-	11.27	2.70	14.45	0.11
Fe3O4	-	-	1,726.96	-	-	-	303.83	-	-	2,030.79	15.96
H2O	3.24	32.05	-	1.58	0.08	-	725.64	2.25	1.08	765.92	6.02
HgO	-	-	-	-	-	-	7.76e-04	-	-	7.76e-04	6.10e-06
K2O	-	-	-	-	-	4.05	174.03	-	-	178.09	1.40
MgO	-	-	29.78	-	-	0.16	163.24	117.21	1.62	312.00	2.45
MnO	-	-	4.58	-	-	-	-	-	0.54	5.12	0.04
NaCl	-	-	-	-	258.82	-	-	-	-	258.82	2.03
Na2O	-	-	-	-	-	0.24	91.99	-	-	92.23	0.72
NiO	-	-	-	-	-	-	0.31	-	-	0.31	2.44e-03
PO4	-	-	-	-	-	-	20.93	-	-	20.93	0.16
P2O5	-	-	0.92	-	-	-	-	-	-	0.92	7.20e-03
PbO	-	-	-	-	-	-	0.18	-	-	0.18	1.40e-03
SO4	4.81	-	-	-	0.21	-	3.02	-	-	8.03	0.06
SeO	-	-	-	-	-	-	8.64e-03	-	-	8.64e-03	6.79e-05
SiO2	3.21	-	109.94	113.40	-	762.66	4,149.70	241.18	269.90	5,649.98	44.40
ThO2	0.21	-	-	-	-	-	-	-	-	0.21	1.64e-03
TiO2	-	-	238.20	-	-	0.08	31.16	-	0.27	269.71	2.12
V2O5	-	-	16.03	-	-	-	-	-	-	16.03	0.13
ZnO	-	-	-	-	-	-	0.98	-	-	0.98	7.73e-03
ZrO2	-	-	-	-	-	-	0.97	-	-	0.97	7.63e-03
BaO+SrO	5.77	-	-	-	-	-	-	-	-	5.77	0.05
Ca	-	-	-	0.63	0.08	-	-	-	-	0.71	5.56e-03
Cl	-	-	-	-	-	-	0.29	-	-	0.29	2.26e-03
Cs	-	-	-	49.98	-	-	-	-	-	49.98	0.39
F	7.37	-	-	-	-	-	-	-	-	7.37	0.06
Fe	-	-	-	0.63	-	-	-	-	-	0.63	4.95e-03
K	-	-	-	1.05	0.10	-	-	-	-	1.15	9.07e-03
Li	-	-	-	0.53	-	-	-	-	-	0.53	4.13e-03
Mg	-	-	-	-	0.05	-	-	-	-	0.05	4.08e-04
Mn	-	-	-	-	-	0.01	-	-	-	0.01	1.12e-04
Na	-	-	-	3.15	-	-	-	-	-	3.15	0.02
Rb	-	-	-	1.26	-	-	-	-	-	1.26	9.90e-03
S	-	-	4.58	-	-	-	-	-	-	4.58	0.04
Si	-	-	-	-	-	-	-	-	2.70	2.70	0.02
Other	-1.14e-14	-	1.37	2.98e-14	0.26	1.10	-1.76e+02	14.43	0.81	-1.58e+02	-1.24e+00
Total	80.15	915.70	2,290.40	210.00	259.60	794.60	7,184.60	450.80	539.80	12,725.65	100.00

Table 3-3. S60-IV surrogate waste mixture additives and composition.

Species	Amount of each species provided by the listed additives (lb)											Tot. amt. of ea. species (lb)	Tot. wt. % of each species
	Cerium Oxide	Gypsum	Ilmenite	Magnetite	Pollucite	Salt	Silica	Soil	Talc	Wollas-tonite	Zircon (ZrSiO4)		
Al2O3	-	-	4.18	123.12	37.80	-	17.87	640.15	9.19	5.45	-	837.75	6.77
Ag2O	-	-	-	-	-	-	-	0.05	-	-	-	0.05	4.27e-04
As2O	-	-	-	-	-	-	-	0.07	-	-	-	0.07	6.05e-04
BaO	-	-	-	-	-	-	-	0.69	-	-	-	0.69	5.55e-03
CaCO3	-	-	-	-	-	-	2.54	799.31	-	1.09	-	802.93	6.49
CaO	3.05	-	0.18	14.36	-	-	0.19	6.89	56.53	256.01	-	337.20	2.72
CaSO4	-	7.33	-	-	-	-	-	-	-	-	-	7.33	0.06
CaSO4*2H2O	-	876.32	-	-	-	-	-	-	-	-	-	876.32	7.08
CdO	-	-	-	-	-	-	-	3.51e-03	-	-	-	3.51e-03	2.84e-05
CeO2	52.50	-	-	-	-	-	-	0.34	-	-	-	52.84	0.43
Cr2O3	-	-	1.01	4.10	-	-	-	1.80	-	-	-	6.92	0.06
Cs2O	-	-	-	-	-	-	-	0.33	-	-	-	0.33	2.63e-03
CuO	-	-	-	-	-	-	-	0.35	-	-	-	0.35	2.80e-03
Fe2O3	-	-	178.80	-	-	-	0.38	-	11.49	2.72	-	193.39	1.56
Fe3O4	-	-	-	1,547.21	-	-	-	260.01	-	-	-	1,807.22	14.60
H2O	3.24	32.05	13.42	-	1.58	0.08	-	621.00	2.30	1.09	-	674.75	5.45
HgO	-	-	-	-	-	-	-	6.64e-04	-	-	-	6.64e-04	5.36e-06
K2O	-	-	-	-	-	-	3.23	148.94	-	-	-	152.17	1.23
MgO	-	-	1.31	26.68	-	-	0.13	139.70	119.50	1.63	-	288.94	2.33
MnO	-	-	7.40	4.10	-	-	-	-	-	0.54	-	12.05	0.10
NaCl	-	-	-	-	-	258.82	-	-	-	-	-	258.82	2.09
Na2O	-	-	-	-	-	-	0.19	78.73	-	-	-	78.92	0.64
NiO	-	-	-	-	-	-	-	0.27	-	-	-	0.27	2.15e-03
PO4	-	-	-	-	-	-	-	17.91	-	-	-	17.91	0.14
P2O5	-	-	0.54	0.82	-	-	-	-	-	-	-	1.36	0.01
PbO	-	-	-	-	-	-	-	0.15	-	-	-	0.15	1.23e-03
SO4	4.81	-	-	-	-	0.21	-	2.58	-	-	-	7.60	0.06
SeO	-	-	-	-	-	-	-	7.39e-03	-	-	-	7.39e-03	5.97e-05
SiO2	3.21	-	1.55	98.50	113.40	-	608.32	3,551.27	245.89	272.35	-	4,894.48	39.54
ThO2	0.21	-	-	-	-	-	-	-	-	-	-	0.21	1.68e-03
TiO2	-	-	386.60	213.41	-	-	0.06	26.67	-	0.27	-	627.01	5.07
V2O3	-	-	1.37	-	-	-	-	-	-	-	-	1.37	0.01
V2O5	-	-	-	14.36	-	-	-	-	-	-	-	14.36	0.12
ZnO	-	-	-	-	-	-	-	0.84	-	-	-	0.84	6.80e-03
ZrO2	-	-	0.24	-	-	-	-	0.83	-	-	-	1.07	8.64e-03
BaO+SrO	5.77	-	-	-	-	-	-	-	-	-	-	5.77	0.05
ZrO2+HfO2	-	-	-	-	-	-	-	-	-	-	315.33	315.33	2.55
Ca	-	-	-	-	0.63	0.08	-	-	-	-	-	0.71	5.72e-03
Cl	-	-	-	-	-	-	-	0.25	-	-	-	0.25	1.99e-03
Cs	-	-	-	-	49.98	-	-	-	-	-	-	49.98	0.40
F	7.37	-	-	-	-	-	-	-	-	-	-	7.37	0.06
Fe	-	-	-	-	0.63	-	-	-	-	-	-	0.63	5.09e-03
K	-	-	-	-	1.05	0.10	-	-	-	-	-	1.15	9.32e-03
Li	-	-	-	-	0.53	-	-	-	-	-	-	0.53	4.24e-03
Mg	-	-	-	-	-	0.05	-	-	-	-	-	0.05	4.19e-04
Mn	-	-	-	-	-	-	0.01	-	-	-	-	0.01	9.22e-05
Na	-	-	-	-	3.15	-	-	-	-	-	-	3.15	0.03
Rb	-	-	-	-	1.26	-	-	-	-	-	-	1.26	0.01
S	-	-	-	4.10	-	-	-	-	-	-	-	4.10	0.03
Si	-	-	-	-	-	-	-	-	-	2.72	-	2.72	0.02
Other	-1.14e-14	-	-	1.23	2.98e-14	0.26	0.88	-1.51e+02	14.71	0.82	161.87	29.15	0.24
Total	80.15	915.70	596.60	2,052.00	210.00	259.60	633.80	6,148.50	459.60	544.70	477.20	12,377.85	100.00

Table 3-4. N80 surrogate waste mixture additives and composition.

Species	Amount of each species provided by the listed additives (lb)					Tot. amt. of ea. species (lb)	Tot. wt. % of ea. species
	Cerium Oxide Conc.	Magnetite	Potash	Soda Ash	Soil		
Al2O3	-	60.65	-	-	969.18	1,029.83	8.22
Ag2O	-	-	-	-	0.08	0.08	6.39e-04
As2O	-	-	-	-	0.11	0.11	9.05e-04
BaO	-	-	-	-	1.04	1.04	8.30e-03
CaCO3	-	-	-	-	1,210.14	1,210.14	9.66
CaO	3.05	7.08	-	-	10.43	20.55	0.16
CdO	-	-	-	-	5.32e-03	5.32e-03	4.24e-05
CeO2	52.50	-	-	-	0.51	53.01	0.42
Cr2O3	-	2.02	-	-	2.72	4.74	0.04
Cs2O	-	-	-	-	0.49	0.49	3.94e-03
CuO	-	-	-	-	0.52	0.52	4.19e-03
Fe2O3	-	-	-	0.01	-	0.01	1.07e-04
Fe3O4	-	762.14	-	-	393.65	1,155.80	9.23
H2O	3.24	-	0.93	2.28	940.19	946.63	7.56
HgO	-	-	-	-	1.01e-03	1.01e-03	8.02e-06
K2CO3	-	-	784.63	-	-	784.63	6.26
KCl	-	-	0.04	-	-	0.04	3.14e-04
K2O	-	-	-	-	225.49	225.49	1.80
KOH	-	-	0.55	-	-	0.55	4.39e-03
K2SO4	-	-	0.05	-	-	0.05	3.77e-04
MgO	-	13.14	-	-	211.50	224.64	1.79
MnO	-	2.02	-	-	-	2.02	0.02
Na2CO3	-	-	-	1,334.04	-	1,334.04	10.65
NaCl	-	-	-	1.07	-	1.07	8.55e-03
Na2O	-	-	-	-	119.19	119.19	0.95
Na2SO4	-	-	-	2.01	-	2.01	0.02
NiO	-	-	-	-	0.40	0.40	3.22e-03
PO4	-	-	-	-	27.12	27.12	0.22
P2O5	-	0.40	-	-	-	0.40	3.23e-03
PbO	-	-	-	-	0.23	0.23	1.84e-03
SO4	4.81	-	-	-	3.91	8.72	0.07
SeO	-	-	-	-	0.01	0.01	8.94e-05
SiO2	3.21	48.52	-	-	5,376.60	5,428.33	43.34
ThO2	0.21	-	-	-	-	0.21	1.66e-03
TiO2	-	105.12	-	-	40.37	145.50	1.16
V2O5	-	7.08	-	-	-	7.08	0.06
ZnO	-	-	-	-	1.27	1.27	0.01
ZrO2	-	-	-	-	1.26	1.26	0.01
BaO+SrO	5.77	-	-	-	-	5.77	0.05
As	-	-	7.86e-04	-	-	7.86e-04	6.28e-06
Cl	-	-	-	-	0.37	0.37	2.97e-03
F	7.37	-	-	-	-	7.37	0.06
Fe	-	-	9.43e-04	-	-	9.43e-04	7.53e-06
Hg	-	-	3.14e-05	-	-	3.14e-05	2.51e-07
Pb	-	-	7.08e-03	-	-	7.08e-03	5.65e-05
S	-	2.02	-	-	-	2.02	0.02
Other	-1.14e-14	0.61	1.12e-13	-1.34e-02	-2.28e+02	-2.27e+02	-1.82e+00
Total	80.15	1,010.80	786.20	1,339.40	9,308.80	12,525.35	100.00

Table 3-5. N80-Mod surrogate waste mixture additives and composition.

Species	Amount of each species provided by the listed additives (lb)							Tot. amt. of ea. species (lb)	Tot. wt. % of ea. species
	Cerium Oxide Conc.	Magnetite	Potash	Soda Ash	Soil	Limestone	Mill Scale		
Al2O3	-	60.65	-	-	969.18	-	-	1,029.83	6.78
Ag2O	-	-	-	-	0.08	-	-	0.08	5.26e-04
As2O	-	-	-	-	0.11	-	-	0.11	7.46e-04
BaO	-	-	-	-	1.04	-	-	1.04	6.84e-03
CaCO3	-	-	-	-	1,210.14	1,687.93	-	2,898.07	19.07
CaO	3.05	7.08	-	-	10.43	-	-	20.55	0.14
CdO	-	-	-	-	5.32e-03	-	-	5.32e-03	3.50e-05
CeO2	52.50	-	-	-	0.51	-	-	53.01	0.35
Cr2O3	-	2.02	-	-	2.72	-	1.20	5.94	0.04
Cs2O	-	-	-	-	0.49	-	-	0.49	3.25e-03
CuO	-	-	-	-	0.52	-	3.09	3.62	0.02
Fe2O3	-	-	-	0.01	-	-	-	0.01	8.81e-05
Fe3O4	-	762.14	-	-	393.65	-	942.08	2,097.87	13.80
H2O	3.24	-	0.93	2.28	940.19	5.17	-	951.80	6.26
HgO	-	-	-	-	1.01e-03	-	-	1.01e-03	6.61e-06
K2CO3	-	-	784.63	-	-	-	-	784.63	5.16
KCl	-	-	0.04	-	-	-	-	0.04	2.59e-04
K2O	-	-	-	-	225.49	-	-	225.49	1.48
KOH	-	-	0.55	-	-	-	-	0.55	3.62e-03
K2SO4	-	-	0.05	-	-	-	-	0.05	3.10e-04
MgCO3	-	-	-	-	-	17.22	-	17.22	0.11
MgO	-	13.14	-	-	211.50	-	-	224.64	1.48
MnO	-	2.02	-	-	-	-	-	2.02	0.01
MnO2	-	-	-	-	-	-	8.12	8.12	0.05
Na2CO3	-	-	-	1,334.04	-	-	-	1,334.04	8.78
NaCl	-	-	-	1.07	-	-	-	1.07	7.05e-03
Na2O	-	-	-	-	119.19	-	-	119.19	0.78
Na2SO4	-	-	-	2.01	-	-	-	2.01	0.01
NiO	-	-	-	-	0.40	-	1.81	2.22	0.01
PO4	-	-	-	-	27.12	-	0.41	27.53	0.18
P2O5	-	0.40	-	-	-	-	-	0.40	2.66e-03
PbO	-	-	-	-	0.23	-	-	0.23	1.52e-03
SO4	4.81	-	-	-	3.91	-	-	8.72	0.06
SeO	-	-	-	-	0.01	-	-	0.01	7.37e-05
SiO2	3.21	48.52	-	-	5,376.60	-	2.03	5,430.36	35.73
ThO2	0.21	-	-	-	-	-	-	0.21	1.37e-03
TiO2	-	105.12	-	-	40.37	-	-	145.50	0.96
V2O5	-	7.08	-	-	-	-	-	7.08	0.05
ZnO	-	-	-	-	1.27	-	-	1.27	8.39e-03
ZrO2	-	-	-	-	1.26	-	-	1.26	8.27e-03
BaO+SrO	5.77	-	-	-	-	-	-	5.77	0.04
As	-	-	7.86e-04	-	-	-	-	7.86e-04	5.17e-06
Cl	-	-	-	-	0.37	-	-	0.37	2.45e-03
F	7.37	-	-	-	-	-	-	7.37	0.05
Fe	-	-	9.43e-04	-	-	-	-	9.43e-04	6.21e-06
Hg	-	-	3.14e-05	-	-	-	-	3.14e-05	2.07e-07
Pb	-	-	7.08e-03	-	-	-	-	7.08e-03	4.66e-05
S	-	2.02	-	-	-	-	-	2.02	0.01
Other	-1.14e-14	0.61	1.12e-13	-1.34e-02	-2.28e+02	12.06	-8.00e+00	-2.23e+02	-1.47e+00
Total	80.15	1,010.80	786.20	1,339.40	9,308.80	1,722.38	950.75	15,198.48	100.00

Table 3-6. N80-IV surrogate waste mixture composition.

Species	Amount of each species provided by the listed additives (lb)							Tot. amt. of ea. species (lb)	Tot. wt. % of ea. species
	Cerium Oxide Conc.	Ilmenite	Magnetite	Potash	Soda Ash	Soil	Zirconia		
Al2O3	-	7.83	33.82	-	-	855.22	1.90	898.77	7.17
Ag2O	-	-	-	-	-	0.07	-	0.07	5.63e-04
As2O	-	-	-	-	-	0.10	-	0.10	7.97e-04
BaO	-	-	-	-	-	0.92	-	0.92	7.31e-03
CaCO3	-	-	-	-	-	1,067.86	-	1,067.86	8.51
CaO	3.05	0.34	3.95	-	-	9.20	0.13	16.66	0.13
CdO	-	-	-	-	-	4.69e-03	-	4.69e-03	3.74e-05
CeO2	52.50	-	-	-	-	0.45	-	52.95	0.42
Cr2O3	-	1.90	1.13	-	-	2.40	-	5.43	0.04
Cs2O	-	-	-	-	-	0.44	-	0.44	3.47e-03
CuO	-	-	-	-	-	0.46	-	0.46	3.69e-03
Fe2O3	-	335.30	-	-	0.01	-	0.13	335.45	2.67
Fe3O4	-	-	425.03	-	-	347.37	-	772.40	6.16
H2O	3.24	25.17	-	0.93	2.28	829.64	-	861.26	6.87
HfO2	-	-	-	-	-	-	8.03	8.03	0.06
HgO	-	-	-	-	-	8.87e-04	-	8.87e-04	7.07e-06
K2CO3	-	-	-	784.63	-	-	-	784.63	6.26
KCl	-	-	-	0.04	-	-	-	0.04	3.13e-04
K2O	-	-	-	-	-	198.98	-	198.98	1.59
KOH	-	-	-	0.55	-	-	-	0.55	4.39e-03
K2SO4	-	-	-	0.05	-	-	-	0.05	3.76e-04
MgCO3	-	-	-	-	-	-	-	-	-
MgO	-	2.46	7.33	-	-	186.63	0.04	196.47	1.57
MnO	-	13.87	1.13	-	-	-	-	15.00	0.12
MnO2	-	-	-	-	-	-	-	-	-
Na2CO3	-	-	-	-	1,334.04	-	-	1,334.04	10.64
NaCl	-	-	-	-	1.07	-	-	1.07	8.54e-03
Na2O	-	-	-	-	-	105.18	0.26	105.44	0.84
Na2SO4	-	-	-	-	2.01	-	-	2.01	0.02
NiO	-	-	-	-	-	0.36	-	0.36	2.83e-03
PO4	-	-	-	-	-	23.93	-	23.93	0.19
P2O5	-	1.01	0.23	-	-	-	-	1.23	9.82e-03
PbO	-	-	-	-	-	0.20	-	0.20	1.62e-03
SO4	4.81	-	-	-	-	3.45	-	8.26	0.07
SeO	-	-	-	-	-	9.88e-03	-	9.88e-03	7.88e-05
SiO2	3.21	2.91	27.06	-	-	4,744.44	8.60	4,786.21	38.16
ThO2	0.21	-	-	-	-	-	-	0.21	1.66e-03
TiO2	-	724.98	58.62	-	-	35.63	1.19	820.42	6.54
V2O3	-	2.57	-	-	-	-	-	2.57	0.02
V2O5	-	-	3.95	-	-	-	-	3.95	0.03
Y2O3	-	-	-	-	-	-	0.66	0.66	5.27e-03
ZnO	-	-	-	-	-	1.12	-	1.12	8.97e-03
ZrO2	-	0.45	-	-	-	1.11	419.97	421.53	3.36
BaO+SrO	5.77	-	-	-	-	-	-	5.77	0.05
As	-	-	-	7.86e-04	-	-	-	7.86e-04	6.27e-06
Cl	-	-	-	-	-	0.33	-	0.33	2.62e-03
F	7.37	-	-	-	-	-	-	7.37	0.06
Fe	-	-	-	9.43e-04	-	-	-	9.43e-04	7.52e-06
Hg	-	-	-	3.14e-05	-	-	-	3.14e-05	2.51e-07
Pb	-	-	-	7.08e-03	-	-	-	7.08e-03	5.64e-05
S	-	-	1.13	-	-	-	-	1.13	8.99e-03
Th	-	-	-	-	-	-	0.07	0.07	5.63e-04
U	-	-	-	-	-	-	0.11	0.11	8.44e-04
Other	-1.14e-14	-	0.34	1.12e-13	-1.34e-02	-2.01e+02	-	-2.01e+02	-1.60e+00
Total	80.15	1,118.80	563.70	786.20	1,339.40	8,214.30	441.10	12,543.65	100.00

Table 3-7. N80-IV-Mod surrogate waste mixture additives and composition.

Species	Amount of each species provided by the listed additives (lb)									Tot. amt. of ea. species (lb)	Tot. wt. % of each species
	Cerium Oxide Conc.	Ilmenite	Magnetite	Potash	Soda Ash	Soil	Zirconia	Pebble Lime	Mill Scale		
Al2O3	-	7.83	33.82	-	-	855.22	1.90	3.91	-	902.68	6.14
Ag2O	-	-	-	-	-	0.07	-	-	-	0.07	4.80e-04
As2O	-	-	-	-	-	0.10	-	-	-	0.10	6.81e-04
BaO	-	-	-	-	-	0.92	-	-	-	0.92	6.24e-03
CO2	-	-	-	-	-	-	-	-	-	-	-
CaCO3	-	-	-	-	-	1,067.86	-	18.29	-	1,086.15	7.39
CaO	3.05	0.34	3.95	-	-	9.20	0.13	1,038.68	-	1,055.34	7.18
CdO	-	-	-	-	-	4.69e-03	-	-	-	4.69e-03	3.19e-05
CeO2	52.50	-	-	-	-	0.45	-	-	-	52.95	0.36
Cr2O3	-	1.90	1.13	-	-	2.40	-	-	1.30	6.73	0.05
Cs2O	-	-	-	-	-	0.44	-	-	-	0.44	2.96e-03
CuO	-	-	-	-	-	0.46	-	-	3.36	3.82	0.03
Fe2O3	-	335.30	-	-	0.01	-	0.13	0.89	-	336.34	2.29
Fe3O4	-	-	425.03	-	-	347.37	-	-	1,022.69	1,795.09	12.22
H2O	3.24	25.17	-	0.93	2.28	829.64	-	38.55	-	899.81	6.12
HfO2	-	-	-	-	-	-	8.03	-	-	8.03	0.05
HgO	-	-	-	-	-	8.87e-04	-	-	-	8.87e-04	6.04e-06
K2CO3	-	-	-	784.63	-	-	-	-	-	784.63	5.34
KCl	-	-	-	0.04	-	-	-	-	-	0.04	2.68e-04
K2O	-	-	-	-	-	198.98	-	-	-	198.98	1.35
KOH	-	-	-	0.55	-	-	-	-	-	0.55	3.75e-03
K2SO4	-	-	-	0.05	-	-	-	-	-	0.05	3.21e-04
MgO	-	2.46	7.33	-	-	186.63	0.04	4.47	-	200.93	1.37
MnO	-	13.87	1.13	-	-	-	-	-	-	15.00	0.10
MnO2	-	-	-	-	-	-	-	0.56	8.82	9.38	0.06
Na2CO3	-	-	-	-	1,334.04	-	-	-	-	1,334.04	9.08
NaCl	-	-	-	-	1.07	-	-	-	-	1.07	7.29e-03
Na2O	-	-	-	-	-	105.18	0.26	0.34	-	105.78	0.72
Na2SO4	-	-	-	-	2.01	-	-	-	-	2.01	0.01
NiO	-	-	-	-	-	0.36	-	-	1.97	2.33	0.02
PO4	-	-	-	-	-	23.93	-	-	0.44	24.37	0.17
P2O5	-	1.01	0.23	-	-	-	-	0.22	-	1.46	9.91e-03
PbO	-	-	-	-	-	0.20	-	-	-	0.20	1.39e-03
SO3	-	-	-	-	-	-	-	1.68	-	1.68	0.01
SO4	4.81	-	-	-	-	3.45	-	-	-	8.26	0.06
SeO	-	-	-	-	-	9.88e-03	-	-	-	9.88e-03	6.72e-05
SiO2	3.21	2.91	27.06	-	-	4,744.44	8.60	8.38	2.21	4,796.80	32.65
ThO2	0.21	-	-	-	-	-	-	-	-	0.21	1.42e-03
TiO2	-	724.98	58.62	-	-	35.63	1.19	0.56	-	820.98	5.59
V2O3	-	2.57	-	-	-	-	-	-	-	2.57	0.02
V2O5	-	-	3.95	-	-	-	-	-	-	3.95	0.03
Y2O3	-	-	-	-	-	-	0.66	-	-	0.66	4.50e-03
ZnO	-	-	-	-	-	1.12	-	-	-	1.12	7.66e-03
ZrO2	-	0.45	-	-	-	1.11	419.97	-	-	421.53	2.87
BaO+SrO	5.77	-	-	-	-	-	-	-	-	5.77	0.04
As	-	-	-	7.86e-04	-	-	-	2.23e-03	-	3.02e-03	2.06e-05
Cl	-	-	-	-	-	0.33	-	-	-	0.33	2.24e-03
F	7.37	-	-	-	-	-	-	0.34	-	7.71	0.05
Fe	-	-	-	9.43e-04	-	-	-	-	-	9.43e-04	6.42e-06
Hg	-	-	-	3.14e-05	-	-	-	-	-	3.14e-05	2.14e-07
Pb	-	-	-	7.08e-03	-	-	-	5.58e-03	-	0.01	8.62e-05
S	-	-	1.13	-	-	-	-	-	-	1.13	7.67e-03
Th	-	-	-	-	-	-	0.07	-	-	0.07	4.80e-04
U	-	-	-	-	-	-	0.11	-	-	0.11	7.21e-04
Other	-1.14e-14	-	0.34	1.12e-13	-1.34e-02	-2.01e+02	-	3.05e-04	-8.68e+00	-2.10e+02	-1.43e+00
Total	80.15	1,118.80	563.70	786.20	1,339.40	8,214.30	441.10	1,116.86	1,032.10	14,692.62	100.00

Table 3-8. M60 surrogate waste mixture additives and composition.

Species	Amount of each species provided by the listed additives (lb)										Tot. amt. of ea. species (lb)	Tot. wt. % of ea. species
	CeO2 Conc.	Mullite	Soil	Wollastonite	Aluminum	Copper	Iron	Lead	Stainless Powde	Zinc		
Al2O3	-	112.87	748.02	2.90	-	-	-	-	-	-	863.78	7.57
Ag2O	-	-	0.06	-	-	-	-	-	-	-	0.06	5.41e-04
As2O	-	-	0.09	-	-	-	-	-	-	-	0.09	7.67e-04
BaO	-	0.09	0.80	-	-	-	-	-	-	-	0.89	7.85e-03
CO2	-	-	-	-	-	-	-	-	-	-	-	-
CaCO3	-	-	934.00	0.58	-	-	-	-	-	-	934.58	8.20
CaO	3.05	-	8.05	136.11	-	-	-	-	-	-	147.20	1.29
CdO	-	-	4.10e-03	-	-	-	-	-	-	-	4.10e-03	3.60e-05
CeO	-	0.05	-	-	-	-	-	-	-	-	0.05	4.06e-04
CeO2	52.50	-	0.40	-	-	-	-	-	-	-	52.90	0.46
Cr2O3	-	-	2.10	-	-	-	-	-	-	-	2.10	0.02
Cs2O	-	-	0.38	-	-	-	-	-	-	-	0.38	3.34e-03
CuO	-	-	0.40	-	-	-	-	-	-	-	0.40	3.55e-03
Fe2O3	-	0.71	-	1.45	-	-	-	-	-	-	2.16	0.02
Fe3O4	-	-	303.83	-	-	-	-	-	-	-	303.83	2.66
H2O	3.24	-	725.64	0.58	-	-	-	-	-	-	729.46	6.40
HgO	-	-	7.76e-04	-	-	-	-	-	-	-	7.76e-04	6.80e-06
K2O	-	1.20	174.03	-	-	-	-	-	-	-	175.24	1.54
MgO	-	0.20	163.24	0.87	-	-	-	-	-	-	164.31	1.44
MnO	-	-	-	0.29	-	-	-	-	-	-	0.29	2.54e-03
Na2O	-	0.43	91.99	-	-	-	-	-	-	-	92.43	0.81
NiO	-	-	0.31	-	-	-	-	-	-	-	0.31	2.73e-03
O2	-	-	-	-	-	2.52e-06	-	-	-	-	2.52e-06	2.21e-08
PO4	-	-	20.93	-	-	-	-	-	-	-	20.93	0.18
PbO	-	-	0.18	-	-	-	-	-	-	-	0.18	1.56e-03
SO3	-	-	-	-	-	-	-	-	-	-	-	-
SO4	4.81	-	3.02	-	-	-	-	-	-	-	7.83	0.07
SeO	-	-	8.64e-03	-	-	-	-	-	-	-	8.64e-03	7.58e-05
SiO2	3.21	38.60	4,149.70	144.80	-	-	-	-	-	-	4,336.31	38.03
SrO	-	0.02	-	-	-	-	-	-	-	-	0.02	1.35e-04
ThO2	0.21	-	-	-	-	-	-	-	-	-	0.21	1.83e-03
TiO2	-	0.20	31.16	0.14	-	-	-	-	-	-	31.50	0.28
ZnO	-	-	0.98	-	-	-	-	-	-	-	0.98	8.63e-03
ZrO2	-	-	0.97	-	-	-	-	-	-	-	0.97	8.51e-03
BaO+SrO	5.77	-	-	-	-	-	-	-	-	-	5.77	0.05
Ag	-	-	-	-	-	1.18e-03	-	-	-	-	1.18e-03	1.03e-05
Al	-	-	-	-	210.00	-	-	-	-	-	210.00	1.84
As	-	-	-	-	-	8.40e-05	-	-	-	-	8.40e-05	7.37e-07
Bi	-	-	-	-	-	2.52e-05	-	-	-	-	2.52e-05	2.21e-07
C	-	-	-	-	-	-	0.02	-	0.30	-	0.32	2.81e-03
Cl	-	-	0.29	-	-	-	-	-	-	-	0.29	2.52e-03
Cr	-	-	-	-	-	-	-	-	194.93	-	194.93	1.71
Cu	-	-	-	-	-	83.97	-	-	-	-	83.97	0.74
F	7.37	-	-	-	-	-	-	-	-	-	7.37	0.06
Fe	-	-	-	-	-	8.40e-05	2,100.37	-	734.14	-	2,834.51	24.86
Mn	-	-	-	-	-	-	0.02	-	-	-	0.02	1.84e-04
N	-	-	-	-	-	-	-	-	0.20	-	0.20	1.75e-03
Ni	-	-	-	-	-	1.01e-03	0.21	-	108.99	-	109.20	0.96
O	-	-	-	-	-	-	0.21	-	0.77	-	0.98	8.55e-03
P	-	-	-	-	-	-	0.02	-	0.21	-	0.23	1.99e-03
Pb	-	-	-	-	-	-	-	84.00	-	-	84.00	0.74
S	-	-	-	-	-	5.04e-04	0.03	-	0.07	-	0.11	9.24e-04
Sb	-	-	-	-	-	1.68e-04	-	-	-	-	1.68e-04	1.47e-06
Se	-	-	-	-	-	8.40e-05	-	-	-	-	8.40e-05	7.37e-07
Si	-	-	-	1.45	-	-	0.05	-	8.38	-	9.88	0.09
Sn	-	-	-	-	-	3.36e-04	-	-	-	-	3.36e-04	2.95e-06
Te	-	-	-	-	-	8.40e-05	-	-	-	-	8.40e-05	7.37e-07
Zn	-	-	-	-	-	8.40e-05	-	-	-	167.33	167.33	1.47
Other	-1.14e-14	0.03	-1.76e+02	0.43	-	0.02	0.07	-	-	0.67	-1.75e+02	-1.53e+00
Total	80.15	154.40	7,184.60	289.60	210.00	84.00	2,101.00	84.00	1,048.00	168.00	11,403.75	100.00

Table 3-9(a). Compositions of feed mixture additives.

	Additive Component (as received wt. %)								
Species	Magnetite	Mullite	Pollucite	Silica	Soil (a)	Soil (b)	Talc	Titania	Wollastonite
Ag2O	-	-	-	-	8.59e-04	-	-	-	-
Al2O3	6.00	73.10	18.00	2.82	10.41	-	2.00	-	1.00
As2O	-	-	-	-	1.22e-03	-	-	-	-
BaO	-	0.06	-	-	0.01	-	-	-	-
CaCO3	-	-	-	0.40	13.00	-	-	-	0.20
CaO	0.70	-	-	0.03	0.11	-	12.30	-	47.00
CdO	-	-	-	-	5.71e-05	-	-	-	-
CeO	-	0.03	-	-	-	-	-	-	-
CeO2	-	-	-	-	5.53e-03	-	-	-	-
Cr2O3	0.20	-	-	-	0.03	-	-	0.20	-
Cs2O	-	-	-	-	5.30e-03	-	-	-	-
CuO	-	-	-	-	5.63e-03	-	-	-	-
Fe2O3	-	0.46	-	0.06	-	-	2.50	0.50	0.50
Fe3O4	75.40	-	-	-	4.23	-	-	-	-
H2O	-	-	0.75	-	10.10	10.10	0.50	-	0.20
HgO	-	-	-	-	1.08e-05	-	-	-	-
K2O	-	0.78	-	0.51	2.42	-	-	-	-
MgO	1.30	0.13	-	0.02	2.27	-	26.00	-	0.30
MnO	0.20	-	-	-	-	-	-	-	0.10
Na2O	-	0.28	-	0.03	1.28	-	-	-	-
NiO	-	-	-	-	4.33e-03	-	-	-	-
PO4	-	-	-	-	0.29	-	-	-	-
P2O5	0.04	-	-	-	-	-	-	-	-
PbO	-	-	-	-	2.48e-03	-	-	-	-
SO4	-	-	-	-	0.04	-	-	-	-
SeO	-	-	-	-	1.20e-04	-	-	-	-
SiO2	4.80	25.00	54.00	95.98	57.76	-	53.50	0.90	50.00
SrO	-	0.01	-	-	-	-	-	-	-
TiO2	10.40	0.13	-	0.01	0.43	-	-	95.80	0.05
V2O5	0.70	-	-	-	-	-	-	0.70	-
ZnO	-	-	-	-	0.01	-	-	-	-
ZrO2	-	-	-	-	0.01	-	-	1.10	-
Ag	-	-	-	-	-	8.00e-04	-	-	-
Al	-	-	-	-	-	5.51	-	-	-
As	-	-	-	-	-	1.10e-03	-	-	-
Ba	-	-	-	-	-	0.01	-	-	-
C	-	-	-	-	-	1.56	-	-	-
Ca	-	-	0.30	-	-	5.28	-	-	-
Cd	-	-	-	-	-	5.00e-05	-	-	-
Ce	-	-	-	-	-	4.50e-03	-	-	-
Cl	-	-	-	-	4.00e-03	4.00e-03	-	-	-
Cr	-	-	-	-	-	0.02	-	-	-
Cs	-	-	23.80	-	-	5.00e-03	-	-	-
Cu	-	-	-	-	-	4.50e-03	-	-	-
Fe	-	-	0.30	-	-	3.06	-	-	-
Hg	-	-	-	-	-	1.00e-05	-	-	-
K	-	-	0.50	-	-	2.01	-	-	-
Li	-	-	0.25	-	-	-	-	-	-
Mg	-	-	-	-	-	1.37	-	-	-
Mn	-	-	-	1.80e-03	-	-	-	-	-
Na	-	-	1.50	-	-	0.95	-	-	-
Ni	-	-	-	-	-	3.40e-03	-	-	-
P	-	-	-	-	-	0.10	-	0.02	-
Pb	-	-	-	-	-	2.30e-03	-	-	-
Rb	-	-	0.60	-	-	-	-	-	-
S	0.20	-	-	-	-	0.01	-	6.00e-03	-
Se	-	-	-	-	-	1.00e-04	-	-	-
Si	-	-	-	-	-	27.00	-	-	0.50
Ti	-	-	-	-	-	0.26	-	-	-
Zn	-	-	-	-	-	0.01	-	-	-
Zr	-	-	-	-	-	0.01	-	-	-
Other	0.06	0.02	1.42e-14	0.14	-2.45e+00	42.71	3.20	0.77	0.15
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

(a) Species composition
(b) Elemental composition

Table 3-9(b). Compositions of feed mixture additives.

	Additive Component (as received wt. %)									
Species	Aluminum Shot	Copper Powder	Electrolytic Iron	Lead Shot	Stainless Powder	Zinc Powder	Limestone	Pebble Lime	Mill Scale (a)	Mill Scale (b)
Al2O3	-	-	-	-	-	-	-	0.35	-	-
CaCO3	-	-	-	-	-	-	98.00	1.64	-	-
CaO	-	-	-	-	-	-	-	93.00	-	-
Cr2O3	-	-	-	-	-	-	-	-	-	0.13
CuO	-	-	-	-	-	-	-	-	-	0.33
Fe2O3	-	-	-	-	-	-	-	0.08	-	-
Fe3O4	-	-	-	-	-	-	-	-	-	99.09
H2O (1)	-	-	-	-	-	-	0.30	3.45	-	-
MgCO3	-	-	-	-	-	-	1.00	-	-	-
MgO	-	-	-	-	-	-	-	0.40	-	-
MnO2	-	-	-	-	-	-	-	0.05	-	0.85
Na2O	-	-	-	-	-	-	-	0.03	-	-
NiO	-	-	-	-	-	-	-	-	-	0.19
PO4	-	-	-	-	-	-	-	-	-	0.04
P2O5	-	-	-	-	-	-	-	0.02	-	-
SO3	-	-	-	-	-	-	-	0.15	-	-
SiO2	-	-	-	-	-	-	-	0.75	-	0.21
TiO2	-	-	-	-	-	-	-	0.05	-	-
Ag	-	1.40e-03	-	-	-	-	-	-	-	-
Al	100.00	-	-	-	-	-	-	-	-	-
As	-	1.00e-04	-	-	-	-	-	2.00e-04	-	-
Ba	-	-	-	-	-	-	-	-	-	-
Bi	-	3.00e-05	-	-	-	-	-	-	-	-
C	-	-	8.00e-04	-	0.03	-	-	-	-	-
Ca	-	-	-	-	-	-	-	-	-	-
Cd	-	-	-	-	-	-	-	-	-	-
Ce	-	-	-	-	-	-	-	-	-	-
Cl	-	-	-	-	-	-	-	-	-	-
Cr	-	-	-	-	18.60	-	-	-	0.09	-
Cs	-	-	-	-	-	-	-	-	-	-
Cu	-	99.97	-	-	-	-	-	-	0.26	-
F	-	-	-	-	-	-	-	0.03	-	-
Fe	-	1.00e-04	99.97	-	70.05	-	-	-	71.70	-
Hg	-	-	-	-	-	-	-	-	-	-
K	-	-	-	-	-	-	-	-	-	-
Mg	-	-	-	-	-	-	-	-	-	-
Mn	-	-	1.00e-03	-	-	-	-	-	0.54	-
N	-	-	-	-	0.02	-	-	-	-	-
Na	-	-	-	-	-	-	-	-	-	-
Ni	-	1.20e-03	0.01	-	10.40	-	-	-	0.15	-
O	-	-	0.01	-	0.07	-	-	-	-	-
O2	-	3.00e-06	-	-	-	-	-	-	-	-
P	-	-	8.00e-04	-	0.02	-	-	-	0.01	-
Pb	-	-	-	100.00	-	-	-	5.00e-04	-	-
S	-	6.00e-04	1.50e-03	-	7.00e-03	-	-	-	-	-
Sb	-	2.00e-04	-	-	-	-	-	-	-	-
Se	-	1.00e-04	-	-	-	-	-	-	-	-
Si	-	-	2.50e-03	-	0.80	-	-	-	0.10	-
Sn	-	4.00e-04	-	-	-	-	-	-	-	-
Te	-	1.00e-04	-	-	-	-	-	-	-	-
Ti	-	-	-	-	-	-	-	-	-	-
Zn	-	1.00e-04	-	-	-	99.60	-	-	-	-
Zr	-	-	-	-	-	-	-	-	-	-
Other	-	0.03	3.40e-03	-	-	0.40	0.70	2.73e-05	27.15	-8.41e-01
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

(1) Balance for pebble lime was assumed to be water.

(a) Elemental composition

(b) Species composition

Table 3-9(c). Compositions of feed mixture additives.

Species	Additive Component (as received wt. %)							
	Cerium Oxide Conc.	Gypsum	Ilmenite	Potash	Salt	Soda Ash	Zircon	Zirconia
Al2O3	-	-	0.70	-	-	-	-	0.43
CaO	3.80	-	0.03	-	-	-	-	0.03
CaSO4	-	0.80	-	-	-	-	-	-
CaSO4*2H2O	-	95.70	-	-	-	-	-	-
CeO2	65.50	-	-	-	-	-	-	-
Cr2O3	-	-	0.17	-	-	-	-	-
Fe2O3	-	-	29.97	-	-	1.00e-03	-	0.03
H2O (1)	4.04	3.50	2.25	0.12	0.03	0.17	-	-
HfO2	-	-	-	-	-	-	-	1.82
KCl	-	-	-	5.00e-03	-	-	-	-
K2CO3	-	-	-	99.80	-	-	-	-
KOH	-	-	-	0.07	-	-	-	-
K2SO4	-	-	-	6.00e-03	-	-	-	-
MgO	-	-	0.22	-	-	-	-	0.01
MnO	-	-	1.24	-	-	-	-	-
NaCl	-	-	-	-	99.70	0.08	-	-
Na2CO3	-	-	-	-	-	99.60	-	-
Na2O	-	-	-	-	-	-	-	0.06
Na2SO4	-	-	-	-	-	0.15	-	-
P2O5	-	-	0.09	-	-	-	-	-
SO4	6.00	-	-	-	0.08	-	-	-
SiO2	4.00	-	0.26	-	-	-	-	1.95
ThO2	0.26	-	-	-	-	-	-	-
TiO2	-	-	64.80	-	-	-	-	0.27
V2O3	-	-	0.23	-	-	-	-	-
Y2O3	-	-	-	-	-	-	-	0.15
ZrO2	-	-	0.04	-	-	-	-	95.21
BaO+SrO	7.20	-	-	-	-	-	-	-
ZrO2+HfO2	-	-	-	-	-	-	66.08	-
As	-	-	-	1.00e-04	-	-	-	-
Ca	-	-	-	-	0.03	-	-	-
F	9.20	-	-	-	-	-	-	-
Fe	-	-	-	1.20e-04	-	-	-	-
Hg	-	-	-	4.00e-06	-	-	-	-
K	-	-	-	-	0.04	-	-	-
Mg	-	-	-	-	0.02	-	-	-
Pb	-	-	-	9.00e-04	-	-	-	-
Th	-	-	-	-	-	-	-	0.02
U	-	-	-	-	-	-	-	0.02
Other	-1.42e-14	3.50	-	1.42e-14	0.10	-1.00e-03	33.92	-
Total	100.00	103.50	100.00	100.00	100.00	100.00	100.00	100.00

(1) Balance for some additives (gypsum, potash, soda ash), is assumed to be water.

4. INTEGRATED MELTING FACILITY

The integrated facility is composed of three primary components: (a) a feed system, (b) a 3-phase electric arc melting furnace, and (c) an air pollution control system (APCS). Many elements of the arc melting furnace and APCS are unique, and the facility as a whole constitutes a state-of-the-art melting facility.[5] A process schematic of the facility is shown in Figure 4-1.

4.1 Feed System

Feed waste mixtures, received in 55 gal barrels, were either transferred directly by barrel-lift into the 60 ft^3 receiving bin of the feed system or mixed with additives in a 2-barrel capacity hopper, which then was transferred by overhead crane to the receiving bin. Twin tapered, counter-rotating, 12 in. diameter screws in the base of the bin discharged to a bucket elevator, and lifted the material 17 ft to a 10 ft^3 residue metering bin. The height of material in the metering bin was controlled by a sonic level indicator with high and low set points.

Two calibrated counter-rotating 6 in. diameter screws discharged the feed material from the metering bin to a 6 in. diameter splitter screw, which delivered feed material to two 6 in. diameter delivery screws. Each delivery screw discharged into the furnace through a pneumatically-activated diverter gate that divided and routed the feed to two separate ports in the furnace roof. Feed was thereby uniformly admitted into the furnace through four ports in the roof (two ports for each delivery screw).

Feed materials entered the furnace roof through four water-cooled tubes that extended through the roof to within 18 in. of the molten pool. These double-walled carbon steel tubes are 48 in. long with an 8.625 in. outside diameter (OD) and 5.5 in. inside diameter (ID). The annular water jacket in each tube is divided length wise by spacers to form 6 water passages. Cooling water for each passage is supplied by nominal 1/4 in. copper tubes that extend down the length of the passage to within 1/2 in. of the bottom of the passage.

The height of unmelted material (cold top) in the furnace was determined manually by lowering a weight suspended on a 1/16 in. diameter stranded stainless steel cable in the manner of a plumb bob through one of the feed tubes. The feed system, rated to deliver up to 2,000 lb/h of minus 1/2 in. screened and dried material with a bulk density of approximately 80 lb/ft^3, could be operated manually or controlled automatically by a programmable controller. A detailed description of the feed system is provided in the operations manual.[6] The receiving bin and charge hopper are shown in Figure 4-2.

Fugitive dust generated during dumping of barrels and operation of the feed system was vented to a baghouse through a system of ducts connected to the receiving bin, bucket elevator, and residue metering bin. The baghouse was emptied after each test, and the weight of fugitive dust was subtracted from the weight of feed material placed in the receiving bin.

4.2 Electric Arc Melting Furnace and Power Supply

4.2.1 Furnace Description and Design

The furnace has a refractory-lined steel shell with water-cooled sidewalls, partially water-cooled roof, and air-cooled bottom. The capacity of the hearth is about 5 ft^3. Figure 4-3 shows a

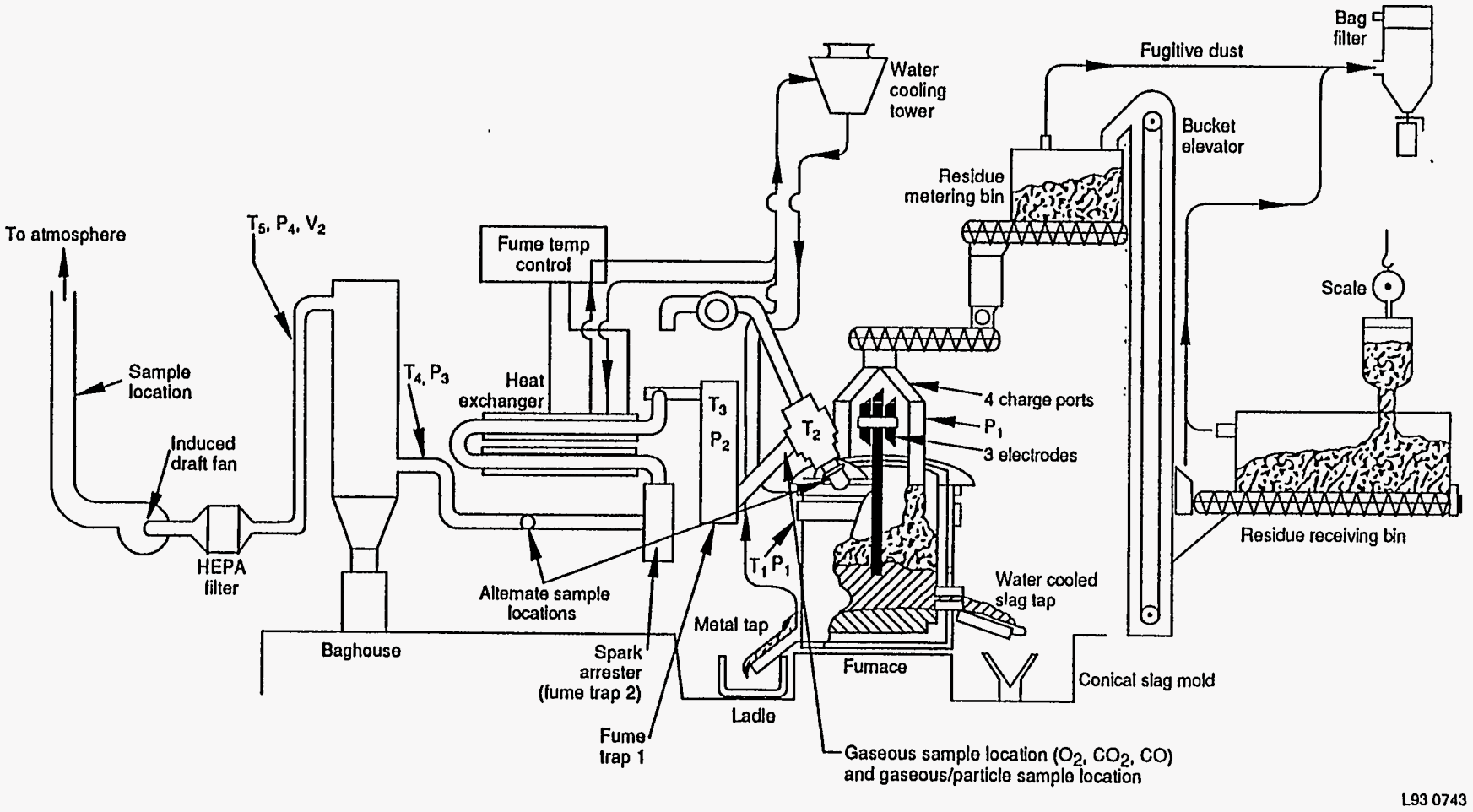


Figure 4-1. Schematic diagram of the Arc Furnace Integrated Waste Processing Test Facility.

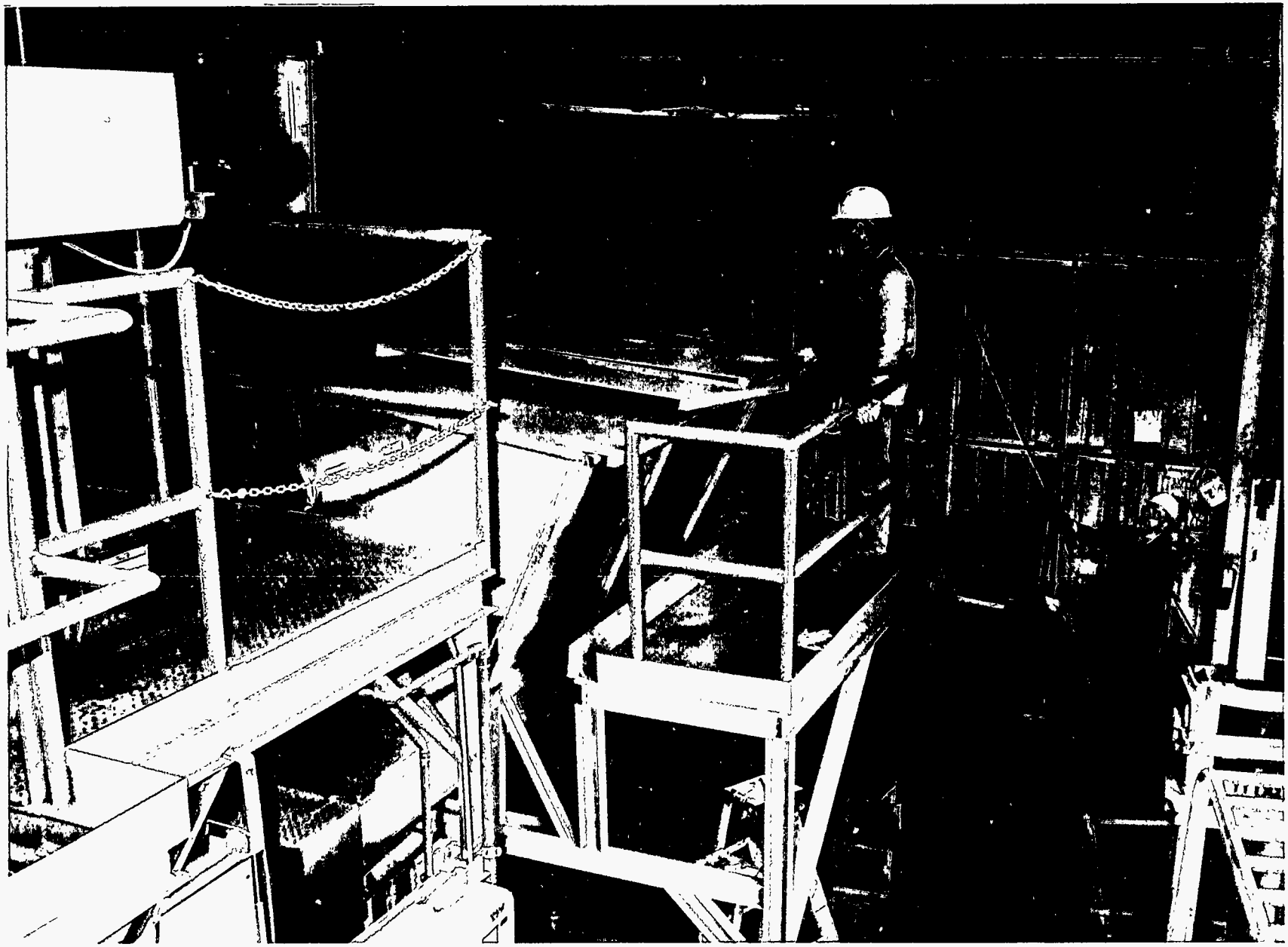


Figure 4-2. Photograph of receiving bin and charge hopper.

vertical section of the furnace shell and roof showing the upper and lower water trough placement, the air plenum for bottom cooling, tap hole locations, launder, and placement of the furnace with respect to floor level. The carbon steel shell is 65 in. high and tapers from 60 in. ID at the bottom to 56 in. ID at the top. Three carbon steel straps (2 in. wide by 0.060 in. thick) were welded to the inside bottom of the shell in a triangular array prior to placing the refractory lining in the shell. These straps were worked between the bricks and through the refractory ramming mix during construction of the hearth to provide an electrical circuit to ground between each pair of electrodes. The furnace shell was then securely grounded on the outside. A concrete pedestal supports the furnace between two rectangular pits, each 3 ft 6 in. deep by 5 ft 10 in. wide by 7 ft long.

The conceptual design and engineering drawings for the modified furnace, including refractory selection and placement, cooling-water needs, voltage/power requirements, water-cooled tapping fixture, and general furnace operating procedures, were provided by Lectromelt Corp.[7]

Figure 4-4 shows the domed carbon steel roof and identifies numerous ports and water passages in the roof. The roof contains a tubular water passage near the outer edge to protect the roof-to-shell seal, which consists of two annular channels in the shell and two knife edges in the roof. The inner channel contains fine sand, and the outer channel contains a silicone elastomer. Water jackets cover about 70% of the exterior surface of the roof encompassing the electrode, charge, and exhaust gas ports.

The three central ports in the roof accommodate 4 in. diameter graphite electrodes. The water-cooled feed tubes, each 8.625 in. OD, extend through the four charging ports in the roof. Exhaust gases exit the furnace through the circular exhaust port in the roof. The square inspection port in the roof was fitted with a door that opens to provide access to the furnace. Figure 4-5 shows the furnace roof and the equipment above the furnace roof. The electrodes and electrode seals, water-cooled feed tubes with their extensive plumbing, and feed delivery screws with transfer tubes are visible.

4.2.2 Furnace Refractories

Refractory placement within the shell and roof is indicated in Figure 4-6. The bottom of the shell was lined with 5 in. (2 courses) of straight Ruby[c] firebrick. Five courses of Ruby key bricks shape the hearth and form the sidewall up to the steel shelf 28 in. above the bottom, which is approximately 7 in. above the slag tap hole. One inch of dry phosphate-bonded silicon carbide (SiC) ramming mix was placed between the steel bottom and the first course of Ruby straights to improve heat transfer to the bottom. This ramming mix, about 1 in. thick, also was placed between the Ruby keys and the sidewall for the same reason. The upper sidewall was lined with 4.5 in. GM 70 DE (70% alumina) insulating arch fire brick. One inch of Fiberfrax (mullite batting) was placed between the sidewall and the arch brick for additional insulation. At mid-height, the finished ID of the furnace is about 46 in. The hearth was rammed to a depth of 6 in. at the center with Permanente 165 AF ramming mix (98% MgO). The volume of the hearth, when finished to 48 in. diameter by 9 in. deep at the center, is approximately 5 ft^3.

c. Reference to specific trade names or manufacturers does not imply endorsement by the Bureau of Mines or INEL.

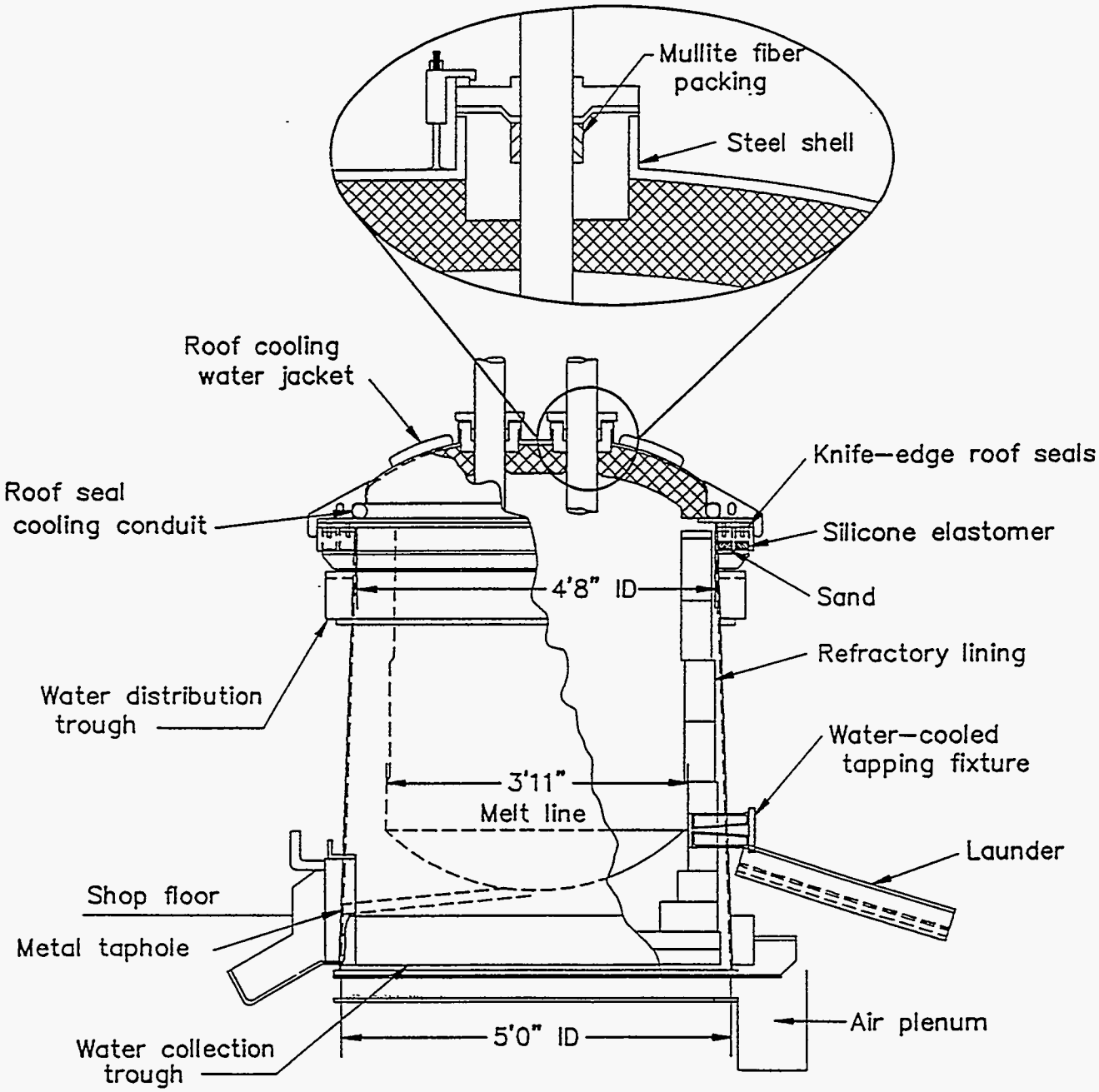


Figure 4-3. Vertical section of electric arc melting furnace.

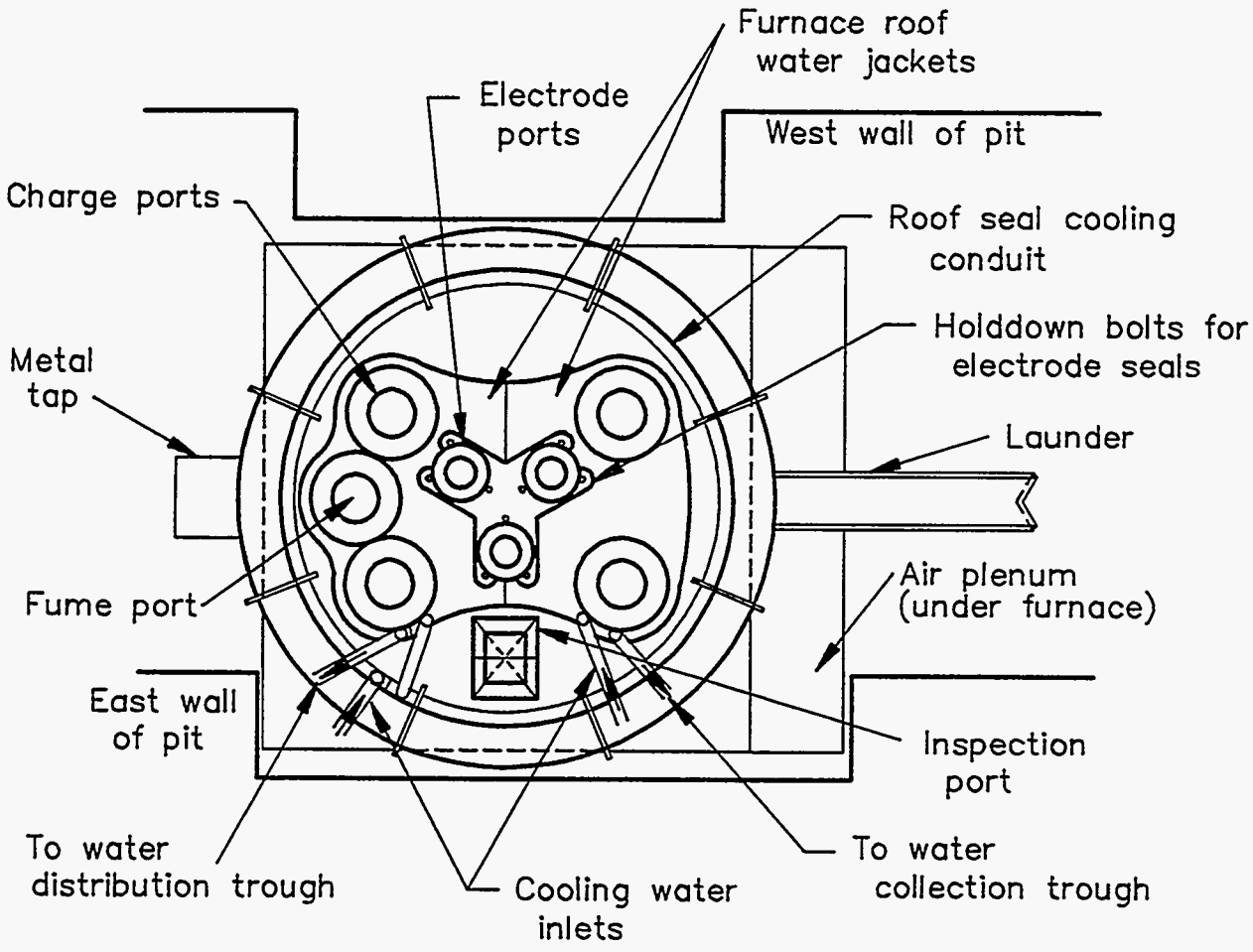


Figure 4-4. Top view of furnace and roof.

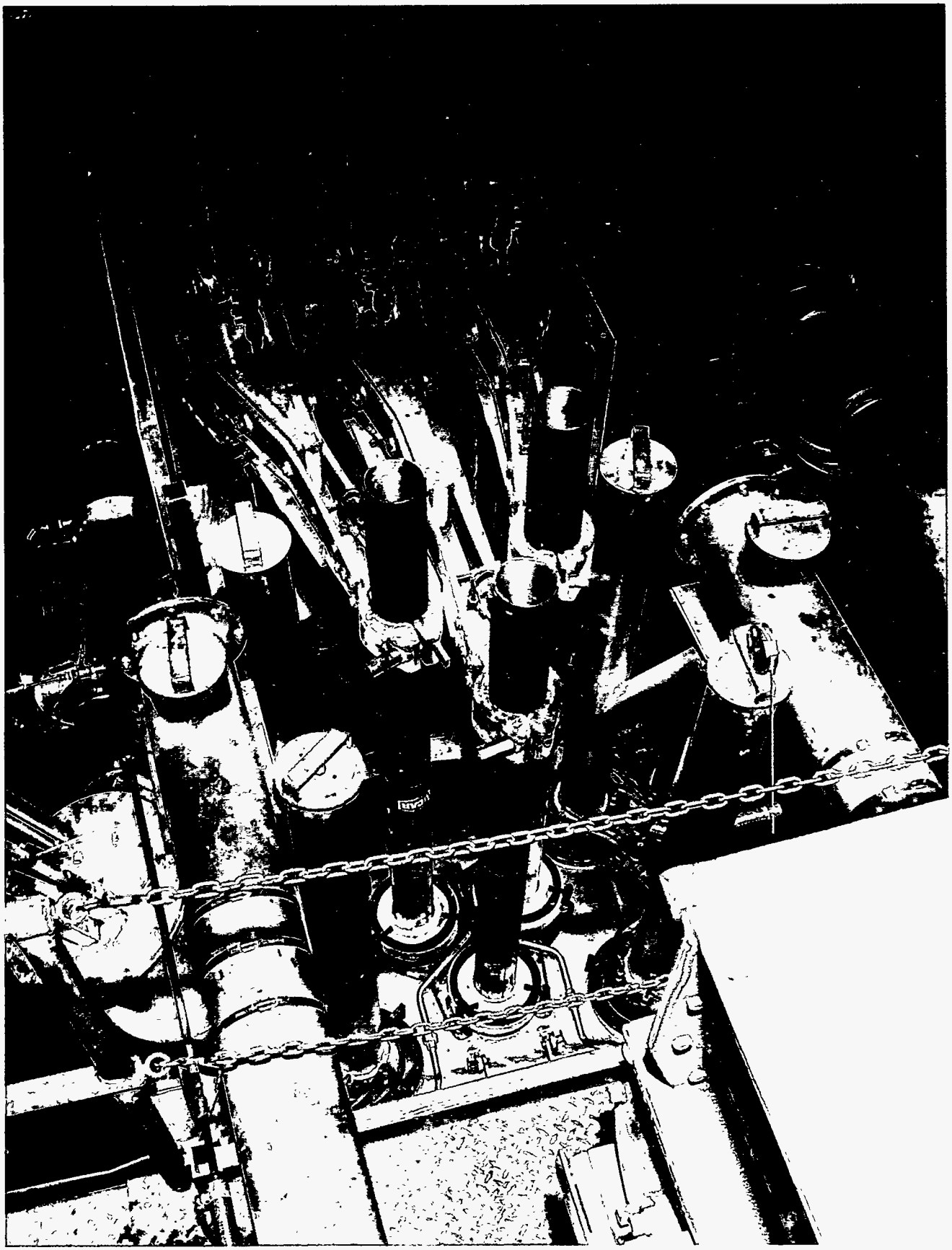


Figure 4-5. Photograph of furnace roof.

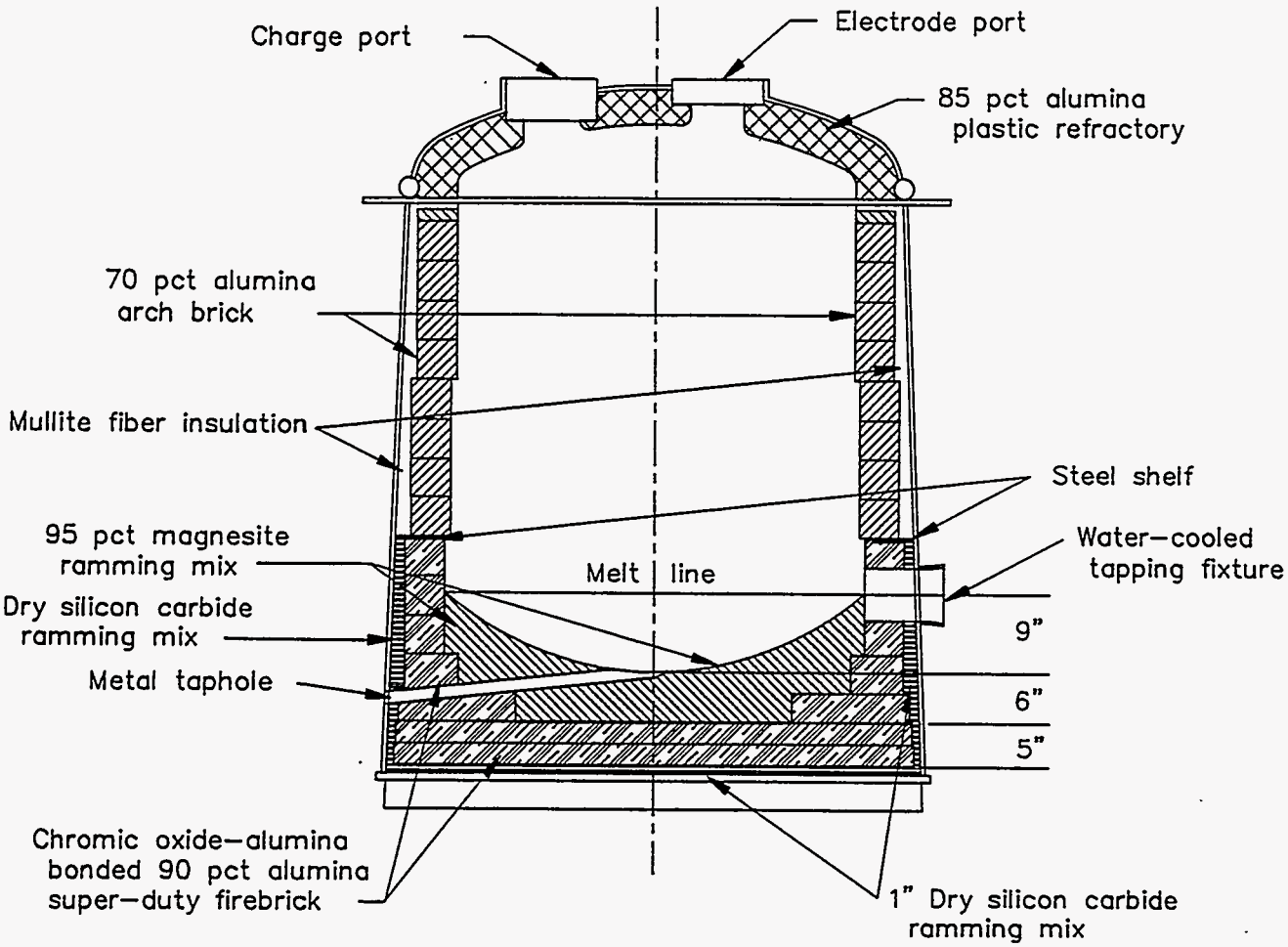


Figure 4-6. Refractory placement in furnace shell and roof.

The roof was lined with 4 in. of NARPHOS 85P plastic refractory (85% alumina). This material was selected for ease of placement considering the complexity of the roof, and for the ability to withstand the potentially corrosive condensable fumes within the furnace and the high temperatures anticipated during open arc operation. The roof refractory was extended into the inspection port to provide a 6 in. square opening. The roof refractory fit closely to the outside of each feed tube, and the annular space between each feed tube and roof port was packed with Fiberfrax to minimize gas leakage.

Two-part ceramic seals prepared from Cast-O-Last G Ad-Tech were fitted into the annular space between electrode and roof port to minimize gas leakage around the electrodes. A completed electrode seal consists of a ceramic fiber gasket between a shelf on the bottom seal and the top of the roof port, and ceramic fiber packing within the annular space between the bottom and top parts of the seal. The upper part of the seal was clamped to the roof to compress the ceramic packing around the electrode.

Tapping metal and draining the furnace was done through the 1.5 in. diameter hole in the bottom center of the hearth that was built into the furnace lining during construction. The water-cooled tapping fixture was grouted in place with the MgO ramming mix. This tapping fixture is a welded, double-walled, copper structure 6 in. diameter by 10 in. long with a 1 in. diameter central hole designed to permit continuous tapping of slag at rates up to 2,000 lb/h.

4.2.3 Furnace and Transformer Cooling

The base of the furnace is cooled by about 1,300 cfm of air flowing through a plenum formed by six 4 in. high I-beams upon which the furnace rests. The furnace shell, roof, slag tapping fixture, launder, metal taphole collar, transformer, feed tubes, emissions control duct, and electrode arms, cables, and clamps are water cooled. Cooling water is pumped to the furnace from a 1,500 gal cool water sump by a 15 hp centrifugal pump. The furnace shell is cooled by a curtain of water (50 gpm) that cascades down the outer shell wall from the annular distribution trough near the top of the shell. All cooling water is collected at the base of the furnace in a trough and is returned by gravity to a 1,500 gal warm water sump through a 6-in. PVC pipe. Water is pumped from the warm water sump to a cooling tower of cross flow, induced draft design.[8] The cooling tower supplies water at a rate of 150 gpm and a temperature of 70°F (when the return water temperature is 142°F and the ambient air wet bulb temperature is 70°F). Figure 4-7 shows a circuit diagram for cooling water indicating maximum anticipated flowrates.

Municipal water is available for emergency cooling in case of general power failure or malfunction of the circulating pumps. The most critical water-cooled components are the slag tapping fixture, which is in direct contact with the molten contents of the furnace and the feed tubes. All other water-cooled components are less susceptible to damage during a short-term stoppage of water if furnace power also is stopped. A flowmeter in the water circuit to the tapping fixture de-energizes and opens the automatic valve in the city water line if power fails or if the flowrate from the cooling tower decreases below 20 gpm in the circuit to the slag tapping fixture. Municipal water then is delivered to the entire cooling water circuit.

4.2.4 Power Supply and Furnace Operation

The power supply is composed of a 3-phase 800 kVA transformer and 3 single-phase, 250 kVA transformers. The primary circuit of each 250 kVA transformer is configured in parallel with the appropriate phase of the 800 kVA transformer. The secondary circuit of each 250 kVA transformer is configured in series with the appropriate phase of the secondary circuit of the 800 kVA transformer. Figure 4-8 shows an electrical line drawing of the power supply beginning

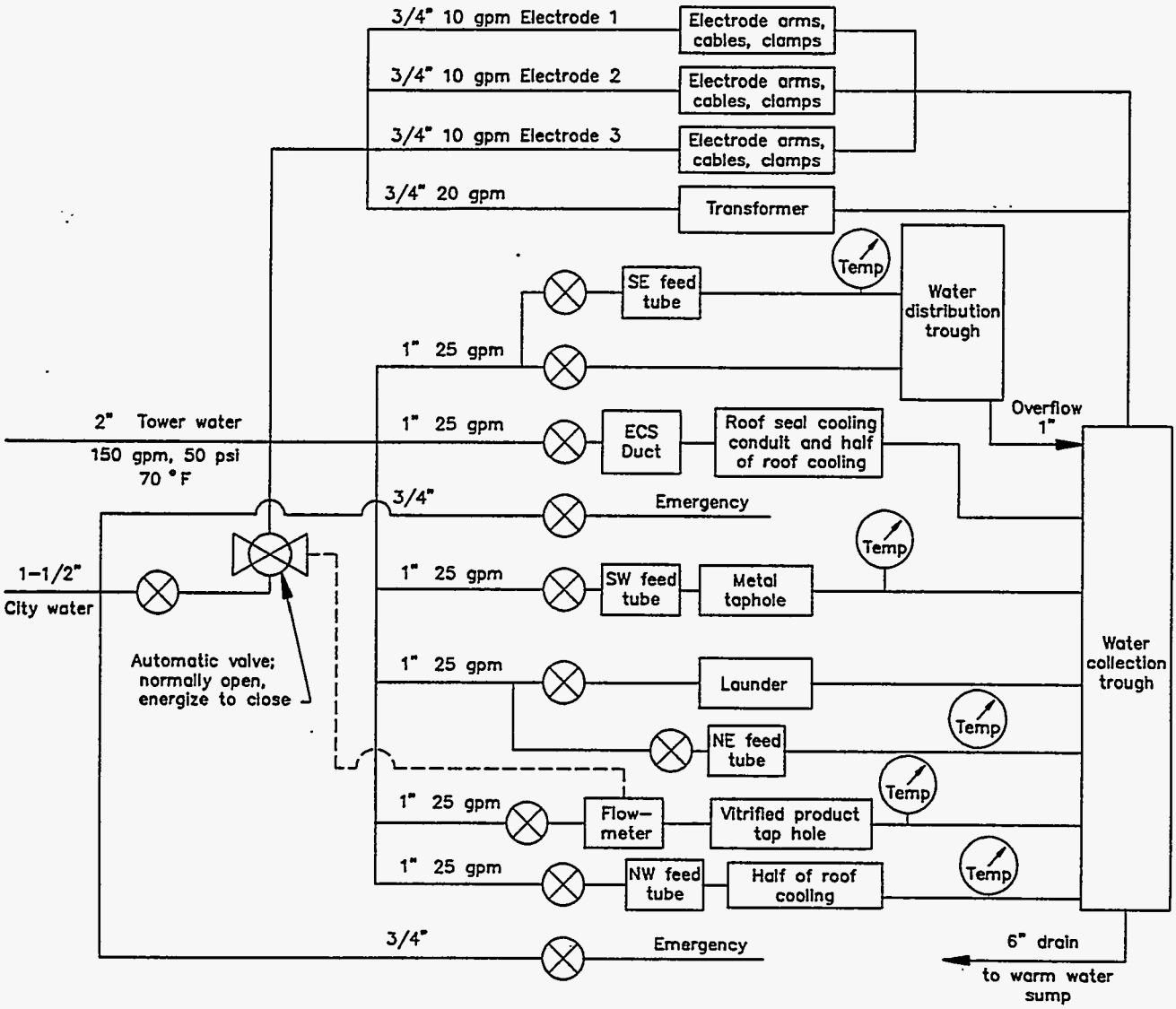


Figure 4-7. Cooling water circuit diagram.

with the 12.5 kV line from the substation and continuing to the electric furnace. The vector sum of the 250 kVA and 800 kVA secondary voltages provided the average open-circuit voltages shown in Table 4-1.

The power supply is a constant voltage supply providing regulation within 3% of the mean from open circuit to full load. The maximum current output of the power supply is 2,080 A. Power can be increased for a given transformer tap position by increasing the rheostats. The 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. The maximum power attainable is a function of the voltage (transformer tap), current (rheostat setting), and the resistivity of the slag. A rheostat controls each electrode, providing a means to balance the power between electrodes.

4.3 Air Pollution Control System

The air pollution control system (APCS) was designed to control emissions of fume and entrained particulate in the offgas and minimize fouling from particulate and condensable fume deposits in the ductwork of the APCS. The primary components were (a) a water-cooled, mechanically-scraped duct at the furnace outlet, (b) an air-dilution temperature-quench system, (c) two fume traps for collecting entrained particulate and condensed fume, (d) a heat exchanger, (e) a pulse-jet baghouse, (f) a High Efficiency Particulate-Air (HEPA) filter unit, and (g) an induced draft (ID) fan.

Exhaust gases exited the furnace roof through a 13 in. length of 8 in. ID, double walled water-cooled duct connected to a short (2.5 in. long) uncooled section of duct containing 3/4 in. nominal diameter sampling and instrumentation ports. A pneumatically-driven scraper was used to periodically remove fume deposits in this section. This section connected to the temperature quench jacketed section into which air was injected to dilute and cool the furnace exhaust gas.

Dilution air was provided by a 5 hp blower that withdrew air from two hoods, one on either side of the furnace. These hoods also served to collect any fugitive emissions and fume from the slag tap and metals tap areas, thereby positively influencing air quality within the building. The design dilution air to offgas ratio was 5:1.

Cooled gases and condensed fume solids exited the quench section into a 9 ft long by 6 in. ID duct containing four 3 in. (nominal) diameter by 4 in. long pipe nipples, which provide access

Table 4-1. Power supply characteristics.

Transformer tap	Phase-to-phase voltage (V)	Phase-to-ground voltage (V)
A	352	192
B	304	168
C	256	145
D	239	134

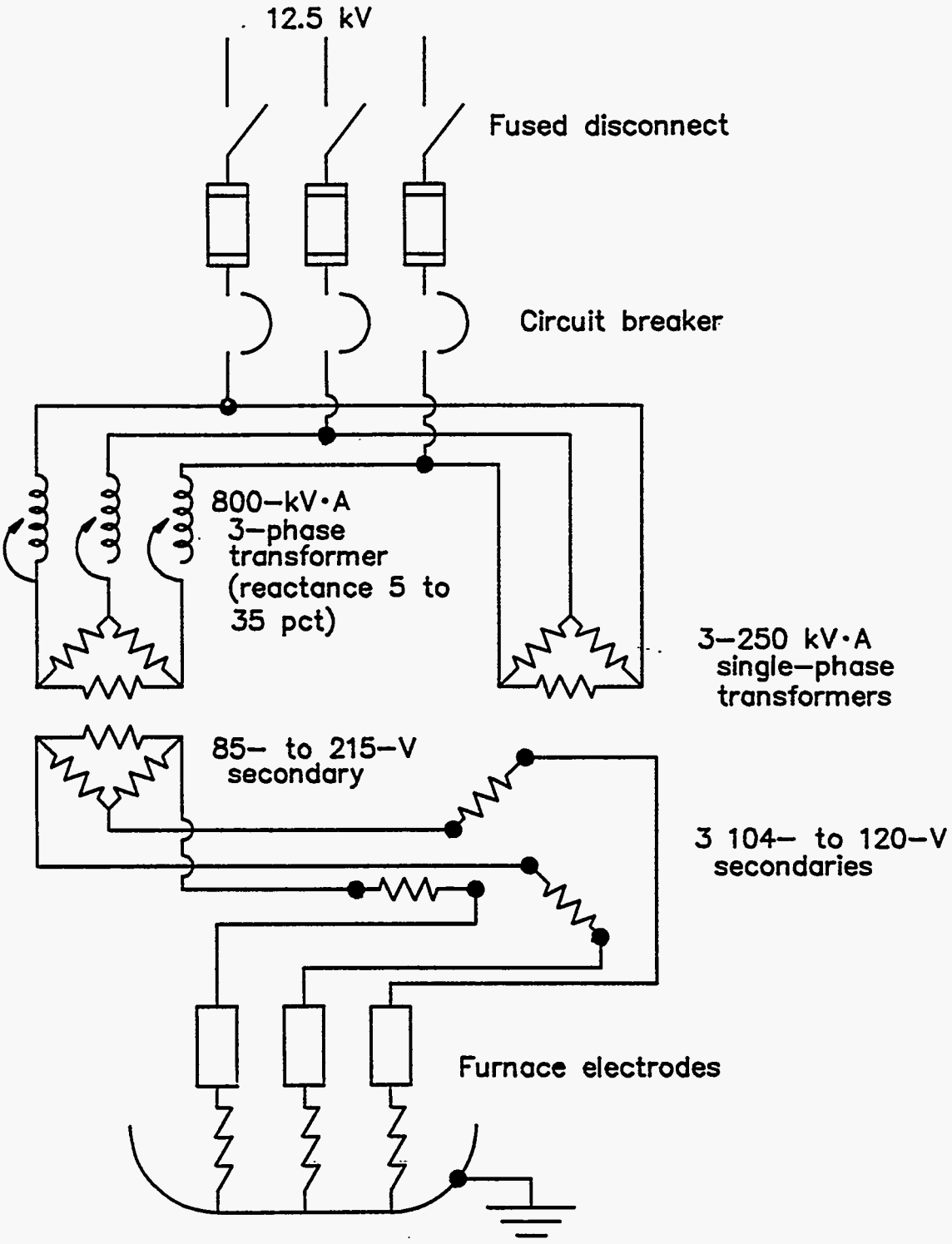


Figure 4-8. Line drawing for electric arc melting furnace power supply.

for exhaust gas analysis. That duct then entered tangentially into a quasi-cyclone settling chamber 13.5 in. ID by 90 in. long (fume trap 1), which allowed large particles to disengage from the gas flow. Accumulated particles were collected within a removable pot on the bottom of the cylinder. Figure 4-9 shows the furnace and the APCS within the building, including the water-cooled section, analysis duct, and fume trap 1. The quench section, pneumatic cylinder, scraper shaft, and dilution air blower and duct are also shown.

The remaining fumes and gases that exited fume trap 1 entered a water-jacketed double-pipe heat exchanger that either heated the cool gas during startup of the furnace or cooled the hot gas during continuous operation to deliver a 250° to 400°F gas to the baghouse. Hot or cold water for the heat exchanger was provided by a SuperTrol temperature control unit.[9] The SuperTrol, which is rated at 36 kW, provided 120 gpm of water at 180° to 250°F to the heat exchanger for heating or cooling. The heat exchanger exited to a spark arrestor to prevent any hot particles from entering the baghouse. Fume trap 2 was located at the bottom of the spark arrestor.

The offgas was ducted from the spark arrestor through 6 in. (nominal) ducting to the baghouse. A number of additional sample ports were located in this section for offgas measurements. The baghouse contained 47 Gortex-membrane Teflon-coated fiberglass bags, 4.5 in. diameter by 10 ft long. These bags are rated to remove 99.98% of particulate greater than 0.3 μm. Bags were cleaned with a back pulse-jet of air at 100 psig. Additional particulate filtration was provided downstream of the baghouse by a HEPA filter unit, also rated to remove 99.98% of particulate greater than 0.3 μm. A 10-hp variable-speed induced draft fan, located after the HEPA filter, discharged the clean gases through a stack into the atmosphere.

The offgas flowrate was established by first setting the dilution air flowrate at 500 acfm by adjusting a damper in the dilution air duct at the outlet of the fan and then adjusting the speed of the fan. The ID fan then was adjusted to provide a negative pressure in the furnace ranging from -0.1 to -0.5 in. water gage. The combined gas flowrate measured at the baghouse inlet ranged from 650 to 900 acfm.

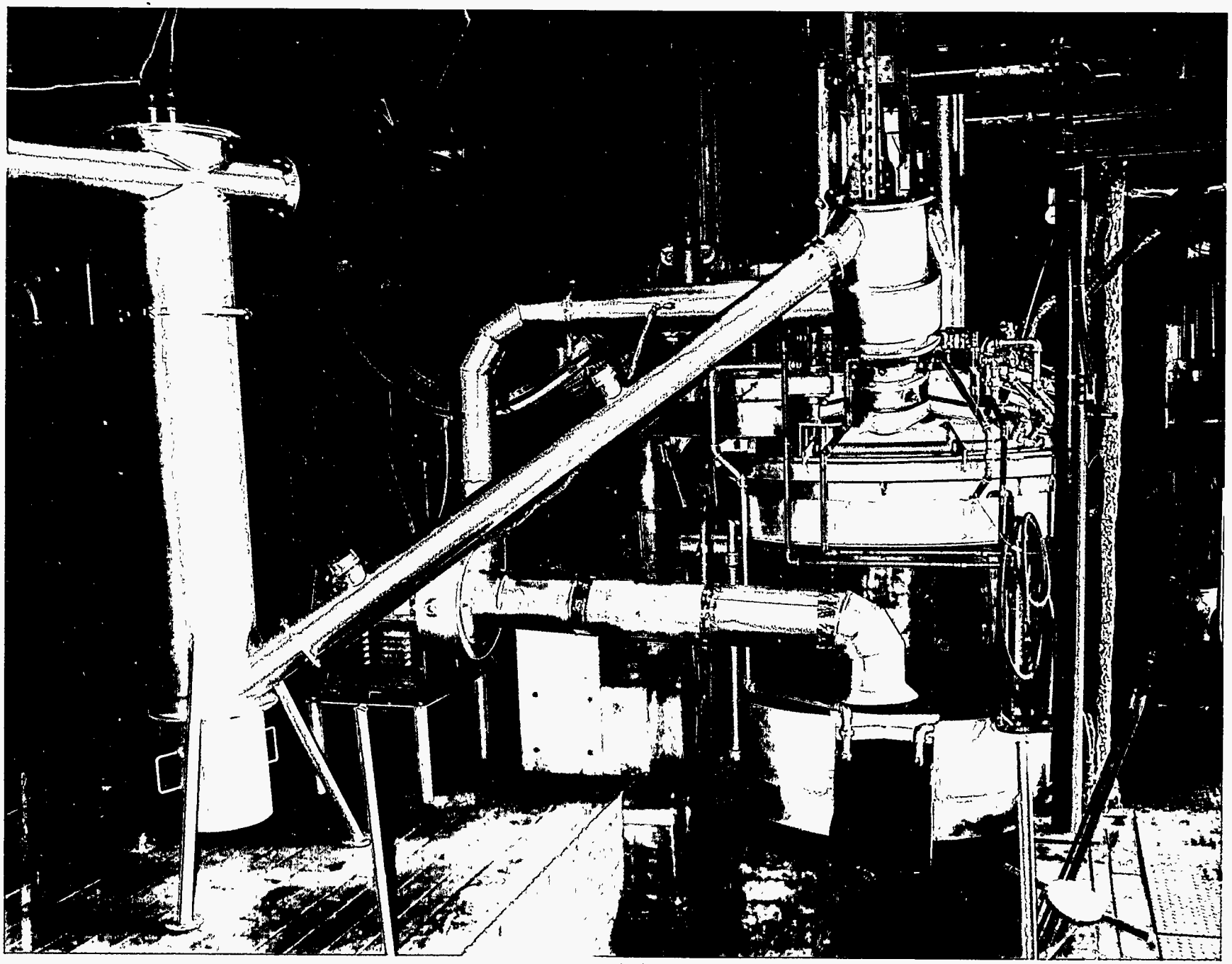


Figure 4-9. View of the furnace and the offgas system within the building.

5. SAFETY AND PERSONNEL PRACTICES

5.1 Staffing

The operating personnel were assigned to perform specific duties during the test series. Two individuals were assigned to tend the furnace and one individual to operate each of the following: electronic data logger, furnace controls, feed and emissions control systems, overhead crane, and fork lift. A supervisor and an electrician were on duty at all times.

5.2 Safety

All personnel attending the furnace were required to wear protective clothing, respirators, gloves, boots, safety glasses, and hard hats. Face shields and reflective heat-resistant clothing were required of the tapping crew. Additional common sense measures were practiced including maintaining a safe distance when not actually conducting a task.

5.3 Air Quality Control

Escape of fumes into the furnace building was significantly decreased by withdrawing dilution air for the offgas quench system through hoods over the tap holes. The hood over the metal tap hole was closed while tapping slag to maximize fume collection over the slag tap hole. Similarly, the hood over the slag tap hole was closed while tapping the metal side.

Air quality within the building was monitored by stationary, continuous ambient air samplers installed on the metering bin platform above the slag and metal tap holes. A reference sampler was installed in the control room. The monitors were operated for 12 h during melting of S60-IV; 11.5 h during melting of N80-IV and N80-IV-Mod; and 9 h during melting of M60 and N80-IV-Mod (on July 23). The samples collected by the monitors are being analyzed for metals content, and the results will be reported when available.

6. FACILITY AND PROCESS DATA COLLECTION METHODS

Facility process monitoring and data acquisition were performed using a computer-based data acquisition system (DAS) and by using manually recorded logs and data sheets. A hard copy of electronically recorded parameters was printed every 5 minutes.

6.1 Arc Furnace Analyzer and Electronic Data Acquisition System

Electrical power measurements for the three-phase electric furnace were measured continuously by a True RMS Power and Demand Analyzer model 3950, which measured the following values: rms voltage (V), rms current (A), apparent power (kVA), active power (kW), reactive power (kVAR), and power factor. These values for each phase referenced to ground were integrated over 1 min intervals, and the integral values were transmitted to a computer for storage. Four channels (V, A, kW, and kWh) were transmitted to a data logger. The data logger received 17 additional inputs from temperature, pressure and velocity probes, applied a linear scaling factor to each input as needed, and transmitted the calculated values to a computer at intervals of 1 min for display and storage. A hard copy was printed at 5 min intervals. The following data were recorded electronically:

Channel	Parameter
0	Feedrate, lb/h
1	T_1, quench air temperature, °C
2	T_2, furnace exit offgas temperature, °C
3	T_3, fume trap 1 offgas temperature, °C
4	T_4, baghouse inlet offgas temperature, °C
5	T_5, baghouse outlet offgas temperature, °C
6	T_6, furnace upper inner sidewall temperature, °C
7	T_7, furnace hearth temperature, °C
8	T_8, furnace shell bottom temperature, °C
9	T_8, slag (at tap hole) temperature, °C
10	P_1, furnace chamber pressure, in H_2O
11	P_2, fume trap 1 pressure, in H_2O
12	P_3, baghouse inlet pressure, in H_2O
13	P_4, baghouse outlet pressure, in H_2O
14	P_5, HEPA filter differential pressure, in. H_2O
15	V_1, quench air flowrate, cfm
16	V_2, baghouse outlet velocity head of standard pitot, in H_2O
17	Electrode phase to ground voltage, V
18	Electrode phase to phase current, A
19	Furnace power, kW
20	Furnace energy, kWh

The printer output from the data acquisition system during the baseline tests is provided in Volume II, Appendix A.

6.2 Manually Recorded Facility Process Data

Many other parameters were less readily instrumented for automatic data acquisition. For this research program, these were more effectively monitored and recorded manually. Manual

logging, while labor intensive during the test periods, assured that operators were mentally aware of the values of the logged parameters. Most of the automatically logged parameters were also manually logged for physical redundancy. This also assured that the operators were continuously aware of the automatically logged data. The redundant logging proved very valuable during the baseline tests, especially when unusual or otherwise notable readings were observed. Process variations and instrument errors were responded to and resolved more quickly, resulting in better process control and data quality. The manually-recorded logs are summarized in the following sections.

The data logs for the baseline tests are provided in Volume II, Appendix B.

6.2.1 Receiving Bin Log

The receiving bin was the first component of the feeder system. Before the feed material was placed in the receiving bin, it was weighed. The date, time, and weight of all feed materials placed in the receiving bin were recorded on the Receiving Bin Log.

6.2.2 Feeder Log

The feedrate of material from the metering bin to the furnace was controlled by two calibrated, counter-rotating metering screws. The feedrate, time, and cumulative feed weight were recorded on the Feeder Log. This log was also used to record other parameters including the furnace pressure, hearth depth, cold top height, and slag temperature.

6.2.3 Furnace Run Data Sheet

Pertinent power supply and furnace information was recorded in real time on the Furnace Run Data Sheet.

6.2.4 Test Log

The Test Log was used to document the hearth depth before each test and to record other important process parameters, including many that are automatically recorded using the data acquisition system. This log enabled the evaluation and comparison of the key feed, furnace, and APCS parameters during each test to enable real time evaluation of the accuracy and performance of the process instrumentation and prompt control of process variations.

The following data from the data acquisition system were recorded on the Test log at half-hour intervals:

Channel	Parameter
2	T_2, furnace exit offgas temperature, °C
4	T_4, baghouse inlet offgas temperature, °C
7	T_7, furnace hearth temperature, °C
8	T_8, furnace shell bottom temperature, °C
12	P_3, baghouse inlet pressure, in H_2O
13	P_4, baghouse outlet pressure, in H_2O
14	P_5, HEPA filter differential pressure, in H_2O
15	V_1, quench air flowrate, cfm
16	V_2, baghouse outlet velocity head of standard pitot, in H_2O
19	Furnace power, kW

Currently used transformer tap and power supply rheostat settings also were recorded on the Test log.

6.2.5 Slag and Metal Product Log

The Slag and Metal Product Log was used to record the beginning and ending tap times and weight for each slag pot filled during tapping from the slag launder. The time and weight of slag and metal tapped from the metal tap hole, and collection times for conical spoon samples of slag and metal were also recorded.

Procedures for the slag and metal sampling were as follows:

- Collect a conical spoon sample of slag when continuous tapping is initiated and collect a spoon sample during filling of each cast iron slag mold.
- Collect additional spoon samples of slag at the beginning, at the midpoint, and at the end of each exhaust gas analysis.
- Collect a spoon sample of metal from each metal tap, and pour four 1-in. buttons.
- Save all slag and metal samples in metal cans. Label each can with the date, time collected, and sample ID number from the log.

6.2.6 Fume Solids Log

The Fume Solids Log was used to record the weights of all fume solids recovered from the APCS following each test. Fume solids were quantitatively recovered and saved from fume trap 1, fume trap 2, and the baghouse. When feed types were changed in the middle of a test day, the fume traps and baghouse were cleaned, and the fume solids and dust were saved. Fume solids and dust from the different feed conditions were not mingled.

The fume solids were stored in 5 gal buckets and labeled with the date, time, and preassigned sample ID number from the log.

6.2.7 Electrode Log

This record contains the weight and length of each electrode segment and the date and time placed in service. Electrodes were not removed and weighed following the melt of calcium silicate to preheat the furnace. Electrode consumption for each waste form was calculated from the total electrode consumption and the fraction of total power used for each waste form.

6.2.8 Operations Log

The Operations Log was used to recap the overall mass balance for the melter system for each test. Feed and tapping rates and cumulative feed, slag, and fume solid weights were recorded. These values were used with the electrode power input to determine the overall mass balance of material through the system, and to calculate the melting energy efficiency.

7. OFFGAS MONITORING AND SAMPLING PROCEDURES

The offgas monitoring and sample collection for the baseline tests included measurements used to characterize the gaseous and particulate emissions from the melter. Measurements were performed during the initial shakedown test (June 3, 1993) and during the baseline tests. The measurements performed during the shakedown test were much more limited than the measurements performed for the baseline tests. These measurements are summarized in Table 7-1.

7.1 Shakedown Test Measurements

Measurements were performed during the shakedown tests primarily to (a) verify suitability of recently installed sample ports and (b) obtain preliminary information about the temperature, velocity, and particulate levels in the offgas. An added benefit of the shakedown test measurements is that they provided limited offgas data when the melter was processing INEL soil, with only some mill scale (Fe_3O_4) added to reduce slag viscosity. These measurements were preliminary and preparatory to the baseline test program. For ease of sampling, several deviations were made to the sampling procedures promulgated by the U.S. EPA for these types of measurements. These deviations included 3-point traversing, non-isokinetic sampling, and approximations of sample volumes using a rotometer.

7.2 Baseline Test Measurements

The offgas measurements performed during the baseline tests essentially complied with EPA-promulgated sampling procedures. The test program was performed in accordance with the

Table 7-1. Offgas monitoring and sample collection for the shakedown and baseline tests.

Test series	Sample location	Measurements
Shakedown Test	Melter outlet	Offgas temperature Approximations of offgas NO_x and CO levels
	Downstream of the air quench, upstream of fume trap 1 and baghouse	Offgas temperature, velocity, and swirl angle Nonisokinetic particulate sample collection
Baseline Tests	Melter outlet	Offgas temperature Limited moisture measurements by wet/dry bulb
	Downstream of the air quench, upstream of fume trap 1 and baghouse	Offgas temperature, velocity and swirl angle Limited moisture measurements by wet/dry bulb Continuous gaseous monitoring for O_2, CO_2, CO, NO_x and SO_2 isokinetic particulate/metals sample collection
	Downstream of fume trap 1 and upstream of baghouse	Continuous gaseous monitoring for O_2, CO_2, CO, NO_x and SO_2
	Downstream of the HEPA filter and baghouse	Continuous gaseous monitoring for O_2, CO_2, CO, NO_x and SO_2

test plan.[2] Few deviations were made to the standard EPA procedures for velocity measurements, gaseous measurements, and particulate and metals sampling.

The particulate and metals sample collection included measurements of stack gas velocity, flowrate, temperature, and moisture content during the sample collection periods. Each sample collection period was about 1.5 h in duration, and the actual sample collection time was 1 h. There were two valid sample periods per test day. The samples collected will be analyzed gravimetrically for determining the total amount of particulate matter entrained in the offgas. The samples were analyzed for the metals evaluated in the baseline tests to determine the degree of metals partitioning to the offgas and to evaluate metals mass balance closure over the melter system.

The continuous monitoring included measurements for oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), and sulfur dioxide (SO_2). These measurements were used to determine the gaseous makeup of the offgas from melting the different surrogate waste mixtures. This determination is important in the data reduction for the metals and particulate measurements, useful in designing the suitable offgas control systems and units, and will provide critical information in controlling gaseous pollutant emissions such as carbon monoxide and acid gases. The most important use of the continuous monitoring data will be to provide information about the conditions in the melter, such as the redox condition and rapidity of volatilization of potentially volatile matter. The volatile matter that results in gaseous effluents includes organic matter, inorganic carbonates, and water of hydration. The carbon monoxide measurements will indicate the degree of oxidation of organic matter. The nitrogen oxide measurements will indicate the degree of thermal NO_x formation because there is little nitrogen-bearing matter in the surrogate wastes. Thermal NO_x levels may be indicative of the cold top effectiveness, redox conditions (excess oxygen) in the gas above the melt, mixing conditions, and gas temperatures.

These offgas measurements were conducted by a 3-person sampling team from Entropy Environmentalists, Inc. Entropy provided a Continuous Emissions Monitoring System (CEMS) in a mobile laboratory. Entropy also provided the metals/particulate sample train equipment and reagents.

7.2.1 Continuous Monitoring Procedures

The continuous monitoring was performed according to EPA Method 3A (for O_2 and CO_2), EPA Method 6C (for SO_2), EPA Method 7E (for NO_2), and EPA Method 10 (for CO). Variations that were done to allow for more effective continuous monitoring during the melter tests included (a) use of less stringent +/- 2% calibration gases rather than EPA protocol gases specified in the methods,
(b) variations in sample periods or averaging to ensure that sample collection can coincide with melter operating periods, and (c) occasionally extending the ranges of the CO and SO_2 instruments beyond the initial calibrated ranges to allow for effective measurement of wide variations in the concentrations of those gas species. These variations provide for sufficient accuracy of the data for the purposes of the baseline tests.

The field summary of the continuous monitoring measurements for the baseline tests is provided in Volume II, Appendix C. Preliminary average offgas concentrations are also summarized in Section 9.3 of this volume. The printouts from the continuous emissions

monitoring system (CEMS), that show 1-minute average recordings for each test day (while the CEMS was operational), are provided in Appendix D of Volume II.

7.2.2 Metals and Particulate Sampling Procedures

Gaseous and particulate metals emissions in the offgas were determined using the EPA multiple metals train (MMT) (Draft EPA Method 29, October 29, 1990). This procedure is modeled after the EPA Method 5 procedure (40 CFR 60, Appendix A, 1990) for determining total particulate emissions from stationary sources.

Variations from the standard Draft EPA Method 29 procedure included (a) elimination of the impingers that contain absorbing solution (acidified potassium permanganate) for capturing mercury, (b) elimination of mercury analysis by CVAAS, and (c) inclusion of gravimetric analysis of the train front half for solid particulate determination. These variations do not impair the data quality of the test results. Because of the small diameter (6 in.) duct at the sample location, the sample collection procedure was modified according to EPA Method 1A for sample and velocity traverses in small ducts.

All of the particulate/metals train sample analysis was conducted at the USBM ALRC. The samples will be analyzed gravimetrically for total particulate and for the metals evaluated in the baseline tests. These metals included Ag, Al, As, B, Ba, Ca, Cd, Ce, Cr, Cs, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, Pb, Se, Si, Sr, Ti, V, Zn, and Zr.

A summary of the key parameters from the manual measurements is shown in Appendix E of Volume II. The raw field data sheets for the particulate metals sampling runs, velocity traverses, and other manual measurements for the baseline tests are shown in Appendix F of Volume II.

8. REVIEW OF THE SHAKEDOWN AND BASELINE TESTS

The FY93 arc melter demonstration test program consisted of a shakedown melting test and a semi-continuous melting test of 5 surrogate waste mixtures. The shakedown test was performed on June 3, 1993, about 6 weeks before the baseline tests. INEL soil modified by adding mill scale (Fe_3O_4) was melted in the shakedown test to evaluate the operability of all of the melter systems and to provide preliminary test data for designing the baseline tests. The baseline tests were conducted July 19–23, 1993. The melter was preheated on July 18, just before the baseline tests. The preheat was performed using a feed mixture of calcium and silicon oxides to remove soil residues from the shakedown test.

8.1 Shakedown Test

This test, exploratory and instructional in nature and about 18 h from arrival to departure of the crew, was conducted on June 3, 1993. The furnace was started and operated for about 3 h using a mill scale to soil mass ratio of 1:10, to produce a slag basicity ratio of 0.31. At this low basicity ratio, the slag viscosity was very high and continuous tapping could be achieved only at high slag temperatures in excess of 1,600°C. Therefore, the mill scale to soil mass ratio was increased to 2:10 (basicity ratio 0.37) for the remaining 10 h of the test. Both fluidity and melting temperature were improved, and continuous slag tapping was achieved. However, it was determined that further viscosity reduction was needed to achieve continuous slag tapping at the target slag temperatures of around 1,400°C. Lime (as limestone, $CaCO_3$, pebble lime, CaO) and mill scale (Fe_3O_4) were considered for fluidizing the waste mixtures in subsequent tests if such action is needed.

Key objectives of the test and resultant significant findings included the following:

- Evaluation of the arc furnace analyzer and data logger: The arc furnace analyzer was connected to monitor phase-to-phase voltages and currents. These data did not provide factual values for input power, contrary to the instructions. The instrument was reconnected to monitor phase-to-ground voltage and phase-to-phase current, and these data provided meaningful derived values for input power and phase angle. The data logger functioned well with only minor adjustments required.

- Feed system evaluation: Operation of the feed system, including the baghouse and duct system for collecting fugitive dust within the building, was satisfactory. A 2-barrel capacity charge hopper was modified to minimize dust generation, to serve as a mixing vessel for soil and additives, and to transfer charge materials to the receiving bin.

- Furnace starting procedure: A triangular course of crushed graphite and/or steel turnings under the electrodes was satisfactory for starting the furnace.

- Evaluation of the water-cooled feed tubes: The water-cooled feed tubes functioned satisfactorily with cooling water flowrates in the range of 20 to 25 gpm. Dust generation within the furnace was significantly reduced by the feed tubes, which extended to within 18 in. of the molten pool. Cold top operation with depths of unmelted material to 14 in. was possible with soil and modified soil compositions.

- Evaluation of the water-cooled tapping fixture: INEL soil melted at about 1,250°C, but its high viscosity precluded tapping at temperatures below about 1,600°C. Additions of mill scale increased the fluidity, but tapping temperatures were not significantly decreased. The maximum slag temperature recorded during melting and continuous tapping was 2,000°C. The tapping fixture was able to tolerate this temperature range.

- Offgas control system evaluation: Many recent modifications of the offgas system were proven. The short section of water-cooled duct that extends through the furnace roof functioned to preclude the formation of physically strong accretions. Any accumulations of condensates were readily removed by the pneumatically operated scraper ring. The activating shaft for the scraper ring was fitted with a scrubbing seal to remove accumulated solids from the shaft and prevent the solids from entering the alignment bushing for the shaft. The air-dilution temperature-quench system performed very satisfactorily. There were no significant problems with the offgas system. For a short duration (around 1 minute) during furnace startup, high temperatures occurred in the ductwork downstream of the temperature quench system. This may have been caused by oxidation in the ductwork of CO evolved from the startup graphite. High temperature damage of the baghouse was avoided by further cooling these gases in the heat exchanger upstream of the baghouse.

- Air ingress to the sealed furnace and gas generation during operation resulted in a furnace offgas flowrate of about 100 scfm, and the exhaust gas temperature was about 500°C under normal operation at feedrates less than 1,500 lb/h. Downstream of the temperature-quench section, the temperature of the diluted offgas was reduced to about 125°C. Coordination of the make-up air and induced draft blowers was readily achieved to provide 650 to 900 SCFM and flowrates in the 6-in. duct of 4,000 to 5,000 ft/min, which was adequate to keep most of the entrained particulate and condensed fume material in suspension until being filtered in the baghouse.

8.2 Baseline Test Series

The furnace was started on July 18 and operated for about 12 h on a calcium silicate slag to preheat the furnace. The surrogate waste mixtures (S60, S60-IV, N80, N80-Mod, N80-IV, N80-IV-Mod, and M-60) were then melted in succession on July 19–23. The total operation time, including pre-startup procedures, furnace startup and operation, and shutdown was about 16 hours per day. The time period from about 0600–0900 was used to install a new thermocouple in the metal tap hole, close the metal tap hole, and start the furnace. Furnace operation while feeding the surrogate waste began around 0900, and tapping slag out of the metal tap hole to empty the furnace was started around 1900. During the last 3 hours of each melting test from 1900 to 2200, the baghouse that serviced the feed system was cleaned, fume solids from the fume traps and baghouse hopper were recovered, and all slag, metal, and fume solids products were logged.

Additives including mill scale, limestone, and <1/4 in. sized pebble lime were on hand to modify waste type compositions if needed. Two and one half pounds of cerium (alloyed with Fe in 50:50 mass ratio ingots) was added to the M60 melt to investigate the extent and rate at which Ce oxidized and distributed to the slag.

8.2.1 Summary of Test Dates, Materials, and Test Duration

The progression of the baseline tests is as follows:

Test day	Test duration	Feed mixture
Sunday July 18	12 h	Calcium silicate slag
Monday July 19	16 h	S60
Tuesday July 20	16 h	S60-IV
Wednesday July 21	16 h	N80 and N80-Mod
Thursday July 22	16 h	N80-IV and N80-IV-Mod
Friday July 23	16 h	M60 and N80-IV-Mod

8.2.2 Objectives

The primary objective of these melting tests was to demonstrate the technical feasibility of existing 3-phase electric arc melting technology to vitrify simulated mixed wastes. Supporting objectives included determination of (a) electrode consumption, (b) energy consumption, (c) continuous slag tapping, (d) metals partitioning to the slag, metal and offgas, (e) physical and chemical properties of the slag, metal, offgas, and particulate and fume in the offgas, (f) influence of unmelted charge depth (cold top) on melting parameters and fume generation, (g) effectiveness of feed downcomers, (h) effects of slag chemistry on process products, and (i) performance of feed and offgas control systems.

8.2.3 Procedures and Conditions Investigated

The following additional parameters, not previously evaluated during the shakedown test, were monitored:

- Temperature within the upper interior of the furnace and of the hearth of the furnace by thermocouples in the upper furnace lining and metal tap hole, respectively
- Temperature of the bottom of the metal furnace shell by thermocouple to indicate effectiveness of plenum cooling
- Pressure drop across the HEPA filter
- Slag temperature by continuous-indicating optical pyrometer to indicate slag temperature during continuous tapping.

In addition, a video camera with a water-cooled mount was installed in the inspection port of the furnace for continuous viewing of the interior of the furnace during operation.

8.2.4 Preheat/Cleanout Melt

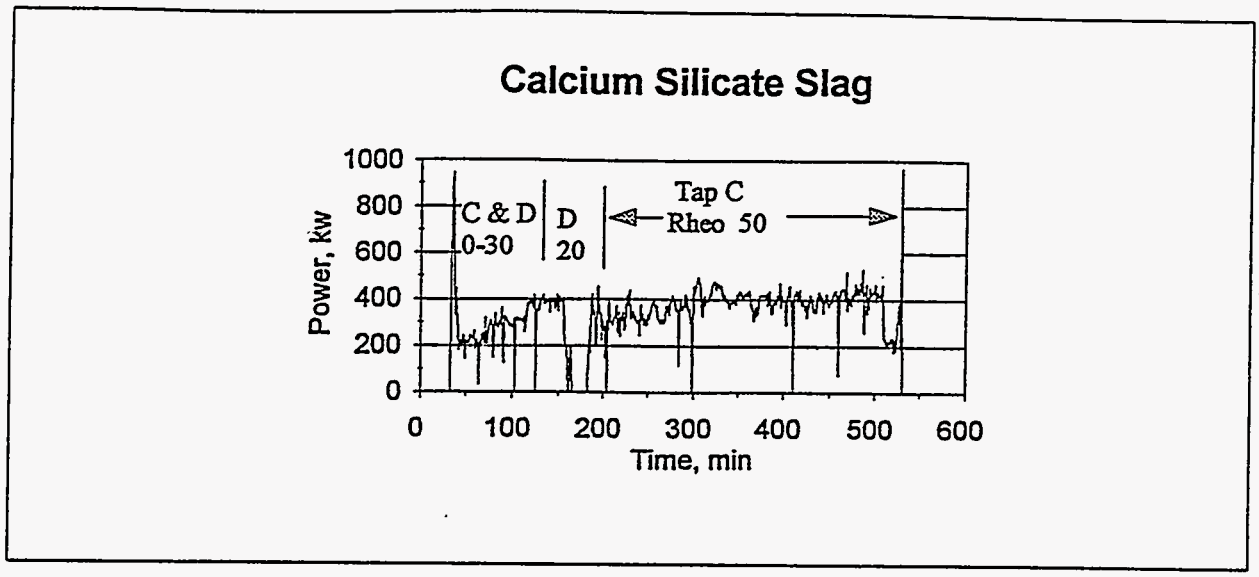
The preheat/cleanout melt began at 0530 on July 18, 1993, and extended to 1750 the same day. Over 4,300 lb of an equimolar mixture of <1/4 in. pebble lime (CaO) and silica sand (SiO_2) were melted. This material, with a basicity ratio of one, produces a fluid slag melting at 1,544°C having good solvent properties for the soil residues suspected to remain in the furnace after the shakedown test. The initial test of a series required additional time at the beginning to allow the Supertrol to reach operating temperature (211°F) and to regulate supporting equipment including the water cooling tower, water distribution pumps, municipal water supply, compressed air supply, make-up air blower, and induced draft fan.

The furnace was started on a triangle of crushed graphite and steel turnings, as successfully practiced for the shakedown test. This procedure was used throughout the baseline tests. Continuous tapping of slag was achieved within 3 h of startup after feeding only 900 lb of material to the furnace, thereby confirming that appreciable soil (500 to 800 lb) remained in the furnace from the shakedown test. At 1138, a fuse failed in the control circuit resulting in loss of phase A electrode control. That electrode withdrew from the furnace, thereby breaking the arc and resulting in stoppage of power. The source of the stoppage was not identified until later in the evening. The furnace was restarted at 1250 with manual operation of phase A during the remainder of the test. Continuous tapping was regained at 1325, and slag temperatures ranged from 1,500° to 1,700°C throughout the test. After 6 h of operation, a constant cold top of 6 to 8 in. was achieved with a feedrate of about 675 lb/h and a power input of about 450 kW for a mean power consumption of 0.67 kWh/lb. Power to the furnace over the duration of the melt to preheat and clean the furnace is shown on Figure 8-1. Transformer tap positions and rheostat settings are indicated in the figure.

The temperature-quench dilution air flowrate ranged from 485 to 588 scfm at 25°C. The combined gas flowrate at the baghouse inlet ranged from 640 to 700 scfm at a maximum temperature of 80°C. Furnace pressure was maintained in the range -0.1 to -0.3 in. water gage by adjusting the ID fan. These values are near design parameters. The thermocouple in the metal tap hole indicated temperatures in excess of 1,200°C, and the bottom of the steel furnace shell exceeded 120°C at 1750 when the metal tap hole was opened to drain the hearth. This short time period devoted to melting calcium silicate served to verify the operational status of the system and to partially preheat the furnace refractories. The melt was not expected to heat the system to equilibrium temperatures. Power to the Supertrol and water cooling tower, and water flow to all circuits were maintained throughout the night.

8.2.5 Waste Mixture S60

A thermocouple was installed within the metal tap hole, and the hole was closed with MgO ramming mix before starting the furnace. S60 was melted beginning at 0819 on July 19 and ending about 1800. Over 9,800 lb of material was melted, and 92.16% was recovered in the slag. Based on the amount of solid fume recovered from the offgas system, 1.43% of the feed material partitioned to the offgas as entrained particulate and vaporized (and recondensed) fume. The remaining 6.38% represents unrecovered volatile matter and/or slag or metal below the metal tap hole. Under normal circumstances, all molten material in the furnace would exit the metal tap hole; however, in this case the hearth had been eroded during the shakedown test, and some material below the tap hole could not be removed. Feedrates to 1,787 lb/h were explored at power input values to 750 kW. The flexibility of the water-cooled copper tapping fixture was confirmed by the observed wide range of tapping rates. The minimum tapping rate was about



Overall Averages based on non-zero power

Voltage	147.5 V
Current	830.9 A
Power	356.0 kW

Stable Operating Range (200-500 min.) Averages

Voltage	147.5 V
Current	877.6 A
Power	378.0 kW
Feed	593.88 lb/hr

Total Energy 2966 kwh

Figure 8-1. Input power for melting calcium silicate slag.

800 lb/h, and the maximum was in excess of 2,000 lb/h. Continuous tapping of S60 slag is shown in Figure 8-2.

The difference between the feedrate and tapping rate during periods of uninterrupted operation provides an indication of the rate of exhaust gas and fume generation. A cold top depth ranging from 6 to 9 in. was maintained without difficulty. Table 8-1 provides a summary of operating parameters for the S60 waste type.

The input energy to the furnace ranged from 0.47 to 0.54 kWh/lb of feed material. Over a 4.8 h period of uninterrupted operation on transformer tap A at 587 kW power input, energy consumption was 0.44 kWh/lb, which represents a very efficient use of energy. The theoretical enthalpy of melting for the INEL soil is 0.39 kWh/lb. Power to the furnace over the duration of the test is shown in Figure 8-3, which clearly indicates the extended period of uninterrupted operation.

Exhaust gas analyses were conducted during periods in which furnace operation including depth of cold top were maintained as constant as possible. Slag samples were collected at the beginning, midpoint, and at the end of the analysis period. The method for collecting slag samples is shown in Figure 8-4.

Fluctuation of furnace pressure frequently occurred throughout the melt because of discontinuous outgassing of feed material. These pressure pulses exceeded the imposed -0.1 in. water gage within the furnace and forced moisture and acid-laden exhaust gases through the electrode and feed tube seals. The odor of acid gases was readily apparent within the building throughout the test. These moist gases also were forced up into the feed tubes where condensation occurred and caused sticking of the feed to the surface of the feed tubes. The accumulation of feed material finally closed the northeast feed tube at 1540. Feed material backed up and plugged the diverter vane, the north feed screw, the splitter screw, and the air lock. The power supply was operated intermittently to maintain the molten pool while the blockages were removed, and the feeder was cleared at 1645. The metal tap hole was opened at 1721 to drain the furnace. No metal was removed with the slag.

8.2.6 Waste Mixture S60-IV

The furnace was prepared as previously described. Melting began at 0907 on July 20 and terminated at 1820 when the metal tap hole was opened. Operating procedures were changed to decrease pressure in the furnace to -0.3 to -0.5 in. water gage, to avoid positive pressure excursions within the furnace. Power to the furnace was stopped at 1425 to clean the feed tubes as a preventative measure, and power was resumed within 10 min. Two near-equilibrium conditions were established during the test. The melting energy was 0.41 kWh/lb over a 2 h period for 1,525 lb/h feedrate and 625 kW power input. Over a 3.3 h period at a feedrate of 897 lb/h and a power input of 409 kW, the energy consumption was 0.46 kWh/lb. Energy consumption per unit weight melted is higher at lower melting rates, because the water-cooled components (feed tubes, roof, and sidewalls) are near-constant sinks for heat regardless of the melt rate, assuming similar slag temperature. Table 8-2 provides a summary of operating parameters, and Figure 8-5 indicates input power to the furnace over the duration of the S60-IV waste mixture test.

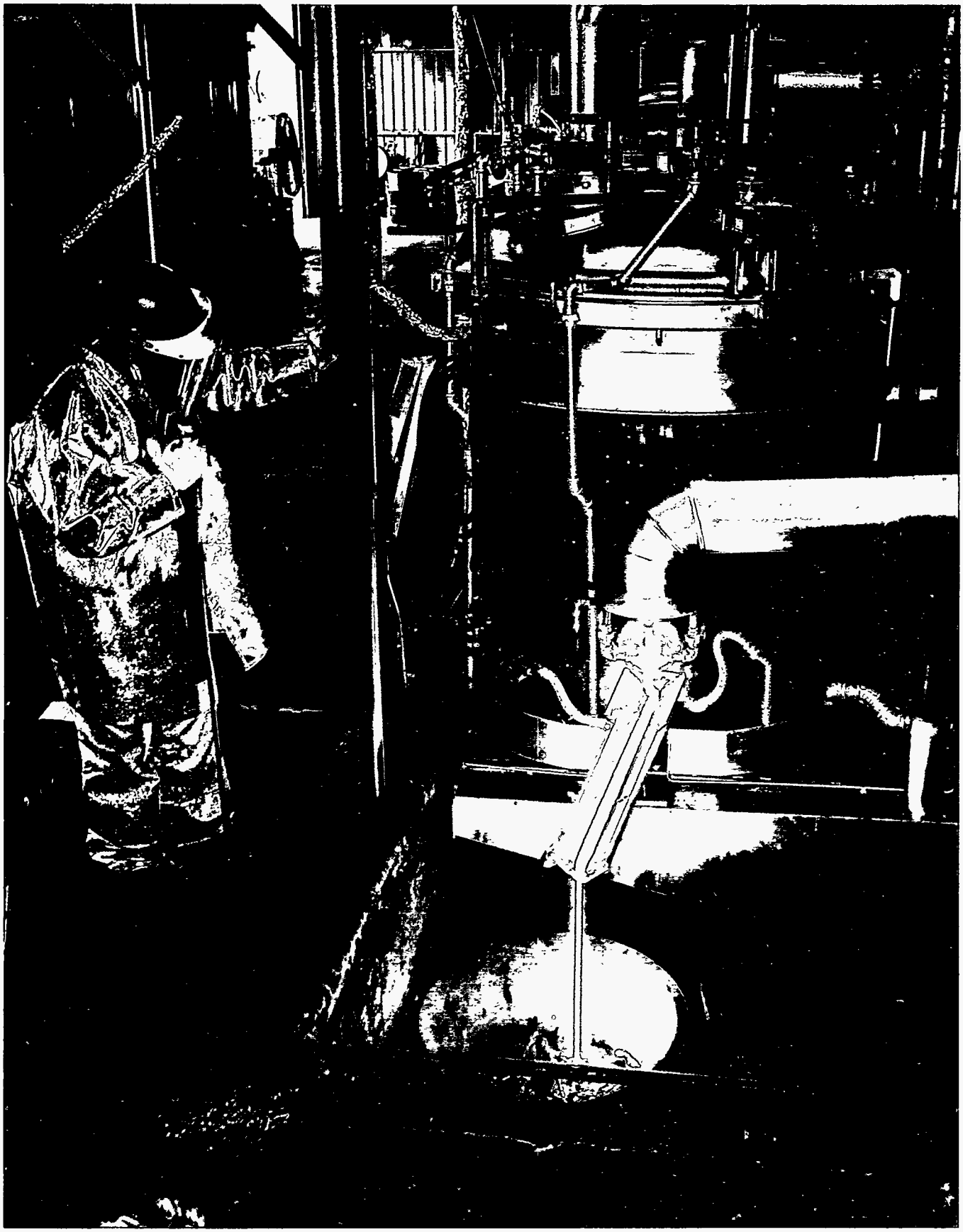


Figure 8-2. Continuous tapping of S60 slag.

Table 8-1. Operations summary: waste S60 waste mixture.

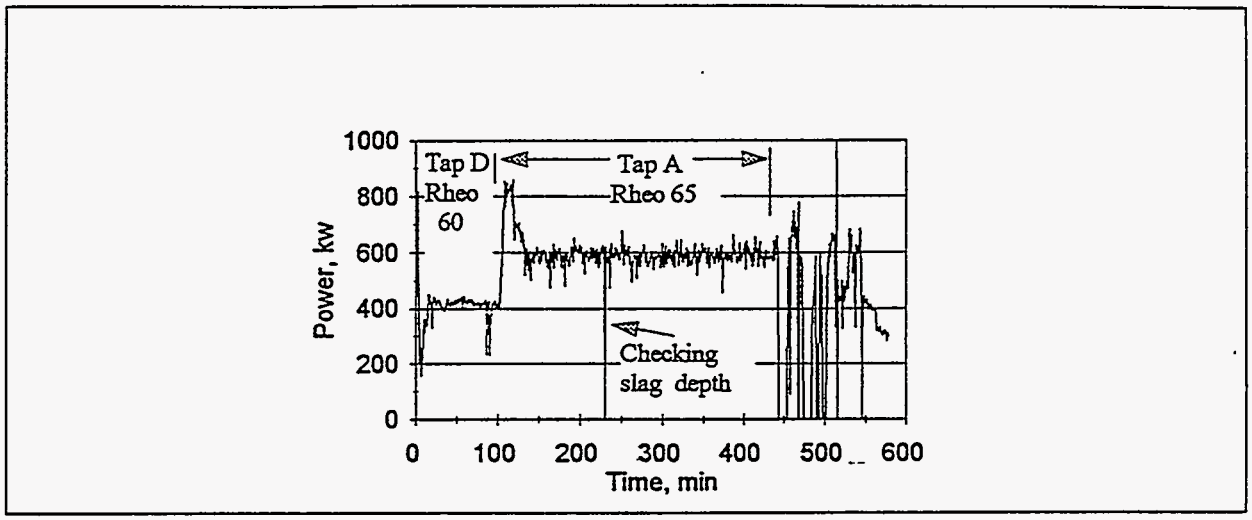
Time	Feed Rate lb/hr	Cumulative Feed, lb	Slag Pot No.	Tap Time min	Tap Weight, lb	Tap Rate lb/hr	Cumulative Tap, lb	Cum. Feed -Cum. Tap	Feed Rate -Tap Rate	kWh	kWh/lb
10:25	1787	1717	1	37	888	1440	888	829	347	1078	0.63
10:43	1117	2551	---	---	---	0	888	1663	1117	---	---
11:13	1225	3109	2	48	865	1081	1753	1356	144	1523	0.49
12:00	1225	4159	3	25	843	2023	2596	1563	798	1980	0.48
12:55	1225	5384	4	60	876	876	3472	1912	349	---	---
13:43	1117	6262	5	35	870	1491	4342	1920	374	3148	0.50
14:58	1158	7025	6	46	848	1106	5190	1835	52	3768	0.54
15:45	1158	7932	7	47	754	963	5944	1988	195	4192	0.53
16:30	1158	8801	8	45	858	1144	6802	1999	14	4425	0.50
17:00	1340	9913	9	---	143	---	6945	2968	---	4674	0.47
---	---	---	L1	---	986	---	7931	---	---	---	---
---	---	---	M1	---	961	---	8892	---	---	---	---
17:55	---	9913	Overflow	---	148	---	9040	873	---	5093	0.51

Material	wt, lb
Feed	9913
Dust*	-107
Total Charge	9806

* Fugitive dust from feed system

Product	wt, lb	pct
Slag	9040	92.19
Fume Solids	140	1.43
Other*	626	6.38
Total	9806	100.00

* Unrecovered volatile matter and/or metal



Overall Averages based on non-zero power

Voltage 179.0 V
Current 1013.7 A
Power 544.0 kW

Stable Operating Range (150–440 min.) Averages

Voltage 194.4 V
Current 999.8 A
Power 586.8 kW
Feed 1324.9 lb/hr

Total Energy 5093 kwh

Figure 8-3. Input power for melting S60 waste mixture.

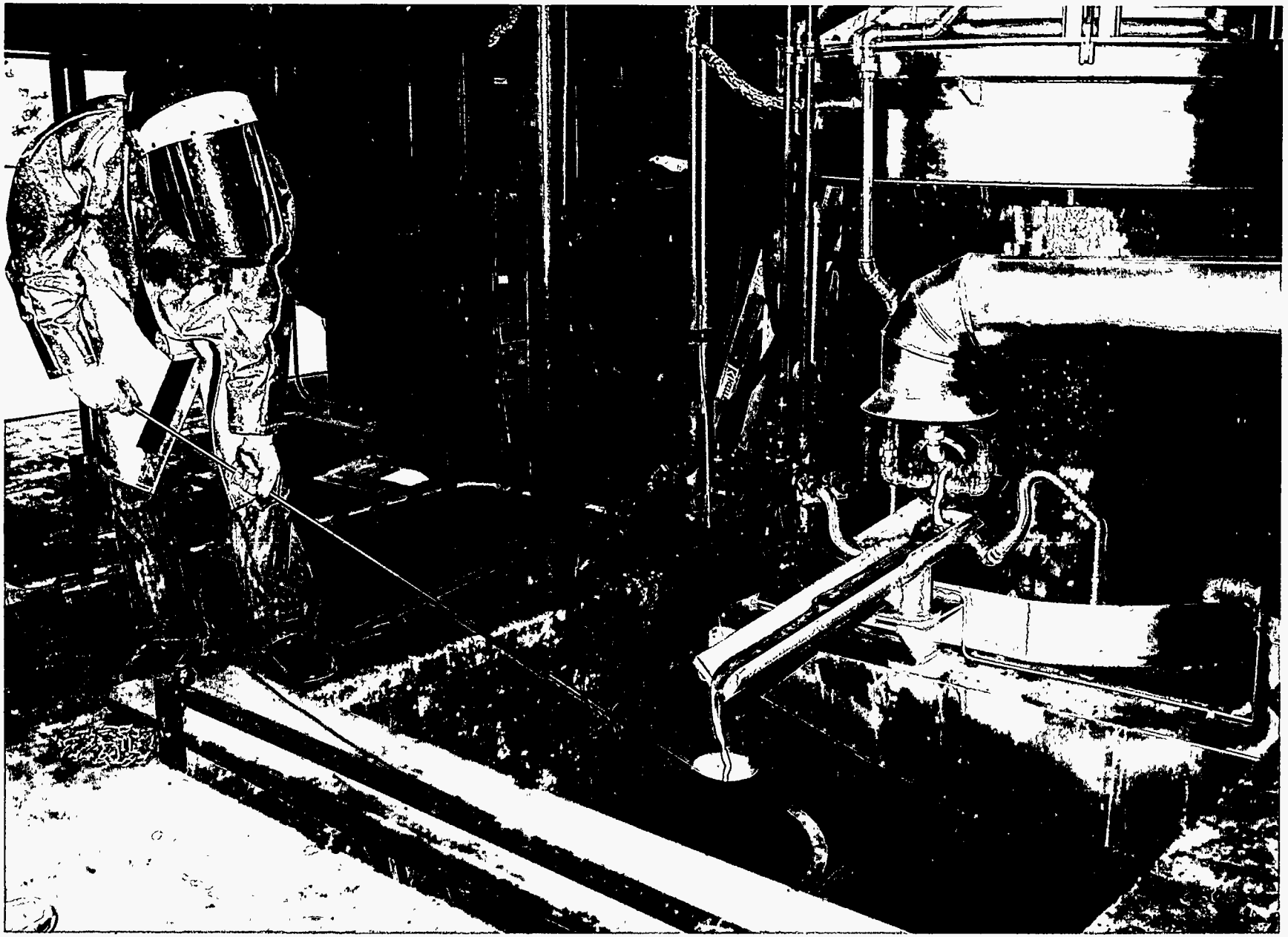


Figure 8-4. Collecting slag sample.

Table 8-2. Operations summary: S60-IV waste mixture.

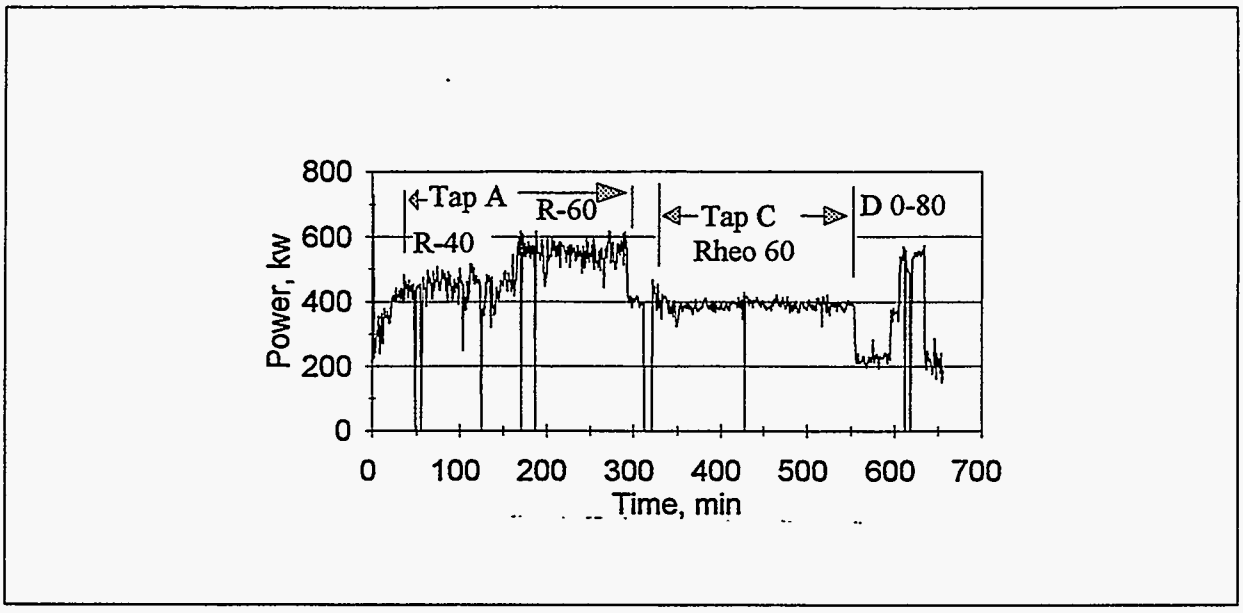
Time	Feed Rate lb/hr	Cumulative Feed, lb	Slag Pot No.	Tap Time min	Tap Weight, lb	Tap Rate lb/hr	Cumulative Tap, lb	Cum. Feed -Cum. Tap	Feed Rate -Tap Rate	kWh	kWh/lb
12:13	1340	3277	1	13	436	2012	436	2841	672	1399	0.43
13:45	1525	5592	2	47	882	1126	1318	4274	399	---	---
13:45	1525	5592	3	50	866	1039	2184	3408	486	2270	0.41
14:58	939	5909	---	---	---	---	2184	3725	939	2655	0.45
15:49	1056	6490	4	100	883	530	3067	3423	526	3002	0.46
17:10	939	7151	5	53	794	899	3861	3290	40	3449	0.48
18:05	1158	8305	6	55	814	888	4675	3630	270	3955	0.48
19:05	1158	8305	7	60	545	545	5220	3085	613	4227	0.51
---	---	---	L1	---	978	---	6198	2107	---	---	---
---	---	---	M1	---	424	---	6622	1683	---	---	---
20:03	---	8305	Overflow	---	397	---	7019	1286	---	4624	0.56

Material	wt, lb
Feed	8305
Dust*	-32
Total Charge	8273

* Fugitive dust from feed system

Product	wt, lb	pct
Slag	7019	84.84
Fume Solids	164	1.98
Other*	1090	13.18
Total	8273	100.00

* Unrecovered volatile matter and/or metal



Overall Averages based on non-zero power

Voltage	164.8 V
Current	859.7 A
Power	421.6 kW

Stable Operating Range (340-540 min.) Averages

Voltage	161.6 V
Current	838.9 A
Power	409.4 kW
Feed	896.6 lb/hr

Total Energy 4624 kwh

Figure 8-5. Input power for melting S60-IV waste mixture.

8.2.7 Waste Mixtures N80 and N80-Mod

Melting began at 0842 on July 21, and 4,593 lb of N80 was melted until 1320 without incident. The N80 waste mixture is slightly more acidic (basicity ratio 0.48) and the slag was more viscous than the S-series slags (basicity ratio 0.51). Temperatures during continuous tapping also were higher. The highest temperature recorded was 1,830°C. The mean energy consumption was 0.40 kWh/lb during 3.3 h of uninterrupted operation on transformer tap B, rheostat at 70, and with feedrates in the range 1,100 to 1,243 lb/h. Slag tapping rates over that time interval ranged from 850 to 1,100 lb/h. Cold top depth was varied from 3 to 10 in. without discernable change in furnace performance. Table 8-3 provides a more complete account of furnace, feeder, and tapping parameters.

At 1320, the composition was changed to increase the basicity ratio to 1.0 by mixing 20.7 lb mill scale and 37.5 lb limestone with every 100 lb of N80. Continuous tapping was re-established at 1424 and continued with greater slag fluidity and lower tapping temperatures in the range of 1,460°C to 1,600°C. Furnace operation was less stable with the modified feed composition, possibly as a result of increased gas evolution of the added limestone and/or discontinuous assimilation of feed material into the molten pool. The finely divided agricultural grade limestone likely changed the rheology of the feed material, resulting in periodic slumping of material into the molten pool. At 1730, the metal tap hole was opened to empty the hearth. No metal was removed from the furnace. Figure 8-6 shows the power input to the furnace over the duration of the test.

8.2.8 Waste Mixtures N80-IV and N80-IV-Mod

Melting began at 0827 on July 22, and 5,518 lb of N80-IV material was melted until 1340. With a basicity ratio of 0.44, the N80-IV is more acidic than the N80, but had similar melting characteristics. Various short-term equilibria were investigated over 5.2 h of uninterrupted operation. Transformer tap B was used, and rheostat settings were varied from 45 to 80 to increase power to the furnace from about 300 to 700 kW. The feedrate was varied from 875 to 1,300 lb/h to maintain a quasi-constant cold top ranging from 0 to 4.5 in. Slag tapping temperature ranged to 1,760°C; reflecting the very acidic and viscous nature of the slag. Table 8-4 provides a more complete account of furnace, feeder, and tapping parameters.

Feeding and melting of the N80-IV-Mod feed mixture were begun at 1410, and 4,986 lb of material was melted. Pebble lime and mill scale were added in the proportion 20.7 lb mill scale and 22.4 lb CaO per 100 lb N80-IV to increase the basicity ratio to 1.0. Melting characteristics were improved by the use of CaO instead of $CaCO_3$, thereby confirming that gas (CO_2) evolution from the limestone was the likely source of the instability during melting of N80-M. Energy consumption was 0.44 Kwh/lb on transformer tap B over a 3.7 h period of continuous operation at, feedrates ranging from 960 to 1,682 lb/h. The metal tap hole was opened at 1824 to drain the furnace. No metal was removed from the furnace. Figure 8-7 indicates power to the furnace over the duration of the test.

8.2.9 Waste Mixtures M60 and N80-IV-Mod

Feeding M60 and melting at about 400 kW power input was begun at 0822. 3,263 lb of material was fed to the furnace without the slag level reaching the tap hole. M60 was more dense than the other waste types because of its 32.4% metal content. If the metals were not oxidized,

Table 8-3. Operations summary: N80 and N80-Mod waste mixtures.

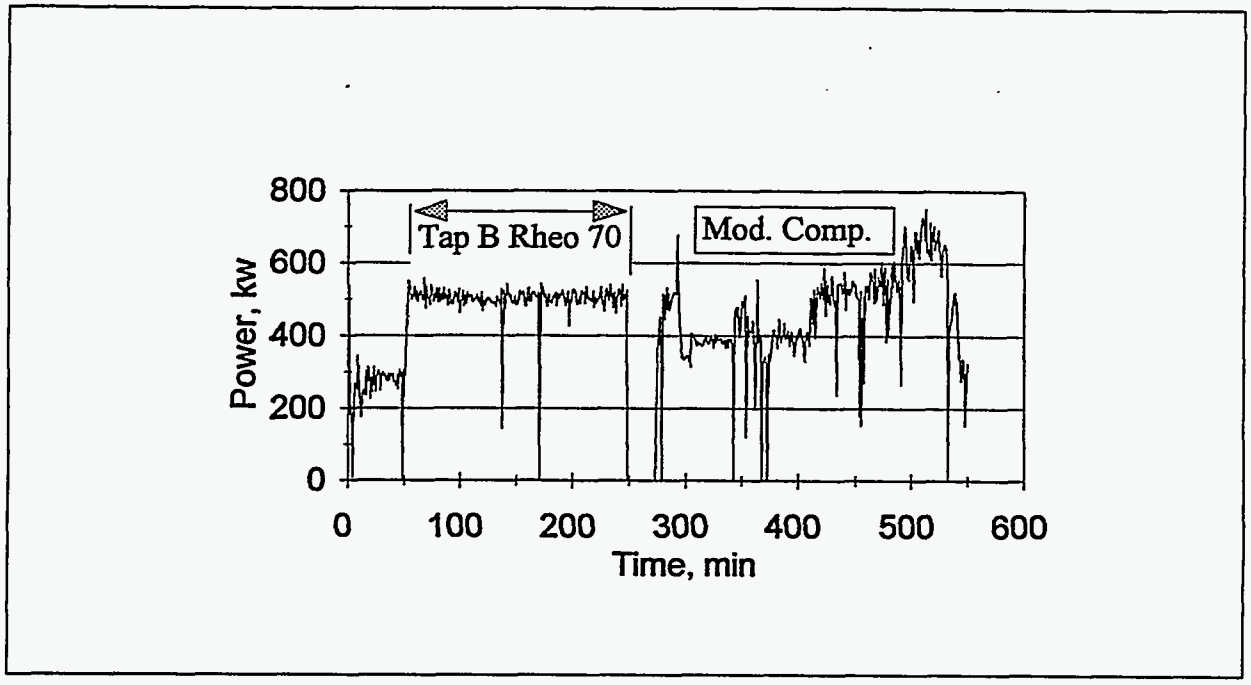
Time	Feed Rate lb/hr	Cumulative Feed, lb	Slag Pot No.	Tap Time min	Tap Weight, lb	Tap Rate lb/hr	Cumulative Tap, lb	Cum. Feed -Cum. Tap	Feed Rate -Tap Rate	kWh	kWh/lb	Net kWh	Net kWh/lb
11:20	1243	2453	1	52	952	1098	952	1501	145	1220	0.50	1220	0.50
12:40	1100	3896	2	48	678	848	1630	2266	253	1900	0.49	1900	0.49
12:49	1100	4619	3	47	667	851	2297	2322	249	1924	0.42	1924	0.42
Subtotal N-80		4619	---	---	---	---	2297	2322	---	---	---	---	---
14:11	1106	824	4	32	758	1421	758	66	315	354	0.43	2278	0.42
15:41	885	2061	5	53	749	848	1507	554	37	1015	0.49	2939	0.44
16:11	885	2523	6	65	804	742	2311	212	143	1328	0.53	3252	0.46
16:56	1032	3793	7	45	734	979	3045	748	53	1730	0.46	3654	0.43
Subtotal N-80M		3793	---	---	---	---	3045	748	---	---	---	---	---
---	---	---	L1	---	934	---	6276	---	---	---	---	---	---
---	---	---	M1	---	1046	---	7322	---	---	---	---	---	---
17:47	---	8412	Overflow	---	88	---	7410	1002	---	4142	0.49	4142	0.49

Material	wt, lb
Feed	8412
Dust*	-48
Total Charge	8364

* Fugitive dust from feed system

Product	wt, lb	pct
Slag	7410	88.59
Fume Solids	230	2.75
Other*	724	8.66
Total	8364	100.00

* Unrecovered volatile matter and/or metal



Overall Averages based on non-zero power

Voltage	162.1 V
Current	950.0 A
Power	461.6 kW

Stable Operating Range (50-248 min.) Averages

Voltage	169.7 V
Current	968.3 A
Power	497.4 kW
Feed	1230.6 lb/hr

Total Energy 4142 kwh

Figure 8-6. Input power for melting N80 and N80-Mod waste mixture.

Table 8-4. Operations summary: N80-IV and N80-IV-Mod waste mixtures.

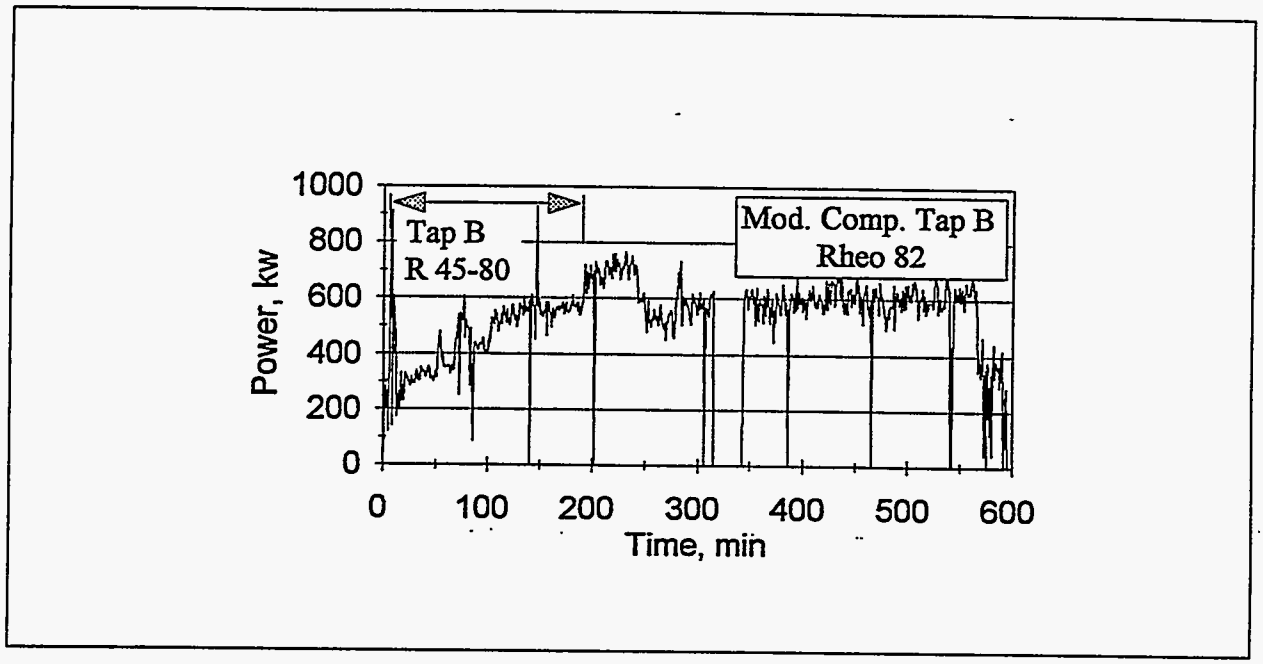
Time	Feed Rate lb/hr	Cumulative Feed, lb	Slag Pot No.	Tap Time min	Tap Weight, lb	Tap Rate lb/hr	Cumulative Tap, lb	Cum. Feed -Cum. Tap	Feed Rate -Tap Rate	kWh	kWh/lb	Net kWh	Net kWh/lb
10:06	885	1598	---	---	---	---	---	---	---	---	---	---	---
11:00	1000	2331	---	---	---	---	---	---	---	---	---	---	---
12:07	1106	3413	1	55	762	831	762	2651	275	1930	0.57	1930	0.57
12:30	1106	3837	2	35	721	1236	1483	2354	130	2103	0.55	2103	0.55
13:07	1106	4711	3	44	717	978	2200	2511	128	2444	0.52	2444	0.52
13:45	1106	5545	4	26	347	801	2547	2998	305	2783	0.50	2783	0.50
Subtotal N-80-IV		5545	---	---	---	---	2547	2998	---	---	---	---	---
14:38	1106	295	5	26	739	1705	739	444	599	292	0.99	3075	0.53
15:12	1327	1114	6	32	842	1579	1581	467	252	672	0.60	3455	0.52
16:20	1290	2778	7	53	788	892	2369	409	398	1312	0.47	4095	0.49
16:48	1290	3380	8	65	818	755	3187	193	535	1736	0.51	4519	0.51
17:40	1408	4498	9	45	732	976	3919	579	432	2174	0.48	4957	0.49
18:10	1024	5010	10	30	317	634	4236	774	390	2398	0.48	5181	0.49
Subtotal N-80M-IV		5010	---	---	---	---	4236	774	---	---	---	---	---
---	---	---	L1	---	981	---	7764	---	---	---	---	---	---
---	---	---	M1	---	1016	---	8780	---	---	---	---	---	---
18:22	---	10555	Overflow	---	0	---	8780	1775	---	5214	0.49	5214	0.49

Material	wt, lb
Feed	10555
Dust*	-51
Total Charge	10504

* Fugitive dust from feed system

Product	wt, lb	pct
Slag	8780	83.59
Fume Solids	237	2.26
Other*	1487	14.16
Total	10504	100.00

* Unrecovered volatile matter and/or metal



Overall Averages based on non-zero power

Voltage	168.3 V
Current	1055.3 A
Power	540.1 kW

Stable Operating Range (53-190 min.) Averages

Voltage	168.2 V
Current	966.9 A
Power	500.6 kW
Feed	997.5 lb/hr

Total Energy 5214 kwh

Figure 8-7. Input power for melting N80-IV and N80-IV-Mod waste types.

then 1,058 lb of metal and 2,205 lb of slagging constituents with basicity ratio 0.28 were contained within the furnace. The slag was very viscous as judged by probing the melt with a steel bar.

At 1231, 100 lb of CaO was fed to the furnace through the air lock, and at 1247 the N80-IV-Mod composition was used to the furnace at rates ranging from 750 to 1,320 lb/h. This waste type was fed rather than a modified M60 mixture because (a) sufficient M60 had already been fed to conduct a full set of measurements and sample collection for the M60 waste type, (b) because of a highly viscous melt more extreme measures were considered necessary to better fluidize the melt, and (c) earlier operation with the N80-IV-Mod feed mixture was very stable. Cold top depth was held relatively constant at about 5 in. The slag tap hole was opened at 1251, but the slag was too viscous to tap freely. Addition of 100 lb CaO was made through the air lock at 1332, and by 1354 slag viscosity further decreased and the slag tapping temperature decreased to 1,670°C. Additions of 100 lb CaO were made through the air lock at 1415 and 1530 to further modify the N80-IV-Mod composition and reduce slag viscosity.

A slag sample was obtained at 1429, and at 1430, 2.5 lb of cerium in a 50% Ce/50% Fe ingot was added through the southwest feed tube. Slag samples were obtained at 10 min intervals over the remaining 1.7 h of the test to investigate the kinetics at which cerium reported to the slag and the partition coefficient of cerium between metal and slag phases. An offgas metals/particulate sampling run was also performed during this time. The slag temperature decreased to 1,500°C by 1640 when the metal tap hole was opened to drain the furnace.

About 900 lb of metal likely to remain in metallic form (Fe, Ni, and Cu) were charged to the furnace during melting of M60; but metal was neither observed in the metal tap or in the conical mold after solidification. Aluminum in the charge was likely oxidized and reported to the slag, whereas significant amounts of Pb and Zn in the charge may have vaporized and reported to the fume solids. Remaining metal elements in the metal phase likely remained within the furnace below the level of the metal tap hole. The operations log for this melt is given on Table 8-5, and the power to the furnace over the duration of the test is shown on Figure 8-8.

8.2.10 Post Test Observations

The feed screws and feed tubes were removed from the roof of the furnace, and the roof was removed after the furnace cooled to room temperature to allow observation of the hearth and interior of the furnace. As suspected, a metal pad remained on the hearth below the level of the metal tap hole. The pad of metal was readily removed by a large electromagnet to expose the bottom of the furnace. The cast-in-place hearth of MgO had been eroded to expose the Ruby bricks on the center of the hearth, but the bricks were undamaged. It is likely that the bricks were not exposed to slag during the test series. Sidewall and roof refractories were unchanged, a tribute to water cooling. The metal pad had been molten at some point but not fully consolidated. Some spherical prills of metal on the upper surface had not been incorporated into the pad.

Inputs and outputs were considered to determine energy and electrode consumption and a material balance. Energy consumption during extended periods of continuous operation ranged from 0.37 to 0.57 kWh/lb. The mean value over the 5-day test of mixed waste types was 0.52 kWh/lb. Electrode consumption over 6 days of melting was 12.15 lb/st (short ton) or 11.38 lb/MWh. Table 8-6 lists the derived data.

Table 8-5. Operations summary: M60 and N80-IV-Mod waste mixtures.

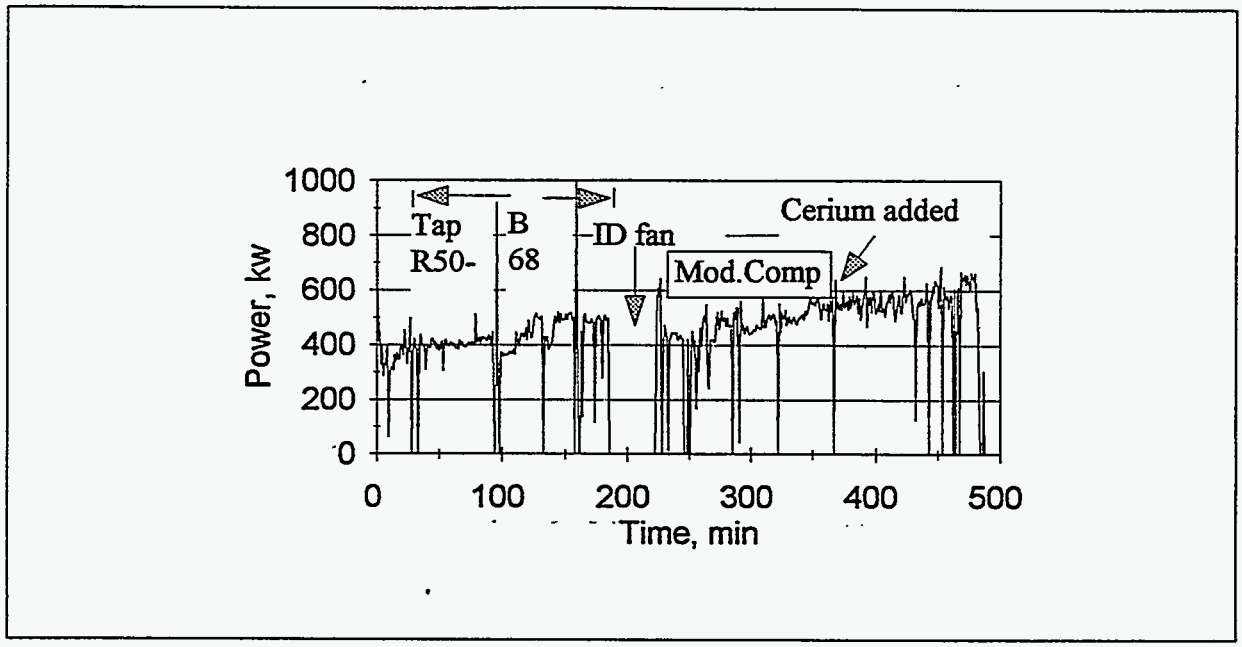
Time	Feed Rate lb/hr	Cumulative Feed, lb	Slag Pot No.	Tap Time min	Tap Weight, lb	Tap Rate lb/hr	Cumulative Tap, lb	Cum. Feed -Cum. Tap	Feed Rate -Tap Rate	kWh	kWh/lb	Net kWh	Net kWh/lb
9:04	1572	849	---	---	---	---	---	849	1572	297	0.35	297	0.35
9:43	1729	1700	---	---	---	---	---	1700	1729	547	0.32	547	0.32
10:43	629	2816	---	---	---	---	---	2816	629	959	0.34	959	0.34
11:23	1100	3265	---	---	---	---	---	3265	1100	1321	0.40	1321	0.40
Subtotal M-60 Run		3265	---	---	---	---	0	3265	---	---	---	---	---
13:27	821	618	---	---	---	---	---	618	821	593	0.96	1914	0.31
14:06	1290	1046	1	70	817	700	817	229	590	921	0.88	2242	0.34
14:29	1290	1540	2	23	770	2009	1587	47	719	1112	0.72	2433	0.34
14:48	1290	1949	3	35	734	1258	2321	372	32	1361	0.70	2682	0.36
15:48	1290	3006	4	42	792	1131	3113	107	159	1878	0.62	3199	0.37
16:20	400 lb CaO	3406	5	40	372	558	3485	79	558	2186	0.64	3507	0.39
Subtotal M-60M Run		3406	---	---	---	---	3485	79	---	---	---	---	---
---	---	---	L1	---	850	---	4335	---	---	---	---	---	---
---	---	---	M1	---	833	---	5168	---	---	---	---	---	---
---	---	---	Metal	---	1235	---	6403	---	---	---	---	---	---
16:30	---	6671	Furnace	---	56	---	6459	212	---	3520	0.53	3520	0.53

Material	wt, lb
Feed	6671
Dust*	-5
Total Charge	6666

* Fugitive dust from feed system

Product	wt, lb	wt, %
Slag	5224	78.37
Metal	1235	18.53
Fume Solids	121	1.82
Other*	86	1.29
Total	6666	100.00

* Unrecovered volatiles



Overall Averages based on non-zero power

Voltage	162.3 V
Current	975.9 A
Power	473.4 kW

Stable Operating Range (38-185 min.) Averages

Voltage	157.6 V
Current	842.2 A
Power	416.0 kW
Feed	986.6 lb/hr

Total Energy 3520 kwh

Figure 8-8. Input power for melting M60 and N80-IV-Mod waste mixtures.

Table 8-6. Derived data for the baseline test series.

Feed and Energy

Feed, lb	Energy, kWh	kWh/lb
43613	22593	0.52

Materials Balance

Product	wt, lb	pct
Slag	37473	85.92
Metal	1235	2.83
Fume Solids	892	2.05
Offgas	4013	9.20
Total	43613	100.00

Electrode Consumption*

Feed, lb	Electrodes, lb	Energy, MWh	lb/ton feed	lb/MWh
47914	291	25.56	12.15	11.38

* electrode consumption calculated for 6 day test, including 8.5 hour run using 4301 lb of CaO.SiO2 to preheat the furnace on 7/18/93

9. SAMPLE DESCRIPTION AND ANALYSIS

9.1 Chemical Analysis of Samples

Process product streams that were sampled or analyzed during the melting tests included slag, metal, exhaust gases, and particulate/fume carry over. Particulate/fume samples were isokinetically obtained using EPA Draft Method 29 (Multiple Metals Train) from the offgas system downstream of the temperature-quench section and upstream of the fume traps, heat exchanger, and baghouse. All particulate/fume samples were submitted to the Albany Research Center analytical laboratory for analysis. The gaseous composition of the offgas (oxygen, carbon monoxide, carbon dioxide, nitrogen oxides and sulfur dioxides) was measured during each test day using a continuous emissions monitoring system (CEMS).

Operating parameters including feedrate and power to the furnace were maintained as constant as reasonably possible during the offgas sampling intervals. Slag samples collected during slag tapping and condensed fume/particulate samples obtained from the fume traps and baghouse were also collected. A 2 kg sample of slag collected during the time that each large cast iron slag mold was filling was submitted for chemical analyses. Slag samples obtained at the beginning, midpoint, and end of each exhaust gas analysis interval were submitted for X-ray diffraction identification of phases and TCLP. Slag obtained from the metal tap hole also was submitted for chemical analysis. Samples from each individual fume trap and the baghouse were submitted for chemical analysis and X-ray diffraction identification of phases. Table 9-1 lists the sampling design.

9.2 EPA Toxicity Characteristic Leaching Procedure (TCLP) Tests

The condensable fume solids for each waste type obtained from fume traps 1 and 2 and the baghouse were combined for the TCLP test and neutron activation analysis. Results will be reported when available.

9.3 Analysis of Furnace Exhaust Gases

The raw gaseous analysis data from the continuous monitoring system are being reduced to obtain instantaneous and time-averaged gas concentration data that are corrected as needed for calibration drift and other adjustments. On-line, continuous gaseous measurements were made for oxygen, carbon dioxide, carbon monoxide, nitrogen oxides and sulfur dioxides in the offgas. The average values for each of the baseline tests are shown in Volume II, Appendix C. The 1-minute average concentrations for each test day are provided in Appendix D of Volume II.

Although HCl from the S60 and S60-IV melts was also known to be present based on the feed material chlorine content, hydrochloric acid measurements were not included in the scope of the baseline tests. Evaluation of the formation and control of acid gases including halogen acids will be included in subsequent phases of this program. Low levels of total hydrocarbons (THC) may have also been present, but like HCl, THC measurements were not included in the scope of the baseline tests. While direct THC measurements are indicators of the completeness of oxidation of organic matter in the feed material, carbon monoxide is also an indicator of oxidation completeness. Carbon monoxide measurements are typically easier and more reliable than THC

Table 9-1. Sampling scheme and analyses.

Number	Sample	Type	Analyses
1	S-60-S1	slag	bulk chemistry*, X-ray diffraction, TCLP, & neutron activation
2	S-60-S2	slag	bulk chemistry
3	S-60-S3	slag	bulk chemistry
4	S-60-S4	slag	bulk chemistry
5	S-60-S5	slag	bulk chemistry
6	S-60-S6	slag	bulk chemistry
7	S-60-S7	slag	bulk chemistry, X-ray diffraction, TCLP, & neutron activation
8	S-60-S8	slag	bulk chemistry
9	S-60-L1	slag from metal tap	bulk chemistry
10	S-60-T1	fume trap 1	bulk chemistry and X-ray diffraction
11	S-60-T2	fume trap 2	bulk chemistry and X-ray diffraction
12	S-60-BH	baghouse	bulk chemistry and X-ray diffraction
13	S-60-FS	#10,11,12 combined	TCLP and neutron activation
14	S-60-IV-S1	slag	bulk chemistry
15	S-60-IV-S2	slag	bulk chemistry
16	S-60-IV-S3	slag	bulk chemistry, X-ray diffraction, TCLP, & neutron activation
17	S-60-IV-S4	slag	bulk chemistry
18	S-60-IV-S5	slag	bulk chemistry
19	S-60-IV-S6	slag	bulk chemistry, X-ray diffraction, TCLP, & neutron activation
20	S-60-IV-S7	slag	bulk chemistry
21	S-60-IV-L1	slag from metal tap	bulk chemistry
22	S-60-IV-T1	fume trap 1	bulk chemistry and X-ray diffraction
23	S-60-IV-T2	fume trap 2	bulk chemistry and X-ray diffraction
24	S-60-IV-BH	baghouse	bulk chemistry and X-ray diffraction
25	S-60-IV-FS	#22,23,24 combined	TCLP and neutron activation
26	N-80-S1	slag	bulk chemistry
27	N-80-S2	slag	bulk chemistry
28	N-80-S3	slag	bulk chemistry, X-ray diffraction, TCLP, & neutron activation
29	N-80M-S4	slag	bulk chemistry
30	N-80M-S5	slag	bulk chemistry
31	N-80M-S6	slag	bulk chemistry, X-ray diffraction, TCLP, & neutron activation
32	N-80M-S7	slag	bulk chemistry, X-ray diffraction, TCLP, & neutron activation
33	N-80M-L1	slag from metal tap	bulk chemistry
34	N-80-T1	fume trap 1	bulk chemistry and X-ray diffraction
35	N-80-T2	fume trap 2	bulk chemistry and X-ray diffraction
36	N-80-BH	baghouse	bulk chemistry and X-ray diffraction
37	N-80-FS	#34,35,36 combined	TCLP and neutron activation
38	N-80M-T1	fume trap 1	bulk chemistry and X-ray diffraction

Table 9-1. (continued).

Number	Sample	Type	Analyses
39	N-80M-T2	fume trap 2	bulk chemistry and X-ray diffraction
40	N-80M-BH	baghouse	bulk chemistry and X-ray diffraction
41	N-80M-FS	#38,39,40 combined	TCLP and neutron activation
42	N-80-IV-S1	slag	bulk chemistry
43	N-80-IV-S2	slag	bulk chemistry
44	N-80-IV-S3	slag	bulk chemistry
45	N-80-IV-S4	slag	bulk chemistry, X-ray diffraction, TCLP, & neutron activation
46	N-80M-IV-S5	slag	bulk chemistry
47	N-80M-IV-S6	slag	bulk chemistry
48	N-80M-IV-S7	slag	bulk chemistry
49	N-80M-IV-S8	slag	bulk chemistry
50	N-80M-IV-S9	slag	bulk chemistry
51	N-80M-IV-S10	slag	bulk chemistry, X-ray diffraction, TCLP, & neutron activation
52	N-80M-IV-L1	slag from metal tap	bulk chemistry
53	N-80-IV-T1	fume trap 1	bulk chemistry and X-ray diffraction
54	N-80-IV-T2	fume trap 2	bulk chemistry and X-ray diffraction
55	N-80-IV-BH	baghouse	bulk chemistry and X-ray diffraction
56	N-80-IV-FS	#53,54,55 combined	TCLP and neutron activation
57	N-80M-IV-T1	fume trap 1	bulk chemistry and X-ray diffraction
58	N-80M-IV-T2	fume trap 2	bulk chemistry and X-ray diffraction
59	N-80M-IV-BH	baghouse	bulk chemistry and X-ray diffraction
60	N-80M-IV-FS	#57,58,59 combined	TCLP and neutron activation
61	M-60-RS	slag	bulk chemistry, X-ray diffraction, TCLP, & neutron activation
62	M-60M-S1	slag	bulk chemistry
63	M-60M-S2	slag	bulk chemistry, X-ray diffraction, TCLP, & neutron activation
64	M-60M-S3	slag	bulk chemistry
65	M-60M-S4 (C2)	slag (after cerium ingot)	bulk chemistry
66	M-60M-S5 (C8)	slag (after cerium ingot)	bulk chemistry, X-ray diffraction, TCLP, & neutron activation
67	M-60M-L1	slag from metal tap	bulk chemistry
68	M-60M-C1	slag (after cerium ingot)	cerium only
69	M-60M-C3	slag (after cerium ingot)	cerium only
70	M-60M-C4	slag (after cerium ingot)	cerium only
71	M-60M-C5	slag (after cerium ingot)	cerium only
72	M-60M-C6	slag (after cerium ingot)	cerium only
73	M-60M-C7	slag (after cerium ingot)	cerium only
74	M-60-M1	metal	bulk chemistry and neutron activation
75	M-60M-M2	metal (after cerium ingot)	bulk chemistry and neutron activation
76	M-60-T1	fume trap 1	bulk chemistry and X-ray diffraction

Table 9-1. (continued).

Number	Sample	Type	Analyses
77	M-60-T2	fume trap 2	bulk chemistry and X-ray diffraction
78	M-60-BH	baghouse	bulk chemistry and X-ray diffraction
79	M-60-FS	#74,75,76 combined	TCLP and neutron activation
80	M-60M-T1	fume trap 1	bulk chemistry and X-ray diffraction
81	M-60M-T2	fume trap 2	bulk chemistry and X-ray diffraction
82	M-60M-BH	baghouse	bulk chemistry and X-ray diffraction
83	M-60M-FS	#78,79,80 combined	TCLP and neutron activation
84	MMT-S60-1 Q074	particulate filter	gravimetric
85	MMT-S60-1 Q076	particulate filter	gravimetric
86	MMT-S60-1 FHAcetone	front half wash (acetone)	gravimetric
87	MMT-S60-1 FHNitric	front half wash (nitric)	gravimetric
88	MMT-S60-2 Q075	particulate filter	gravimetric
89	MMT-S60-2 FHAcetone	front half wash (acetone)	gravimetric
90	MMT-S60-2 FHNitric	front half wash (nitric)	gravimetric
91	MMT-S60-IV-1 Q079	particulate filter	gravimetric
92	MMT-S60-IV-1 Q078	particulate filter	gravimetric
93	MMT-S60-IV-1 FHAcetone	front half wash (acetone)	gravimetric
94	MMT-S60-IV-1 FHNitric	front half wash (nitric)	gravimetric
95	MMT-S60-IV-2 Q081	particulate filter	gravimetric
96	MMT-S60-IV-2 Q080	particulate filter	gravimetric
97	MMT-S60-IV-2 FHAcetone	front half wash (acetone)	gravimetric
98	MMT-S60-IV-2 FHNitric	front half wash (nitric)	gravimetric
99	MMT-N80-1 Q082	particulate filter	gravimetric
100	MMT-N80-1 Q083	particulate filter	gravimetric
101	MMT-N80-1 FHAcetone	front half wash (acetone)	gravimetric
102	MMT-N80-1 FHNitric	front half wash (nitric)	gravimetric
103	MMT-N80-2 Q084	particulate filter	gravimetric
104	MMT-N80-2 FHAcetone	front half wash (acetone)	gravimetric
105	MMT-N80-2 FHNitric	front half wash (nitric)	gravimetric
106	MMT-N80-IV-2 Q087	particulate filter	gravimetric
107	MMT-N80-IV-2 Q089	particulate filter	gravimetric
108	MMT-N80-IV-2 FHAcetone	front half wash (acetone)	gravimetric
109	MMT-N80-IV-2 FHNitric	front half wash (nitric)	gravimetric
110	MMT-N80-IV-3 Q090	particulate filter	gravimetric
111	MMT-N80-IV-3 Q086	particulate filter	gravimetric
112	MMT-N80-IV-3 FHAcetone	front half wash (acetone)	gravimetric
113	MMT-N80-IV-3 FHNitric	front half wash (nitric)	gravimetric
114	MMT-M60-1 Q092	particulate filter	gravimetric

Table 9-1. (continued).

Number	Sample	Type	Analyses
115	MMT-M60-1 Q091	particulate filter	gravimetric
116	MMT-M60-1 FHAcetone	front half wash (acetone)	gravimetric
117	MMT-M60-1 FHNitric	front half wash (nitric)	gravimetric
118	MMT-M60-2 Q096	particulate filter	gravimetric
119	MMT-M60-2 Q097	particulate filter	gravimetric
120	MMT-M60-2 FHAcetone	front half wash (acetone)	gravimetric
121	MMT-M60-2 FHNitric	front half wash (nitric)	gravimetric
122	MMT-S60-1 FH	dry solids (#82,83,84,85)	complete digestion, ICP**
123	MMT-S60-1 BH	back half wash	complete digestion, ICP
124	MMT-S60-2 FH	dry solids (#86,87,88)	complete digestion, ICP
125	MMT-S60-2 BH	back half wash	complete digestion, ICP
126	MMT-S60-IV-1 FH	dry solids (#89,90,91,92)	complete digestion, ICP
127	MMT-S60-IV-1 BH	back half wash	complete digestion, ICP
128	MMT-S60-IV-2 FH	dry solids (#93,94,95,96)	complete digestion, ICP
129	MMT-S60-IV-2 BH	back half wash	complete digestion, ICP
130	MMT-N80-1 FH	dry solids (#97,98,99,100)	complete digestion, ICP
131	MMT-N80-1 BH	back half wash	complete digestion, ICP
132	MMT-N80-2 FH	dry solids (#101,102,103)	complete digestion, ICP
133	MMT-N80-2 BH	back half wash	complete digestion, ICP
134	MMT-N80-IV-2 FH	dry solids (#104,105,106,107)	complete digestion, ICP
135	MMT-N80-IV-2 BH	back half wash	complete digestion, ICP
136	MMT-N80-IV-3 FH	dry solids (#108,109,110,111)	complete digestion, ICP
137	MMT-N80-IV-3 BH	back half wash	complete digestion, ICP
138	MMT-M60-1 FH	dry solids (#112,113,114,115)	complete digestion, ICP
139	MMT-M60-1 BH	back half wash	complete digestion, ICP
140	MMT-M60-2 FH	dry solids (#116,117,118,119)	complete digestion, ICP
141	MMT-M60-2 BH	back half wash	complete digestion, ICP

* bulk chemistry includes: Ag, Al, As, B, Ba, C, Ca, Cd, Ce, Cl, Cr, Cs, Cu, Fe, Hg, K, Mg, Mn Na, Ni, P, Pb, S, Se, Si, Sr, Ti, V, Zn, Zr

** ICP will be used for all elements, those for which ICP is not sensitive enough may have to be run by graphite furnace

measurements, and carbon monoxide measurements are widely accepted as indicators of combustion performance and oxidation efficiency.[9]

Preliminary average offgas concentrations ranges of average values for selected test periods at the outlet of the quench section (dry basis) for the baseline tests are as follows:

Gas species	Concentration range as measured
Oxygen	20.0–21.0%
Carbon Dioxide	0.3–3.8%
Carbon Monoxide	270–8,600 ppm
Nitrogen Oxides	<1–39 ppm
Sulfur Dioxide	52–7,700 ppm

These values must be corrected for the amount of temperature-quench air added to the furnace offgas, because the measurements were performed downstream of the temperature-quench section. Early in the baseline test program, gaseous measurements were attempted upstream of the temperature quench section at the furnace outlet. The amount of condensed fume and entrained particulate was so high at the furnace outlet that the filters in the sampling system rapidly plugged and severely limited the sampling time.

While the design value for the temperature-quench diluting air flowrate was a volume ratio of 5:1 compared to the furnace offgas, the instantaneous values varied. Correcting the above values by the same factor to account for air dilution may be misleading, because the larger values for carbon monoxide, carbon dioxide, nitrogen oxides, and sulfur dioxide may have occurred simultaneously with (and partially because of) larger furnace offgas flowrates relative to the diluting air flowrate. The relative furnace offgas and diluting air flowrates varied when the amount of gases evolving from the melts varied due to feed composition and flowrate variations, and due to variations in furnace draft. The larger concentrations of sulfur dioxide (and hydrogen chloride, although this was not measured) occurred for only the S60 and S60-IV melts. Larger amounts of carbon dioxide and carbon monoxide occurred when larger amounts of carbonates and limestone were present in the feed mixtures.

10. CONCLUSIONS

The results obtained during the 80 h of melting experience demonstrate the applicability of existing arc melting technology for treating thermally oxidized buried TRU-contaminated mixed wastes and soils. The 3-phase graphite-electrode arc melting furnace used in these demonstration melting tests additionally provided design data for scale-up estimates. The potential also was established for vitrifying untreated (not preincinerated) wastes.

Feeding, melting and tapping of slag continuously at rates to 1,500 lb/h were demonstrated for INEL soil, 3 general waste types (S, N, and M Series), and 7 different modified waste type mixtures. On-demand tapping of slag at rates to 2,000 lb/h was also achieved. Metalliferous wastes were melted without difficulty. Average electrode usage over 6 days of melting 47,914 lb of material was 12.15 lb/st or 11.38 lb/MWh. These values are well within the industrial norm. Energy consumption during extended periods of continuous operation ranged from 0.37 to 0.57 kWh/lb.

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