Arc Melter Demonstration Baseline Test Results

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ABSTRACT

An initial series of pilot-scale electric arc melter baseline tests were conducted on five mixtures of surrogate buried mixed wastes and soil that simulate those present at the Idaho National Engineering Laboratory (INEL). This test series was the first of several planned on behalf of Buried Waste Integrated Demonstration Program (BWID) for the U.S. Department of Energy (DOE) in cooperation with the U.S. Bureau of Mines (USBM) in Albany, Oregon for evaluating and demonstrating commercially available electric arc furnace technology for potential waste treatment applications. The test system at the USBM Albany Research Center included a small, industrial scale, three phase ac electric arc furnace. Additional waste application and system modification tests are planned for later phases.

Surrogate waste mixtures that simulated "as incinerated" buried wastes and soil located at the INEL were melted in this baseline test series. TiO_2 and ZrO_2 were added to two mixtures in order to investigate leachability in higher durability, tailored glass-ceramic final waste forms. All mixtures contained cerium oxide added as a surrogate for transuranic (TRU) oxides to investigate partitioning of TRU elements in the furnace. Structural and toxic metals and metallic cerium were added to one of the feed mixtures.

The results show the feasibility of using existing industrial arc melter technology for treating "previously incinerated" buried mixed wastes and soils on a production basis. Furnace operating parameters were generally within expected values and typical of reliable industrial arc furnace practice norms. Over 52,000 lb of surrogate materials were processed at rates representative of those anticipated as needed for full scale production processing of buried mixed wastes and soils (1,000 to 2,000 lb/hr) during a semi-continuous 80-hour test period essentially without failure. Extensive additional design, testing, and evaluation is required to optimize the arc furnace system and improve operations. Modifications such as an enhanced the feed system, overall system containment, and a remote tapping operation will enable application at the existing technology represented by the USBM system for radioactive waste treatment.

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ACRONYMS

APCS	Air Pollution Control System
ASME	American Society for Mechanical Engineers
BWID	Buried Waste Integrated Demonstration
CEMS	Continuous Emissions Monitoring System
DAS	Data Acquisition System
DOE	U.S. Department of Energy
EPA	Environmental Protection Agency
HEPA	High Efficiency Particulate Air
IEB	Iron Enriched Basalt
ID	Induced Draft
ID	inside diameter
INEL	Idaho National Engineering Laboratory
LOI	Loss on Ignition
MCC-1	Materials Characterization Center
MMT	Multiple Metals Train
MRSC	most representative slag composition
PCT-1	Product Characterization Test
QA	quality assurance
RCRA	Resource Conservation and Recovery Act
RWMC	Radioactive Waste Management Complex
TC	thermocouple
TCLP	Toxicity Characteristic Leachability Procedure
TRU	transuranic

USBM	U.S. Bureau of Mines
VRF	Volume Reduction Factor
XRD	X-Ray Diffraction

Arc Melter Demonstration Baseline Test Results

1. EXECUTIVE SUMMARY

An initial series of pilot-scale electric arc melter baseline tests were conducted on five mixtures of surrogate buried mixed wastes and soil. This test series was the first of several planned by the Buried Waste Integrated Demonstration Program (BWID) of the U.S. Department of Energy (DOE) in cooperation with the U.S. Bureau of Mines (USBM) in Albany, Oregon for evaluating and demonstrating commercially available electric arc furnace technology for potential waste treatment applications. The baseline tests were conducted in a small industrial scale, three phase ac electric arc furnace waste processing system at the USBM Albany Research Center. The system was originally designed by the USBM and the American Society for Mechanical Engineers (ASME) for a series of municipal waste incinerator ash vitrification tests conducted in 1992. The system included an automated feed system, an 800 kVA ac power supply, a graphite electrode arc furnace designed for a steel capacity of 1 ton in the hearth, and an air pollution control system. Minor modifications to this system were made for the baseline tests based upon the ASME test experience.

Surrogate waste mixtures that simulated "as incinerated" buried wastes and soils located at the Idaho National Engineering Laboratory (INEL) were melted in this baseline test series. The mixtures were designated: S60 (60% soil and 40% simulated "as incinerated" organic oils and solvents solidified in inorganic absorbent material), S60-IV (S60 with zircon and ilmenite added to provide around 3% ZrO_2 and 6% TiO_2 in the mixture), N80 (80% soil and 20% simulated evaporator nitrate salts), N80-IV (N80 with zirconia and ilmenite added to provide around 3% ZrO_2 and 6% TiO_2 in the mixture), and M60 (60% soil and 40% metallic Fe, Pb, Zn, Cu, Al, stainless steel, etc.). The TiO_2 and ZrO_2 were added to investigate processing of lower leachability, higher durability, tailored glass-ceramic final waste form materials.

All waste mixtures contained 0.35–0.42% cerium oxide added as a surrogate for transuranic (TRU) oxides. The M60 test also included the addition of elemental cerium, in the form of a metal alloy ingot with iron, to investigate partitioning of TRUs potentially present in the metal state.

1.1 Results

A shakedown melting test was conducted on soil in June 93 followed by the baseline test series in July 93. All feed types were successfully processed. Over 55,000 lb of total material was melted and processed. Average feed and tap rates ranged from 600 to 1,200 lb/hr with a maximum of 2,000 lb/hr. These rates are similar to expected full scale processing rates for buried wastes. Waste volume was reduced by a factor of 2.58 even though the initial feed density was higher (and thus lower specific volume) than would be expected for actual as received wastes and soil.

The baseline tests were conducted in five consecutive test days, following one preheat day. The actual operating time for each test day was 7.7–10.7 hours. Average power input ranged between 350–550 kW. Average energy use was 0.51 kWh/lb, which is very thermally efficient

despite the relatively small size of this arc furnace. Electrode consumption over the course of the tests was not excessive (11.9 lb/ton or 12 lb/MWh) and well within industrial norms even though the furnace was operated with excess air (oxidizing conditions in the plenum).

Sidewall and roof refractories experienced essentially no wear. This indicates the effectiveness of the water cooled side walls for skull (frozen slag layer) operation, and the effective thermal shielding of the cold top.

No downtime failures were incurred with the exception of a partial feed blockage in the feed tubes within the furnace during the early S60 test. A short downtime was required to clear the blockage. The blockage was caused by process induced positive pressure spikes in the furnace, leading to backflow of moist process gases into the feed tubes and moist agglomeration bridging of the feed material. This was successfully prevented in subsequent tests by increasing the negative pressure in the furnace and better controlling furnace pressure fluctuations to ensure no positive pressure backflow.

Slag was continuously tapped through the water cooled tapping fixture at average temperatures ranging from 1,450 to 1,800°C. Slag tapping rates as high as 2,000 lb/hr were achieved. The slags were highly viscous due to high silica and alumina content. Mill scale (Fe_3O_4) and limestone (CaCO_3), were added to the N80 feed mixture, while mill scale and pebble lime (CaO) were added to the N80-IV feed mixture, to increase slag fluidity and reduce required slag tapping temperatures. The pebble lime was found to be most effective of the two sources of lime.

The MgO ramming mix used to formulate the hemispherical hearth was dissolved by the highly siliceous S60 slag at high temperatures in the initial baseline test run. The Ruby brick (90% alumina, Al_2O_3) underlying the hearth was not affected. The hearth dissolution increased the effective volume of the hearth at a level below the bottom metal tap hole and prevented separate tapping of reduced and melted metals present on the hearth. Capability for separate tapping through the bottom metal tap hole was demonstrated by draining the furnace at the end of each test day.

Although not directly measured, mass balances indicated that some iron was reduced from iron oxide in each test run and accumulated on the hearth from test to test. Some slag was also retained each day in the increased hearth volume. Much more metal was added to the reduced iron from the M60 feed, which contained 40% metals. Observations of the metal heel removed at the end of the test series indicate this metal was melted and could have been separately tapped if the hearth had not been dissolved.

Overall mass and elemental partitioning results were generally consistent with expectations and desired separations for all test feeds. Eighty-four percent of the feed material mass was melted or dissolved into the molten slag phase, tapped, and cooled, yielding a durable glass/ceramic solid. Approximately 2.9% of the feed mass partitioned as a separate tappable metal alloy product phase (over 90% Fe) in the bottom of the furnace below the slag phase. Approximately 13% of the feed material decomposed or reacted to produce typical combustion gases H_2O , CO_2 , CO , SO_2 , HCl , and NO_x . These gases were ducted to the Air Pollution Control

System (APCS) for cooling and filtration. Roughly 1.5% was entrained in APCS flow as feed particulate and 0.5% of the mass was volatilized and transported as fume solids (condensed particulate) captured in the APCS. Overall mass balance closure (total mass out divided by total mass in) at 1.01 was very good.

Around 98% of the Ce (TRU surrogate) reported to the slag phase. No Ce was detected in the metal product. Less than 2% reported to the offgas (APCS) solids and can be attributed solely to entrainment of the fine CeO_2 powder that was used in the feed. The elemental cerium added as a metal alloy was completely oxidized in the melter and reported to the slag.

Toxic and structural metals partitioning was determined by elemental mass balances for the product slag, metal, and APCS solids. No metal was recovered until after the entire test series, but this metal was produced primarily during the M60 run, which was the final test condition of the series. The amounts of metals in the offgas were determined by two methods, by the Environmental Protection Agency (EPA) Multiple Metals Train (MMT) and by quantitative collection and analysis of the APCS baghouse and fume trap catches.

Most metals were only present in the feed in trace amounts during all feed tests, with much larger amounts of selected metals added in the M60 tests. During all but the M60 tests most of the trace metals partitioned to the slag phase at levels ranging from 65% to 100% with even the more volatile metals (Pb, Zn) reporting largely to the slag. Some of the metals (Fe, Cu, P, As, and Ni) reported significantly to the metal product during the M60 test. The remainder of the trace metals reported to the offgas. Except for the more highly volatile species of As, K, Na, Se, Hg, Pb, Zn, and Cd, the carryover to the offgas was essentially all attributable to feed entrainment of fine particulate. Feed mixtures were made up of small particle-sized materials with fine particulate susceptible to entrainment. For some volatile metals, however, it was difficult to separate feed entrainment from volatilization followed by capture of condensed metal particulate.

In the M60 test significant quantities of metals (Fe, Al, Cu, Pb, Ni, Cr, and Zn) were added as shot, flakes, or metal powder less susceptible to entrainment. With much larger metal amounts present, essentially all of the nonvolatile metals partitioned to the slag or the metal phase as expected. Iron partitioned under 15% to the slag as oxide and over 85% to the tappable metal phase. Even the more volatile Pb and Zn partitioned significantly to the combined slag and metal products (80% for Pb and 44% for Zn), with the remainder partitioning to the offgas. Most of the Pb and Zn partitioning to the offgas was from volatilization rather than entrainment because of the unlikelihood of Pb and Zn additives to be entrained.

The glass/ceramic (slag) product easily passed the Toxicity Characteristic Leachability Procedure (TCLP) for all eight TCLP metals. Offgas solids also passed TCLP in many cases, but failed as expected in some. The glass/ceramic and metal products were homogeneous and readily analyzed. Process gases were monitored and typical of those expected (CO_2 , H_2O , NO_x , SO_2 , HCl) from volatilization, thermal decomposition, and gas evolution from components in these feed materials.

1.2 Conclusions and Recommendations

The first overall conclusion is that the baseline tests have satisfied the primary test objectives as the first test campaign in a planned three campaign series. Results have provided a better understanding of arc melter performance for treating "as incinerated" surrogate wastes. Results also provide information useful for test system modification for future tests, and for designing and performing future tests. In the second series of tests, arc melting of raw, as received buried and mixed wastes (without prior incineration) will be evaluated using nonradioactive, surrogate waste mixtures. The second test series is necessary to evaluate arc furnace applicability for treating as-received buried and mixed wastes, as opposed to treating ash residuals from a preincinerator step.

The second overall conclusion is that it is feasible to use existing industrial arc melter technology as a thermal treatment system to successfully process "previously incinerated" buried mixed wastes and soils on a production basis. Extensive additional design, testing, and evaluation is required to optimize the arc furnace system and improve operations to reduce the level of personnel involvement and risk for mixed/buried waste applications. Current design and operating practices used for this test system are based on those commonly used in the metals smelting industry. The test system and procedures were further modified for optimum personnel access to the equipment and process materials. This access is necessary for researchers to monitor and control conditions and understand the melter process operations. Modifications such as an enhanced feed system, overall system containment, and a remote tapping operation will enable application of the existing technology represented by the USBM system to radioactive waste treatment. Automation of many activities such as tapping is done currently to some extent in the commercial metals industry.

The arc melter technology is capable of reliable production operation for this application. Furnace operating parameters were generally within expected values and typical of reliable industrial arc furnace practice norms. Electrode wear was not excessive even though the furnace plenum was operated under excess air flow conditions (oxidizing conditions in the plenum). Slag was continuously tapped at steady state. Separate bottom tapping capability for use with metals was partially demonstrated by draining the furnace through the bottom tap hole each day. Insufficient metal was present for separate metals tapping due to the hearth erosion volume increase. The small industrial scale graphite electrode ac powered arc furnace system (800 kVA, 1 ton hearth) was able to process over 52,000 lbs of surrogate materials at rates representative of those anticipated as needed for full scale production processing of buried mixed wastes and soils (1,000 to 2,000 lb/hr) during a semi-continuous 80 hr test period essentially without failure (unplanned downtime).

The highly viscous, high-silica melts of some of the soil and feed mixtures required melt temperatures exceeding 1,800°C in order to achieve sufficient fluidity to tap the slag. While the arc furnace easily achieved the required temperatures, additions of mill scale (Fe_3O_4) and either limestone (CaCO_3) or pebble lime (CaO) were also used to substantially reduce viscosity and required tapping temperatures, to reduce concerns for potential metals volatilization and refractory wear. The magnesium oxide hearth was also dissolved by the acidic (high silica) S60 feed slag at high temperatures. This did not require a shut-down during the test, but prevented complete draining of the furnace through the bottom metal tap hole in all subsequent tests. The metal product at the bottom of the hearth could not be tapped as a result. Additional testing and

analytical modeling evaluations are recommended to improve tapping of higher viscosity slags, and to determine optimum slag conditions for maximum glass/ceramic waste form durability (high silica, high temperature slag) while minimizing additives, furnace wear, and metals volatilization (lower silica, lower viscosity, lower temperature slag).

The arc furnace produced process conditions desired for controlled separations, destruction of complex waste compounds, and stabilization of TRU and selected toxic metals in the slag. The slag was the primary product material and yielded a homogeneous, durable glass/ceramic product upon cooling that easily passed TCLP leachability tests. A separate, tappable, homogeneous metal alloy product was also produced, as were relatively small amounts of condensed fume and entrained feed particulate which were successfully captured and retained in the APCS. Each product material was essentially homogeneous (much more so than the waste feeds), and properties evaluated were generally acceptable. The APCS solids collected would likely require additional processing. Recycling through the furnace would be the first recommended approach for the APCS solids after agglomeration into a larger feed size.

Based upon observed partitioning of the cerium metal and cerium oxide in the tests, any TRU metal or oxide fed into the high temperature melt would be rapidly oxidized or remain oxidized and partition to the slag as desired.

A small amount of the CeO_2 additive was entrained in the offgas. This entrainment was due to the small particle size of the CeO_2 additive. Such entrainment is not representative for actual TRU elements that are contaminants of actual waste. Elimination of feed entrainment in general is a controllable design and operations issue that needs to be addressed but is largely independent of process temperature. Entrainment can be minimized by increasing the feed material size distribution and by reducing furnace plenum gas velocities.

Powdered materials and fines in the soil used in the feed mixtures were entrained and increased the solids collected in the APCS. This entrainment biased APCS elemental partitioning analyses and made it difficult to differentiate between volatilization and entrainment for some elements. The only materials too large to be easily entrained were mullite, pollucite, NaCl, pebble line, aluminum, copper, lead, and zinc. Results have been interpreted with this in mind, but future tests should avoid entrainment of feed materials by using larger-sized additives or pelletizing feed additives as much as possible. Added feed and APCS solids analyses are also recommended for better determination of metals transport mechanisms. Predictions based on analytical models should be developed to better understand the data and as design tools. Excessive downsizing of actual wastes, leading to entrainable particulates during feed preparation and treatments should be avoided.

Metal vaporization and carryover was very low for all but the most volatile metals, Pb, Zn, and Hg. Cold top operation may have helped to reduce volatilization by condensing and refluxing vapors into the melt. Cold top operations clearly reduced temperatures in the plenum of both gases and surface materials. The thermal insulation effect of the cold top likely contributed significantly to the high thermal efficiency of the melter. These conclusions are based upon qualitative comparison of the baseline test results with similar tests run earlier by the USBM and ASME on municipal incinerator ashes.

A cold top was present most of the time for all runs during the baseline tests. The thickness varied and was difficult to monitor and control with the manual means utilized. No effects of thickness variation were detectable. Future tests should include operation both with and without the cold top to better quantify cold top effects under identical operating conditions.

Although all measured temperatures were useful for interpreting performance additional measurements, measurement methods, and analytical support for data interpretation and extrapolation is needed. Measurement and interpretation of temperature readings in the high temperature environment of the arc furnace are difficult at best. Tapped slag temperatures determined using an external infrared pyrometer were the most representative and accurate indicator of slag temperatures achieved in the furnace, but were lower than actual melt temperatures within the furnace. The slag cooled as it flowed through the water cooled tapping fixture, and infrared pyrometer readings were sensitive to placement of the visual spot on the slag pour. Refractory temperatures were measured at several locations, but furnace temperatures at key locations (in the metal phase, at the metal/slag interface, at locations in the slag, in the furnace plenum, cold top, etc.) could not be directly measured using instrumentation available during the baseline tests. Clearly the temperature distribution within the furnace is a key to understanding and controlling the process. Analytical modeling is also recommended for interpretation of data and prediction of temperatures of other regions.

The dissolution of the magnesium oxide hearth points out the need to evaluate hearth and slag compatibility similar operations, and especially prior to the next test series. Although the magnesium oxide ramming mix that made up the hemispherical hearth was dissolved, the underlying bottom and side Ruby refractory bricks were unaffected. A hearth made of Ruby ramming mix may be more durable. Operation with a protective metal heel or slag skull should also be further investigated.

2. INTRODUCTION

This report describes the test results and evaluation for the Phase 1 (baseline) arc melter vitrification test series conducted for the BWID program. Phase 1 tests were conducted on surrogate mixtures of "as-incinerated" wastes and soil according to the scope of the overall demonstration project defined in the BWID Technical Task Plan ID 132010, Revision 0, and based on the detailed test plan.¹ Phases 2 and 3 test series are planned for FY-94 and FY-95 to address waste streams containing raw organics, varied soil mixtures, and other process variations.

Some buried wastes, soils, and stored wastes at the INEL and other DOE sites, are contaminated with transuranic (TRU) radionuclides and hazardous organics and metals. The high temperature environment in an electric arc furnace may be used to process these wastes to produce materials suitable for final disposal. An electric arc furnace system can treat heterogeneous wastes and contaminated soils by (a) dissolving and retaining TRU elements and selected toxic metals as oxides in the slag phase, (b) destroying organic materials by dissociation, pyrolyzation, and combustion, and (c) capturing separated volatilized metals in the offgas system for further treatment. Structural metals in the waste may be melted and tapped separately for recycle or disposal, or these metals may be oxidized and dissolved into the slag. The molten slag, after cooling, will provide a glass/ceramic final waste form that is homogeneous, highly nonleachable, and extremely durable. These features make this waste form suitable for immobilization of TRU radionuclides and toxic metals for geologic timeframes. Further, the volume of contaminated wastes and soils will be substantially reduced in the process.

2.1 Background

Industrial arc melter technology is well developed for high-temperature pyrometallurgical applications for routinely processing large volumes of heterogeneous ore materials similar to buried wastes and soils. Electric arc furnaces are available in various design configurations for various applications. Possible configurations can include (a) three-phase alternating current (ac) with three or more electrodes, (b) single-phase ac with two or more electrodes, and (c) direct current (dc) with two side-by-side top electrodes, or with one top electrode and a hearth electrode(s) under the melt. Power levels up to 105 MW have been built that are capable of processing up to 130 ton/hr of ore material. Units built for processing phosphorous have been well sealed to prevent influx of air (tramp air) or fugitive emissions. High processing temperatures are possible in the arc furnace. For example, melt processing of refractory oxides, such as magnesia, can achieve temperatures of 2,800°C.

Among arc melter processes, three-phase ac electric arc furnaces have been the most widely used for industrial applications and represent a baseline arc melter technology. Most recently, dc powered configurations have reemerged in the steel industry and may offer lower carbon electrode consumption and more efficient electrical power use, although advanced process control technologies for smoothing line power fluctuations in the ac systems are also being utilized.

Electric arc furnace processing technologies have not yet been proven for mixed, radioactive, and hazardous waste processing applications. Heterogeneous, buried radioactive and mixed wastes represent a complex materials processing problem because the chemical, radiological, and physical

makeup and properties vary widely and are often difficult to characterize. Buried wastes and similar retrievably stored wastes at the INEL consist of (a) discarded lab and shop materials such as paper, cloth, rubber, glass, various metals, and graphite items, (b) construction debris such as wood, metals, concrete, brick, drywall, and plastic, (c) secondary sludges and salts from nuclear fuels reprocessing, and (d) contaminated soils. These wastes are contaminated primarily with TRU radionuclides, Resource Conservation and Recovery Act (RCRA) hazardous organics (oils and solvents), and toxic metals (Pb, etc.) in small, but significant, quantities dispersed throughout the waste materials.^{2,3}

An electric arc furnace thermal treatment system can accept a wide variety of heterogeneous solid wastes and soils. The electric arc furnace will provide a controllable, thermally-driven, chemical processing environment for the complete breakdown of complex waste compounds. It will also provide the desired partitioning of elements of concern into a few simpler homogeneous product materials. The primary product materials—glass/ceramic from the molten slag phase, metal alloy from the metal phase, and product gases—will be more readily characterized and suitable for either final disposal or recycle.

Based upon earlier thermal treatment system scoping studies^{2,4} two primary system concepts for using an arc melter were identified. The first concept employs an up-front incinerator to combust organic components in the waste and thermally decompose and volatilize nitrates and/or hydrated compounds. The melter then processes the incinerator ash and noncombustible wastes such as soils and metals. The second concept specifies arc melting for waste feeds without a preincineration step.

In the arc melter high temperature environment, organics will pyrolyze and partially oxidize in the furnace with complete gaseous combustion in a secondary oxidizer. Inorganic waste feed materials, including toxic and TRU metal oxides, will melt and dissolve into the high temperature molten slag. Structural metals may be melted into a reduced metal product phase or oxidized and dissolved into the slag phase. Gaseous volatilization, decomposition, and oxidation products go to the APCS for cooling, scrubbing, filtration, and analysis before release to the environment.

A key advantage that arc melter technologies have over many other thermal treatment technologies is the ability to process waste into a glass ceramic waste form that easily meets regulatory requirements, is more durable, is more resistant to physical dispersion, and is more leach resistant than other waste forms, such as compacted or cemented incinerator ash.^a For this reason, considerable motivation exists for performing demonstration tests to collect engineering data and optimize arc melter technology for processing radioactive and mixed wastes.

a. P. C. Kong, G. A. Reimann, S. O. Bates, B. A. Detering, and G. L. Anderson, *Final Waste Form Option Scoping Studies for RWMC Wastes*, Unpublished Report, EG&G Idaho, Inc., March 1993.

2.2 Objectives

2.2.1 Project Objectives

The primary objective of the BWID Arc Melter Vitrification Project is to evaluate and demonstrate the application of existing industrial arc melter processing technology to the treatment of buried/mixed wastes and soils. Other top level project objectives include:

- Obtain performance data for systems design
- Provide data on a large scale for use in developing or verifying analytical tools, models, and scaling relationships for melter system and process design evaluations
- Identify technology gaps and development needs that require closure for deployment of the technology in a production environment
- Define and evaluate potential process, equipment, and operations improvement modifications
- Cooperatively extend applications evaluations and development to related public and private sector waste needs.

2.2.2 Baseline Test Objectives

The BWID arc melter vitrification demonstration test and evaluation project has been organized to include three sequential test series. The initial series was the baseline (Phase 1) test series, conducted in July 1993 on "as-incinerated" surrogate wastes and soils. Based upon thermal systems scoping studies^{2,4,5} and previous municipal incinerator ash vitrification tests performed for the USBM and ASME,⁶ specific objectives and conditions were defined for the FY-94 baseline test series. This report presents an evaluation of the baseline test results with respect to these objectives:

- Evaluate equipment capability to achieve the desired melting and vitrification process conditions and products for a range of "as-incinerated" surrogate buried mixed wastes and soil compositions.
- Evaluate continuous slag tapping and on-demand metals tapping capability. The highly variable metals content and variable composition of the waste feeds make this a more complex problem than a tightly controlled metals melting operation.
- Determine partitioning (thermal separations and distribution) of TRUs (using a surrogate) and toxic metals among the slag, offgas, and metal phases.
- Determine composition, homogeneity, and properties of the slag (glass/ceramic final waste form), metal product, and offgas solid materials (particulates in the offgas from feed dust entrainment or from volatilization from the melt).

- Determine the effectiveness of operation with a layer of the unmelted feed material (cold top) on top of the melted slag for controlling volatilization of metals and the TRU surrogate and reducing thermal radiation and temperatures in the furnace plenum.
- Determine the effectiveness of water-cooled feed tubes on particulate generation control. Feed tubes deliver the feed to the surface of the melt, reducing the entrainment of feed components in the furnace offgas.
- Evaluate effects of slag chemistry, feed composition, and process temperature on process products, particularly TRU and metals partitioning, retention, and properties.
- Evaluate feed subsystem performance.
- Evaluate air pollution control subsystem performance.

2.3 Arc Furnace Waste Treatment Test System

The BWID baseline tests were performed using an existing pilot-scale, three-phase electric arc melter system at the USBM Albany Research Center in Albany, Oregon. The system includes an automated feed system, an electric arc furnace, and an air pollution control system (APCS). This system has been previously described in detail in the test plan,¹ in the baseline test data report,⁷ and in a USBM Report of Investigations.⁸ A schematic of the system is shown in Figure 2-1. For convenience, Appendix Q provides a more detailed description of the facility.

The furnace is a stationary, carbon steel shell, refractory-lined, small industrial-scale ac electric arc melting furnace that is sealed for atmospheric control. The furnace has three moveable 4 in. diameter solid graphite electrodes, with automatic power and electrode vertical positioning control. Power is supplied by a fully instrumented 800 kVA 3-phase supply. The electrodes are positioned at the apexes of an equilateral triangle 11.25 in. from electrode center to center. The electrodes and four water-cooled feed tubes extend through ports in the furnace roof. The feed tubes, furnace roof, sidewalls, and copper slag tapping fixture are water-cooled. The external furnace base is air cooled. Slag can be continuously tapped from the furnace; metal is tapped (and the hearth is emptied) when desired through a tap hole in the bottom center of the hearth.

The finished inside diameter of the furnace is about 46 in. at mid-height. The hearth is hemispherical in shape and constructed of magnesium oxide (MgO) refractory ramming mix over Ruby (high alumina, Al_2O_3) bricks. The volumetric capacity of the hearth below the slag tap hole is approximately 5 ft³, or 1 ton of steel. The slag tap hole is a water-jacketed, copper fixture 6 in. outside diameter by 10 in. long, that penetrates through the refractory and steel side-wall. The slag tap hole is 1 in. in diameter.

The carbon steel shell of the furnace is 65 in. high and tapers from 60 in. inside diameter (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

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Figure 2-1. Schematic diagram of the Arc Furnace Integrated Waste Processing Test Facility.

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.

The feed system can deliver material to the furnace at a maximum rate of about 2,000 lb/hr. The feed system is comprised of the: receiving bin, bucket elevator, metering bin with calibrated delivery screws, rotating air lock, splitter screw, and two feed screws. Each feed screw delivers to a pneumatically operated diverter gate that routes material equally through an inverted Y downcomer to two water-cooled feed tubes. Materials to be melted thereby are delivered uniformly to the furnace through four feed tubes which extend to within 18 in. of the surface of the molten slag and are located between the electrodes and sidewall of the furnace.

The air pollution control system (APCS), is comprised of: a double-walled, water-cooled, 8 in. ID offgas exit duct through the furnace roof; an air dilution temperature quench section with ambient air supplied by a 5-hp blower immediately following the water-cooled section; a linear section of duct 6 in. ID by 10 ft long with four 3-in. diameter by 4-in. long pipe nipples for offgas sampling; a vertical settling chamber 14 in. ID by 90 in. high (fume trap 1); a double-pipe heat exchanger 6 in. ID by 40 ft long with a Supertrol control unit to modify the temperature of the offgas; a settling chamber 36 in. ID by 48 in. high (fume trap 2); a 2,000 acfm capacity baghouse; a High Efficiency Particulate-Air (HEPA) filter; 10-hp induced draft (ID) fan, and exhaust stack. The short section of water-cooled duct through the furnace roof and the interior of the wind box are cleaned by a mechanical scraper driven by a pneumatic cylinder to prevent the accumulation of deposits. The APCS has numerous additional access ports for offgas sampling and for temperature, pressure, and velocity sensors.

The melter system includes a control room with operator panels and a computer data acquisition system (DAS) for monitoring and controlling process conditions. The following permanently installed data acquisition instrumentation is used to continuously monitor, record, and control process conditions:

- Thermocouples (TCs) for temperature measurement at many furnace locations, fume trap 1, baghouse inlet, and baghouse outlet.
- Rotation rate indicator for indicating feed rate of the calibrated feed screws in the metering bin.
- A infrared pyrometer for monitoring slag temperature during continuous tapping.
- A hot-wire anemometer and standard pitot tube (with pressure transducer) for monitoring the quench air and the baghouse outlet gas velocities and flowrates.
- Static pressure taps with pressure transducers for measuring furnace and APCS static pressures.
- A true RMS Power and Demand Analyzer for monitoring electrode power, voltage and current.

All instruments and sensors reported to a data logger which applied a scaling factor, if needed, and then digitized and transmitted the integral values to a personal computer (PC) for storage and display.

2.4 Measurements, Sample Collection, and Analyses

During the shakedown and baseline tests, various parameters were monitored to assure safe operation, maintain process control, and provide test data for evaluating performance of the arc melter system. Much of the data was automatically collected using the installed process instrumentation and a computer-based data acquisition system (DAS). Some redundant and additional data were taken using manual sampling and instrumentation.

More extensive data was collected during the baseline tests than during the earlier shakedown and preheat periods. A separate continuous emissions monitoring system (CEMS) was used to monitor the offgas composition. Numerous process samples were collected for subsequent analysis. A detailed listing of measurements and data collected during the baseline tests is shown in Table 2-1. The samples collected and analyses performed for the baseline tests are shown in Table 2-2. The shakedown test and the preheat day did not include continuous gas monitoring of the offgas or isokinetic particulate and metals sample collection.

Results from the sample analyses are shown in Appendices H through N. Identifying labels, prepared beforehand for all anticipated furnace products, were affixed to the appropriate product as it was collected to avoid confusion during the tests. Furnace products were indicated by a furnace feed designation and a descriptor for the collector or form of the product. Slag was indicated by S, metal by M, and slag or metal collected from the metal tap hole in a ladle were indicated by L. All of the tapped slag was collected in conical slag molds that were numbered sequentially as collected. For example, S60-S1 designates the first slag mold filled during melting of S60 waste mixture.

A 2 kg slag grab sample was collected mid-way through the filling of each slag pot. This grab sample was collected in a small steel ladle placed in the slag stream as it flowed off of the slag launder. Slag was not tapped from the furnace during melting of unmodified M60. The only available sample of M60 slag obtained prior to adding the modified composition is the rod sample, designated M60-RS, which was obtained by immersing a cold iron rod into the molten pool. The sample was chipped off of the immersed portion of the rod after it was removed from the furnace. A sample of the M60 metal product was also obtained from the very tip of the rod, but this sample was too contaminated with slag particles for use in data evaluation.

For analysis, each slag sample was crushed to pass an 80-mesh sieve (particulate size <0.175 mm), coned, and quartered to obtain representative split samples for chemical, X-ray diffraction (XRD), and TCLP analysis. The TCLP leachability analysis only requires that particles pass a 1/4-in. (<6.35 mm) sieve, so the leachability tests of <80-mesh material are much more severe than required.

The solid residues recovered from the APCS are indicated in the analysis tables by T1 for fume trap 1, T2 for fume trap 2, and BH for the baghouse. These residues were sampled individually for elemental and phase structure (XRD, phase identification) analysis and then

Table 2-1. Measurements and instrumentation during the baseline tests.

Measurement	Sensor location	DAS channel	Frequency/duration/comments
Weights of all feed materials	Manual measurement at receiving bin.	—	Every time feed material was added to the receiving bin. This measurement, the measured amount of feed dust collected in the feed system baghouse (material not fed to the furnace), any material fed by hand, and the operating time were used to determine the average feed rate for each test.
Weight of feed system fugitive dust	Manual measurement of feed system fugitive dust in facility baghouse.	—	At the end of every test the feed fugitive dust collection system baghouse hopper was emptied and weighed.
Feed rate, lb/hr	Feed metering screws.	0	Continuous indication from the two calibrated metering augers; used for instantaneous monitoring and controlling feed rate.
Electrode phase to ground voltage, V	—	17	Continuous.
Electrode phase to phase current, A	—	18	Continuous.
Furnace power, kW	—	19	Continuous.
Furnace energy, kWh	—	20	Continuous.
Furnace cold top depth measurement	"Plumb Bob" weight on steel cable through one of the feed tubes indicated height of solid surface in furnace. The height difference between the slag tap hole and the solid surface was assumed to be the thickness of the cold top.	—	This measurement was made at least several times per hour.
T ₆ , furnace upper inner sidewall temperature, °C	K-type TC located in the wall refractory near the inner refractory surface; not inserted through refractory into the plenum gas.	6	Continuous.
T ₇ , furnace hearth temperature, °C	K-type TC grouted into the metal tap hole, positioned near the center of the hearth; not inserted above the hearth into the melt.	7	Continuous; replaced every time after the metal tap hole is tapped.
T ₈ , furnace shell bottom temperature, °C	K-type TC welded to the bottom outside metal shell of the furnace.	8	Continuous.
T ₉ , slag (at tap hole) temperature, °C	Infrared pyrometer measurement of the slag stream during tapping.	9	Continuous during tapping.
Slag bath temperature (inside the furnace)	Sacrificial TC, manually inserted through side wall port into slag.	—	Typically performed prior to tapping to obtain slag temperature when slag temperature could not be measured at the slag tap hole. These temperature readings were provided for a short time (a few seconds) until each TC was destroyed.

Table 2-1. (continued).

Measurement	Sensor location	DAS channel	Frequency/duration/comments
P ₁ , furnace chamber pressure, in. H ₂ O	Uses the same port in the upper side-wall occupied by T ₆ .	10	Continuous.
T ₂ , furnace outlet duct wall temperature, °C	K-type TC inserted almost flush with the inner sidewall of the outlet duct.	2	Continuous; this temperature is considerably lower than the actual offgas temperature because it does not insert into the gas stream and may be affected by conductive heat transfer to the adjacent water-cooled section.
Furnace outlet offgas temperature	K-type TC manually inserted into the gas stream through a small port in the furnace outlet duct, occasionally during the testing.	—	Periodically up to several times per test condition for several minutes each time; observed temperature may be slightly increased due to radiation heat transfer from molten pool or arc zone.
Furnace outlet gas moisture content	Wet/dry TC probe manually inserted into the gas stream through a small port occasionally during the testing.	—	Periodically up to several times per test condition for several minutes each time; observed dry bulb temperature may be slightly increased due to radiation heat transfer from molten pool or arc zone.
T ₁ , quench air temperature, °C	K-type TC inserted into the quench air duct downstream of the blower.	1	Continuous.
V ₁ , quench air flowrate, cfm	Hot-wire anemometer in the quench air duct downstream of the blower.	15	Continuous.
Quench outlet gas temperature, velocity and flowrate	K-type TC and S-type pitot manually inserted in sample ports.	—	Periodically during each test condition before, during and after each MMT sampling run; both traversing and single point.
Quench outlet gas composition (O ₂ , CO ₂ , CO, NO _x , SO ₂)	Extractive sample probe inserted in sample ports.	—	Continuous during sample collection, single point following initial traverse to evaluate stratification.
T ₃ , fume trap 1 gas temperature, °C	K-type TC inserted into the gas stream.	3	Continuous.
P ₂ , fume trap 1 pressure, in. H ₂ O	Pressure tap in the port where T ₃ is located.	11	Continuous.
Baghouse inlet gas temperature	K-type TC manually inserted in sample ports upstream of baghouse.	—	Only occasionally during the testing, as corroboration to the continuous baghouse inlet temperature measurement.
Baghouse inlet gas composition (O ₂ , CO ₂ , NO _x , SO ₂)	Extractive sample probe manually inserted in sample ports upstream of baghouse.	—	Only occasionally during the testing, to estimate the degree of air dilution (if any) between the quench outlet and the baghouse inlet.
T ₄ , baghouse inlet gas temperature, °C	K-type TC in baghouse inlet duct.	4	Continuous.
P ₃ , baghouse inlet pressure, in. H ₂ O	Pressure tap at the baghouse inlet location.	12	Continuous.
T ₅ , baghouse outlet offgas temperature, °C	K-type TC in baghouse outlet duct.	5	Continuous.

Table 2-1. (continued).

Measurement	Sensor location	DAS channel	Frequency/duration/comments
P ₄ , baghouse outlet pressure, in. H ₂ O	Pressure tap at the baghouse outlet location.	13	Continuous.
V ₂ , baghouse outlet velocity head of standard pitot, in. H ₂ O	Standard pitot at the baghouse outlet location.	16	Continuous.
P ₅ , HEPA filter differential pressure, in. H ₂ O	Pitot taps upstream and downstream of the HEPA filter.	14	Continuous.
Stack gas composition (O ₂ , CO ₂ , CO, NO _x , SO ₂)	Extractive sample probe manually inserted in sample ports in the stack.	—	Only occasionally during the testing, to estimate the degree of air dilution (if any) between the baghouse inlet and the baghouse outlet.

Table 2-2. Sample collection summary.

Sample	Sample location	Analysis parameters ^a	Sample frequency
Metal product	Metal dip rod (during M60 test) and metal heel	Full set metals, P, S; total C, Cl	Once during M60 melt, and once from metal heel after test series
Slag product	Slag launder (and 1 sample from metal dip rod during M60 test)	Full set metals, Hg, P, S; total C; Cl	Once per slag pot (8–11 per test day)
Fume traps 1 and 2 solids ^b	Fume trap 1	Total weight; full set metals, Hg, P, S; total C, Cl	End of each test condition
Baghouse ash ^b	Baghouse hopper	Total weight; full set metals, Hg, P, S; total C, Cl	End of each test condition
MMT samples	Quench outlet duct	Total particulate, front half metals, back half metals	Two per test day

a. Full set metals = Ag, Al, As, Ba, Ca, Cd, Ce, Cr, Cu, Cs, Fe, Hg, K, Mg, Na, Ni, Pb, Se, Si, Ti, Zn, and Zr.

b. The offgas system residues were collected as completely as possible from the baghouse hopper and fume traps.

were thoroughly mixed and sampled to provide material for TCLP leachability analysis. The samples of mixed APCS solids are designated by FS.

Offgas measurements during the baseline tests were made by personnel from Entropy Environmental Inc. Particulate and metals sample collection and analysis was done using EPA Draft Method 29 Multiple Metals Train (MMT)⁹ for isokinetic sample collection and analysis of metals emissions from stationary sources. The duration of each sampling interval was around 1.5 hr, of which 1 hr was actual sample collection. Two valid EPA Method 29 samples were collected for each test day. The designations for these samples are prefixed by MMT and followed by the collecting solvent or solution. All samples were analyzed by the USBM analytical laboratory. Operating parameters including feed rate, cold top depth, and power to the furnace, were maintained as constant as possible during the sampling interval.

Gaseous emissions from the furnace were analyzed continuously for O₂, CO₂, CO, NO_x, and SO₂ at the quench section outlet, with occasional checks for short periods of time at the baghouse inlet and at the stack. EPA Methods⁹ 3A, 6C, 7E, and 10 were used for these measurements.

2.5 Feed Mixtures

The baseline test feed mixtures were prepared by mixing soil from the Radioactive Waste Management Complex (RWMC) with selected buried waste surrogate materials. The description of each feed mixture is shown in Table 2-3. The surrogate waste materials were specified to represent buried wastes that have been previously incinerated. Mixture proportions of the soil and surrogate waste materials were calculated so that the resultant vitrified slag product 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.¹⁰ Other additives [limestone (CaCO₃), pebble lime (CaO), and magnetite (Fe₃O₄)] were also used in some of the tests to reduce the slag viscosity and enable continuous slag tapping at more reasonable slag temperatures consistent with the existing furnace design capability. A general background discussion of slag chemistry and related properties is provided in Appendix R.

The elemental compositions (shown in Table 2-4) of the feed mixtures were calculated from the compound compositions (Table 2-5) and amounts of each additive in the feed mixtures as given in Appendix G. The compositions of the feed mixtures were not determined by analysis of feed mixture samples because of the potential for error due to 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. Rather, the calculated feed mixture compositions based on the known quantity and compositions of additives in the mixtures are considered more accurate. The compositions of the additives were obtained from the suppliers of the materials. In many cases, the materials specifications only provided a range of typical compositions, and identified a certain small percentage of the material as "other."

The soil (without additives) was analyzed for moisture content (weight loss after heating to 110°C for 12 hr), for Loss on Ignition [(LOI) weight loss after heating to 1,000°C for 1 hr] and elemental composition prior to testing. The moisture content (not including water of hydration) ranged from 2 to 3.5%. The LOI ranged up to 10% (in addition to the moisture content). The

Table 2-3. Description of buried wastes and surrogate mixtures.

Feed mixture designation	Description of buried wastes and surrogate mixtures
S60	The S-0 series of wastes describes organic oils and solvents immobilized by mixing with Micro-Cell E (CaSiO_3) and Oil-Dri (SiO_2). These wastes were generated at EG&G's Rocky Flats Plant, and include Organic Setups (prefix 743, also identified as INEL Content Code 3). ^a Waste mixture S60 is 60% RWMC soil (A-100) and 40% simulated thermally oxidized S-0. Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and NaCl were added to provide the desired sulfur and chlorine concentrations, respectively.
S60-IV	This waste mixture is the S60 mixture with added zircon (66% ZrO_2) and ilmenite (65% TiO_2) to provide around 3% ZrO_2 and 6% TiO_2 in the feed mixture.
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. Preincineration of the nitrate salts would be expected to yield alkali metal oxides and evolve substantial quantities of gas. The subsequent melting of sodium and potassium oxides would not be difficult. The direct processing of nitrate salts in the melter could, however, produce a vigorous reaction rapidly generating gas affecting the slag and burden layers by causing foaming and dusting and resulting in furnace pressure spikes. For these baseline tests sodium and potassium carbonates were used in the surrogate waste mixtures to approximate effects of rapid gas generation by sodium and potassium nitrates to investigate potential problems with rapid chemical reaction of the nitrates during melting.
N80-Mod	The N80 waste mixture was modified during the melting test (to reduce the slag viscosity) with limestone and mill scale in the ratio 100 lb N-80: 37.5 lb limestone: 20.7 lb mill scale.
N80-IV	This waste mixture is the N80 mixture with additions of zirconia and ilmenite to provide around 3% ZrO_2 and 6% TiO_2 in the feed mixture.
N80-IV-Mod	The N80-IV waste mixture was modified (to reduce the slag viscosity) 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.

Table 2-3. (continued).

Feed mixture designation	Description of buried wastes and surrogate mixtures
M60	<p>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. The surrogate waste mixture M60 is 60% RWMC soil and 40% simulated thermally oxidized M-0 waste, assumed to be primarily elemental metals, not metal oxides.</p> <p>Notes:</p> <ol style="list-style-type: none"><li>1. All waste mixtures contained 0.35–0.42% CeO_2 added as a surrogate for the TRU radionuclides, particularly PuO_2.<li>2. The N80-IV-Mod feed mixture with additional pebble lime was fed during the M60-Mod condition.<li>3. During the M60-Mod test a 3-lb metal alloy ingot (50% Ce, 50% Fe) was added to investigate partitioning of added metallic Ce (Pu surrogate).
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a. W. S. Roesener, N. R. Soelberg, and A. L. Ayers, <i>Identification of a Treatment Process for the Idaho Waste Processing Facility Project—A Preconceptual Design Study</i> , unpublished report, September 1992.	

Table 2-4. Calculated elemental composition of the surrogate waste mixtures.

Element	Surrogate waste mixture elemental composition (as received ppm)								
	RWMC soil	S60	S60-IV	N80	N80-Mod	N80-IV	N80-IV-Mod	M60	M60-Mod
Ag	8.00	4.52	3.97	5.95	4.90	5.24	4.47	5.14	4.35
Al	55,100	39,927	35,819	43,513	35,860	37,920	32,515	58,501	31,696
As	11	6.21	5.46	8.24	6.79	7.27	6.36	6.94	6.24
Ba	100	463	467	321	264	311	266	341	259
Bi	-	-	-	-	-	-	-	2.21E-03	-
C	15,588	8,840	7,778	29,081	37,444	27,679	23,780	9,855	23,197
Ca	52,863	64,685	62,164	39,865	77,330	35,043	80,940	42,046	96,566
Cd	0.50	0.28	0.25	0.37	0.31	0.33	0.28	0.32	0.27
Ce	45	3,384	3,475	3,446	2,840	3,437	2,934	3,780	2,955
Cl	40	12,358	12,702	83	68	79	68	25	66
Cr	200	359	382	259	267	296	313	17,219	305
Cs	50	3,956	4,063	37	31	33	28	32	27
Cu	45	25	22	33	190	29	208	7,392	202
F	-	579	596	589	485	588	525	647	519
Fe	30,600	116,317	116,628	66,772	99,881	63,262	104,418	267,971	101,745
H	11,222	7,488	6,880	8,398	6,959	7,630	6,805	7,107	6,725
Hf	-	-	13,638	-	-	543	463	-	451
Hg	0.10	0.06	0.05	0.08	0.06	0.07	0.06	0.06	0.06
K	20,109	11,708	10,299	50,425	41,556	48,597	41,489	12,757	40,381
Li	-	41	42	-	-	-	-	-	-
Mg	13,702	14,790	14,082	10,816	9,240	9,446	8,248	8,689	8,091
Mn	-	313	755	125	441	926	1,194	22	1,171
N	-	-	-	-	-	-	-	17	-
Na	9,500	13,628	13,213	53,366	43,980	52,475	44,817	6,013	43,626
Ni	34	19	17	25	115	22	124	9,597	121
O	541,353	477,294	456,138	499,650	483,494	483,613	456,322	359,704	452,429
P	950	573	528	722	604	672	591	618	578
Pb	23	13	11	18	15	16	14	7,380	13
Rb	-	99	102	-	-	-	-	-	-
S	140	13,507	13,837	431	355	346	341	238	348
Sb	-	-	-	-	-	-	-	0.01	-
Se	1.12	0.63	0.56	0.83	0.68	0.73	0.62	0.71	0.61
Si	270,000	207,759	185,066	202,594	167,024	178,368	152,617	178,622	148,635
Sn	-	-	-	-	-	-	-	0.03	-
Sr	-	383	394	157	129	157	134	174	130
Te	-	-	-	-	-	-	-	7.37E-03	-
Th	-	14	15	15	12	20	17	16	17
Ti	2,600	12,706	30,368	6,964	5,739	39,211	33,498	1,656	32,612
U	-	-	-	-	-	8.44	7.21	-	7.01
V	-	793	806	356	293	337	288	-	280
Y	-	-	-	-	-	42	35	-	35
Zn	110	62	55	82	67	72	62	14,742	60
Zr	100	56	7,034	74	61	24,878	21,239	63	20,672
Other	-24,495	-12,153	2,615	-18,232	-14,758	-16,070	-14,313	-15,239	-13,931
Total	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000

Table 2-5. Species compositions of the surrogate waste mixtures.

Species	Surrogate waste mixture species composition (as received ppm)								
	RWMC soil	S60	S60-IV	N80	N80-Mod	N80-IV	N80-IV-Mod	M60	M60-Mod
Al2O3	104,114	75,443	67,682	82,219	67,758	71,652	61,438	75,745	59,890
Ag2O	8.59	4.85	4.27	6.39	5.26	5.63	4.80	5.41	4.68
As2O	12.17	6.87	6.05	9.05	7.46	7.97	6.81	7.67	6.62
BaO	112	63	55	83	68	73	62	78	61
CaCO3	130,000	73,730	64,868	96,616	190,682	85,131	73,925	81,953	72,383
CaO	1,120	26,444	27,243	1,640	1,352	1,328	71,828	12,908	94,553
CaSO4	-	576	592	-	-	-	-	-	-
CaSO4*2H2O	-	68,863	70,798	-	-	-	-	-	-
CaO	0.57	0.32	0.28	0.42	0.35	0.37	0.32	0.36	0.31
CeO	-	-	-	-	-	-	-	4.06	-
CeO2	55	4,157	4,269	4,232	3,488	4,221	3,604	4,638	3,508
Cr2O3	292	525	559	379	391	433	458	184	446
Cr2O	53	30	26	39	32	35	30	33	29
CuO	56	32	28	42	238	37	260	35	253
Fe2O3	-	1,135	15,624	1.07	0.88	26,743	22,892	189	22,302
Fe3O4	42,288	159,582	146,004	92,277	138,032	61,577	122,176	26,643	118,914
H2O	101,000	60,187	54,513	75,577	62,625	68,661	61,242	63,967	60,522
HfO2	-	-	-	-	-	640	546	-	532
HgO	0.11	0.06	0.05	0.08	0.07	0.07	0.06	0.07	0.06
K2CO3	-	-	-	62,643	51,625	62,552	53,403	-	51,977
KCl	-	-	-	3.14	2.59	3.13	2.68	-	2.60
K2O	24,223	13,994	12,294	18,003	14,836	15,863	13,543	15,367	13,181
KOH	-	-	-	44	36	44	37	-	36
K2SO4	-	-	-	3.77	3.10	3.76	3.21	-	3.12
MgCO3	-	-	-	-	1,133	-	-	-	-
MgO	22,721	24,517	23,344	17,935	14,781	15,663	13,676	14,408	13,417
MnO	-	402	973	161	133	1,196	1,021	25	994
MnO2	-	-	-	-	535	-	638	-	634
Na2CO3	-	-	-	106,507	87,775	106,352	90,797	-	88,373
NaCl	-	20,339	20,910	86	71	85	73	-	71
Na2O	12,804	7,248	6,376	9,516	7,842	8,406	7,199	8,105	7,015
Na2SO4	-	-	-	160	132	160	137	-	133
NiO	43	24	21	32	146	28	158	27	154
O2	-	-	-	-	-	-	-	2.21E-04	-
PO4	2,913	1,645	1,447	2,165	1,811	1,908	1,659	1,835	1,615
P2O3	-	72	110	32	27	98	99	-	102
PbO	25	14	12	18	15	16	14	16	13
SO3	-	-	-	-	-	-	114	-	151
SO4	420	631	614	696	574	658	562	686	547
SiO	1.20	0.68	0.60	0.89	0.74	0.79	0.67	0.76	0.65
SiO2	577,583	443,984	395,422	433,387	357,296	381,565	326,477	380,253	317,960
SrO	-	-	-	-	-	-	-	1	-
ThO2	-	16	17	17	14	17	14	18	14
TiO2	4,337	21,194	30,656	11,616	9,573	65,405	55,877	2,763	54,399
V2O3	-	-	111	-	-	205	175	-	170
V2O5	-	1,260	1,160	565	466	315	269	-	261
Y2O3	-	-	-	-	-	53	45	-	44
ZnO	137	77	68	102	84	90	77	86	75
ZrO2	135	76	86	100	83	33,605	28,690	85	27,924
BaO+SrO	-	453	466	461	380	460	393	506	382
ZrO2+HfO2	-	-	25,476	-	-	-	-	-	-
Ag	-	-	-	-	-	-	-	0.10	-
Al	-	-	-	-	-	-	-	18,415	-
As	-	-	-	-	-	-	-	7.37E-03	-
Bi	-	-	-	-	-	-	-	2.21E-03	-
C	-	-	-	-	-	-	-	28	-
Cl	-	-	-	-	-	-	-	25	-
Cr	-	-	-	-	-	-	-	17,093	-
Cu	-	-	-	-	-	-	-	7,364	-
F	-	-	-	-	-	-	-	647	-
Fe	-	-	-	-	-	-	-	248,560	-
Mn	-	-	-	-	-	-	-	2	-
N	-	-	-	-	-	-	-	17	-
Ni	-	-	-	-	-	-	-	9,576	-
O	-	-	-	-	-	-	-	86	-
P	-	-	-	-	-	-	-	20	-
Pb	-	-	-	-	-	-	-	7,366	-
S	-	-	-	-	-	-	-	9	-
Sb	-	-	-	-	-	-	-	0	-
Se	-	-	-	-	-	-	-	7.37E-03	-
Si	-	-	-	-	-	-	-	867	-
Sn	-	-	-	-	-	-	-	0	-
Te	-	-	-	-	-	-	-	7.37E-03	-
Zn	-	-	-	-	-	-	-	14,673	-
Other	-24,455	-6,727	8,163	-17,377	-14,053	-15,296	-13,626	-15,324	-13,056
Total	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000

LOI includes weight loss of the solid sample from gases evolved from the decomposition of carbonates and sulfates, evolution of water of hydration, and volatilization of any other materials at that temperature. The combined moisture content and LOI weight loss for the soils averaged around 12%. Since soil comprised 60–80% of the feed mixtures, this is also the general range of moisture content and LOI expected for the feed mixtures. Soil samples were obtained by conventional cone-and-quartering procedures from 200 lb of thoroughly mixed soil.

The carbon content (including carbon from carbonates and from small amounts of organic matter in the soil) was under 4%. Sulfur and chlorine content ranged under 1.5% for the S60 and S60-IV feed mixtures, and under 0.1% for the other mixtures. The composition of each feed mixture in terms of oxides, carbonates and sulfates is shown in Appendix G-2.

3. TEST OBSERVATIONS AND MELTER SYSTEM PERFORMANCE

The performance of the melter system was evaluated during an initial shakedown test day on soil feed, during a preheat day on calcium oxide and silicon dioxide feed prior to the baseline tests, and on the waste surrogate soil feed mixtures during the five day baseline test series. Process monitoring and sample collection were performed during each furnace operating period in order to monitor and control system operation and to obtain operating data to satisfy the test objectives listed in Section 2.2. An overview of the operating conditions and an evaluation of performance for the melter system components are presented in this section.

3.1 Operating Conditions and Results Summary

A global summary of the operating conditions and results parameters from the shakedown test, the preheat day, and the semi-continuous baseline tests is shown in Table 3-1. The following subsections briefly discuss each test period.

3.1.1 Shakedown Test

The shakedown test was conducted on June 3, 1993. This test was conducted to assure suitable performance of the modified system and facility prior to the baseline tests. RWMC soil with added mill scale was the feed material, because the soil was expected to be one of the more challenging, highly viscous melt compositions. Satisfactory performance of all system modifications was demonstrated. Arc furnace system modifications had been made based on the experience obtained in processing municipal incinerator ash for the ASME test program, and to meet the objectives of the BWID baseline tests. Modifications included (a) installation of water-cooled feed tubes, (b) installation of a video camera in the furnace inspection port, (c) elimination of the nitrogen gas inerting system, (d) modification of the furnace offgas duct to minimize solids deposition, (e) installation of an air-dilution temperature quench system for cooling the furnace offgas, (f) elimination of the afterburner at the outlet of the baghouse, and (g) installation of a HEPA filter at the outlet of the baghouse. All modifications performed as intended, as discussed in Section 3.2.3.

Trends of operating parameters including the furnace pressure, offgas flowrates, and offgas temperatures are shown in Appendices A-F. The furnace was started and operated for about 3 hr to melt 1,962 lb of soil and mill scale (Fe_3O_4) in the ratio of 10 lb mill scale per 100 lb soil (9.1% mill scale in the mixture). This feed mixture had a calculated basicity ratio of 0.31 (Appendix R). Tapping of slag was difficult owing to inadequate fluidity, but possible at undesirably high tapping temperatures ($1,800^\circ\text{C}$); therefore, in an attempt to fluidize the slag, the proportion of mill scale was increased to the ratio 20 lb per 100 lb soil (basicity ratio 0.37) for the remaining 10 hr of the test. Additional mill scale, added from time to time to further fluidize the slag, increased the average ratio of mill scale to soil during the shakedown test to 25.3 lb per 100 lb soil (20.2% in the mixture).

At 2330 the metal tap hole was opened to drain the hearth from which 1,050 lb of slag was recovered. Metal was neither observed during the tap nor in the slag mold after cooling, although

Table 3-1. Global summary of baseline tests.

Feed type	Test day	Operating run duration (hr)(j)	Average power (kW)	Total electrode energy input (MWh)	Total feed material (lb)	MgO dissolved from refractory (lb)	Total feed input to furnace (lb)	Average feedrate (lb/hr)	Average slag tapping rate (a) (lb/hr)	Slag bath temperature (C)(i)	Tap temperature (C)(a)
RWMC soil & mill scale	3-Jun	13			7,516	10	7,526	579	464		
CaO + SiO2	18-Jul	7.3	356	2.97	4,301	0	4,301	589	592	1530	1450-1700
S60	19-Jul	9.25	544	5.09	9,806	910	10,716	1,158	977	1430	1550-1600
S60-IV	20-Jul	10.7	422	4.62	8,273	57	8,330	779	656	1380	1550-1650
N80	21-Jul	4.2		1.92	4,601	0	4,601	1,095	969	1300	1650-1800
N80-Mod (h)	21-Jul	4.3		1.73	3,778	0	3,778	879	777	NM	1450-1550
	Daily total	8.5	462	3.65	8,379	0	8,379	987	872		
N80-IV	22-Jul	5.2		2.78	5,518	0	5,518	1,061	887	1325	1650-1750
N80-IV-Mod (h)	22-Jul	4.25		2.40	4,986	0	4,986	1,173	981	NM	1550-1590
	Daily total	9.45	540	5.18	10,504	0	10,504	1,117	929		
M60	23-Jul	3.1		1.32	3,263	0	3,263	1,053	0	NM	no tap
M60-Mod (h)	23-Jul	4.6		2.19	3,403	0	3,403	740	1,136	NM	1550-1690
	Daily total	7.7	473	3.51	6,666	0	6,666	897	678		
Average (Baseline tests)		5.7	483	2.76	5,454	121	5,574	992	798		
Average (for all days)		6.59	441	2.78	5,545	97.7	5,642	911	744		
Subtotal (Baseline tests)		45.6		22.1	43,628	967	44,595	7,938	6,382		
Totals (for all days)		65.9		25.0	55,445	977	56,422	9,106	7,438		

Notes:

1. The 4,322 lb of slag obtained for the CaO+SiO2 feed type includes the addition of residual soil from the shakedown test conducted on June 3, 1993.
2. NM = Not measured; NC = Not calculated due to insufficient measurements.

- a. During continuous tapping period(s) only. The reported tap temperatures are corrected for deviations in the optical pyrometer measurements when the slag did not completely fill the pyrometer field of view. The correction was determined each day by manual, closer pyrometer measurements.
- b. Total solid material collected and quantitatively removed from fume trap 1, fume trap 2, and the baghouse.
- c. Mass of feed material volatilized and measured in the form of vapor, H2O, SO2, CO2 (from carbonates) and HCl (See Table 4-1). This corresponds to % Loss On Ignition (LOI).
Minor amounts of potentially vaporized metals (oxides, sulfates and chlorides) are not included in this calculation.
- d. Electrode consumption calculated for baseline tests, not including 8.5 hour run to preheat the furnace on 7/18/93.
- e. Calculated from the density and mass of the feed material and the density and mass of the vitrified slag. The relatively smaller amounts of fume solids and metal product are not included.
- f. Calculated from (Sum output mass -Sum input mass)/Sum input mass.

Table 3-1. (continued).

Feed type	Total slag tapped		Total metal product (g)		Total APCS solids (b)		Total amount of vaporized material (c)	
	(lb)	(wt % of initial feed mass)	(lb)	(wt % of initial feed mass)	(lb)	(wt % of initial feed mass)	(lb)	(wt % of initial feed mass)
RWMC soil & mill scale	6,030	80.1	162	2.15	65	0.86	NM	NM
CaO + SiO ₂	4,322	100.5	0	0	NM	NM	NM	NM
S60	9,040	84.4	40	0.37	141	1.32	1,100	10.3
S60-IV	7,019	84.3	1	0.01	164	1.97	1,109	13.3
N80	4,069	-	33	0.72	109	2.37	NM	NC
N80-Mod	3,341	-	28	0.74	122	3.23	613	16.2
	7,410	88.4	61	0.73	231	2.76	NC	NC
N80-IV	4,612	-	96	1.74	112	2.03	976	17.7
N80-IV-Mod	4,168	-	86	1.72	126	2.53	530	10.6
	8,780	83.6	182	1.73	238	2.27	1,506	14.3
M60	0	-	789	24.2	53	1.62	357	11.0
N80-IV-Mod	5,224	-	0	0	68	2.00	353	10.4
	5,224	78.4	789	11.8	121	1.82	711	10.7
Average (Baseline tests)	4,684	83.8	134	2.94	112	2.02	720	13.0
Average (for all days)	4,783	85.7	124	3.16	107	1.99	720	12.8
Subtotal (Baseline tests)	37,473		1,073		895		5,038	
Totals (for all days)	47,825		1,235		960		5,038	

g. No metal was tapped from the furnace, although it was molten based on post test observations. The metal resided in the region of the eroded hearth below the metal tap hole.

h. The N80-Mod mixture included powdered limestone (mainly CaCO₃) and millscale to reduce slag viscosity. The N80-IV-Mod mixture included pebble lime (mostly CaO) and millscale to reduce slag viscosity.

i. Bath temperatures measured during non-tapping periods, usually when slag was too viscous to tap.

j. Duration was taken from power on to power off.

Table 3-1. (continued).

Feed type	Electrode consumption (d)		Average power utilization (kWh/lb feed material)	Waste mixture volume reduction (e)	TCLP leachability (pass/fail)		Global mass balance closure (f)
	(lb)	(lb/MWh)	(lb/ton feed material)		Slag	Total particulate solids	
RWMC soil & mill scale	-	-	-				NC
CaO + SiO ₂	-	-	0.69				1.00
S60	-	-	0.48	2.62	Pass	Pass except Lead	0.96
S60-IV	-	-	0.56	2.58	Pass	Pass except Lead	0.99
N80	-	-	0.42	2.48	Pass	Pass	NC
N80-Mod	-	-	0.46		Pass	Pass	1.08
	-	-	0.44				NC
N80-IV	-	-	0.50	2.56	Pass	Pass	1.04
N80-IV-Mod	-	-	0.48	2.66	Pass	Pass	0.98
	-	-	0.49				1.01
M60	-	-	0.40		Pass	Pass except Lead	NC
N80-IV-Mod	-	-	0.64		Pass	Pass	NC
	-	-	0.53				1.02
Average (Baseline tests)			0.49	2.58			1.01
Average (for all days)			0.51	2.58			1.00
Subtotal (Baseline tests)	265	12.0	11.9				
Totals (for all days)							

some reduced iron was expected. Based on iron material balance calculations, 162 lb of metallic iron was produced by carbothermic reduction of a portion of the mill scale during the test.

Observation of the interior of the furnace after cooling to room temperature revealed a band 6 to 8 in. thick of sintered, but unmelted, feed material extending about 6 in. up the sidewall from the slag line, and additional melted material on the hearth that had been melted but was too viscous to tap from the furnace. The combined weight of materials remaining in the furnace was estimated to be about 600 lb, which decreased the weight of material actually melted and tapped to 5,510 lb RWMC soil and 1,390 lb mill scale. Soil and mill scale remaining in the furnace from the shakedown test were later removed during the preheat day prior to the semi-continuous baseline tests.

3.1.2 Preheat Day

The furnace was preheated on July 18 during operation for about 12 hr on an equimolar mixture of $<1/4$ in. pebble lime (mostly CaO) and silica sand (SiO_2). The basicity ratio of the resulting calcium silicate slag was 1.0. In addition to preheating the furnace for the baseline tests the preheat run was used to (a) remove the residual sintered deposits of soil material in the furnace from the shakedown test, (b) startup and stabilize the Supertrol control unit for the offgas heat exchanger and other supporting equipment including the water-cooling tower, water distribution pumps, city water, compressed air, dilution air blower, and induced-draft blower, and (c) verify the operational status of the system. The melter system did not and was not expected to achieve completely steady-state temperatures during the preheat run.

Continuous slag tapping was achieved within 3 hr of startup after feeding only 900 lb of preheat material to the furnace, thereby confirming that appreciable material (estimated 600 lb) remained in the furnace from the shakedown test. At 1138 a fuse failed in the electrode control circuit for phase A, causing the phase A electrode to withdraw from the furnace. The source of the problem was not identified until later in the evening, but in the meantime (beginning at 1250), the furnace was operated successfully with manual control of phase A. Continuous tapping was regained at 1325, and slag temperatures measured by a slag tap pyrometer ranged from 1,450 to 1,700°C throughout the test. After 6 hr of operation, a constant cold top of 6 to 8 in. was achieved at a feed rate of 675 lb/hr and a power input of about 450 kW.

The quench air flowrate ranged from 485 to 588 acfm at 25°C, and the offgas flowrate at the baghouse outlet 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. Operating conditions were within design parameters. The temperature of the hearth, as measured by a thermocouple in the metal tap hole, increased to about 1,200°C, and the bottom of the steel furnace shell increased to about 120°C during the melting test. At 1750 the metal tap hole was opened to drain the hearth. Metal was not observed during the tap. Power to the Supertrol and water-cooling tower, and water flow to all circuits were maintained throughout the following night.

3.1.3 Baseline Tests

Following the preheat day the surrogate waste mixtures were melted in succession in five consecutive, daily, semi-continuous tests. The actual operating time for each day was 7.7–10.7 hours, with additional time each day for test preparation, sample collection and handling, maintenance, and data handling.

Five surrogate waste mixtures were consecutively melted each on a separate day in the baseline tests. The five surrogate waste mixtures had been prepared to simulate soil mixed with preincinerated (a) solidified organic oils and solvents (denoted S60 and S60-IV), (b) solidified evaporator salts containing potassium and sodium nitrates (denoted N80 and N80-IV), and (c) contaminated scrap metals (denoted M60). In order to achieve sufficiently low molten slag viscosities to enable continuous slag tapping at reasonable temperatures, some of these mixtures were further modified during the testing by adding mill scale (Fe_3O_4) and either limestone (CaCO_3) or pebble lime (CaO) with additional feed material to the existing molten mass in the furnace.

The furnace was generally operated with a cold top of feed material ranging from 3 to 10 inches during all but the early startup portion of each test day.

Waste mixtures S60 and S60-IV were successfully melted without modifying the compositions. Continuous tapping of slag was achieved at temperatures ranging from 1,550 to 1,650°C. The N80 and N80-IV waste mixtures were more viscous and required higher tapping temperatures, up to 1,800°C. These waste feeds were processed for about 4 hours each while process and offgas data and samples were collected. Following a full set of sample and data collection (except for metal samples) these melts were modified by adding limestone or pebble lime and mill scale to the feed mixture to decrease the slag viscosity for easier tapping. 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 40% metal powders, flakes, and shot. About 3,260 lb of M60 was melted in 4 hours at feed rates up to 1,500 lb/hr, while process and offgas data and samples (except for metal samples) were collected. During this time highly viscous slag could not be successfully tapped at the existing power and at slag temperatures up to 1,850°C. Further increasing the temperature (power), while possible, was not desirable and could potentially damage the furnace refractory, feed tubes, or other components. Since the slag was not tappable for this condition, samples could not be obtained from the slag tap. Therefore, 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 to reduce viscosity for tapping 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 and continued at tapping temperatures from 1,550–1,690°C. Another set of process data and sample collection was performed at this operating condition.

During the M60-Mod run a 3 lb metal alloy ingot (50 wt% Ce, 50 wt% Fe) was added to the melt to investigate the partitioning of Ce metal as a surrogate for plutonium. This was in addition to the 0.38 wt% of Ce oxide present in the M60 feed mixture. As later discussed, the plutonium

surrogate (Ce) metal oxidized and partitioned to the slag. No Ce was detected in the metal phase.

The MgO hearth was determined to have been dissolved early in the baseline test series by the siliceous, acidic S60 slag. The increased hearth capacity, consequently led to daily carryover of reduced metals and slag in the region below the metal tap hole. The hearth bricks were not, however, affected.

3.2 Arc Melter System Performance

The performance of the sealed melter system and system components was evaluated during the shakedown test, the preheat, and the baseline tests. Primary subsystems included the feed system, the furnace, and the APCS.

3.2.1 Feed System Performance

Operation of the feed system, including the baghouse and ducting for collecting fugitive dust within the building, was satisfactory and as expected. The feed system was designed for measuring, controlling, and delivering aggregate and soil-type materials of sizes less than 1 inch diameter to the furnace. The feed system was sealed from the receiving bin onward to control fugitive dust release. A rotary air lock seal downstream of the metering bin minimized air inleakage through the feed system. Segregation of aggregate, granular, and powder materials is a frequent occurrence in handling equipment due to vibration and stirring of augers. Larger-sized and less dense materials tend to float to the surface while denser and smaller particles tend to sink to the bottom of processing hoppers that contain these kinds of materials. The feed mixtures, especially the M60 metals mixture, contained additives of various particle sizes and densities. Efforts made to minimize segregation in the feed hoppers included adding the feed mixtures one barrel at a time and achieving near emptiness in the receiving bin before adding another barrel. Samples were collected periodically from the metering bin. Bulk density measurements showed little variation during the baseline tests.

There were no significant failures of measurement, control, or feed equipment during the baseline tests. Dust generation was minimized by using a 2-barrel-capacity charge hopper for charging the receiving bin and to serve as a mixing vessel for preparing the modified furnace feeds. There was no jamming of the feed screws that was observed occasionally during the earlier ASME ash tests. This was prevented in the baseline tests by using feed materials of low aspect ratio that were smaller than one-half inch in diameter. On the first day of the test program, the feed tubes bridged with feed material after several hours of operation. This occurred apparently when furnace moisture, evolved from the feed material, were forced back into the feed tubes during positive pressure fluctuations and condensed. The dampened feed material in the feed tubes adhered to the tube walls and bridged. The furnace feed and power had to be shut down while the feed tubes were cleaned out before continuous feeding was resumed. The furnace positive pressure fluctuations occurred primarily when sample ports in the offgas system were temporarily opened for offgas and particulate measurements. This feed blockage occurrence was prevented on subsequent test days by reducing the frequency and duration that sample ports were open, and by increasing furnace draft. Occasional inspections of the feed tubes confirmed that these measures were effective and no additional blockage occurred.

Feed rate measurement and control were generally very reliable. The two variable-speed delivery screws used to meter the feed material into the furnace were calibrated for feed rate. Feed material density measurements were made, by which the instantaneous feed rate measurements were corrected during the tests. The mass of material fed during each test day averaged from the calibrated feed screws typically agreed to within 10% with weight measurements for all of the processed barrels as shown in Table 3-2. Metering variations greater than 10% occurred occasionally when the feed hopper was purposely allowed to run empty to clear feed material from the feed system, when the auger feed rate was less than the gravimetric feed rate. For two test conditions, the auger feed rate was much higher than the gravimetric feed rate. The daily average feed input masses and average feed rates were determined from the weight measurements rather than from the feed screw measurements.

Water-cooled feed tubes were installed prior to the test series so the feed material could be delivered through the feed tubes to within 18 in. of the top of the melt. During the earlier ASME test series, the steel feed tubes were not water cooled and were melted off completely to the furnace roof during early test operations. For the baseline test series, the feed tubes easily tolerated the high temperatures in the furnace at cooling water rates of 20–25 gpm. The maximum temperature rise of the feed tube cooling water was 15°C.

Following the baseline tests, the feed tubes were removed, inspected, and cleaned. A light, fluffy deposit about 1/2 in. thick covered the entire length of the tubes while the tubes were in the furnace, but most of that material was scraped away as the tubes were removed through the roof ports. It is likely that the light, fluffy deposit was an effective thermal insulator during the melting tests. The very thin layer (less than 0.1 inches) of material remaining on the feed tube surface consisted largely of corrosion products (Figure 3-1), which were readily removed by sand blasting. The thin corrosion layer did not penetrate significantly into the steel of the feed tubes.

Feed tube corrosion was not problematic in any way during the operating time of 66 hours for the shakedown test, the preheat day, and the semi-continuous tests. Some corrosion of the feed tubes is unavoidable due to the high plenum gas temperatures and acid-forming chlorides and sulfates in the furnace gas. Corrosion observed in the baseline tests may be conservatively high. The various test conditions may have been more severe than continuous production operations would be due to the repeated heating and cooling cycles during the semi-continuous tests. Furnace gas temperatures were high during each day but were allowed to cool during the night. Corrosion in thermal processes is typically less severe when such temperature cycling is limited. Long-term corrosion may be very low in a continuous operation following the initial buildup of a relatively inert insulating layer of corrosion products. Longer term corrosion resistance, however, is an issue requiring further evaluation for a production arc melter waste processing facility.

By using the feed tubes to deliver the feed material to the top of the melt, a "cold top" of unmelted feed material on the surface of the molten melt was successfully maintained. Also, feed dust generation was minimized. The cold top and the reduced dust generation resulted in far less dust entrainment and fume generation in these tests compared to results of the ASME ash tests. In the ASME ash tests, the feed material fell several feet from the entry ports at the roof of the furnace to the surface of the melt since the uncooled feed tubes had been melted off to the level of the furnace roof during early operations.

Table 3-2. Calibrated auger feedrate compared to gravimetric feedrate.

Feed type	Test day	Auger feedrate (lb/hr)				Gravimetric feedrate (lb/hr)			Feedrate difference (%)
		Operating time (hr)	Maximum	Minimum	Average feedrate	Operating time (hr)	Total feed (lb)	Average feedrate	
S60	7/19/93	9.02	1,613	325	966	9.25	9,806	1,060	8.85
S60-IV	7/20/93	9.18	1,954	245	1,114	10.7	8,273	773	44.13
N80	7/21/93	4.62	1,581	294	954	4.20	4,601	1,095	12.87
N80-Mod	7/21/93	4.13	2,058	260	881	4.30	3,778	879	0.28
N80-IV	7/22/93	5.70	1,460	299	973	5.20	5,518	1,061	8.27
N80-IV-Mod	7/22/93	3.68	1,694	778	1,286	4.25	4,986	1,173	9.61
M60	7/23/93	4.55	1,685	110	1,061	3.10	3,263	1,053	0.79
N80-IV-Mod	7/23/93	2.87	2,048	1,002	1,716	4.60	3,403	740	132
Total average		5.47	1,762	414	1,119	5.70	5,454	979	27.1

Notes:

1. Auger feedrate was obtained from the data acquisition system.
2. Gravimetric feedrate computed as total feed divided by the operating time.
3. Feedrate difference (%) is the percent difference between the auger feedrate and the gravimetric feedrate.

Figure 3-1. Exterior of feed tube showing corrosion products.

3.2.2 Furnace Performance

Continuous melting of feed material was successfully demonstrated in the furnace. Procedures for starting, operating, and tapping were established and demonstrated. Cold top operations were routinely achieved. The furnace power controls, seals, refractory and cooling systems performed satisfactorily. Operating parameters were all well within design conditions and typical of industrial arc furnace practices. Problems that were encountered were:

- A fuse failed in the electrode control circuit. This was resolved by operating the electrode in manual instead of automatic operation until the fuse was replaced.
- Tapping the highly viscous slags through the water-cooled copper slag tapping fixture was difficult. RWMC soil melts at about 1,250°C, but its high viscosity precluded tapping at temperatures below about 1,600°C, with 1,800°C needed to achieve fluidity for continuous tapping. Additions of mill scale increased the fluidity somewhat, but did not significantly lower tapping temperatures. The maximum slag temperature recorded during melting and continuous tapping was 2,000°C, which is considered unnecessarily high, can cause increased metals volatilization, and can cause refractory concerns. The fluidity of the slag was slightly improved by the mill scale, but additional improvement was needed. Limestone (CaCO_3) or pebble lime (CaO) was also added and more effectively reduced the slag viscosity for improved tapping at lower temperatures. Other possible solutions to aid slag tapping could include increasing the diameter or reducing the length of the water-cooled, copper, tapping fixture (to reduce slag cooling while passing through the fixture) or further revising the slag tapping design.
- Dissolution of the furnace hearth refractory (MgO) occurred during some of the test conditions, especially the early S60 test, due to high hearth and slag temperatures, and a slag composition that was very corrosive for the MgO cast refractory. Prior soil contamination in and under the cast refractory due to localized patching over older, used refractory and soil residues may have also contributed. The underlying Ruby (90% alumina, Al_2O_3) brick readily withstood the furnace and slag conditions during the duration of the testing. The refractory dissolution lowered the bottom of the hearth below the level of the metal tap hole, so some material remained continuously in the furnace from one test to another, even after tapping the entire melt through the metal tap hole.

3.2.2.1 Startup. The furnace was started each test day after feeding in several hundred pounds of feed material into the furnace. Since the cold feed material had very high electrical resistance, a triangular course of crushed graphite (from graphite electrode material) and steel turnings was placed on the surface of the feed material in the furnace. Steel turnings alone were not suitable owing to a tendency to cause an open circuit on arc initiation. Crushed graphite, or a duplex layer of graphite and steel turnings, was satisfactory. The latter was used for the baseline tests because of momentarily high CO and temperature peaks observed in the offgas during startup when using graphite only. Lower CO and temperature spikes resulted from using the layered graphite and steel turnings, due to smaller amounts of graphite or dissolution and slower oxidation of some of the C in the melted steel turnings. This conductive starting material was placed so that the three electrodes could contact the graphite/steel starting material when lowered

onto the surface of the feed material. With power applied to the electrodes, arcing to the graphite/steel mixture quickly initiated melting of the feed material. After a few moments, sufficient feed material was molten (with significantly reduced conductivity in the molten phase) to enable continued arcing and initiation of continuous feeding to the furnace.

3.2.2.2 Process Operations. Following initiation of a molten slag, the feed rate and power levels were quite rapidly increased to steady operating levels. Trend charts showing feed rate and power level for each test are shown in Appendices A-F. For each test day, power was typically increased to around 400 kW within just a few minutes after startup. The feed rate was typically increased to over 500 lb/hr within 10 minutes after the power was increased to about 400 kW. Typically within 1-2 hours, the power levels and feed rates were increased to operating levels of up to 600 kW and up to 1,325 lb/hr. The highest short-term power levels and feed rates that were demonstrated ranged to 800 kW (maximum transformer output) and 2,000 lb/hr. Operation on different voltage taps (A, B, C, or D) for providing phase-to-ground voltages ranging from 192-134 V was demonstrated. The phase-to-ground voltage was established by operating on one of the taps A-D. Then the rheostat was adjusted for the desired current level. The current level was the set-point for the automatic electrode positioning controller. When the automatic controller reads actual current as below the set-point, the electrodes were automatically lowered slightly into the furnace for closer contact with the melt (reduced resistance) and higher current. When the current exceeded the set-point, the electrodes were slightly raised by the controller to reduce contact with the melt (increased resistance) and thereby reduce the current. The most stable operation for the feed materials processed was typically achieved using voltage tap B or C, with phase to ground voltage ranges of 168 and 145 V respectively, with the rheostat set at 50-82.

This operation was achieved with the electrodes penetrating slightly into the molten slag bath. In this mode of operation, there was little arcing; heat was generated by joule heating in the melt rather than by electric arc from the electrodes. Lack of an arc was indicated by the power wave-forms on an oscilloscope. These wave-forms were typically smooth curves rather than curves with sharp peaks.

The furnace was generally operated with a "cold top" of unmelted feed burden on top of the molten bath. The cold top was established by initially feeding in material at a rate sufficiently higher relative to the melting rate to produce a layer of unmelted feed material on the top of the melt. The ability of the feed tubes to deliver the feed material in a relatively quiescent manner to the top of the melt also contributed to the ease with which the cold top was established for all of the tests. The theoretical benefits from operating with a cold top include (a) reduced evolution of volatile toxic metals from the melt due to the cooling and refluxing effect of the cold top as volatile gases from the melt pass through the cold top, (b) slower, less violent heatup of feed materials (with reduced dust generation) as they add to the cold top rather than immediately fall into the high temperature melt, (c) cooler plenum gas and upper furnace surface temperatures due to the shielding effect of the cold top on radiation heat transfer from the melt, and (d) higher bulk slag temperatures for a given power input due to the thermal insulating effect of the cold top layer. Cooler plenum gas temperatures also reduce the formation of thermal NO_x from oxidation of N_2 in the furnace plenum.

The presence of the cold top did indeed have significant effects. In comparison with the previous ASME tests where the cold top was not maintained, the particulate entrainment and gas temperatures in these baseline tests were indeed significantly lower. However, no quantitative correlations were established between the thickness of the cold top and the furnace outlet NO_x levels, the upper furnace refractory wall temperature, or the furnace outlet duct wall temperature. Apparently, from the existing data, the presence of any measurable cold top was as effective as many inches of cold top on the melt for achieving the above listed benefits. While the cold top thickness and related pool surface area covered should theoretically affect furnace temperatures, the measurement of the cold top depth under only one of the feed tubes was not sufficiently representative of the entire surface of the melt to reliably correlate to measured temperatures or other parameters. A more representative measurement method should be developed for subsequent tests to determine cold top depth and coverage.

During startup, furnace plenum temperatures quickly reached steady state levels while slag temperatures increased and the melt front moved out towards the furnace wall. Heatup of a completely cold furnace can take more than six to eight hours. For the baseline tests, a preheat day was used to allow near steady state temperatures to be achieved before the waste feed test processing series. Partial furnace cooldown at night was then overcome within the first two to four hours of heatup each subsequent test day.

Electrode consumption was reasonably low, averaging 11.9 lb/ton of feed material, even though (a) the furnace operated in a relatively oxidizing mode, with oxygen levels at the outlet of the furnace ranging between 8 to 15% (dry basis), and (b) the electrodes were still exposed in the hot furnace after shutdown each test day, while no material was fed to the furnace. It is likely that electrode consumption compared to feed input would be even lower in continuous operation. The electrodes were not severely tapered. This has two important implications: (a) the electrodes were not severely attacked by hot gases in the furnace plenum during processing, and (b) oxidation of the hot electrodes within the furnace after feeding was stopped and power shut off (but while the furnace interior was still warm) was not severe. The relatively cool furnace gases (typically ranging from 300–700°C during operation) contributed to the low electrode consumption.

Plots of furnace pressure versus time are provided in Appendices A–E. The furnace operated at an average draft of -0.8 to +0.008 in. H_2O . The furnace draft was established by manually adjusting the speed of the ID fan. Initially, the furnace draft was set to be -0.1 to -0.2 in. H_2O , but in order to better control fugitive emissions and avoid back-pressuring gases into the feed system, the average draft was increased as the baseline tests progressed until the draft reached -0.8 in. H_2O . The higher draft provided better control of short-duration positive pressure excursions in the furnace. Such occasional pressure fluctuations of 0.1 to 0.5 in. H_2O occurred largely due to temporarily opening sampling ports in the APCS for inserting and removing sample probes. This condition would not typically occur in a production waste treatment system, so such pressure fluctuations would not be expected.

Frequent, but smaller, furnace pressure variations have been attributed to variations in gas temperatures and variable gas generation rates due to periodic sluffing of feed material into the melt from the cold top. The amount of pressure fluctuation related to volatilization and material sluffing may be affected by the gas and melt temperatures, the furnace power input, and the feed

composition. At higher temperatures and power levels, the pressure fluctuations from a given material sluff can be more extreme due to the more rapid heatup and evolution of volatiles in the sluffed material. The feed composition, particularly the presence of solids such as carbonates that evolve gases upon heating, also strongly influences the magnitude of pressure fluctuations due to sluffing. These effects were observed for the N80, N80-Mod, and the N80-IV-Mod tests. During the N80 test, the furnace operated stably with the phase-to-ground voltage setting of 168 V (transformer tap B). Furnace pressure fluctuations increased and electrode control became unstable during the N80-Mod test at the same phase-to-ground voltage setting (transformer tap) as for the N80 test. Furnace conditions were restabilized by reducing furnace voltage to 145 V (which reduced the furnace power). The furnace instability appeared to be related to the difference in the amount of volatile materials and particle sizes of the two feed mixtures. The main difference was the addition of finely divided limestone in the N80-Mod mixture, which increased the combined calcium, sodium, and potassium carbonates from 27 to 33%, compared to the N80 mixture. The limestone in the N80-Mod test may also have affected the rheology of the feed material, resulting in more periodic slumping of cold top material into the melt and attendant rapid gas generation than for N80. For the later N80-IV-Mod test, pebble lime (CaO) was used instead of limestone (CaCO_3). Furnace stability was improved, confirming the limestone as the source of instability during the N80-Mod test.

Almost all thermal systems, including furnaces, typically operate under slight negative pressure to prevent positive pressurization during pressure fluctuations. Even when well sealed, furnaces operating under negative pressure will experience some inleakage of "tramp" air. Avenues of normal air leakage into the furnace were (a) the feed tubes, along with the feed material flow, (b) seals around the three moveable electrodes, and (c) other entry points such as seals around the feed tubes. Air inleakage with the feed material through the feed tubes was minimized using a rotary valve in the feed system at the top of the furnace. Air inleakage through stationary seals in the joint between the furnace lid and the sidewalls, and between the feed tubes and ports in the furnace roof, was minimized by tightly packing and sealing these connections. Air inleakage around the electrodes was less easy to minimize because the seals had to be sufficiently loose to allow up and down movement of the electrodes without binding.

This air inleakage provided oxygen for oxidizing components in the feed materials such as trace amounts of organic materials, chlorides, reduced metals, and reduced sulfur. With the small amount of organic and reduced (unoxidized) materials present in the feed mixtures the amount of air inleakage was sufficient to provide an oxidizing atmosphere in the furnace plenum.

The amount of reactant air (or oxygen) supplied to the furnace plenum will need to be increased in future planned tests when feeding materials with significantly higher amounts of fixed carbon (such as solidified organics, wood, graphite waste, etc.) to oxidize the carbon and remove it from the melt. Maximum levels of carbon in the cooled slag (glass/ceramic), that are compatible with acceptable immobilization performance of metals and radionuclides in the slag, are not yet well established. Also, excess carbon buildup in the furnace may impair electrical performance by short circuiting the arc and joule heating pathways. Minimization of carbon in the slag via complete oxidation is therefore desirable.

Some of the feed mixtures exhibited significant gas evolution, primarily through water vaporization (moisture content and also water of hydration) and decomposition of carbonates and

sulfates to CO_2 and SO_2 . The measured mass of feed material that evolved as gas from the melt averaged 13% by weight. The furnace and APCS readily tolerated these amounts of volatilization, although the gas flow (air inleakage and evolved gases) from the furnace tended to entrain the less dense and finer feed material particles.

Solid material captured in the furnace offgas system resulted from a combination of (a) the entrainment of feed material fines, and (b) volatilization of materials from the high temperature melt followed by condensation in the APCS. Comparison of the solid material captured in the fume traps and the baghouse with the total solid and condensable particulate collected in the MMT samples indicates that essentially all of the volatilized material condensed and was captured as particulate in the APCS. Volatilized matter may homogeneously condense as very fine fume particles in the gas flow or heterogeneously condense on the surfaces of entrained feed particles in the gas flow, or on the interior surfaces of the furnace and the APCS. Total particulate, by definition, includes all entrained feed material, condensed fume and volatilized material that has not yet condensed to solid form, but would do so at ambient conditions. The total particulate measured in the baseline tests APCS flow averaged 2.0% of the feed material.

The total particulate concentration (13–38 gr/dscf) in the furnace offgas was determined from MMT measurements made downstream of the air dilution quench section. These particulate concentration levels are high compared to other combustion equipment, such as controlled-air incinerators that are designed and operated to minimize particulate entrainment. However, the levels are not high compared to fluidized bed combustors and aggregate processing equipment such as sieves and crushers where significant fines generation exists. Good APCS designs, commonly used for controlling such high concentrations of particulate, include cyclonic separators to remove coarse material, followed by a baghouse to efficiently remove the fine particulate. The USBM arc melter facility APCS uses this approach, with the added assurance of a HEPA filter for redundant, high efficiency, particulate filtration.

Continuous slag tapping was achieved when the slag viscosity was sufficiently low (fluid) to enable flow through the slag tap hole. Slag viscosity is a function of slag temperature and composition. Higher slag temperatures (which lowers viscosity) were required for continuous tapping when the slag composition basicity ratio was significantly less than unity. The basicity ratio is the molar ratio of total basic oxides to total acidic oxides in the slag. The basicity ratio is a useful indicator of slag viscosity, melting temperature, and refractory compatibility. A slag with basicity ratio less than 1 is considered acidic, greater than 1 is basic. Acidic slags are more viscous. With high proportions of soil in the surrogate waste mixtures, the resultant slags had high silica (SiO_2) levels and were highly acidic (viscous). Appendix R contains additional background discussion. High silica content in the cooled slag product (glass/ceramic) is desirable for low leachability, high strength, and durability.

The water-cooled copper tapping fixture performed successfully over a wide operating range, from a tapping rate minimum of about 800 lb/hr to a maximum in excess of 2,000 lb/hr. The tapping fixture doesn't assert any active control over tapping rate. It simply acts as a port, on or off, and is designed to be resistant to erosion and corrosion under repeated usage. The flow rate is fixed by slag viscosity, tap fixture inside diameter and length, and the static pressure head from the height of molten slag above the tap hole. Slag viscosity is determined by temperature and composition and the static pressure head is determined by feed rate versus tap flow rate. The

water cooled tap fixture cools the slag to some extent as it passes through. The slag temperature was continuously measured at the slag tap (during tapping) using an external infrared pyrometer. Once slag tapping was initiated, it was maintained continuously by maintaining existing slag temperature and feed to the furnace.

Many components of the furnace system were water-cooled to ensure safe operation and provide better material resistance to the high heat loads. These included the power supply equipment (transformer, electrode arms, cables, and clamps), feed tubes, the furnace roof and sidewalls, the roof seal, the slag tapping fixture and launder, and the metal tap-hole. The cooling system operated well during the test program. Water flowrates and outlet temperatures were measured separately for each cooled component during furnace operation. Flowrates ranged around 25 gpm for each cooled component, and the water temperature increase was typically less than 6°C except for the feed tube cooling water, which had a temperature increase of up to 15°C.

Thermal conditions in the furnace were indicated during operation using thermocouples at various locations in the furnace. Temperature measurement in electric furnaces is difficult for many reasons, including thickness of the refractory, high temperatures, high dust levels, electrical continuity and grounding, radiant heat transfer, and growth of deposits that shield thermocouples. This test furnace was no exception, but was instrumented with several thermocouples where possible. Locations and temperatures observed were:

- Hearth refractory temperature (T_7 on Channel 7 of the DAS). Since the thermocouple (TC) was embedded in the grout sealing the metal tap hole, this measurement was not expected to be the temperature at the interface of the hearth refractory and the melt, but was an intermediate temperature between the interface temperature and the steel shell temperature. Typical temperatures at startup were 35–75°C, and temperatures typically increased to 115–450°C by the end of each test day. This TC was destroyed at the end of each test day when the metal tap hole was opened to drain the furnace. It was then replaced prior to the next test.
- Furnace bottom shell outside temperature (T_8 on Channel 8 of the DAS). This TC was used to monitor the shell temperature at the furnace bottom, where the surface was not cooled by the water curtain cooling the sidewalls. Typical temperatures at startup were 90–150°C, and temperatures typically increased to 190–315°C by the end of each test day.
- Sidewall refractory temperature (T_6 on Channel 6 of the DAS). This TC was near the inner surface of the wall refractory, and was frequently covered with melt material deposits. Since the TC was usually covered with deposits, it did not indicate the temperature of the inner surface of the refractory, but an intermediate temperature between the refractory surface temperature and the water-cooled steel shell. Typical temperatures at startup were 50–115°C, and temperatures typically increased to 150–500°C by the end of each test day.
- Furnace offgas outlet duct wall temperature (T_2 on Channel 2 of the DAS). This TC was located in a small access port almost flush with the inner wall of the steel duct, just downstream from the water-cooled furnace roof connection. This temperature was an

intermediate temperature between the offgas temperature and the temperature of the water-cooled section.

The measured temperatures indicate that the water cooling was effective in thermally protecting the furnace sidewall refractory and the furnace shell. Post test observations showed that there was no thermal damage to the steel shell or the sidewall refractory.

Bulk slag temperature readings were taken at a single location in the furnace slag melt by inserting a sacrificial platinum-rhodium TC through a furnace roof port and into the slag near the melt center. These single manual TC readings were taken prior to attempting tapping and they indicate lower temperatures due to lower power conditions at the time of measurement. Later slag tap temperatures measured by an infrared pyrometer are higher since, upon attempted tapping, insufficient slag fluidity was observed and power levels were raised to increase slag temperature to achieve steady tap flow. Analytical modeling to relate the various temperature readings taken at different locations and conditions to the slag temperature is being developed, but is not presently available. Therefore, the infrared pyrometer readings are believed to be the best indication of slag temperatures for the baseline tests.

Additional and more direct temperature readings within the furnace are needed. A proposed method using a millimeter wave radiometer is currently under development at MIT that may be useful for future tests. In the interim, additional TCs are needed as are analytical heat transfer models to properly interpret TC readings.

3.2.2.3 Furnace Refractory Performance. The hearth was constructed of MgO cast refractory with underlying Ruby bricks. Even though the hearth temperature measurement did not indicate temperatures sufficiently high for melting the MgO cast refractory hearth, significant dissolution of this refractory occurred. Mass balances for MgO show that a minor amount (10 lb) of refractory dissolved into the melt during the soil shakedown test, and the remainder of the MgO refractory (910 lb) was dissolved during the S60 and S60-IV tests. Dissolution occurred due to contact with high temperature slag that was very corrosive for the MgO cast refractory. Prior soil contamination in and under the cast refractory (from localized repair of the original refractory) may have also physically contributed to the hearth erosion by weakening the refractory and enabling penetration of slag into cracks. The Ruby bricks used to line the steel shell were undamaged and showed no evidence of contact with or attack by molten slag. A metal heel remained for all subsequent tests and may have aided in protecting the bottom brick from high temperature slag attack. Essentially all of the MgO refractory was dissolved during the S60 test day. It is clearly necessary to evaluate the compatibility of alternative hearth refractory materials with the acidic slags produced for future applications testing. Operation with a metal heel as a hearth protective measure should also be considered.

The refractory dissolution lowered the bottom of the hearth below the level of the metal tap hole. Therefore some material remained in the furnace from one test to another, even after tapping the entire melt through the metal tap hole. The estimated slag carryover from test to test following the S60 test was 600 lb.

3.2.2.4 Localized Iron Reduction. High power input to increase slag temperature and decrease slag viscosity resulted in the carbothermic reduction of iron oxide to metal during several

of the tests. Viscous (high silica) slags are susceptible to localized high temperature reduction of metal oxides by electrode carbon under conditions of high power input. This occurred during the baseline tests. The high energy density near the electrodes and the inability of the viscous, low conductivity slag to dissipate heat led to high local temperatures and reduction of some of the iron oxide by oxidation of some of the carbon in the electrodes. Material balances in Section 4 indicate that iron was produced in this manner in all tests but the M60 test, in which elemental Fe was fed to the furnace and melted directly. Table 3-1 shows the amount of metal product provided by this reduction in each test. Metal was not observed, however, either while tapping the hearth or in the tapped slag ingots after cooling. The metal was retained within the furnace hearth and carried over to each succeeding melt. During the baseline tests, following dissolution of the entire MgO hearth, there was plenty of room in the furnace below the metal tap hole for this reduced metal to reside.

In the soil shakedown test, when significant MgO dissolution did not occur, the metal was also not tapped from the metals tap hole. In this case the reduced metal present on the hearth was not molten at the time of furnace draining. It is not unusual for reduced or melted metal to remain on the hearth as a semi-consolidated agglomeration of prills if the temperature of the hearth does not exceed the melting temperature of the metal. The short time devoted to the shakedown test, together with a very viscous slag having poor thermal conductivity, renders it likely that the metal on the hearth was not molten when the hearth was tapped. Solid metal on the hearth at the end of the melting test equates to low hearth temperature and also explains the absence of significant dissolution of the hearth by the slag.

3.2.3 APCS Performance

The APCS was designed to cool the hot furnace offgases and control furnace particulate emissions while minimizing fouling of the ductwork from deposited solids. Evaluation of the offgas emissions (both gaseous and particulate) and system performance was done using measurements and analyses of gas temperatures, velocities and flowrates, static pressures, gas composition, total particulate, and particulate composition. Without exception, the APCS performed as designed.

3.2.3.1 Offgas Cooling and Accretion Control. Hot offgas exited from a port in the roof of the furnace through a water-cooled duct that connected to the temperature quench section. The offgas was cooled by dilution with ambient air in the quench section. The average temperature difference between the furnace outlet and the inlet to the baghouse was 350°C for all runs except M60, where the temperature difference was approximately 1,040°C. The M60 runs produced higher overall temperatures than any of the other runs.

With a design dilution factor (ratio of the quench outlet flowrate compared to the furnace outlet flowrate) of 5:1, the temperature quench section had the capacity to cool the furnace offgas from over 900 to 200°C, the maximum temperature for preventing thermal damage of the bags in the baghouse. Baghouse inlet temperatures never exceeded the 200°C limit except for a few moments at startup on the S60 test, when oxidation of the graphite starting material in the furnace, and possibly oxidation of resultant CO in the offgas, caused high offgas temperatures. Temperature excursions at startup were less severe on successive test days due to the use of less

graphite starting material, and possibly some dissolution of some of the starter graphite in the molten starter iron.

During operation, there was no perceptible buildup of accretions in the furnace outlet duct, the wind box for the quench section, or the horizontal ductwork and heat exchange section leading to the baghouse. Post-test inspection of these sections verified only a minimal dust layer on the inside surfaces of the APCS equipment and duct. This minimal deposition was very much lower than rapid deposition and consequent duct blockage observed during the previous ASME municipal incinerator ash vitrification tests. Differences between the BWID baseline tests and the ASME ash tests that could have contributed to the reduced deposition include:

- Different particle sizes of the feed mixtures—the municipal incinerator ashes were 8–75 wt% less than 100 mesh (150 μm) compared to around 3% less than 100 mesh for the soil (based on measured particle sizes for soil at the INEL Test Reactor Area Warm Waste Pond, several miles from the RWMC).¹⁰
- Lesser amounts of potentially fouling elements in the feed mixtures—Potentially fouling elements include Cl, Na, and S. Carbon can also contribute to fouling if present as soot, high-molecular weight oils and tars that can condense on cooler APCS surfaces. There was very little organic carbon in the surrogate waste mixtures, and organic carbon was present only as trace amounts of organic matter in the soil. Carbon levels in the municipal incinerator ashes were 3.8–16.1%, and much of this carbon was likely organic carbon that could form soot or other condensed compounds in the APCS. Cl, Na, and S in the BWID surrogate waste mixtures were below 1.3%, 5.3%, and 1.4% respectively. Cl, Na, and S in the municipal incinerator ashes were up to 20.2%, 3.1%, and 4.1% respectively.
- Different operating conditions—furnace gas temperatures were higher during the municipal incinerator ash tests, and oxygen levels from air leakage into the furnace atmosphere were maintained under 5% using N_2 blanket gas. This more reducing condition during the municipal incinerator ash tests likely increased the propensity for soot, tar, and oil formation and condensation, and also increased the formation of condensible chlorides and sulfur compounds that would have been oxidized under more oxidizing conditions. A cold top could not be maintained on the melt for the municipal incinerator tests. The cold top during the BWID baseline tests reduced volatilization of condensible metals, and also reduced gas temperatures in the plenum by minimizing thermal radiation from the melt.
- Recent modifications—Several modifications were made to the furnace and offgas system following the ASME tests. These included a mechanical scraper at the outlet of the furnace, the use of air dilution to rapidly quench the offgas and increase entraining flow velocities for particulate condensed and present in the ductwork, and two fume traps. The furnace outlet duct was water-cooled steel, and the mechanical scraper was used to physically scrape off any deposits on the cooled wall. The scraper was used less and less during the baseline tests, because no deposits built up on the cooled surface. The cooled surface may have tended to prevent the formation of strong bonding between potential particulate deposits or sticky condensates and the surface.

Rapid cooling of the offgas to form solid particulate in the temperature quench section, coupled with high flow velocities and rapid mixing, is believed to have minimized condensation and deposition of solid material on the duct surfaces. The added dilution air also increased gas velocities and minimized opportunity for solids deposition in the downstream ductwork. Gas velocities in the 6-in. diameter APCS ductwork typically exceeded 50 ft/s, high enough to maintain significant particulate entrainment. Typical duct velocities for particulate laden offgas streams range in thermal processes between 10–60 ft/s.

The furnace outlet offgas temperatures were measured periodically during the demonstration tests using a thermocouple inserted into the offgas stream through a port in the furnace outlet duct. The furnace outlet offgas temperatures were also calculated using an energy balance and the gas temperature measured downstream of the temperature quench section, the temperature of incoming quench air, and the quench air flow rate (dilution factor). Furnace outlet offgas temperatures were around 300–700°C for all baseline tests except the M60 test, which averaged almost 1,200°C. Oxidation of elemental metals in the M60 feed mixture may have contributed to this increase in furnace gas temperature. Metals partitioning results for the M60 test show that essentially all of the aluminum (5.85% of the feed), almost all of the chromium (1.7% of the feed), over 90% of the copper (0.74% of the feed), approximately one-third of the iron (26.8% of the feed), and significant portions of the lead and zinc (0.74% and 1.5% in the feed) oxidized and dissolved into the slag.

4. FATE OF FEED MATERIALS, METALS, AND TRU SURROGATE

Arc melter vitrification of radioactive and mixed wastes can thermally separate heterogeneous waste mixtures into a few, more homogeneous, easily handled and characterized output streams. The TRU elements and most toxic metals can be permanently stabilized in the glass/ceramic product, which can have very durable, nonleaching properties suitable for shipping and permanent disposal. Other metals, such as recyclable structural metals, may be decontaminated of radionuclides and RCRA hazardous components and separated in the metal alloy product. Hazardous organic contaminants are thermally destroyed. Furthermore, arc melting can achieve substantial waste volume reduction and homogenization of product materials, resulting in direct cost savings for subsequent waste characterization, shipping, storage, and disposal.

Successful implementation of arc melter technology for vitrifying radioactive and mixed wastes depends not only on the production of a durable and nonleachable slag, but also the minimization and control of offgas, particulates in the offgas, and production of a metal product only if readily disposable or recyclable. Most critical is the control of hazardous and radioactive contaminants by oxidizing the hazardous organic matter and immobilizing the hazardous metals and radionuclides, especially the TRU isotopes, in the slag monolith. Much of the sample collection, sample analysis, and on-line measurements were made during the shakedown and baseline tests to evaluate the fate and partitioning of feed materials, toxic metals, and a TRU surrogate during the arc furnace vitrification process.

4.1 Input and Output Mass Balances and Feed Material Partitioning

Mass balances were performed to compare the mass of output products to the mass of input products and to identify partitioning (distribution) of the feed materials among the output products (slag, metal, and offgas). A simplified process model of the furnace is shown in Figure 4-1. Mass inputs to the furnace include the feed material, oxidation of the graphite electrodes, air inleakage with the feed material and through seals in the furnace and dissolution of the hearth refractory (as discussed in Section 3).

Heat was generated during the baseline tests primarily by joule heating in the slag between the electrodes rather than by electric arc from the electrodes. The electrodes slightly penetrated into the slag, as indicated by the power wave-forms and the related reduction of iron oxide in the high temperature zone near the electrodes.

Furnace mass outputs include the tapped glass/ceramic slag product, the tappable metal product, and the furnace offgas. The offgas includes the gases evolved from the melt, gaseous oxidation products, air inleakage into the furnace that mixes with the evolved gases, entrained feed dust, and volatilized materials (that condense upon cooling).

In normal operation, the feeding and slag tapping was continuous. A cold top was formed by initially feeding in material at a rate faster than the melting rate. The thickness of the cold top was maintained relatively constant by matching the feed rate and the melting rate. With the three electrodes arranged near the center of the furnace and the four feed tubes arranged outside the

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Figure 4-1. Simplified process model of the furnace.

perimeter of the electrodes, unmelted feed material (cold top) probably built up under each feed tube. The buildup potentially was up to 18 inches, which was the distance between the level of the slag tap hole (top of the melt during continuous tapping) and the end of each feed tube. Cold top depth at one location beneath a feed tube was determined from measurement of surface locations using a manual depth plumb bob. Cold top depth ranged from 3 to 10 inches during all but the early startup portions of each test feed run.

Continuous cold top coverage may have occurred on the melt between the feed tubes and the furnace wall. The continuity of this coverage depends on the angle of repose and height of the cold feed material under each feed tube, crusting or agglomeration of the feed material, and turbulence of the melt. This could not be visually observed during operation due to dust generation in the furnace. Dust was generated from (a) direct entrainment of feed material in the air entering the furnace through the feed tubes with the feed material, (b) feed dust entrainment from the cold top in gases evolved from the melt, and (c) dust blown into the furnace gases from turbulence during rapid heating and from the arc zone.

Cold top coverage was unlikely within the perimeter of the three graphite electrodes in the center of the furnace. In this high temperature zone between the electrodes and in the melt directly below the electrodes, the high melting rate and turbulence may prevent the formation of an unmelted cold top. Temperatures in this central area may be much higher than needed for melting the feed material, due to relatively low thermal conductivity of the slag, on the order of 10 times lower than metal thermal conductivity. The localized redox conditions in this zone may also be more reducing in both the molten bath and the local gas above the bath, due to (a) limited ingress of oxygen-containing plenum air as gases evolve from the melt, and (b) consumption of available oxygen through oxidation of feed materials and the graphite electrodes.

If, as expected, a cold top effectively covers the melt outside the region of the electrodes, then metals volatilization from the melt between the feed tubes and the furnace wall may be minimized by the cooling and reflux filtering action of the cold top as hot gases and volatilized metals pass through the cold top. The greatest amount of metals volatilization may be from the small but high temperature area between the electrodes, where there is no cold top and local gas and melt temperatures are the highest. The relatively more reducing conditions in this area would be expected to increase the generation of more volatile reduced metal species including elemental metals and metal chlorides.

The total furnace mass balance is shown in Table 4-1. The percentage distribution of the total input mass among the output streams is shown graphically in Figures 4-2 (a) and (b). Overall mass balance closure (the value of the sum of output masses divided by the sum of the input masses) was 0.96 to 1.08, and averaged 1.01. An average of 84% of the feed material stayed in the slag, 2.9% separated as metal product, and only 2.0% evolved with the offgas as total particulate. About 13% of the feed material volatilized as H_2O , CO_2 , CO , HCl , and SO_2 . These gases were from absorbed moisture, water of hydration, carbonates, small amounts of organic material, chlorides, and sulfates in the feed mixtures. This level of gas evolution was consistent with expectations based upon pre-test LOI measurements on the feed mixtures.

Total input mass partitioning to the slag and the offgas products varied little for all of the baseline test conditions. Most of the input mass reported to the slag phase. The total APCS

Table 4-1. Total mass balance closure.

Test day	Feed type	Total input feed amount (a) (lbs)	Electrode consumption (lb)	Total slag tapped (b)		Total metal product		Total APCS solids (c)		Total moisture evolution (d) (lb)
				(lb)	(wt % of initial feed mass)	(lb)	(wt % of initial feed mass)	(lb)	(wt % of initial feed mass)	
7/19/93	S60	10,716	63.7	9,040	84.4	40	0.37	141	1.32	624
7/20/93	S60-IV	8,330	49.5	7,019	84.3	1	0.01	164	1.97	606
7/21/93	N80	4,601	27.3	4,069	-	33	0.72	109	2.37	289
7/21/93	N80-Mod-1	3,778	22.5	3,341	-	28	0.74	122	3.23	222
	Daily total	8,379	49.8	7,410	88.4	61	0.73	231	2.76	510
7/22/93	N80-IV	5,518	32.8	4,612	-	96	1.74	112	2.03	414
7/22/93	N80-IV-Mod-1	4,986	29.6	4,168	-	86	1.72	126	2.53	257
	Daily total	10,504	62.4	8,780	83.6	182	1.73	238	2.27	671
7/23/93	M60	3,263	19.4	0	-	789	24.2	53	1.62	187
7/23/93	M60-Mod	3,403	20.2	5,224	-	0	0	68	2.00	136
	Daily total	6,666	39.6	5,224	78.4	789	11.8	121	1.82	323
	Average	8,919	53.0	7,495	83.8	215	2.94	179	2.02	547
	Totals	44,595	265	37,473		1,073		895		2,734

a. Based on total weight of feed material plus MgO refractory dissolution.

b. Calculated from slag pots collected

c. From combined catches in fume trap 1, fume trap 2, and baghouse

d. From offgas moisture measurements during offgas metals/particulate runs, calculated for entire test duration in proportion with the relative amount of feed material processed during the metals/particulate runs compared to the entire test (less moisture contribution from ambient air humidity). Water of combustion from H in feed materials is assumed to be negligible.

e. CO and CO₂ from oxidation of the graphite electrodes is assumed to be negligible, although it is accounted for in the total mass balance for all test days.

f. Assumes that SO₂ evolves from the feed and that the contribution of reduced sulfur species in feed (S, H₂S, etc.) that oxidize to SO₂ is negligible.

g. Calculated HCl levels based on Cl mass balance, assuming no production of Cl₂.

h. Sum of output mass/Sum input mass.

NC = Not Calculated.

Table 4-1. (continued).

Feed type	Total carbon dioxide evolution(e)		SO2 evolution(f)	HCl evolution(g)	Total gaseous evolution		Total corrected output mass (lb)	Mass balance closure(h)
	As CO (lb)	As CO2 (lb)			(lb)	(wt. % of initial feed mass)		
S60	38.4	239	112	86.1	1,100	10.3	10,321	0.96
S60-IV	56.4	254	137	55.7	1,109	13.3	8,293	0.99
N80	NC	NC	0.052	0	NM	NC	NC	NC
N80-Mod-1	48.4	343	0.205	0	613	16.2	4,104	1.08
Daily total	NC	NC	0.256	0	NC	NC	NC	NC
N80-IV	54.1	506	1.48	0	976	17.7	5,796	1.04
N80-IV-Mod-1	31.6	241	0.63	0	530	10.6	4,910	0.98
Daily total	85.7	747	2.11	0	1,506	14.3	10,706	1.01
M60	12.5	158	0.044	0	357	11.0	1,199	NC
M60-Mod	16.0	201	0.042	0	353	10.4	5,645	NC
Daily total	28.5	359	0.086	0	711	10.7	6,845	1.02
Average	51.5	388	50.3	28.4	1,008	13.0	8,054	1.01
Totals	257	1,942	251	142	5,038		40,268	1.01

Figure 4-2 (a). Feed material partitioning to the output products [Total is the sum of the slag, metal, offgas, and APCS solids (from MMT)].

Figure 4-2 (b). Feed material partitioning to entrained feed and condensed volatiles.

- Notes:
1. Entrained feed includes material from the fume traps as well as a portion of the baghouse catch that was assumed to be entrained feed material.
 2. Condensed volatiles was the portion of the baghouse catch assumed to be condensed volatile material.

solids were a small fraction of the total process mass and included both directly entrained feed dust and also volatilized materials from the melt. Because of the small amounts of APCS solids, there was greater relative variation in APCS solids from test condition to test condition.

The volatilized metal compounds (reduced and oxidized forms) began to condense as soon as the offgas cooled in the offgas system. The entrained feed dust and the condensed fume particulate were captured in the APCS fume traps and the baghouse. There were two independent determinations of APCS solids made during the baseline tests. Solid particulate emissions were determined by (a) quantitative recovery of the solids captured in the fume traps and baghouse, and (b) isokinetic sampling and analysis of the APCS flow using the EPA MMT modified to quantify not only emissions of individual metals but also total particulate. The solids recovered in the fume traps and the baghouse are representative of the integrated emissions to the APCS during the entire run time of each test condition. Since the operating temperatures and feed rate varied during each test condition from startup to completion, the amounts and composition of the recovered solids may be somewhat different than would be obtained from a long-term continuous operation under more constant conditions. The MMT samples were collected during discrete sample times for each test condition, when the operating conditions were more constant. The MMT results may be considered more representative of long-term continuous operation under more constant conditions.

The MMT is designed to sample all of the solid material in the offgas and also any volatilized metals not yet condensed. The MMT results would be significantly higher than the total captured APCS solids if the slag temperatures were higher, causing more metals volatilization during the MMT test periods, or if significant amounts of volatilized metals were not captured in the baghouse or fume traps.

The measured levels of many metals from the MMT samples were indeed larger than the measured levels from the APCS catches, even though the total particulate mass emission rate measured using the MMT and from the APCS catches were very similar. The masses of metals collected in the MMT samples was done during slag tapping periods for all test conditions except the M60 test, so slag temperatures were higher than during earlier periods in each test when the slag bath was being heated up to tapping temperatures. Higher amounts of metals collected during the MMT runs were likely, due to higher metals volatilities caused by the higher slag temperatures. Incomplete capture of volatilized metals in the fume traps and the baghouse, or deposition onto the internal APCS duct surfaces, may also contribute to this difference. The HEPA filter was used as a final, high efficiency filtration step to assure that even a small amount of sub-micron fume that may have passed through the baghouse was not vented to the atmosphere. However, no data from the HEPA filter is available.

Because of the possible presence of some uncondensed or otherwise uncollected volatile metals in the offgas, the metals mass emission rates reported in Section 6 are based on the MMT flow sampling results rather than the integral APCS catches. The overall total and elemental mass balances, based on the day-long operation, however, were calculated using the measurements from the APCS catches because the mass of volatilized metals not captured in the APCS was very small relative to those in the other output streams. Also, the differentiation between entrained and volatilized particulate was easier to determine using the fume trap and baghouse catches, as discussed in the following section.

4.1.1 Entrained and Volatilized Particulate

Fume condensation may be heterogeneous as materials condense onto existing particles entrained in the offgas or onto internal surfaces in the APCS. Condensation may also be homogeneous as vapors condense onto nucleation sites, resulting in new fume particles. Unless significant agglomeration of these fume particles occurs, these particles are characteristically very small, under 1 micron in diameter. Even in heterogeneous condensation, the condensed toxic metals are often concentrated on smaller particles due to their larger surface areas compared to particle mass. Conversely, the largest mass of entrained feed dust may be concentrated in the larger particle sizes, because of the smaller surface area compared to particle mass.

Chemical and physical analysis of the fume trap and baghouse catches (discussed in Section 5) suggests that the material captured in the fume traps was primarily larger particles of entrained feed material, while the baghouse catch was smaller particles enriched in some condensed volatile species (fume). This finding was consistent with the expected performance of the fume traps, which were designed to be quasi-cyclonic collectors of larger-sized particulate. The baghouse was a much more efficient total filtration collector of even very small-sized particulate. Well designed and operated baghouses can readily exceed 99% collection efficiency. The higher concentrations of condensed volatiles in the baghouse are also consistent with the expected homogeneous and heterogeneous condensation of volatile material in and on small sized particulate, with minimal condensed volatile matter associated with larger particles.

The assumption that all entrained feed is caught in the fume traps, and that the baghouse contains only condensed fume is not totally correct. In reality, some of the fume likely condensed on the surfaces of the entrained particulate, and was captured in the fume traps. Also, much of the fine material in the baghouse was certainly entrained feed material fines too small to be captured in the fume traps. The mineralogy analysis (Section 5) suggests that the material in the fume traps and much of the material captured in the baghouse was entrained feed particles. For this analysis, it was assumed that the fume traps contained only entrained feed, and the baghouse contained both entrained feed and condensed volatiles.

The amounts of entrained and volatilized particulate in the baghouse were estimated for each test condition by comparing the concentrations of the different elements in fume trap 1, fume trap 2, and the baghouse. As discussed in Section 4.2.2, increasing concentrations from fume trap 1 to the baghouse suggest volatilization of those elements rather than entrainment. Oxides of those elements in the baghouse catches that increased in concentration from fume trap 1 to the baghouse were summed to approximate the total portion of each baghouse catch represented by volatilized matter. The remainder (the sum of the oxides of those elements that did not increase in concentration from fume trap 1 to the baghouse) was used to approximate the material in the baghouse catches that was entrained feed. Assuming only oxides for these elements rather than also carbonates and chlorides can introduce some error in these approximations. However, this error is within 10% or less, as shown by summing all of the oxides in Appendix K.

The partitioning of feed material to entrained feed and to volatilized matter approximated in this manner is shown in Figure 4-2 (b). The total partitioning of feed material to the offgas solids (both entrained feed and volatilized matter) as measured by the total fume trap and baghouse

catches and as measured by the MMT sampling is also shown. These two independent measures of total APCS solids are in relatively good agreement, with the combined fume trap and baghouse measurement somewhat higher than the MMT measurement for four of the five runs and the total average of all runs.

Attempts to correlate the variations in the mass partitioning to the APCS solids from test to test with theoretical causes for the variations such as slag temperatures, feed compositions, feed particle sizes, furnace feed rate, presence of cold top, and power levels were largely unsuccessful. This was due to a combination of the limited amount of replicate data, slight but competing variations in operating conditions from test to test, and limited feed particle size data. One comparison that did show a correlation as expected for the total APCS solids is shown in Figure 4-3. This figure shows empirically an increase in the total APCS solids (measured from the fume traps and baghouse catches) with increasing volatiles (evolved gas) content of the feed mixtures. The volatiles content was calculated by mass balance using the flowrate and composition of the offgas for each test. The increase is attributed to the increased entrainment of feed dust and fume in the increased gas evolution from the melt.

4.1.2 Volatilization (Gas Evolution) from the Feed Materials

The feed mixtures contained varied levels of constituents that decomposed, vaporized, or chemically reacted and then vaporized to gaseous products upon heating to slag temperatures. These included absorbed moisture, water of hydration, carbonates, sulfates, chlorides, and small amounts of organic matter. Gas evolution from the feed mixtures based on offgas measurements is shown in Table 4-2. Total volatiles ranged from 6.1 to 18.3% of the input feed mixtures. The amounts of measured CO and CO₂ were corrected for the amount of these gases produced from oxidation of the graphite electrodes. The portion of combined CO and CO₂ that was derived from graphite oxidation ranged from 18.2 to 51.9%.

4.2 Elemental Mass Balances and Partitioning

Mass balances and partitioning calculations were done for individual elements to compare the elemental output measurements to the elemental input measurements, and to determine the distribution of the TRU surrogate, toxic metals, and other elements between the slag, metal, and APCS solids. Elemental partitioning between the furnace output products was calculated as follows:

$$P_{i,j} = c_{i,j}m_j / \sum_j(c_{i,j}m_j) \times 100\%$$

where

P = Partitioning value (mass fraction) in %

i = Element

j = Output product

c = Mass concentration

Figure 4-3. Total APCS solids compared to measured feed mixture volatiles content.

Table 4-2. Volatilization of feed mixture components and offgas composition.

Feed type	Stable averaging period	Input feedrate (lb/hr)	Electrode usage (lb/hr)	Quench outlet offgas composition							Quench air flowrate (wscfm)	Furnace outlet air and quench air flowrate		Total offgas species mass emission rate (lb/hr)						
				O2 (%)	CO2 (%)	CO (ppm)	NOx (ppm)	SO2 (ppm)	H2O (%)	HCl(d) (ppm)				O2	CO2	CO	NOx	SO2	H2O	HCl(d)
S-60	10:13 - 11:31	1,400	7.37	19.9	2.17	3,362	35.7	1,045	6.44	5,198	308	457	454	68.0	6.71	0.076	4.77	82.6	13.3	
S-60	14:06 - 15:22	975	7.30	20.3	1.58	1,372	14.4	4,846	6.89	3,709	308	446	453	48.3	2.67	0.030	21.6	86.2	9.3	
S-60-IV	12:29 - 13:40	1,340	6.80	19.7	2.70	6,224	31.4	6,287	9.00	4,210	286	450	442	83.4	12.2	0.066	28.3	114	10.6	
S-60-IV	15:23 - 16:45	997	4.68	20.6	1.60	2,689	9.00	3,060	6.60	3,051	329	462	475	50.7	5.42	0.019	14.1	85.6	7.91	
N-80	10:50 - 12:08	1,243	6.17	20.2	NM	NM	0.820	2.54	5.81	0	501	511	514	NC	NC	0.002	0.013	83.3	0.00	
N-80-Mod-1	15:20 - 16:25	686	6.03	20.0	3.21	5,682	4.62	10.5	4.80	0	497	474	474	104	11.8	0.010	0.050	63.9	0.00	
N-80-IV	12:20 - 13:34	1,240	7.17	19.6	3.87	5,211	7.54	62.2	6.95	0	423	477	467	127	10.85	0.017	0.297	93.0	0.00	
N-80-IV-Mod-1	16:31 - 16:55	1,324	7.70	19.9	3.01	4,228	1.53	36.9	6.09	0	342	447	444	92.3	8.25	0.003	0.165	76.4	0.00	
M-60	10:05 - 11:25	1,015	5.61	19.9	2.09	1,766	43.7	2.73	4.87	0	441	513	510	73.6	3.96	0.105	0.014	70.1	0.00	
N-80-IV-Mod-2	14:12 - 15:22	1,804	6.70	20.1	2.79	2,519	11.5	2.88	4.08	0	496	530	532	101	5.83	0.028	0.015	60.7	0.00	

- Notes:
1. Values used in calculating are from stable operation.
 2. No H2O or C are assumed to partition to solid particulate, fume, slag or metal phases.
 3. Feed nitrogen is assumed to be zero.
 4. The amounts of CO, NOx and SO2 from the ambient air was assumed to be zero

- a. Amount of oxidized carbon from electrodes is proportionately subtracted from the CO2 amount.
- b. Determined using electrode usage.
- c. Determined from the input feedrate and the sum of the corrected offgas species mass emission rates.
- d. HCl values were calculated from a mass balance of feed, slag, and metal HCl values.

Table 4-2. (continued).

Feed type	Offgas species mass emission rates from ambient air (lb/hr)			Corrected offgas species mass emission rates (a) (lb/hr)							Portion of combined CO2/CO that is from electrode oxidation(b) (%)	Percent of feed material that is:				
	O2	CO2	H2O	O2	CO2	CO	NOx	SO2	H2O	HCl(d)		Total volatiles(c)	Moisture	SO2	CO2 from carbonates	HCl(d)
S-60	478	1.03	9.62	-23.6	40.0	6.71	0.076	4.77	73.0	13.3	34.8	8.16	5.21	0.34	1.86	0.952
S-60	466	1.01	9.39	-13.5	20.6	2.67	0.030	21.6	76.9	9.3	51.9	12.1	7.88	2.21	1.02	0.952
S-60-IV	470	1.02	9.47	-28.0	57.4	12.2	0.066	28.3	104	10.6	24.5	13.8	7.78	2.11	3.23	0.794
S-60-IV	483	1.05	9.72	-8.0	32.5	5.42	0.019	14.1	75.9	7.91	29.5	12.8	7.61	1.42	2.30	0.794
N-80	534	1.16	10.8	-20.3	NC	NC	0.002	0.013	72.6	0.00	NC	NC	5.84	0.00	NC	0.000
N-80-Mod-1	495	1.07	9.98	-21.4	81.2	11.8	0.010	0.050	53.9	0.00	18.2	18.3	7.85	0.01	9.69	0.000
N-80-IV	499	1.08	10.0	-31.6	99.3	10.85	0.017	0.297	83.0	0.00	18.4	13.1	6.69	0.02	6.53	0.000
N-80-IV-Mod-1	467	1.01	9.41	-23.3	63.1	8.25	0.003	0.165	67.0	0.00	27.1	8.70	5.06	0.01	3.47	0.000
M-60	536	1.16	10.8	-26.0	51.8	3.96	0.105	0.014	59.3	0.00	26.1	8.79	5.84	0.00	3.77	0.000
N-80-IV-Mod-2	554	1.20	11.2	-21.8	75.7	5.83	0.028	0.015	49.5	0.00	22.4	6.06	2.75	0.00	3.25	0.000

m = Mass of each output product for each test.

This method uses the measured elemental concentrations and the output masses to calculate elemental partitioning fractions of the feed materials among the output products. The input masses of each element based on the feed rate and feed mixture concentrations were not used. This approach was used because even though the overall, total mass balance closure (value of total output mass divided by the total input mass), at 1.01 is very close to unity, the mass balance closure for many individual elements deviates more significantly from unity. This deviation is due largely to inaccuracies in the specified elemental concentrations in the input feed mixtures, especially for many of the trace level metals. Elemental mass partitioning determinations were more accurate when based upon the measured concentrations and masses of the output products.

Eight metals are listed in the EPA TCLP leachability procedure for evaluation of leachability for solid wastes: Ag, As, Ba, Cd, Cr, Hg, Pb, and Se. The EPA Multiple Metals Train is, however, designed for measuring 16 toxic or otherwise potentially hazardous metals emissions from stationary sources. These include the eight TCLP metals plus Be, Cu, Mn, Ni, P, Sb, Tl, and Zn. These additional metals can also be considered toxic, and all but Be, Mn, Sb, and Tl were included in the sample analyses of the melter product streams. The four metals that were excluded were not expected, even in reasonable trace levels, in the feed mixtures. Essentially all of the other toxic metals were present at only trace levels in the feed mixtures, so some of the measured concentrations in some of the product streams were at or near detection limits. Analytical error near the detection limits can increase and cause variability in measured concentrations and partitioning results that are not related to process conditions or feed variations. Analytical results below detection limits are shown as "less than the detection limit value" in the product composition tables of Appendices H and K.

Metals measurements in the output streams were subject to some inaccuracy due to low or nondetectable levels of some elements. Spiking additional toxic metals into the feed materials can improve the data quality but was not done in the baseline tests because metal spiking would have made the feed mixtures less representative of the actual buried wastes. Elemental partitioning for elements in very low concentrations (at or near the detection limit) in either the slag, metal, or APCS solids should be considered semi-quantitative. In addition, partitioning to the APCS solids should be considered less accurate because only a small fraction (2%) of the feed material partitioned to the APCS solids, resulting in greater relative error.

4.2.1 Elemental Partitioning to the Glass/Ceramic Slag Product

Partitioning of Ce (the TRU surrogate) and the toxic metals to the slag is shown in Figure 4-4. The partitioning behavior for the M60 and M60-Mod tests that had added elemental metals was somewhat different from the partitioning for the other tests when there were no added elemental metals. Some metals were present only at trace levels as metal compounds in the soil and additives. Of these trace metals, Ag and Cd, shown in Figure 4-4, were not detected in most of the slag samples. The reported partitioning to the slag for these two elements was calculated using their detection limits in the slag, and are maximum values. The actual partitioning for these metals is between 0% and the reported values.

Figure 4-4. Partitioning of toxic metals in the surrogate feed mixtures to the slag.

- Notes: 1. Toxic metals = Ag, As, Ba, Cd, Ce, Cr, Cu, Ni, P, Pb, and Zn.
 2. Down arrows indicate that levels were non-detectable in the slag, where data point indicates maximum partitioning value based on the detection limit.

Toxic metals that significantly partitioned to the slag (>80% for most runs, excluding the M60 run) included Ba, Cr, Cu, and Ni. Cerium also partitioned almost entirely to the slag for all runs. These metals existed in the S60 series and N80 series feed mixtures primarily as oxides and were effectively dissolved into the slag. Toxic metals that were less effectively captured in the slag include As, P, Pb, and Zn. Species of these elements, especially the chlorides, are known to have lower boiling points and higher volatilities, and tend to volatilize significantly to the offgas under some operating conditions.

The oxides of As, Ba, Cd, Ce, Cr, Cu, Ni, P, Pb, and Zn reported sufficiently to the slag for most runs (30–100%) so that APCS residues containing these metals could be recycled to the furnace by mixing with fresh feed material to achieve effective net capture of these elements in the slag product. Many metals such as As, Ni, and Se will also partition significantly to the metal product, if present, as discussed in Section 4.2.3. This behavior was also observed in the prior ASME municipal incinerator ash vitrification tests.

4.2.2 Elemental Partitioning to the APCS

The APCS solids included both entrained feed material (dust) and volatilized feed material. Feed entrainment and volatilization should be evaluated separately for determining the elemental partitioning to the APCS. Separate determinations of entrainment and volatilization are important because the physical and chemical properties of the entrained material will be different from the properties of volatilized/condensed fume. Different particle size, mineralogy, and chemical content for entrained and volatilized materials can lead to different methods for control via APCS equipment designs and final disposal of the collected material. For example, volatilized/condensed fume is often very small particle sized and enriched by the more volatile toxic metals. It is, therefore, more difficult to capture in an APCS and can require stabilization of fines and leachable metals prior to disposal. Entrained feed material by comparison is often larger-sized particles, easier to collect, and can be readily recycled to the furnace without increased volatilization and further concentration of volatile metals. Entrained feed may contain radionuclides that are not volatile and would otherwise not partition to the APCS. Mechanisms and approaches to control of feed entrainment in the furnace are much different than in-furnace mechanisms and control of volatilization. It is therefore important to be able to quantify the relative presence of both types of elemental partitioning.

Toxic metals and Ce partitioning to the fume traps (assumed to be primarily entrained feed as discussed earlier) and partitioning to the baghouse (assumed for some metals to be volatilized/condensed fume) is shown in Figures 4-5 through 4-8. As shown in Appendix K, only 1/3 to 1/2 of the total mass collected in the baghouse for each test was from fume volatilized from the melt. Much of the material captured in the baghouse was entrained feed material fines rather than volatilized/condensed material. Considerable variability existed in some of the reported values due to low measured concentrations of trace elements and due to variation in furnace operating conditions from test to test. Some metals (Hg, Cd, Se, and Ag) were not detected in the slag samples. Partitioning to the APCS for these metals was calculated using the slag detection limit. The data points in the figures represent minimum partitioning values. The actual partitioning values for these metals to the APCS is between the reported values and 100%.

Figure 4-5. Partitioning of P, Pb, Cu, and Hg to the fume traps and the baghouse.

Note: Up arrows indicate that levels were non-detectable in the slag samples, where data point indicates minimum partitioning value based on the detection limit.

Figure 4-6. Partitioning of Ba, Zn, Cr, and Ni to the fume traps and the baghouse.

Figure 4-7. Partitioning of Ce, Cd, As, and Se to the fume traps and the baghouse.

Note: Up arrows indicate that levels were non-detectable in the slag samples, where data point indicates minimum partitioning value based on the detection limit.

Figure 4-8. Partitioning of Ag to the fume traps and the baghouse.

Note: Up arrows indicate that levels were non-detectable in the slag samples, where data point indicates minimum partitioning value based on the detection limit.

The key to understanding the transport mechanism (entrainment versus volatilization) for each element is to observe the concentration trends in each of the two fume traps and baghouse and the trend from fume trap 1 to the baghouse. If the concentration increased from fume trap 1 to the baghouse, then either that element was concentrated in very fine particles in the feed, or else the element (or compounds of that element) volatilized from the melt and then condensed to fine particulate prior to the baghouse. If the concentration of an element increased from fume traps 1 and 2 to the baghouse, then the element was included with material possibly volatilized from the melt in the calculations of Appendix K. If the concentration was greater in fume trap 1 and 2 catches than in the baghouse catch, then the element was likely transported in entrained feed dust as oxides, carbonates, or other species in the feed mixtures.

The furnace gas temperatures, flowrates, and compositions were not directly measured during the baseline tests, but were estimated using mass and energy balances from offgas measurements made in the APCS. These estimates are discussed in Section 5. These estimates of furnace gas conditions should be considered semi-quantitative, but may be used to get a perspective of the feed material entrainment from the furnace. From tables in Section 5, the average furnace gas temperature was 511°C, and the average furnace offgas flowrate was 110 wscfm. The average gas velocity in the furnace, and the diameter of a spherical particle that can be entrained at that average velocity may be estimated (Appendix T). At the estimated average gas velocity of 0.5 ft/sec, a particle diameter of 66 microns (0.066 mm, or slightly smaller than 200 mesh) was estimated as the maximum entrainable diameter using Stokes' Law.¹¹ Particles smaller than this diameter may be able to be entrained in the gas flow, while entrainment of larger particles is less likely. The actual gas velocity gradient (variation in local velocities) for each test likely varied widely, with somewhat higher gas velocities near the feed tubes and the electrodes from feed tube air influx and from gas evolution from the melt, while gas recirculation (downward or negative velocities) was likely near the sidewalls.

The kinds of minerals in the feed mixtures most likely to be entrained may be estimated by considering particles sizes for the different feed additives. Although full particle size analyses are not available for the feed mixture additives, Table 4-3 shows the weight percentage of each additive for the feed mixtures that is less than 0.175 mm (80 mesh). Those additives with large fractions less than 80 mesh also likely have significant fractions under 200 mesh. The only additives for which at least some entrainment was not likely were mullite, pollucite, NaCl, pebble lime, aluminum, copper, lead, and zinc. The other additives, including soil (with a large variety of major and trace compounds) had potential for at least some entrainment based on their small particle sizes. Other studies for similar INEL soils report soil particle sizes of 1.6% <200 mesh.¹² This size range correlates well with the estimated total feed entrainment of 1.5%.

The possible mechanisms for partitioning to the offgas of each element may be evaluated by considering relative volatilities, mineralogy, possible chemical reactions, and feed entrainment. This evaluation of elemental entrainment and volatilization is summarized in Table 4-4. Boiling points for various metal species are shown in Figure 4-9. The chlorides of many toxic metals have relatively low boiling points, indicating that the metal chlorides will be relatively volatile in the furnace. However, only the S-series tests had significant amounts of chlorine. Also, the furnace gas and the melt in each test except the M60 test was relatively oxidizing, which would minimize the formation of the metal chloride in favor of the oxide. One exception to this for each test is

Table 4-3. Particle size and density of RWMC soil and additives.

Feed Component	Physical form	Bulk density (lb/ft ³)	Particle size (% <0.175 mm ^a)
RWMC soil	Dried	82	35
Cerium oxide, CeO ₂	Mineral concentrate	122	100
Gypsum, CaSO ₄ • 2H ₂ O	Fine grind	58	64
Ilmenite, FeTiO ₃	Mineral concentrate	136	98
Magnetite, Fe ₃ O ₄	Mineral concentrate	160	27
Mullite, Al ₆ Si ₂ O ₁₃	Sintered	180	1
Pollucite, Cs ₂ Al ₂ Si ₄ O ₁₂ • H ₂ O	Mineral concentrate	107	2
Potash, K ₂ CO ₃	Powder	82	>60
Silica, SiO ₂	Masonry sand	91	19
NaCl	Table salt	76	<5
Soda ash, Na ₂ CO ₃	Powder	62	>60
Talc, Mg ₃ Si ₄ O ₁₀ (OH) ₂	Fine grind	77	56
Wollastonite, CaSiO ₃	Acicular	36	16
Limestone, 98% CaCO ₃	Fine grind	89	85
Pebble lime, 93% CaO	-1/4 in.	NA	<5
Mill Scale, Fe ₃ O ₄	Flake	151	12
Zirconia, ZrO ₂	Fine grind	85	100
Zircon, ZrSiO ₄	Mineral concentrate	177	25
Aluminum	Shot	NA	0
Copper	Shot	NA	0
Iron	Flake	210	<50
Lead	Shot	NA	0
Zinc	Coarse powder	NA	<5
Stainless steel	Fine powder	137	27

NA = Not analyzed

a. Particles passing an 80-mesh sieve.

Table 4-4. Evaluation of elemental entrainment and volatilization.

Element	Present as (species) in (additive), at (concentration) in feed mixtures	Likelihood of entrainment based on% <0.175 mm	Partitioning to baghouse (%)	Volatilized or entrained	Mechanism
Ag	Ag ₂ O in soil, 4–9 ppm; Ag in copper powder, 14 ppm	Likely. Soil 35% <0.175 mm, and 1.6% <75 μ	>3–100 (Ag detected in only 1 slag sample)	Insufficient data	With moderate volatility, the Ag could be volatilized, especially as AgCl during the S-series tests. Entrainment of Ag in soil fines is also possible.
Al	Al ₂ O ₃ in magnetite, mullite, pollucite, silica, soil, talc, wollastonite, pebble lime, ilmenite, and zirconia, 0.35–73.1%; Al in aluminum shot, 100%	High	0.09–0.4	Entrained	The minimal partitioning of Al to the baghouse is most likely due to entrainment of Al due its presence in both ilmenite and zirconia which are 98 and 100% <0.175 mm, respectively
As	As ₂ O in soil, 12.2 ppm; As in copper powder, pebble lime, and potash, 1–2 ppm	Somewhat	1–33	Insufficient data	With a relatively low boiling point, and high volatility, As likely was volatilized and recondensed in the baghouse.
Ba	BaO in mullite and soil, 100–600 ppm	Somewhat	0.7–2	Entrained	The minimal partitioning of Ba to the baghouse is most likely due to entrainment of Ba in soil fines.
Ca	CaCO ₃ in silica, soil, wollastonite, limestone, and pebble lime, 0.2–98%; CaO in magnetite, silica, soil, talc, wollastonite, pebble lime, cerium oxide, ilmenite, and zirconia, 0.03–93%; CaSO ₄ in gypsum, 0.8%; CaSO ₄ ·2H ₂ O in gypsum, 95.7%; Ca in pollucite and salt, 0.03–0.3%	High	0.2–1	Entrained	Ca was most likely entrained as CaCO ₃ , CaO, and CaSO ₄ ·2H ₂ O; There may have been insufficient time and temperatures (around 1,000°C) in the furnace for decomposition.
Cd	CdO in soil, 0.57 ppm	Somewhat	>13–100 (not detected in slag samples)	Volatilized	A volatile metal, Cd most likely vaporized and recondensed in the baghouse.

Table 4-4. (continued).

Ce	CeO in mullite, 300 ppm; CeO ₂ in soil and cerium oxide, 0.0055–65.5%	High	0.2–2	Entrained	Ce was most likely carried to the baghouse as entrained feed dust.
Cl	Cl in soil, 40 ppm; KCl in potash, 50 ppm; NaCl in salt and soda ash, 0.08–99.7%	Somewhat	62–94	Volatilized	Cl most likely reacted to HCl gas in the furnace, and then reacted with entrained carbonates in the baghouse filter cake to form alkali chlorides in the baghouse. Some Cl may have formed metal chlorides in the furnace and volatilized.
C	CaCO ₃ in silica, soil, wollastonite, limestone, and pebble lime, 0.2–98%; C in soil, electrolytic iron, and stainless powder, 8–15,600 ppm; MgCO ₃ in limestone, 1%; K ₂ CO ₃ in potash, 99.8%; Na ₂ CO ₃ in soda ash, 99.6%	Likely	1–26	Entrained	C, present as carbonates in the feed mixtures, mostly formed CO ₂ upon heating to slag temperatures in an oxidizing atmosphere. C in baghouse was entrained as carbonates.
Cr	Cr ₂ O ₃ in magnetite, soil, titania, mill scale, and ilmenite, 0.03–0.2%; Cr in stainless powder, 18.6%	Likely	0.03–2	Entrained	A less volatile metal, Cr was likely carried to the baghouse as entrained feed dust and may also have reduced to the metal within the furnace. Cr (with Ni and Fe) was likely entrained as stainless steel powder in the M60 run.
Cs	Cs ₂ O in soil, 53 ppm; Cs in pollucite, 23.8%	Slight	21–84	Volatilized	With moderate volatility, the Cs could be volatilized, especially as CsCl ₂ during the S-series tests.
Cu	CuO in soil and mill scale, 56.3–3,300 ppm; Cu in copper powder, 99.97%	Slight	0.3–23	Volatilized	The highest partitioning of Cu, excluding the M60 test, occurred for the S60 or S60-IV tests, when there was large amounts of Cl, consistent with the known higher volatilities of toxic metals in the presence of Cl. Thus, copper was likely transported to the baghouse as the volatile chloride trimer, Cu ₃ Cl ₃ .

Table 4-4. (continued).

Fe	Fe ₂ O ₃ in mullite, silica, talc, titania, wollastonite, pebble lime, ilmenite, soda ash, and zirconia, 0.001–30%; Fe ₃ O ₄ in magnetite, soil, and mill scale, 4.23–99.09%; Fe in pollucite, copper powder, electrolytic iron, stainless powder, mill scale, and potash, 1 ppm–99.97%	High	0.05–0.6	Entrained	Entrainment of Fe is most likely due to its presence in ilmenite and zirconia which are 98 and 100% <0.175 mm, respectively. It was likely transported to the baghouse as entrained feed dust.
Hg	HgO in soil, 0.11 ppm; Hg in potash, 0.04 ppm	Somewhat	>37–100 (not detected in slag)	Volatilized	About ½ of the Hg partitioned to the baghouse while <10% was detected in the fume traps, suggesting significant volatilization of Hg compounds.
K	K ₂ O in mullite, silica, and soil, 0.51–2.42%; KCl in potash, 50 ppm; K ₂ CO ₃ in potash, 99.8%; KOH in potash, 0.07%; K ₂ SO ₄ in potash, 60 ppm; K in salt and pollucite, 0.04–0.5%	Somewhat	2–21	Insufficient data	A more volatile metal, K may have vaporized to a reasonable degree, although any carbonates of K were most likely entrained due to insufficient time and temperatures in the furnace for decomposition. Large amounts of KCl in the baghouse for the S-series was probably from volatilization before or after reaction to form KCl. KCl in the baghouse for the N-series tests and the M60-Mod test were likely from feed entrainment of K ₂ CO ₃ (up to 6% in the feed) followed by reaction to form KCl. KCl was not observed in the baghouse for the M60 test, when there was little KCl or K ₂ CO ₃ in the feed, but still 1.5% K ₂ O in the feed.
Mg	MgO in magnetite, mullite, silica, soil, talc, wollastonite, pebble lime, ilmenite, and zirconia, 0.01–26%; MgCO ₃ in limestone, 1%; Mg in salt, 0.02 wt%	High	0.06–0.8	Entrained	The minimal partitioning of Mg to the baghouse and small particle size of Mg-containing additives suggests that it was largely entrained feed dust.

Table 4-4. (continued).

Na	Na ₂ O in mullite, silica, soil, pebble lime, and zirconia, 0.03–1.28%; NaCl in salt and soda ash, 0.08–99.7%; Na ₂ CO ₃ in soda ash, 99.6%; Na ₂ SO ₄ in soda ash, 0.15%; Na in pollucite, 1.5%	Likely	2–16	Insufficient data	With moderate volatility, Na may be volatilized, but entrainment of Na in the soil fines is also possible, especially for any carbonates of Na. High NaCl levels in the S-series baghouse catches may be due to volatilization from the melt since the S-series feed mixtures contained 2% NaCl. Lower baghouse NaCl levels in the other tests may be from chemical reactions of entrained Na ₂ CO ₃ in the baghouse filter cake with gaseous HCl in the baghouse.
Ni	NiO in soil and mill scale, 43.3–1,900 ppm; Ni in copper powder, electrolytic iron, and stainless powder, 0.0012–10.4%	Slight	0.03–30	Volatilized	Ni (with Cr and Fe) was likely entrained as stainless steel powder in the M60 run; with moderate volatility, some Ni may have volatilized.
P	PO ₄ in soil and mill scale, 0.04–0.29%; P ₂ O ₅ in magnetite, pebble lime, and ilmenite, 0.02–0.09%; P in electrolytic iron, stainless powder, mill scale, and titania, 8–200 ppm	Somewhat	0.3–57	Insufficient data	P, with a low boiling point and high volatility, most likely volatilized significantly to the offgas, and recondensed in the baghouse.
Pb	PbO in soil, 24.8 ppm; Pb in lead shot, pebble lime, and potash, 5 ppm–100%	Somewhat	0.9–64	Volatilized	The presence of Pb in the baghouse catch from M60 and M60-Mod tests indicates that Pb volatilized appreciably from the melt in elemental, oxide, or chloride forms. Pb, with a high vapor pressure and low boiling point, has extreme volatility under all conditions & experienced enhanced vaporization in the S60 and S60-IV melts as the chloride.
S	SO ₄ in soil, cerium oxide, and salt, 0.04–6%; SO ₃ in pebble lime, 0.15%; S in magnetite, titania, copper powder, electrolytic iron, and stainless powder, 6–2,000 ppm	Somewhat	12–73	Volatilized	S was primarily oxidized to gaseous SO ₂ and may have been scrubbed from the gas by carbonates in the baghouse filter cake; some CaSO ₄ may have been entrained.
Se	SeO in soil, 1.2 ppm; Se in copper powder, 1 ppm	Slight	>4–100	Volatilized	With high volatility, Se most likely vaporized to a reasonable degree and partitioned significantly to the baghouse.

Table 4-4. (continued).

Si	SiO ₂ in magnetite, mullite, pollucite, silica, soil, talc, titania, wollastonite, pebble lime, mill scale, cerium oxide, ilmenite, and zirconia, 0.21–96%; Si in wollastonite, electrolytic iron, stainless powder, and mill scale, 25–8,000 ppm	High	0.3–0.7	Entrained	The minimal partitioning of Si to the baghouse was most likely due to entrainment of Si from the feed material fines such as cerium oxide, ilmenite, and zirconia, which are 100, 98, and 100% <0.175 mm, respectively.
Ti	TiO ₂ in magnetite, mullite, silica, soil, titania, wollastonite, pebble lime, ilmenite, and zirconia, 0.01–95.8%	High	0.04–0.2	Entrained	Ti was most likely carried as entrained feed dust to the baghouse due to its low volatility.
Zn	ZnO in soil, 100 ppm; Zn in copper powder and zinc powder, 1 ppm–99.6%	Slight	17–43	Volatilized	Zn primarily volatilized to the baghouse due to its high vapor pressure and low boiling point.
Zr	ZrO ₂ in soil, titania, ilmenite, and zirconia, 0.01–95%; ZrO ₂ +HfO ₂ in zircon, 60%	High	0.01–0.8	Entrained	Present in ilmenite and zirconia, (with particle size of 98 and 100% < 0.175 mm), Zr was most likely entrained in the offgas from the feed material fines.

Figure 4-9. Boiling point of selected metals, metal oxides, and metal chlorides.

the gas and melt region around the electrodes, where conditions may be more reducing due to the reducing effect of the graphite electrodes. Chlorides of some metal species may volatilize from this region especially during the S-series tests. The relatively cool offgas temperatures during the baseline tests may have tended to "freeze" redox and other reactions in very nonequilibrium proportions, increasing the potential for chlorides and other reduced metal species.

The partitioning to the baghouse increases significantly for compounds with boiling points below 1,600°C, which is the range of most of the slag temperatures during the baseline tests. Perhaps the main reasons that partitioning to the baghouse for these low-boiling point compounds was not much higher were (a) the effect of the cold top, (b) the solubility of the oxides of these species in the slag, and (c) the solubility of some of the metal elements in the metal heel.

Up to about 64% of the Pb and 43% of the Zn in the feed partitioned to the baghouse, while about 18% of the Pb and less than 15% of the Zn was detected in the fume traps. This enrichment of Pb and Zn suggests significant volatilization of Pb and Zn compounds as was expected at melt temperatures up to 1,800°C. Pb was present in the M60 feed as large shot which could not be entrained. It was clearly transported as a vapor from the melt to the APCS. Excluding the M60 test when several of the toxic metals were spiked into the feed mixture, the highest partitioning of Pb, Cu, and P occurred for the S60 or S60-IV tests, when large amounts of Cl existed. This result is consistent with known higher volatilities of toxic metals in the presence of Cl.^{11,13,7}

Tables K.1 through K.9 in Appendix K, list for each furnace feed the most representative slag composition (MRSC) and the composition of residues recovered from the fume traps and baghouse. The concentrations of metal with known higher vapor pressure, such as As, Pb, and Zn, were higher in the baghouse solids, less in the fume trap residues, and least in the slags. Concentration factors for Pb, (mg/kg in feed compared to mg/kg in fume trap and baghouse solids) were very large (71 for S60, 83 for S60-IV, 58 for N80, and 48 for N80-IV), indicating extreme volatility under all conditions and enhanced vaporization in the S60 and S60-IV melts as the chloride.

Other volatile metals, such as Cd, Cs, K, Na, and Se, were also concentrated in the baghouse solids. Transport of these metals may occur by reduction of the oxide to metal in the vicinity of the electric arc, or distillation of the metal from the molten slag, followed by reaction with atmospheric species to form very fine particles including oxides, hydroxides, chlorides, and sulfates. The resulting fine particles could then be entrained within the offgas and carried out of the furnace. The concentrations of chlorine and sulfur in the baghouse were also higher than in the fume traps, probably due to reaction or absorption of gaseous HCl and SO₂ with carbonates of sodium and potassium in the filter cake.

Copper, which also was concentrated in the baghouse solids, was likely transported as the volatile chloride trimer, Cu₃Cl₃, suggesting that the volatility of Cu is similar to the volatility of Pb in the presence of Cl, Cd, and Hg.

The volatility of Ag is also increased in the presence of Cl. Ag₂O was not detected in the slags (detection limit of 1 mg/kg), except for the S60 slag, for which the last four slag molds filled during the S60 test (4,000 lb of slag) contained from 5 to 9 mg/kg Ag₂O (Table H-2 in

Appendix H). The concentration of Ag_2O paralleled the concentration of CuO in the S60 slag as the test progressed, with both reaching maximum concentrations in the seventh large slag ingot (6,000 lb). CuO , present in the soil at the 56 mg/kg level, was present at the 3,300 mg/kg level in the mill scale, which was melted with RWMC soil in the shakedown test. The correlation indicates that Ag and Cu originated from the same source, and that source is likely the mill scale. A plausible explanation is that copper was carried over in the metal ingot that was formed during the shakedown test. The delay in the appearance of Ag_2O and CuO in the S60 slag is the time interval required to melt the metal ingot.

4.2.3 Partitioning of the M60 Feed Mixture

The M60 feed mixture was unlike the other feed mixtures in that it contained significant quantities (32.4%) of elemental metals including iron (27% of the total mixture), nickel (0.96%), chromium (1.7%), aluminum (5.85%), lead (0.74%), and copper (0.74%). Cerium alloyed with iron was also added as a single feed spike input to the M60 bath during the M60-Mod test. The partitioning of these metals plus the oxides of these metals in the soil and other feed additives for both the single M60 run and the combined M60 plus M60-Mod tests are shown in Figures 4-10 (a) and (b).

Some metals that partitioned significantly to the slag or the APCS solids during the other feed mixtures partitioned significantly to the metal phase during the M60 and M60-Mod tests. The slag was not sufficiently oxidizing to oxidize all of the metals in the M60-test, although out of 1,057 lb of total elemental metals fed during the M60 run, only 789 lb were added to the metal heel. Approximately one-fourth of the elemental metal was oxidized into the slag, with some volatilized into the offgas. Like the other tests, the Pb and Zn partitioned significantly to the furnace offgas and were captured in the APCS. Zinc was retained only slightly in the metal phase. Over half of the Zn partitioned to the offgas due to its volatility, while most of the remainder was oxidized and retained in the slag. As, Cr, and P partitioned to the offgas in significantly decreasing amounts compared to the earlier tests. Very little chromium was evolved to the APCS. Three-fourths of the Cr was oxidized to the slag, and the remainder was retained as metal in the metal phase. No Ce was detected in the metal product, even after the ingot of Ce/Fe alloy was added to the furnace.

With the presence of the metal heel and elemental metal additives, Fe, Ni, As, P, and Cu partitioned significantly (85% or more) to the metal phase. Most (>97%) of the Al and Ce partitioned to the slag, implying nearly complete oxidation and retention of these elements in the slag. The behavior of Ce in this test indicates that essentially all plutonium will partition to the slag as desired, leaving the metal product uncontaminated.

As shown in Figure 4-10 (b), there were some subtle changes in the partitioning for the combined M60 and M60-Mod test day compared to the single M60. During the M60 test, carbon partitioned over 60% to the metal phase and less than 30% to the slag. Partitioning values for the all-day test showed carbon partitioning less than 30% to the metal and almost 60% to the slag. Partitioning to the metal for P, As, S, and Cr also decreased. This suggests that as the test proceeded, there was continued oxidation of these metal alloy components and net mass transfer from the heel to the slag. As, S, and Pb were further volatilized from the slag into the offgas

Figure 4-10 (a). Metals partitioning of the M60 feed mix.

Figure 4-10 (b). Metals partitioning of the M60 and M60-Mod feed mix.

where they were captured in the APCS, increasing the partitioning values to the baghouse. Thus, for C, P, and Cr, the rate of oxidation was greater than the rate of volatilization while for As, S, and Pb rate of volatilization from the slag exceeded the rate of oxidation from the metal.

The amounts of even the more volatile Pb and Zn retained in the slag or the metal suggest that up to one-half or more of these demands may be retained in the glass-ceramic product or in the recyclable metal alloy. This partitioning also suggests that APCS solids can be recycled back into the furnace for a net reduction in the amount of these volatile metals and total APCS solids that must be disposed of.

4.2.4 Elemental Mass Balances

Mass balances for individual elements are shown in Tables U-1 through U-5, Appendix U, and are also shown graphically in Figure 4-11. The input and output mass balances were used to calculate the amount of MgO hearth refractory dissolution by assuming unity (mass out divided by mass in = 1) for the Mg balance. The difference between the output mass of Mg and the input mass of Mg from the feed was assumed to be due to dissolution of the MgO refractory. The mass balances suggest that only a small amount of MgO hearth refractory dissolution (10 lb of MgO) occurred during the shakedown test, but that the S60 slag at the operating melt temperatures was very corrosive to the refractory, causing dissolution of 910 lb MgO during the S60 test and 57 lb during the S60-IV test. Smaller amounts, thought to be within the analysis accuracy of the feed mixtures and the products, were calculated for the subsequent test days. Since these amounts of potential refractory dissolution were small, they were not included in the mass balance; Mg closure for these test days was not assumed to be unity.

There was also a difference between the amount of iron measured in the furnace products compared to the input amount in the feeds. No metal product was tapped for any of the feed mixtures, including the M60 feed mixture that contained 32.4% elemental metals. All of the metal product that may have been produced during the shakedown and baseline tests was removed as a solidified metal heel after completion of the test program. This metal heel could not be tapped out of the furnace due to the lowering of the hearth below the metal tap hole by the dissolution of the MgO refractory hearth early in the test program. Therefore, the iron balance closure for the different test days was also assumed to be unity, to estimate the amount of iron that apparently was added to the metal heel for each test. Between 1–180 lb of iron was calculated as added to the metal heel for each of the feed mixtures except for the M60 mixture. For the M60 feed mixture, 666 lb of iron was calculated for addition to the metal heel. The added iron (and other metals) to the heel for the M60 test was due to added elemental metals in the feed mixture, rather than from reduction of oxides as suspected for the other tests.

Iron, added to the metal heel for all feed mixtures except the M60 feed mixture, was from reduction of iron oxide in the melt by carbon from the graphite electrodes. This was possible within the immediate vicinity of the electrodes, where the levels of oxygen were likely considerably lower than the average levels in the furnace, and the carbon in the graphite electrodes can act as a reducing agent for metal oxides. Metal formation by carbothermic reduction of metal oxides is increased by viscous slags like those of the baseline tests that have poor thermal and electrical conductivity, elevating the minimum slag temperatures needed for continuous tapping.

Figure 4-11. Mass balances of individual elements.

Mass balance closure was significantly above or below unity for many of the metals. Causes for closure deviating from unity for individual metals included (a) low or nondetectable measured levels in the feed or output streams, (b) incomplete feed material analyses from suppliers, or (c) erroneous feed material analyses from suppliers. Very low or nearly nondetectable levels of measured values in the feed mixtures or in the product was the most prevalent cause of mass balance deviation. Elements in this category for which the analyses and mass balances are very inaccurate include As, Cd, Hg, Mn, and Se. Other elements have especially low or high closure values due probably to inaccurate assays of feed additives. These assays were provided by the additive suppliers. Some feed material analyses provided by suppliers were partially proprietary, and some others did not include complete analyses. These inaccuracies can have a large effect especially when the feed concentrations used in the calculations are low or nondetectable. Elements with undesirably high closure values include Cd, Cu, Pb, Hg, Ni, Se, and Zn.

The closure for Ce, the TRU surrogate, was below unity for some of the tests (S60, N80, N80-Mod, M60, and M60-Mod). This was due to erroneous composition information from the CeO_2 supplier. The supplier claimed 60% CeO_2 in the cerium oxide concentrate, whereas the measured concentration (by neutron activation) of one canister was 35% CeO_2 .

A carbon balance (Table 4-5) can lend insight into the fate of carbon in the system. Sources of carbon include the graphite electrodes (oxidizing to CO and CO_2), inorganic carbonates in the feed mixtures, and trace amounts of organic carbon in the feed mixtures. This carbon balance is based on the comparison of the measured total output carbon (CO and CO_2 in the offgas and the much smaller output levels of carbon in the slag, metal product, and APCS solids) to the total input carbon measured in the feed mixtures and from graphite electrode weight loss. The carbon balance for the S60 and S60-IV tests is reasonably good except for a low mass balance closure of 0.71 for the second S60 sampling period. This was likely due to lower input amounts of feed carbonates due to segregation during feeding for the sample period or lower carbonate levels than expected in the feed mixtures. Erroneous offgas CO and CO_2 measurements were not likely because the continuous monitoring procedure strictly followed the EPA sampling methods for CO and CO_2 , including all specified calibrations, bias checks, leak checks, and drift calculations. These quality assurance (QA) activities are used in source emissions testing to verify the validity of the measured data. Any data found to be questionable from the QA checks was invalidated and not used. The QA checks have validated the accuracy of the measured CO and CO_2 for the other reported time periods.

The carbon balance for the M60 test (mass closure of 0.90) was somewhat low but within reasonable combined accuracies for the input and output measurements. The carbon balance for all of the valid N80 series of mixtures (N80-Mod, N80-IV, N80-IV-Mod and M60-Mod) was generally low, ranging from 0.57 to 0.69. This low carbon balance trend for the same series of mixtures (all N-series) suggests that the carbonate material was lower in the original N80 mixture than was calculated.

Table 4-5. Carbon balance for the baseline tests.

Feed type	Feed conc. (%)	Amt. of C in feed (lb/hr)	Electrode consumption (lb/hr)	Conc. of C in slag (ppm)	Amt. of C in slag (lb/hr)	Conc. of C in APCS solids (ppm)	Amt. of C in APCS solids (lb/hr)	Conc. of C in metal product (ppm)	Amt. of C in metal product (lb/hr)	Conc. of CO at quench outlet (%)	Conc. of CO at quench outlet (ppm)	Amt. of C from CO ₂ in offgas (lb/hr)	Amt. of C from CO in offgas (lb/hr)	Mass balance closure
S60	0.88	9.8	6.61	245	0.0352	1,280	0.0312	0	0	2.17	3,362	15.8	2.44	1.12
S60	0.88	8.6	5.80	245	0.0276	1,280	0.0230	0	0	1.58	1,372	10.9	0.94	0.83
S60-IV	0.78	12.5	9.54	443	0.0801	1,250	0.0312	0	0	2.68	6,224	18.6	4.31	1.04
S60-IV	0.78	7.77	5.93	443	0.0475	1,250	0.0218	0	0	1.63	2,689	11.6	1.90	0.99
N80	2.91	36.2	7.40	576	0.1962	2,850	0.0542	0	0	NM	NM	NC	NC	NC
N80-Mod	3.74	25.6	4.08	185	0.0282	37,400	0.7819	0	0	3.21	5,682	22.4	3.96	0.91
N80-IV	2.77	34.3	7.38	225	0.0553	14,700	0.3713	0	0	3.21	4,302	22.1	2.96	0.61
N80-IV-Mod	2.38	31.7	7.92	327	0.0999	14,213	0.1934	0	0	3.01	4,228	19.1	2.68	0.56
M60	0.99	10.1	6.04	260	0.0000	4,205	0.0951	4,340	1.70	2.09	1,766	12.0	1.01	0.92
M60-Mod	2.32	41.9	10.73	702	0.4931	5,480	0.1157	1,490	0	2.79	2,519	20.3	1.83	0.43

Notes:

1. Feedrate for each sampling run was determined from the DAS system as the average feedrate for the respective time period.
2. Electrode consumption for each sampling period was determined by multiplying the average feedrate by the pounds electrode consumed per ton of feed material.
3. Slag product rates were calculated from the concentration of carbon in the slag times the weighted slag tap rate.
4. Metal product rates were calculated from the concentration of carbon in the metal product times the weighted amount of metal product divided by the time of the respective MMT test.
5. APCS solids rates were determined from the concentration of carbon in the fume multiplied by the particulate emission rate for the respective MMT test.

5. PROPERTIES OF FURNACE PRODUCTS

The ability to thermally treat complex heterogeneous mixtures and produce a homogeneous solid slag (glass/ceramic) waste form is a key advantage of arc melting for the treatment of radioactive and mixed wastes.

In addition to the primary slag product, other products from arc melting may include a tappable metal alloy product, offgas, and total particulate (entrained feed material and condensed material volatile) in the offgas. Slag and metal products, particulate collected in the fume traps and baghouse, and particulate collected isokinetically using Multiple Metals Train were analyzed in this test series to determine physical properties, chemical composition, crystalline makeup, and leachability.

5.1 Slag Density and Waste Volume Reduction

Volume reduction, an important consideration when handling, shipping, and storing the final waste form material, was determined by comparing the volume of the furnace feed material with the volume of the resultant slag. The volume reduction factor [(VRF) the ratio of feed volume to solid slag volume] is defined as:

$$VRF = \frac{V_{feed}}{V_{slag}} = \frac{\rho_{slag}}{\rho_{feed}} \frac{m_{feed}}{m_{slag}}$$

where V_{feed} and V_{slag} are the respective volumes of the material fed to the furnace and the slag tapped from the furnace, calculated using the densities (ρ) and masses (m) of the feed and the slag.

Values for VRF are shown in Table 3-1 (in Section 3). The feed density used in the calculations was the measured bulk density of the feed, while the slag density was measured from the 2-kg samples of slag. This comparison is based on a monolithic product slag, as obtained by casting slag into containers that would serve as shipping and storage containers.

Overall, the volume reduction factor for these surrogate wastes was 2.58. The average volume of the product slag was the inverse of this value, or 39%, of the feed material volume. This volume reduction is primarily due to the differences in the feed material density and the slag density, but also due to the reduction of solid material through gas evolution. The small volumes of APCS solids and metal product were not included in this evaluation, since the production of these other products can be tailored according to operating conditions.

Appreciable segregation of solid solution phases occurred during natural cooling of the large slag (glass/ceramic) ingots, leading to speculation about changes in chemical composition and mineralogy from edge to center of each ingot. This segregation occurred when the center of each slag ingot cooled much more slowly than the outside edge. The rate of cooling is known to affect the solid solution phase formation.¹⁰ No attempt was made in this series of tests to tailor the glass ceramic formation via controlled cooling due to limited funding. Glass ceramic tailoring by controlled cooling and analysis of resultant mineralogy is strongly recommended for future studies.

Fiscal constraints also precluded detailed chemical and morphological characterization of each ingot, but archived samples provide that option in the future.

The specific gravity of rim and core material was determined for the ingot of slag that was most representative of each waste mixture. The results, listed in Table 5-1, reveal generally that slag in the core was more dense than slag in the rim, thereby supporting the visual observation of phase segregation during cooling. Crystalline phases were also visually identifiable in the cores of numerous slag ingots.

5.2 Mineralogy of the Furnace Products

The mineralogy of the 2-kg slag samples was provided by X-ray diffraction (XRD) analyses. The resulting data are in Appendix J. The data indicate nearly complete vitrification of these relatively small samples of molten slag undergoing natural but rapid cooling. The only significant exception is the S60 slag, which contained about 16% MgO (partially from dissolution of cast hearth refractory). The sample of S60, obtained after tapping nearly 6,000 lb of slag from the furnace, contained the mineral forsterite (Mg_2SiO_4), which is a very stable naturally occurring mineral. Each of the waste mixtures, in the absence of major contamination, produced a vitreous slag by moderately rapid cooling.

Residues from the fume traps and baghouse were also characterized by XRD analysis (Appendix J). The results indicate that the contents of the fume traps were comprised largely of minerals present in the soil and additives from which the furnace feeds were compounded. This result is to be expected from entrainment of feed considering the particle size range of the soil and most of the additives, which were finely divided mineral concentrates. Examples of feed minerals that were detected in the APCS solids include calcite, cerium oxide, ilmenite, lime, magnetite, potassium carbonate, quartz, sodium carbonate, talc, wollastonite, zircon, zirconia, and common minerals in the soil including albite, forsterite, and plagioclase feldspar. Clearly the minerals such as calcite and carbonates of sodium and potassium represent entrained feed material that also did not experience sufficient time and temperatures (around 1,000°C) in the furnace for decomposition.

The only minerals detected by XRD analyses of the baghouse catches not traceable to direct entrainment of these minerals from the feed materials were the alkali metal chlorides and compounds of Pb and Zn. The concentrations of these materials in the XRD analyses increased from trace levels (1–10 wt%) in fume trap 1 to secondary levels (20–60%) in the baghouse. The significant presence of NaCl and KCl in the baghouse must be due to either (a) volatilization of materials from the melt preceded by or followed by chemical reactions, or (b) reaction of entrained feed materials (sodium and potassium carbonates or lime) in the baghouse filter cake with gaseous HCl in the baghouse.

The highest baghouse NaCl levels were observed for the S-series tests, when there was 2% NaCl in the feed mixtures. While NaCl volatilization was likely for the S-series tests, reactions of entrained feed material carbonates in the baghouse with gaseous HCl is also a likely source of alkali chlorides in the baghouse. Indeed, this is the principle of dry acid gas scrubbing, and carbonates and lime were present in large amounts in all of the feed mixtures as components of the soil and additives.

Table 5-1. Specific gravity of large slag ingots.

Slag ingot	Specific gravity		Specific gravity increase in core (%)
	Rim	Core	
S60-S1	2.83	3.06	7.5
S60-S6	2.92	2.96	1.4
S60-S7	2.94	NA	NC
S60 Average	2.90	3.01	3.7
S60-IV-S3	3.01	3.10	2.9
S60-IV-S6	2.99	3.00	0.3
S60-IV Average	3.00	3.05	1.6
N80-S3	2.70	2.73	1.1
N80-Mod-S6	2.97	3.02	1.7
N80-Mod-S7	3.13	2.97	5.4
N80-Mod-Mean	3.05	3.00	1.7
N80-IV-S4	2.81	2.84	1.1
N80-IV-Mod-S10	3.08	3.16	2.5
M60-Mod-S1	NA	2.92	NC
M60-Mod-S2	2.87	2.91	1.7
M60-Mod-Mean	2.87	2.91	1.7

Pb and Zn were metal additives in the M60 feed. The particle sizes and densities of these metals were too large for entrainment to be a likely scenario. Also, the volatilities of these metals and post reaction species of these metals are relatively high (Section 6.2.2) so volatilization in the furnace followed by condensation in the APCS and collection in the baghouse is the most likely cause for the appearance of Pb and Zn species in the baghouse. This is especially true for the final M60-Mod feed test, when Pb and Zn were not included as components in the N80-IV-Mod feed material used during this test. Pb and Zn were present in the existing melt inventory from when M60 was fed to the furnace.

5.3 Elemental Composition of Furnace Product Slag, Metal, and APCS Solids

The 2-kg samples of slag obtained during the filling of each conical slag mold were chemically analyzed for 26 elements. In the slag, it can be accurately assumed that the elements exist as oxides. The chemical analyses weighted in terms of slag oxides are shown in Appendix H. This appendix also shows the weight of each slag ingot and the weighted mean composition of product slag for each furnace feed. The analyses for individual slag ingots do not add up to exactly 100% as they should, owing to analytical error for specific components, incomplete analysis for all components, different oxidation states for components within the analytical sample, and the absorption of moisture by the analytical samples. The analyses were not normalized to 100% to avoid changing any of the analyses and to show the combined accuracy of the analyses. Since the total compositions add up to very near 100% in most cases, the assumptions regarding the oxides and the analytical results are believed to be quite accurate for most of the elements.

Significant changes in the composition of the slag occurred as each melting test progressed. These changes are highlighted by the graphs in Appendix I, which present the concentrations of important slag-forming oxides and heavy metals (Cs_2O , PbO , and ZnO , and the TRU surrogate CeO_2) in the product slags as a function of the weight of slag tapped from the furnace. The slag compositions at the beginning of each different test condition were affected by slag remaining in the furnace from the prior feed mixture, even after the metal tap hole was opened to drain the furnace. Approximately 600 lb of slag and metal heel remained in the furnace from test to test, in the region below the metal tap hole where the MgO cast refractory hearth was dissolved.

After some hours of operation on each feed mixture while the residual slag was diluted and tapped out of the furnace, the slag tended to reach a steady state composition, termed "most representative slag composition" (MRSC). The MRSC for each furnace feed is shown in Table 5-2 and Appendix K. The MRSC for slag derived from each furnace feed is the weighted mean composition of slag tapped from the furnace after the product slag reached a steady state composition. For most furnace feeds, the slag reached a steady state composition after 3,000 to 4,000 lb was tapped from the furnace. The modified feeds, N80-Mod, N80-IV-Mod, and M60-Mod, were fed to existing molten pools of N80, N80-IV, and M60 slag, respectively. Therefore, the initial slags tapped after feeding the modified compositions were diluted with existing slag in the furnace. The weight of product slag derived from each modified furnace feed was calculated on the assumption that the weight of product slag was proportional to the weight of furnace feed.

Table 5-2. Compositions of the slag products.

Component	Most representative slag compositions (MRSC) (mg/kg) from the different surrogate waste mixtures							Concentration (mg/kg) for the M60 waste mixture (from single M60 rod sample)
	RWMC soil	S60	S60-IV	N80	N80-Mod	N80-IV	N80-IV-Mod	
Ag ₂ O	<1	7	<1	<1	<1	<1	<1	<1
Al ₂ O ₃	88,003	74,960	70,969	91,998	68,557	69,435	59,324	139,823
As ₂ O ₃	10	4	3	3	8	3	11	3
BaO	940	696	770	931	637	979	683	1,082
CaO	32,065	78,918	108,042	81,763	163,595	71,489	184,136	113,755
CdO	<1	<1	<1	<1	<1	<1	<1	<1
CeO ₂	NC	2,852	4,679	2,436	2,138	4,034	3,392	4,825
Cl	<100	151	100	25	30	8	8	60
CO ₂	247	1,151	2,511	1,682	539	781	1,174	953
CrO ₂	1,120	947	727	350	555	442	591	21,004
Cs ₂ O	10	1,573	2,194	366	543	62	58	66
CuO	715	651	63	49	248	56	300	413
Fe ₃ O ₄	229,175	173,293	183,757	146,714	221,287	115,935	212,407	81,538
HgO	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
K ₂ O	20,262	7,506	9,550	60,693	39,410	60,317	46,234	24,092
MgO	20,464	163,917	33,705	24,847	27,152	23,809	17,859	24,208
Na ₂ O	17,380	5,979	20,228	75,491	53,507	79,489	61,412	17,793
NiO	311	90	74	85	143	59	165	842
P ₂ O ₅	708	527	121	675	1,392	12	730	34
PbO	20	52	10	10	10	26	23	1,217
SO ₃	17	8	114	390	200	231	206	750
SeO ₂	<1	<1	<1	<1	<1	<1	<1	<1
SiO ₂	458,015	462,101	484,504	509,025	383,023	439,043	278,494	549,815
TiO ₂	8,873	17,467	44,580	15,413	13,562	80,686	50,557	11,376
ZnO	178	149	119	115	118	110	108	3,299
ZrO ₂	526	217	22,211	1,717	3,184	31,367	24,935	4,593
Total	879,000	994,000	991,000	1,014,777	979,837	976,000	942,806	1,001,541

The elemental composition of the metal phase remaining in the hearth is shown in Appendix K. Cerium, the TRU surrogate, was not detectable at a detection limit of 10 mg/kg. The pad sample was taken following the spike of elemental cerium alloyed in a 3-lb ingot with 50% iron that was added during the M60/M60-Mod test day. Lack of detectable Ce in this sample supports the feasibility of decontaminating structural metals of TRU contaminants by oxidizing the TRU elements which then partition totally to the slag phase. It is apparent from the increase in the Ce concentration in the slag, and from lack of detectable Ce in the metal, that this desirable selective separation was accomplished in this test.

5.4 Slag and APCS Solids Leachability

Slag samples and APCS solids for each of the baseline tests were analyzed for leachability using the EPA Toxicity Characteristic Leachability Procedure (TCLP). The separate samples from the fume traps and baghouse for each test were combined and a single integrated APCS sample was analyzed for each test. Since the slag composition was known to change during each test, 2 kg samples taken during the filling of the first and the last slag molds were used for TCLP analysis. These two samples represent the extreme composition range for each product slag. Cerium, the TRU surrogate, was included in the TCLP analysis in lieu of conducting a separate analysis such as Materials Characterization Center (MCC-1) or Product Characterization Test (PCT-1) for the leachability of radionuclides. Archived samples may be further analyzed for leachability with later funding.

5.4.1 Slag Leachability

Cooling of these small 2 kg samples was uncontrolled and much more rapid than required to allow for the formation of tailored zirconolite crystals known to capture Ce even more effectively than the vitreous IEB product. The cooled slag product that was leach tested is representative of the glassy (vitreous) IEB.

Each sample was crushed to <80 mesh (0.175 mm), whereas the TCLP requires sizing to only <1/4 in. (6.35 mm). The specific surface area of <80 mesh particles is over 36 times the area of <1/4-in. particles, and since leachability increases with increasing surface area, these TCLP tests were much more severe than required.

The TCLP results for the slag samples are shown in Appendix N. Where possible (when the slag concentration of Ce or the RCRA TCLP metal was measurable), the percent of that element that leached was calculated based on the measured concentration in the slag and the amount that dissolved into the TCLP solution. Results are summarized as follows:

- All of the slags passed the TCLP test. TCLP metal leachability results were typically below detection limits, and less than one-tenth of the TCLP limits. Slags from the M60 and M60-Mod furnace feeds provided a severe test regarding chromium, which was present at levels exceeding 1% in the M60-S1 slag sample.
- The percent of dissolution (leaching) of cerium and toxic metals present in the slag was also typically low, when the detected concentrations were sufficient to enable calculation of the percent dissolved into the leachate. Percent of barium dissolved

(leached) was fairly constant, under 8% of the barium in the slags. Chromium dissolution varied from essentially zero to around 19% of the chromium in the slag. Lead dissolution ranged under 6%, while cerium dissolution ranged from near zero to 13%. Ce dissolution was low or lower than for other metals, even without the presence of zirconolite crystals. Leaching percentages for the other metals could not be calculated due to low levels of those metals present in the slags or undetectable levels in the leachate.

- Increasing molar basicity slightly increased the tendency for chromium and cerium to leach from the slag (Figure 5-1), although the barium was not affected. The data indicate a positive correlation between molar basicity and the tendency for Ce to leach from the slag, consistent with the expectation that acidic slags are more resistant to weathering than basic slags. Even so, only a small or nondetectable amount of Ce and other metals were leached from the slag in any of the leach tests. Higher leach resistance of more acidic slags was expected, because higher levels of SiO_2 (occurring in more acidic slags) increase the formation of silicate lattice structures.
- The presence of TiO_2 and ZrO_2 in the slag did not seem to affect the leachability of barium, chromium, lead, or cerium (Figure 5-2). This was not surprising because the samples were cooled too fast to enable formation of the zirconolite crystals expected regardless of the levels of TiO_2 and ZrO_2 used in the baseline tests. Specific post furnace cooling rate control for the slag will be required to obtain the tailored zirconolite crystals.
- The slag most susceptible to leaching of Ce was M60-Mod-S5, which contained the highest concentration of Fe_3O_4 , thereby indicating a tenuous positive correlation between the iron oxide content of the slag and the tendency for Ce to leach from the slag.

5.4.2 Leachability of APCS Residues

The APCS residues represented primarily very finely divided feed material that was entrained into the offgas, and condensed volatile matter. Relative surface area for these samples was very large compared to that of the crushed slag samples. Also, the APCS residues were enriched in As, Ba, Cd, Ce, Cl, C, Hg, K, Na, Pb, SO_3 , Se, and Zn. In a mixed waste vitrification operation, the APCS solids are not necessarily expected to pass TCLP leachability for all elements due to the high surface area and possible enrichment of TCLP metals.

The TCLP results for the APCS solid samples are shown in Appendix N. Where possible (when the concentration of Ce or the TCLP metal was measurable), the percent dissolution of that element was calculated based on the measured concentration in the APCS solids and the amount that dissolved into the TCLP solution. Results are summarized as follows:

- APCS solids, owing to their very small particle size and the prevalence of chlorides, were more susceptible to leaching than the associated slags. Nevertheless, TCLP metal leachability results were typically below detectable limits, and less than one-tenth of the TCLP limits for all elements except for Cd, Pb, and Hg. Cd and Hg were passing but

Figure 5-1. Elemental dissolution of the slag compared to slag basicity.

Note: Down arrows indicate that levels were non-detectable in the slag, where data point indicates maximum partitioning value based on the detection limit.

Figure 5-2. Elemental dissolution of slag compared to TiO₂ and ZrO₂ in the slag.

approached the limits in some cases. Although Hg was typically not detected, the detection limit was only one-half of the TCLP limit of 0.2 mg/l, which is much lower than the limits for the other metals. Pb did not pass the TCLP limit for the APCS residues from the S60, S60-IV, and M60 tests. Pb was 33 times higher than the limit for the residues from the M60 test when the feed mixture contained 0.74% elemental Pb.

- The percent dissolution of many of the elements was much higher than for the slag samples.
- The percent dissolution for Ce correlated strongly with the chloride content of the residue (Figure 5-3). The dissolution for barium, chromium, and lead was only slightly affected by the chloride content in the measured ranges.

Figure 5-3. Elemental dissolution of the APCS solids (mg/kg).

6. OFFGAS EMISSIONS

6.1 Operating Conditions and Emissive Summary

A summary of the furnace emissions and the operating conditions for distinct sampling periods during the baseline tests is provided in Table 6-1. During these sampling periods, concurrent offgas composition, velocity, flowrate, temperature, particulate loading, and metals emissions measurements were made. These measurements were made primarily at the quench section outlet, upstream of the fume traps and the baghouse. The particulate and metals emissions were measured using the EPA Draft Multiple Metals Train (MMT). Temperature and flowrate measurements were redundant with installed temperature and flowrate sensors in the APCS, to assure accuracy and determine comparability of the measurements. Occasionally during the baseline tests, offgas composition measurements were also made immediately upstream of the baghouse and at the stack. Occasional gas temperature measurements were also made at the furnace outlet location.

The furnace outlet gas composition, temperature, and flowrate were calculated using the measurements at the quench section outlet and the quench section dilution factor. The dilution factor was calculated two different ways: (a) using independent mass and energy balances from temperature and flowrate measurements for the offgas at the quench section outlet for the quench air, and (b) occasional temperature measurements at the furnace outlet. However, considerable variability existed in the calculated dilution factors due to the variability in the infrequent furnace outlet temperature measurements and variability in the quench air flowrate measurements. Since the design dilution factor was 5:1, the calculated dilution factors nearest to 5 were used in the furnace outlet gas composition, temperature, and flowrate calculations (Appendix S). Due to the potential variability of the dilution factor, the calculated furnace outlet values should be considered semi-quantitative.

Operating conditions shown in Table 6-1 are slightly different from those shown in Table 3-1 because the Table 6-1 conditions represent a discrete sampling time for each test while Table 3-1 shows average conditions and totals for each feed mixture. Two replicate MMT sampling runs were made for the S60 and S60-IV feed mixtures. Only a single MMT sampling run was made for the other feed mixtures. The sampling periods were during the most stable operating conditions for the S60 melt. The power level, feed rate, offgas flowrate, and offgas temperatures were relatively constant. Operating conditions for the S60-IV sampling periods were stable for each sampling period, but the power level and the feed rate were much lower for the second sampling period than for the first sampling period.

For the N80 sampling period, the furnace power was very stable, but the feed rate varied from 1,000–1,300 lb/hr. Furnace operation for the N80-Mod period was less stable, with the power ranging as high as 600 kW but occasionally dropping as low as 200 kW, and the feed rate ranging from 800 to 1,000 lb/hr. Also, the cold top in the furnace melted into the melt during a portion of this sampling run. When the cold top melted, the gas temperature at the quench outlet rose from 74 to 97°C, which equates to an increase in the furnace temperature of 76°C. Conditions in the furnace for the N80-Mod feed mixture were less stable, likely due to the

Table 6-1. Detailed overview of baseline test results.

Run No.	Feed type	Sampling period start-end clock time	Feed rate (lb/hr)(d)	Slag tapping (f)		Offgas temperature (C)			Offgas flowrate (wscfm)			Calculated furnace air influx (wscfm)	Dilution factor (b)
				Slag tap temp (C)	Time recorded	Furnace outlet(e)	Quench outlet	Baghouse outlet(d)	Melter outlet (a)	Quench section outlet	Baghouse outlet		
MMT-S60-1	S60	1156-1321	1,111	1480	1317	323	67.8	76.3	102	486	311	56.3	4.77
MMT-S60-2	S60	1406-1522	975	1,515	1317;1720	324	77.8	76.6	115	477	296	79.2	4.16
MMT-S60-IV-1	S60-IV	1214-1340	1,603	1,630	1458	330	78.9	78.0	117	490	380	60.8	4.18
MMT-S60-IV-2	S60-IV	1523-1645	997	1,510	1549	337	79.4	74.9	116	493	331	87.5	4.24
MMT-N80-1	N80	1050-1208	1,243	1,830	1050 L&N	281	85.6	75.8	164	541	393	125	3.29
MMT-N80-2	N80-Mod-1	1520-1625	686	1,460	1611 L&N	692	94.4	72.1	67.8	497	384	27.4	7.33
MMT-N80-IV-2	N80-IV	1220-1334	1,240	1,707	1221-1307 L&N	599	102	82.9	87.0	510	370	34.2	5.86
MMT-N80-IV-3	N80-IV-Mod-	1545-1655	1,330	1,562	1545-1645 L&N	393	109	81.0	132	474	363	89.9	3.59
MMT-M60-1	M60	1005-1125	1,015	1,560	1354	1,169	211	99	96.9	538	390	51.2	5.55
MMT-M60-2	M60-Mod	1412-1522	1,804	1,500	1548	665	121	89.4	101	552	401	61.8	5.49

Notes: 1. NM = Not measured; NC = Not calculated due to insufficient measurements.

- a. Calculated from measurements at the quench section outlet using the dilution factor.
- b. Dilution factors were calculated from mass/energy balances performed at the quench section.
- c. Calculated from CI mass balance, not directly measured.
- d. Calculated average values from the DAS system.
- e. Furnace outlet offgas temperature was calculated using mass and energy balances, the temperatures and flow rates of the quench air and the cooled, diluted offgas at the quench section outlet.
- f. All slag tap temperatures are taken using either the baseline pyrometer or the L&N pyrometer.

Table 6-1. (continued)

Run No.	Average furnace pressure (in H ₂ O)(d)	Calculated offgas composition, furnace outlet (dry basis except as noted) (a)							Offgas composition, quench outlet (dry basis except as noted)							Baghouse delta P (in H ₂ O)(d)
		O ₂ (%)	CO ₂ (%)	CO (ppm)	NO _x (ppm)	SO ₂ (ppm)	H ₂ O (wet %)	HCl (c) (ppm)	O ₂ (%)	CO ₂ (%)	CO (ppm)	NO _x (ppm)	SO ₂ (ppm)	H ₂ O (wet %)	HCl (c) (ppm)	
MMT-S60-1	-0.060	11.6	10.4	16,036	170	4,986	28.9	22,796	19.9	2.17	3,362	35.7	1,045	6.05	4,779	1.32
MMT-S60-2	0.008	14.5	6.56	5,708	60.0	20,161	26.8	18,042	20.3	1.58	1,372	14.4	4,846	6.45	4,337	1.31
MMT-S60-IV-1	-0.178	10.9	11.2	26,026	131	26,288	34.4	17,598	19.7	2.68	6,224	31.4	6,287	8.20	4,210	1.62
MMT-S60-IV-2	-0.254	15.8	6.92	11,399	38.3	12,972	26.2	12,665	20.6	1.63	2,689	9.04	3,060	6.20	2,987	1.62
MMT-N80-1	-0.206	15.9	NC	NC	2.70	8.37	18.1	0	20.2	NM	NM	0.82	2.54	5.49	0	2.01
MMT-N80-2	-0.257	8.50	23.5	41,647	33.8	77.1	33.6	0	20.0	3.21	5,682	4.62	10.5	4.58	0	2.51
MMT-N80-IV-2	-0.339	8.26	18.8	25,210	44.0	326	38.1	0	19.8	3.21	4,302	7.51	55.7	6.50	0	2.13
MMT-N80-IV-3	-0.294	14.3	10.8	15,177	5.50	132	20.6	0	19.9	3.01	4,228	1.53	36.9	5.74	0	2.26
MMT-M60-1	-0.362	11.1	11.6	9,802	242	15.1	25.8	0	19.9	2.09	1,766	43.7	2.73	4.64	0	2.47
MMT-M60-2	-0.843	12.9	15.3	13,831	63.1	15.8	21.5	0	20.1	2.79	2,519	11.5	2.88	3.92	0	2.35

thermal decomposition and gas evolution of the limestone (CaCO_3) additive, used to modify the slag viscosity for tapping at lower slag temperatures.

During the N80-IV sampling period, the furnace power decreased from 700 to 550 kW, while the feed rate decreased from 1,400 to 1,300 lb/hr. There were several changes in the power and feed rate for this feed mixture, in an attempt to achieve an optimum, stable power level and feed rate. Operating time was insufficient to establish a long-term stable condition until the operation on the N80-IV-Mod feed mixture. Furnace power and feed rate were relatively stable for the N80-IV-Mod sampling period at approximately 600 kW and 1,250–1,350 lb/hr.

Furnace conditions for the M60 feed mixture varied somewhat, and operating time was insufficient to establish a long-term stable condition. Since slag tapping could not be initiated due to high viscosity slag, the M60 feed mixture was stopped after 3.1 hours, and feeding with N80-IV-Mod feed mixture was started. Manual additions totalling 400 lb of pebble lime (CaO) were also added to adjust the slag viscosity and enable continuous slag tapping. Furnace operation during the M60-Mod sampling period was relatively stable with a power level of 500–550 kW and a feed rate of 1,700–1,800 lb/hr.

6.2 Offgas Compositions

The offgas compositions depended upon the compositions of the feed mixtures and the feed rates, relative to the furnace air leakage. Air leakage into the furnace occurred due to the furnace negative pressure through the feed tubes with the feed, and through seals in the roof around the feed tubes and the electrodes. While this leakage was not measured directly, it was calculated by difference from the furnace outlet gas flowrate (also a calculated variable) and the amount of volatilization from the feed material, calculated from the measured CO_2 , CO , SO_2 , and H_2O values in the offgas. For the S60 and S60-IV feed mixtures that contained significant Cl, the calculated amount of Cl volatilization was also included in the total feed volatilization calculation.

Since the air leakage was calculated by mass balance from other calculated and measured variables, there was a variation in the leakage values, ranging from 27 to 125 scfm. The data shows no correlation between the furnace draft and the air leakage, although one would be expected. This poor correlation is due to the method used to calculate the air leakage. The air leakage was calculated by subtracting two numbers, the furnace outlet gas flowrate and the feed material volatilization rate. These calculated leakage values should be considered qualitative. The air leakage as a function of furnace draft may be determined experimentally prior to the FY-94 tests by operating all of the systems without feeding soil through the feeder, and measuring the furnace draft and the flowrate at the furnace outlet.

Oxygen levels were relatively high (8.3–15.9%, dry basis) indicating oxidizing conditions in the furnace atmosphere. Only a portion of the oxygen in the air leakage was consumed through oxidation of reduced species (organic carbon, sulfur and chlorine compounds, and in the M60 test, elemental metals) in the feed mixtures and from oxidation of the graphite electrodes.

Moisture in the offgas (18–38%) resulted from vaporized water and water of combustion. The majority of the carbon was carbon dioxide in the offgas (up to 23.5% carbon dioxide, compared to carbon monoxide levels under 42,000 ppm). Nitrogen oxide levels were typically

under 100 ppm except for the M60 test condition, when NO_x levels averaged 242 ppm. These are relatively low NO_x levels compared to many other types of thermal and combustion equipment, due to negligible amounts of fuel nitrogen (source of fuel NO_x) and low gas temperatures (source of thermal NO_x). The higher NO_x level for M60 occurred due to thermal NO_x formation when the gas temperatures and furnace outlet gas temperatures averaged almost $1,200^\circ\text{C}$ compared to temperatures of 300 to 700°C for the other test conditions. Sulfur dioxide levels ranged up to 325 ppm or less except for the S60 and S60-IV melts, when higher levels ranging up to 26,000 ppm resulted from decomposition of 6.9–7.1% calcium sulfate in the feed mixtures.

The offgas CO_2 and CO levels for the second S60 sampling period were significantly lower than for the first test period, even though the feed rate was only slightly lower for the second sampling period. This same trend was also true for the S60-IV sampling periods, when the same feed mixture, with the exception of added cerium and zirconium oxides, was fed to the furnace. CO_2 and CO in the offgas was primarily from decomposition of carbonates in the feed mixtures, and to a smaller extent, oxidation of the graphite electrodes and trace amounts of organic carbon in the soil. The lower CO_2 and CO levels for the second S60-IV sampling period were due at least partially to significantly lower feed rates of the S60-IV feed mixture (997 lb/hr compared to 1,603 lb/hr). However, the variation in CO_2 and CO levels for the S60 feed mixture and also the S60-IV feed mixture may also be due to size segregation of carbonate-containing feed materials in the feed system. The SO_2 in the offgas also varied from that in the S60 and S60-IV tests, due to variations in the furnace feed rate and to feed segregation. Variations in the feed mixture compositions due to incomplete mixing or due to stratification during shipping and handling is also a likely cause for offgas composition variations. While the soil particle size ranged 10 wt% less than 80 mesh (0.175 mm), the gypsum ($\text{CaSO}_4 \cdot \text{H}_2\text{O}$) particle size was much finer at 64% less than 80 mesh. If calcium carbonate in the soil was concentrated in larger soil particles, then the calcium carbonate may segregate opposite to the gypsum, as the offgas composition data suggests.

6.3 Particulate and Metals Emissions

The total particulate in the offgas includes (a) feed dust entrained in the furnace gas, (b) material volatilized from the hot melt that has condensed as particles or droplets (also termed fume) in the cooler offgas sections, and (c) material volatilized from the hot melt that would condense at ambient temperatures (given sufficient time and nucleation sites), but that has not yet condensed in the APCS. The volatilized material can condense on the surfaces of entrained feed material and also form very small particle-size fume particles that may or may not grow in size with continued condensation or agglomeration. The entrained feed particles, having possibly bypassed higher temperatures in the furnace, can have the same appearance, mineral content, and composition as particles of the same size in the feed mixtures. The fume particles and the very fine entrained feed particles can be enriched with materials volatilized from the melt such as toxic metals.

Levels of total particulate concentrations shown in Table 6-2 were measured using the isokinetic MMT. This procedure is designed to capture not only the solid particulate but also any metals in gaseous form at the conditions and location in the APCS. The total particulate concentrations are within the range of particulate emissions for fluidized bed combustors and aggregate processing equipment, where the process material is soil and other finely divided, dusty materials such as the feed mixtures in this test program.

Table 6-2. Comparison of particulate results from the MMT sampling tests and the fume trap/baghouse catches.

Feed type	MMT sampling runs				Calculations from fume trap 1, fume trap 2 and baghouse hopper solid particulate catches(a)				
	Run number	Total particulate concentration	Total particulate emission	Total metals concentration	Total metals emission	Solid particulate emission	Solid metals emission	Total particulate % Diff(b)	Total metal % Diff(b)
		(gr/dscf)	rate (lb/hr)	(gr/dscf)	rate (lb/hr)	rate (lb/hr)	rate (lb/hr)		
S-60	MMT-S60-1	6.22	24.3	2.37	9.27	17.2	8.17	29.2	11.8
S-60	MMT-S60-2	4.68	17.9	1.93	7.37	16.1	7.64	10.0	-3.61
S-60-IV	MMT-S60-IV-1	6.46	24.9	2.34	9.05	30.1	15.3	-20.8	-69.1
S-60-IV	MMT-S60-IV-2	4.40	17.4	2.13	8.45	19.3	9.79	-10.7	-15.9
N80	MMT-N80-1	4.34	19.0	2.26	9.89	27.1	13.0	-42.7	-31.4
N80-Mod	MMT-N80-2	5.15	20.9	1.98	8.03	29.5	13.6	-41.1	-69.7
N80-IV	MMT-N80-IV-2	6.17	25.2	3.01	12.3	22.3	11.4	11.7	7.40
N80-IV-Mod	MMT-N80-IV-3	3.55	13.6	1.94	7.43	32.5	17.1	-139	-130
M-60	MMT-M60-1	5.35	22.6	3.10	13.1	16.5	7.64	26.9	41.8
M60-Mod	MMT-M60-2	4.81	21.1	2.57	11.3	25.1	14.2	-18.9	-25.9
Average % Diff								-13.9	-22.5

a. Emission rates proportioned to MMT test feed rates.

b. % Diff = (Total particulate/metals emission rate - Solid emission rate)/Total particulate/metals emission rate * 100

The material collected in the two fume traps tended to be particles too large and too dense to stay entrained in the offgas as the offgas passed through the traps. While these traps were not designed as cyclones, the gas entrances to the traps induced a cyclonic action in the offgas to better disengage particles from the gas stream. Of the total particulate, portions that were collected in these fume traps are shown in Table 6-3. Analysis of the fume trap samples indicates that the material collected in the fume traps was mostly feed material. X-ray diffraction results show that the physical forms match very closely to the denser components of the feed mixtures. X-ray diffraction of the baghouse samples shows that the material captured in the baghouse was enriched with recondensed fume that volatilized from the slag melt.

The amounts of material captured in the fume traps and the baghouse should depend on such furnace operating conditions as slag temperature, power input, feed rate, cold top depth, or offgas velocity in the fume traps. Values for these variables are listed in Table 6-4. However, no apparent measurable correlation exists to any of these other variables.

Concentrations and mass emission rates for the metals and Ce, the TRU surrogate, are shown in Tables 6-4 and 6-5. The concentrations and mass emission rates were determined from the MMT samples at the outlet of the quench section. Furnace outlet concentrations were estimated from the quench section outlet measurements by multiplying the reported values by the calculated dilution factors. These levels are indicative of the amounts of material that would need to be controlled in a full-scale processing facility, unless the process is configured to have less entrainment of feed material and less volatilization from the melt. Each of these phenomenon may be controlled by different mechanisms. For example, feed entrainment may be minimized by reducing levels of volatile material (carbonates, organics, sulfates, etc) in the feed material, by pelletizing the feed, removing or tuyere injection of soil fines, or by minimizing the amount of gas flow and turbulence in the furnace plenum above the melt. Volatilization of toxic metals from the melt can be controlled by minimizing temperatures, maintaining oxidizing conditions in the melt, or by operating with a cold top.

6.4 Offgas Composition Trends

The gas species concentrations in the offgas were continuously monitored downstream of the quench section. These concentrations are shown in Figures 6-1 through 6-5. Concentrations varied widely due to variations in feed volatilization rates and pressure fluctuations (that caused variations in the rate of air leakage into the furnace).

Table 6-3. Distribution of particulate in fume traps and baghouse.

Feed mixture	Cold top depth (in.)		Feedrate (lb/hr)	Power input (kWh/lb)	Slag temp (C)	Total particulate concentration (gr/dscf)	Percent of total solid particulate collected in:			
	Range	Average					Total in			
							Fume Trap 1	Fume Trap 2	Fume Traps	Baghouse
S60	3 - 8	5.0	1,180	0.017	1550-1600	24.5	5.70	34.9	40.6	59.4
S60-IV	0 - 14	6.5	1,251	0.013	1550-1650	22.8	6.70	26.2	32.9	67.1
N80	0 - 11	6.5	1,155	0.015	1650-1800	14.3	13.8	12.4	26.2	73.7
N80-Mod	0 - 13	5.5	917	0.018	1450-1550	37.8	10.5	38.7	49.2	50.8
N80-IV	0 - 6	3.0	1,106	0.016	1650-1750	36.1	23.1	34.8	57.9	42.1
N80-IV-Mod	0 - 6	3.5	1,302	0.015	1550-1590	12.7	11.3	35.3	46.6	53.4
M60	0 - 8	4.0	1,033	0.014	no tap	29.7	9.10	37.3	46.4	53.6
M60-Mod	2 - 12	5.5	1,240	0.014	no tap	26.4	16.7	36.9	53.6	46.4
Average		4.9	1,148	0.015	-	25.5	12.1	32.1	44.2	55.8

Table 6-4. Metals and TRU surrogate concentrations in the offgas (mg/dscm).

Element	S-60			S60-IV			N80	N80-Mod	N80-IV	N80-IV		M60	N80-IV	
	Test 1	Test 2	Average	Test 1	Test 2	Average				Mod-1			Mod-2	
Arsenic	< 2.96	< 2.23	< 2.59	< 3.06	< 2.11	< 2.59	2.72	2.46	2.92	2.02	< 2.56	< 2.28		
Aluminum	258	163	210	195	143	169	388	138	326	182	190	257		
Barium	15.1	10.4	12.7	18.5	6.04	12.3	10.9	12.6	21.2	16.5	16.3	16.8		
Boron	0.168	0.342	0.255	0.297	0.176	0.237	0.246	< 0.106	< 0.101	< 0.082	< 0.112	< 0.083		
Cadmium	0.143	0.118	0.131	0.178	0.121	0.150	0.199	0.130	0.142	0.147	0.160	0.143		
Calcium	613	333	473	621	2,388	1,505	495	414	463	1,064	368	1,123		
Cerium	48.2	15.5	31.8	50.5	25.8	38.2	30.4	23.3	107	75.2	20.8	74.6		
Chromium	1.87	2.61	2.24	2.05	1.61	1.83	3.10	1.40	4.54	2.79	5.68	20.7		
Copper	8.95	43.6	26.3	4.80	3.96	4.38	2.01	3.60	1.86	5.24	5.19	8.67		
Iron	656	488	572	706	254	480	431	644	387	336	159	468		
Lead	5.67	11.5	8.59	7.98	2.61	5.29	5.37	6.64	6.60	5.01	1,762	60.0		
Magnesium	133	86.7	110	111	94.5	103	101	78.0	98.1	65.2	53.9	83.9		
Manganese	6.25	6.32	6.28	8.04	3.03	5.53	3.82	7.24	5.36	3.65	4.93	5.48		
Mercury	< 2.92	< 2.23	< 2.58	< 3.06	< 2.11	< 2.59	< 2.09	< 2.46	< 2.92	< 1.71	< 2.56	< 2.28		
Nickel	0.829	0.772	0.801	0.707	0.508	0.608	1.30	0.757	0.688	0.687	1.54	1.79		
Phosphorus	53.2	147	100	51.7	35.3	43.5	125	60.5	117	38.7	18.9	56.8		
Potassium	999	977	988	923	674	798	769	877	1,206	651	203	888		
Selenium	< 2.92	< 2.23	< 2.58	< 3.06	< 2.11	< 2.59	< 2.09	< 2.46	< 2.92	< 1.71	< 2.56	< 2.28		
Silicon	1,579	1,125	1,352	1,371	756	1,064	1,759	1,163	2,046	1,064	1,444	1,386		
Silver	< 0.30	< 0.24	< 0.27	< 0.32	< 0.23	< 0.27	< 0.23	< 0.26	4.02	1.77	0.69	2.45		
Sodium	967	945	956	1,208	462	835	968	1,025	1,338	579	127	798		
Strontium	5.26	3.60	4.43	5.91	3.54	4.73	3.12	4.08	5.81	5.35	4.38	6.28		
Titanium	30.9	16.4	23.6	35.4	12.0	23.7	30.9	23.4	48.7	24.9	11.3	30.9		
Vanadium	3.39	2.87	3.13	3.72	1.64	2.68	2.89	3.35	5.13	1.87	0.35	2.08		
Zinc	25.2	27.3	26.3	27.0	10.1	18.6	25.4	27.7	15.4	6.59	2,691	154		
Zirconium	0.687	0.483	0.585	1.45	0.548	1.00	0.859	2.37	662	301	6.65	419		

< Value below detection limit.

Table 6-5. Mass emission rates for metals and TRU surrogate in the offgas (g/hr).

Element	S-60			S60-IV			N80	N80-Mod	N80-IV	N80-IV		M60	N80-IV	
	Test 1	Test 2	Average	Test 1	Test 2	Average				Mod-1			Mod-2	
Arsenic	< 2.29	< 1.69	< 1.99	< 2.34	< 1.66	< 2.00	2.36	1.98	2.37	1.53	<	2.15	<	1.99
Aluminum	201	123	162	149	112	131	337	112	264	138		159		224
Barium	11.7	7.90	9.79	14.2	4.74	9.45	9.46	10.1	17.2	12.5		13.7		14.6
Boron	0.130	0.259	0.195	0.227	0.138	0.183	0.214	< 0.085	< 0.082	< 0.062	<	0.094	<	0.072
Cadmium	0.111	0.089	0.100	0.136	0.095	0.116	0.173	0.105	0.115	0.112		0.134		0.125
Calcium	475	252	364	475	1,874	1,175	430	333	375	809		308		978
Cerium	37.4	11.7	24.6	38.6	20.3	29.5	26.4	18.7	86.9	57.2		17.5		65.0
Chromium	1.45	1.98	1.72	1.57	1.26	1.42	2.69	1.13	3.68	2.12		4.76		18.00
Copper	6.95	33.1	20.0	3.67	3.10	3.39	1.74	2.90	1.51	3.98		4.36		7.55
Iron	509	370	439	540	199	370	374	519	314	255		133		408
Lead	4.40	8.72	6.56	6.10	2.05	4.07	4.66	5.35	5.35	3.81		1,478		52.3
Magnesium	103	65.7	84.4	85.1	74.1	79.6	88.1	62.9	79.5	49.6		45.2		73.1
Manganese	4.85	4.79	4.82	6.15	2.38	4.26	3.31	5.83	4.34	2.77		4.13		4.77
Mercury	< 2.27	< 1.69	< 1.98	< 2.34	< 1.66	< 2.00	< 1.81	< 1.98	< 2.37	< 1.30	<	2.15	<	1.99
Nickel	0.643	0.585	0.614	0.541	0.399	0.470	1.13	0.610	0.558	0.522		1.29		1.56
Phosphorus	41.2	111	76.3	39.5	27.7	33.6	109	48.7	94.5	29.4		15.9		49.5
Potassium	775	741	758	706	529	617	668	706	978	495		170		774
Selenium	< 2.27	< 1.69	< 1.98	< 2.34	< 1.66	< 2.00	< 1.81	< 1.98	< 2.37	< 1.30	<	2.15	<	1.99
Silicon	1,225	852	1,039	1,049	593	821	1,527	936	1,658	809		1,211		1,208
Silver	< 0.235	< 0.180	< 0.207	< 0.247	< 0.177	< 0.212	< 0.202	< 0.211	3.26	1.34		0.577		2.14
Sodium	751	716	733	924	362	643	841	826	1,085	440		107		695
Strontium	4.08	2.73	3.40	4.52	2.78	3.65	2.71	3.28	4.71	4.07		3.67		5.47
Titanium	24.0	12.4	18.2	27.1	9.40	18.2	26.8	18.8	39.5	18.9		9.47		26.9
Vanadium	2.63	2.17	2.40	2.85	1.29	2.07	2.51	2.70	4.16	1.42		0.297		1.81
Zinc	19.6	20.7	20.1	20.7	7.90	14.3	22.1	22.3	12.5	5.01		2,258		135
Zirconium	0.533	0.366	0.450	1.11	0.430	0.768	0.746	1.91	536	229		5.57		365

< Value below detection limit.

Furnace outlet offgas composition for melt S60

Figure 6-1. Furnace outlet offgas composition for melt S60.

Figure 6-2. Furnace outlet composition for melt S60-IV.

Furnace outlet offgas composition for melts N80 and N80-Mod

Figure 6-3. Furnace outlet composition for melts N80 and N80-Mod.

Figure 6-4. Furnace outlet composition for melts N80-IV and N80-IV-Mod.

Furnace outlet offgas composition for melts M60 and N80-IV-Mod

Figure 6-5. Furnace outlet offgas composition for melts M60 and N80-IV-Mod.

7. CONCLUSIONS AND RECOMMENDATIONS

The baseline tests represent the initial test series campaign in a three phase BWID test and evaluation project. The extensive amount of data has required considerable evaluation effort to date, yet further evaluation is always possible. These baseline test results are being used in the planning of future test series, evaluations, and supporting studies. The following are key conclusions and recommendations from the baseline test results.

1. The first overall conclusion is that the baseline tests have successfully addressed the primary test objectives identified in Section 2.2, as the first test campaign in a planned three campaign series. Results have provided a better understanding of arc melter performance for treating "as incinerated" surrogate wastes. Results also provide information useful for test system modification for future tests, and for designing and performing future tests. In the second series of tests, arc melting of raw, as received buried and mixed wastes (without prior incineration) will be evaluated using nonradioactive, surrogate waste mixtures. The second test series is necessary to evaluate arc furnace applicability for treating as-received buried and mixed wastes, as opposed to treating ash residuals from a preincinerator step.

2. The second overall conclusion is that it is feasible to use existing industrial arc melter technology as a thermal treatment system to successfully process "previously incinerated" buried mixed wastes and soils on a production basis. Extensive additional design, testing, and evaluation is required to optimize the arc furnace system and improve operations to reduce the level of personnel involvement and risk for mixed/buried waste applications. Current design and operating practices used for this test system are based on those commonly used in the metals smelting industry. The test system and procedures were further modified for optimum personnel access to the equipment and process materials. This access is necessary for researchers to monitor and control conditions and understand the melter process operations. Modifications such as an enhanced feed system, overall system containment, and a remote tapping operation will enable application of the existing technology represented by the USBM system to radioactive waste treatment. Automation of many activities such as tapping is done currently to some extent in the commercial metals industry.

3. The arc melter technology is capable of reliable production operation for this application. Furnace operating parameters were generally within expected values and typical of reliable industrial arc furnace practice norms. Electrode wear was not excessive even though the furnace plenum was operated under excess air flow conditions (oxidizing conditions in the plenum). Slag was continuously tapped at steady state. Separate bottom tapping capability for use with metals was partially demonstrated by the draining of the furnace each day. Insufficient metal was present for separate metals tapping due to the volume increase of the hearth from dissolution of the hearth refractory. Over 52,000 lbs of surrogate materials were processed at rates representative of those anticipated as needed for full scale production processing of buried mixed wastes and soils (1,000 to 2,000 lbs/hr) during a semi-continuous 80 hr test period essentially without failure (unplanned downtime).

There were two minor and preventable downtime problems incurred. The first was a fuse failure in the control circuit for the Phase A electrode. This was quickly resolved by operating that electrode manually while the failed fuse was diagnosed and replaced without difficulty. The

second downtime occurrence was a partial blockage of the feed tubes in the furnace due to positive pressure spikes in the furnace leading to back flow of moist process gases into the feed tubes and agglomeration and blockage of the feed. After a short shut-down to clear the blockage, operation with increased negative pressure in the furnace (higher ID fan suction) and more control over open ports in the APCS (used for sample collection) satisfactorily prevented further occurrences. The positive pressure also caused very short duration but undesirable leakage of furnace gases into the melter room.

4. Although the arc furnace technology can clearly produce a wide range of process conditions, additional process optimization work is needed. The highly viscous, high-silica melts of some of the soil and feed mixtures required melt temperatures exceeding 1,800°C in order to achieve sufficient fluidity to tap the slag. While the furnace easily achieved the required temperatures, additions of mill scale (Fe_3O_4) and either limestone (CaCO_3) or pebble lime (CaO) were used to substantially reduce viscosity and required tapping temperatures, to reduce concerns for potential metals volatilization and refractory wear. The magnesium oxide hearth was also dissolved by the acidic (high silica) S60 feed slag at high temperatures. This did not require a shut-down during the test, but prevented complete draining of the furnace through the bottom metal tap hole in all subsequent tests. The metal product at the bottom of the hearth could not be tapped as a result. Additional testing and analytical modeling evaluations are recommended to improve tapping of higher viscosity slags, and to determine optimum slag conditions for maximum glass/ceramic waste form durability (high silica, high temperature slag) while minimizing additives, furnace wear, and metals volatilization (lower silica, lower viscosity, lower temperature slag).

5. The arc furnace produced process conditions desired for controlled separations, destruction of complex waste compounds, and stabilization of TRU and selected toxic metals in a highly durable glass/ceramic product (slag phase). Overall mass and elemental partitioning results were generally consistent with expectations and desired separations for all test feeds. An average of 84% of the feed material mass was melted or dissolved into the fluid slag phase, tapped, and cooled to produce a durable glass/ceramic solid. Approximately 2.9% of the feed mass partitioned as a separate tappable metal product phase (over 90% Fe) in the bottom of the furnace (hearth) below the slag phase. Approximately 15% of feed material decomposed or reacted to produce typical combustion gases (H_2O , CO_2 , CO , SO_2 , HCl , NO_x) flowing out through the APCS. Roughly 1.5% was entrained feed particulate and 0.5% of the mass was volatilized fume solids (condensable particulate).

6. The slag was the primary furnace product material and yielded a homogeneous, durable glass/ceramic phase (tapped slag) upon cooling that easily passed TCLP. A separate tappable, homogeneous, structural metal alloy phase material product was also produced, as were relatively small amounts of secondary furnace product solids (condensed fume and entrained feed particulate) which were successfully captured and retained in the APCS. Each product material was essentially homogeneous (much more so than the waste feeds), and properties evaluated were generally acceptable. The APCS solids would likely require additional processing. Recycling through the furnace is recommended for the entrained particulate after agglomeration into a larger feed size. In a continuous operation, the amount of effluent APCS solids may be significantly reduced by recycling most of this material to the melter.

7. The arc furnace system process should be capable of partitioning essentially all TRU in the waste to the desired glass/ceramic (slag) phase without volatilization of any TRU or contamination of tappable metal. No cerium (the TRU surrogate) was detected in the metals product. Only 2% of the Ce was transported into the APCS system, due to direct feed entrainment. The feed entrainment of Ce was due to the presence of very fine particle-sized CeO_2 concentrate, and would not be normal under normal processing of actual buried and mixed wastes.

Results of the M60 test indicate that any TRU metal in waste processed under these conditions would rapidly oxidize and partition to the slag. In addition to the CeO_2 concentrate that was added in all the tests, elemental Ce was added to the M60 test. This Ce rapidly oxidized. No Ce was detected in the metal product, and the Ce detected in the APCS solids did not increase. The measured increase in Ce in the slag also confirmed this partitioning. This oxidation of Ce and partitioning to the slag occurred even though conditions in the furnace slag were locally reducing enough to not oxidize over 95% of the copper, over 90% of the nickel, and over 85% of the iron that were added as elemental metals. These elements reported primarily to the melted metal phase in the bottom of the furnace. The lack of any Ce in the APCS solids that was attributable to volatilization is consistent with the low volatility of CeO_2 , and meets expectations that this readily oxidized material would entirely report to the slag phase even under high temperature melt conditions. The presence of the cold top may have also contributed to the lack of any volatile Ce carryover.

The presence of CeO_2 in the feed mixtures represents a worst case situation for potential feed entrainment and consequent Ce carryover to the APCS. Despite the small size of the CeO_2 powder in the feed, an average of 98% of the Ce partitioned to the slag. This is due in part to the effectiveness of the feed tubes and the cold top in minimizing dusting.

There was also little change in the partitioning of Ce to the baghouse from run to run, even for the higher temperature N80, N80-IV, and M60 runs. Since there was no apparent influence of temperature on the partitioning of Ce to the APCS, the small amount of Ce that was partitioned to the APCS was from entrainment of the fine Ce oxide powder in the feed. Elimination of feed entrainment and carryover may be minimized by design and operation modifications, such as increasing the feed material size distribution and reducing furnace plenum gas velocities.

8. Additives used in preparing the surrogate feed mixtures tended to have fine particle size distributions and contributed markedly to the solids collected in the APCS. This entrainment biased APCS elemental partitioning analyses and made it very difficult to detect volatilization versus entrainment for most materials and elements. Only a few of the additives (mullite, pollucite, NaCl, pebble line, aluminum, copper, lead, and zinc) had particle sizes too large to be at least partly entrained. All of the other materials had sufficient fines to be at least partially entrained. Especially critical additives that had large amounts of fine material included the soil, cerium oxide concentrate, limestone, potash, and soda ash. Even iron was entrainable, as oxides in magnetite powder in all tests but the M60 test, in mill scale flakes in all of the modified composition tests (N80-Mod, N80-IV-Mod, and M60-Mod), as elemental iron in stainless steel powder and iron flake in the M60 test, and as oxides in the soil of all tests. Partitioning results have been interpreted with consideration of this entrainment potential, and estimates of

volatilized and entrained amounts for different components have been made. However, measures are recommended for future tests to avoid or better differentiate between entrained and volatilized materials in the offgas. Such measures may include reducing entrainment of feed materials by using larger feed particle sizes, pelletizing feed additives, reducing plenum gas velocities, or more effectively identifying and separating entrained and volatilized materials. Excessive size reduction of actual wastes during feed preparation for production operations should be avoided.

9. Toxic metal vaporization and carryover was very low for all but the most volatile species of As, Cd, Pb, P, Hg, Se, and Zn. Correlations for less volatile metals were difficult and masked by feed entrainment carryover. Also, most of the metals were present at only trace levels as metal oxides in the feed mixtures except for the M60 feed mixture, so small or nondetectable amounts of some metals affected the partitioning calculations. While metals volatilization was expected to increase with increasing melt temperatures and with increasing Cl in the feed, these trends were not clearly evident for all metals due to the hour-to-hour variations in melt temperatures and the difficulty in differentiating between entrainment and volatilization of trace-level metals. However, the highest volatilization for As, Cd, Pb, P and Hg occurred during the S-series (high chlorine) and N80 (highest melt temperature) tests. Volatilization was also high for Zn during these tests, but was even higher during the M60 test.

While the trace metals in the soil and in the N and S-series tests were present as oxides, the metals in the M60 were added as metals, not metal oxides. The oxides were typically higher melting point compounds, so they tended to be less volatile than the elemental metals in the M60 test. However, the presence of chlorine in the S-series tests and the high melt operating temperatures (1,650–1,800°C) for the N80 and N80-Mod tests resulted in significant metals volatilization. At the higher melt temperatures, there may have been more volatilization from the oxide forms and also from metals reduced from oxides in the more reducing area surrounding the graphite electrodes. In future tests, activities to better characterize metals transport mechanisms are recommended. These include feed preparation to reduce entrainment, physical separation of entrained and volatilized materials, better control and measurement of parameters that affect volatilization such as chlorine content and bath temperature, and added feed and APCS solids analyses. Predictions based on analytical models should be developed to better understand the data and allow for developing design tools.

10. Although all measured temperatures were useful for interpreting performance, temperature measurement in furnace environments is an area where additional measurements, measurement methods, and analytical support for data interpretation and extrapolation is needed. In-furnace TC measurements were difficult due to TC material failure at the high temperatures. Short-duration sacrificial TC measurements were done occasionally but involved opening ports to access the furnace and were not continuous. In-furnace infrared temperature measurements were not possible due to dust levels in the furnace plenum. Tapped slag temperatures determined with an external infrared pyrometer were the most representative and accurate indicators of slag bath temperatures, but were lower than actual melt temperatures within the furnace. The slag was cooled as it passed through the water cooled tapping fixture. The slag occasionally formed a cooler crust on the surface of the slag stream, and infrared pyrometer readings are sensitive to placement of the visual spot on the slag stream.

Furnace hearth, refractory, and wall temperatures were measured at several locations as reported. These generally track well with each other consistently over time. They are useful indicators but do not provide furnace temperatures in the metal phase, at the metal/slag interface, at locations throughout the slag, in the furnace plenum, cold top, etc. Clearly the temperature distribution within the furnace is a key to understanding and controlling the process. Analytical modeling is needed to interpret data and to predict temperatures of other regions. Development of analytical modeling is in process under other BWID funding, but should be accelerated, focused, and simplified wherever possible. Additional furnace TCs should be utilized in future tests, and potential alternative temperature measurement techniques such as the millimeter wave radiometer under development in a related BWID project should be tested in the next test series.

11. The arc furnace has the capability to melt metals and separate the metal product from the slag for tapping, if desired or needed. Although tapping of metal was not possible in the baseline series due to the hearth dissolution by high temperature viscous slag during the early S60 test, tapping through the bottom tap hole was demonstrated successfully by draining slag from the furnace through the bottom tap hole at the end of each test day.

12. The metal heel in the bottom of the hearth may not have been molten during every test. While mass balances indicate the formation of a metal heel from reduced iron for many of the test days prior to the M60 test, complete melting of the metal product may not have occurred until the M60 test. The M60 test was the last test of the series, and the metal heel was removed following furnace cool-down after this test. The monolithic, alloyed appearance of the metal heel indicates that the metal was completely molten at least at the end of or following the M60 test. Since the melting temperature of iron is 1,550°C, the temperature at the bottom of the hearth exceeded this temperature late in the M60 or M60-Mod tests, though such high temperatures at the bottom of the hearth may also have occurred sooner.

Iron metal reduced from the mill scale in the earlier tests may have resolidified at the bottom of the hearth if the temperature was less than 1,550°C. According to mass balances, about 162 lb of iron was reduced from the oxide in the shakedown test when soil was the feed material. Although the melt temperatures were high enough to tap the slag, the low slag thermal conductivity and short run time may have resulted in a relatively cool bottom temperature compared to later tests such as the S60 test, in which the MgO refractory portion of the hearth was dissolved. Some slag was present in the hearth after draining the furnace through the metal tap hole. This indicates that the hearth was too cool during this run to have molten metal or slag on the hearth.

Analytical modeling of the heat transfer conditions are recommended to estimate if the metal heel was molten at other times during the baseline tests.

13. The dissolution of the MgO refractory indicates the need to evaluate hearth and slag compatibility prior to the next test series. Although the MgO ramming mix that made up the hemispherical hearth was dissolved, the underlying bottom and side Ruby refractory bricks were unaffected. A hearth made of Ruby ramming mix may be more durable.

The hearth bottom brick may have been protected in part by the metal heel on the hearth. Maintaining a noncorrosive metal heel or a cooled slag layer (skull) in the hearth may be an

acceptable strategy for protecting the hearth refractory. This practice is used in some industrial metallurgical and waste treatment processes. The metal heel or skull may only be removed occasionally to completely drain the furnace. This mode of operation should be further evaluated as a means for hearth protection.

14. The existence of a cold top reduced volatilization transport from the melt and reduced plenum surface and gas temperatures. Although the melt temperatures ranged to 1,800°C or higher, the plenum wall temperatures and gas temperatures were far lower, typically in the 300–700°C range. A cold top was present almost continuously during operation. The thickness varied and was difficult to monitor with the manual means utilized, but no effects of thickness variation were detectable. The next test series should include operation both with and without a cold top under otherwise identical operating conditions to better quantify cold top effects.

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Appendix A

Operating Conditions During Shakedown Test of RWMC Soil and Mill Scale

Figure A-1. Furnace exit wall temperature (—) and offgas temperature at the fume trap 1 (-) for the shakedown test.

Figure A-2. Offgas temperatures upstream (-) and downstream (—) of the baghouse for the shakedown test.

Figure A-3. Flow rate of quench air (—) and offgas at the baghouse outlet (-) for the shakedown test.

Figure A-4. Furnace pressure for the shakedown test.

Figure A-5. Baghouse pressure drop for the shakedown test.

Appendix B

Operating Conditions During Melting of S60

Overall Averages based on non-zero power

Voltage 179.0 V
Current 1013.7 A
Power 544.0 kW

Stable Operating Range (10:19 - 15:09) Averages

Voltage 194.4 V
Current 999.8 A
Power 586.8 kW

Total Energy 5093 kwh

Figure B-1. Input power to the furnace for the S60 tests.

Overall Averages based on non-zero feed rate

Feed Rate 977 lb/h
Total Feed 9806 lb
Energy Consumption 0.52 kWh/lb

Stable Operating Range (10:19 - 15:09) Averages

Feed Rate 1041 lb/h
Total Feed 5028 lb
Energy Consumption 0.56 kWh/lb

Figure B-2. Feed rate for the S60 tests.

Figure B-3. Furnace pressure for the S60 tests.

Figure B-4. Flow rate of quench air (—) and offgas at the baghouse outlet (-) for the S60 tests.

Figure B-5. Furnace exit wall temperature (—) and offgas temperature at the fume trap 1 (-) for the S60 tests

Figure B-6. Offgas temperatures upstream (—) and downstream (-) of the baghouse for the S60 tests.

Figure B-7. Baghouse pressure drop for the S60 tests.

Appendix C

Operating Conditions During Melting of S60-IV

Overall Averages based on non-zero power		Stable Operating Range (14:23 - 17:43) Average	
Voltage	164.8 V	Voltage	161.6 V
Current	859.7 A	Current	838.9 A
Power	421.6 kW	Power	409.4 kW
Total Energy 4624 kwh			

Figure C-1. Input power to the furnace for the S-60-IV tests.

Overall average based on non-zero feed rate		Stable Operating Range (14:23 - 17:43) Average	
Feed Rate	1109 lb/h	Feed Rate	866 lb/h
Total Feed	8277 lb	Total Feed	2884 lb
Energy Consumption	0.56 kWh/lb	Energy Consumption	0.47 kWh/lb

Figure C-2. Feed rate for the S60-IV tests.

Figure C-3. Furnace pressure for the S60-IV tests.

Figure C-4. Flowrate of quench air (-) and offgas at the baghouse outlet (-) for the S60-IV tests.

Figure C-5. Furnace exit wall temperature (—) and offgas temperature at the fume trap 1 (---) for the S60-IV tests.

Figure C-6. Offgas temperatures upstream (—) and downstream (---) of the baghouse for the S60-IV tests.

Figure C-7. Pressure drop over baghouse for the S60-IV tests.

S60-IV 7/20/93

Figure C-8. Upper sidewall inner surface refractory temperature for S60-IV.

[TIME6.XLW]A

S60-IV 7/20/93

Figure C-9. Furnace hearth temperature for the S60-IV test.

S60-IV 7/20/93

Figure C-10. Slag tap temperature (C+150) for the S60-IV test.

Appendix D

Operating Conditions During Melting of N80 and N80-Mod

Overall Averages based on non-zero power

Voltage 162.1 V
Current 950.0 A
Power 461.6 kW

Stable Operating Range (8:57 - 12:15) Averages

Voltage 169.7 V
Current 968.3 A
Power 497.4 kW

Total Energy 4142 kwh

Figure D-1. Input power for the N80 and N80-Mod tests.

Overall average based on non-zero feed rate

Feed Rate 917 lb/h
Total Feed 8366 lb
Energy Consumption 0.49 kWh/lb

Stable Operating Range (8:57 - 12:15) Average

Feed Rate 1067 lb/h
Total Feed 3538 lb
Energy Consumption 0.47 kWh/lb

Figure D-2. Feed rate for the N80 and N80-Mod tests.

Figure D-3. Furnace pressure for the N80 and N80-Mod tests.

Figure D-4. Flowrate of quench air (—) and offgas at the baghouse outlet (---) for the N80 and N80-Mod tests.

Figure D-5. Furnace exit wall temperature (-) and offgas temperature at the fume trap 1 (-) for the N80 and N80-Mod tests.

Figure D-6. Offgas temperatures upstream (-) and downstream (-) of the baghouse for the N80 and N80-Mod tests.

Figure D-7. Baghouse pressure drop for the N80 and N80-Mod tests.

N80/N80-Mod 7/21/93

Figure D-8. Upper sidewall inner surface refractory temperature for N80 and N80-Mod.

[TIME6.XL.W]A

N80/N80-Mod 7/21/93

Figure D-9. Furnace hearth temperature for the N80/N80-Mod tests.

N80/N80-Mod 7/21/93

Figure D-10, Slag tap temperature for the N80/N80-Mod tests.

Appendix E

Operating Conditions During Melting of N80-IV and N80-IV-Mod

Overall Averages based on non-zero power	Stable Operating Range (9:13 - 11:30) Average
Voltage 168.3 V	Voltage 168.2 V
Current 1055.3 A	Current 966.9 A
Power 540.1 kW	Power 500.6 kW
Total Energy 5214 kwh	

Figure E-1. Input power to the furnace for N80-IV and N80-IV-Mod tests.

Overall Averages based on non-zero feed rate	Stable Operating Range (9:13 - 11:30) Average
Feed Rate 1124 lb/h	Feed Rate 999 lb/h
Total Feed 10504 lb	Total Feed 2331 lb
Energy Consumption 0.50 kWh/lb	Energy Consumption 0.50 kWh/lb

Figure E-2. Feed rate for N80-IV and N80-IV-Mod tests.

Figure E-3. Furnace pressure for N80-IV and N80-IV-Mod tests.

Figure E-4. Flowrate of quench air (—) and offgas at the baghouse outlet (---) for the N80-IV and N80-IV-Mod tests.

Figure E-5. Furnace exit wall temperature (-) and offgas temperature at furnace trap 1 (-) for the N80-IV and N80-IV-Mod tests.

Figure E-6. Offgas temperatures upstream (-) and downstream (-) of the baghouse for the N80-IV and N80-IV-Mod tests.

Figure E-7. Baghouse pressure drop for the N80-IV and N80-IV-Mod tests.

Figure E-8. Upper sidewall inner surface refractory temperature for N80-IV and N80-IV-Mod

[TIME6.XLW]A

N80-IV/N80-IV-Mod 7/22/93

Figure E-9. Furnace hearth temperature for the N80-IV/N80-IV-Mod tests.

N80-IV/N80-IV-Mod 7/22/93

Figure E-10. Slag tap temperature for the N80-IV/N80-IV-Mod tests.

Appendix F

Operating Conditions During Melting of M60 and M60-Mod

Overall Averages based on non-zero power

Voltage 162.3 V
Current 975.9 A
Power 473.4 kW

Stable Operating Range (8:56 - 11:23) Averages

Voltage 157.6 V
Current 842.2 A
Power 416.0 kW

Total Energy 3520 kwh

Figure F-1. Input power to the furnace for M60 and M60-Mod tests.

Overall Averages based on non-zero feed rate

Feed Rate 1425 lb/h
Total Feed 6666 lb
Energy Consumption 0.53 kWh/lb

Stable Operating Range (8:56 - 11:23) Averages

Feed Rate 1132 lb/h
Total Feed 2773 lb
Energy Consumption 0.37 kWh/lb

Figure F-2. Feed rate for M60 and M60-Mod tests.

Figure F-3. Furnace pressure for M60 and M60-Mod tests.

Figure F-4. Flowrate of quench air (-) and offgas at the baghouse outlet (-) for the M-60 and M60-Mod tests.

Figure F-5. Furnace exit wall temperature (-) and offgas temperature at fume trap 1 (-) for the M60 and M60-Mod tests.

Figure F-6. Offgas temperatures upstream (-) and downstream (-) of the baghouse for the M60 and M60-Mod tests.

Figure F-7. Baghouse pressure drop for M60 and M60-Mod tests.

Figure F-8. Upper sidewall inner surface refractory temperature for M60 and M60-Mod.

[TIME6.XLW]A

M60/M60-Mod 7/23/93

Figure F-9. Furnace hearth temperature for the M60/M60-Mod tests.

M60/M60-Mod 7/23/93

Figure F-10. Slag tap temperature for the M60/M60-Mod tests.

Appendix G

Additive and Feed Mixture Compositions

Appendix G-1

Compositions of Feed Mixture Additives

Table G-1-1(a). Compositions of feed mixture additives.

Species	Additive Component								
	Magnetite	Mullite	Pollucite	Silica	Soil (a)	Soil (b)	Talc	Titania	Wollastonite
Ag ₂ O	-	-	-	-	8.59e-04	-	-	-	-
Al ₂ O ₃	6.00	73.10	18.00	2.82	10.41	-	2.00	-	1.00
As ₂ O	-	-	-	-	1.22e-03	-	-	-	-
BaO	-	0.06	-	-	0.01	-	-	-	-
CaCO ₃	-	-	-	0.40	13.00	-	-	-	0.20
CaO	0.70	-	-	0.03	0.11	-	12.30	-	47.00
CdO	-	-	-	-	5.71e-05	-	-	-	-
CeO	-	0.03	-	-	-	-	-	-	-
CeO ₂	-	-	-	-	5.53e-03	-	-	-	-
Cr ₂ O ₃	0.20	-	-	-	0.03	-	-	0.20	-
Cs ₂ O	-	-	-	-	5.30e-03	-	-	-	-
CuO	-	-	-	-	5.63e-03	-	-	-	-
Fe ₂ O ₃	-	0.46	-	0.06	-	-	2.50	0.50	0.50
Fe ₃ O ₄	75.40	-	-	-	4.23	-	-	-	-
H ₂ O	-	-	0.75	-	10.10	10.10	0.50	-	0.20
HgO	-	-	-	-	1.08e-05	-	-	-	-
K ₂ O	-	0.78	-	0.51	2.42	-	-	-	-
MgO	1.30	0.13	-	0.02	2.27	-	26.00	-	0.30
MnO	0.20	-	-	-	-	-	-	-	0.10
Na ₂ O	-	0.28	-	0.03	1.28	-	-	-	-
NiO	-	-	-	-	4.33e-03	-	-	-	-
PO ₄	-	-	-	-	0.29	-	-	-	-
P ₂ O ₅	0.04	-	-	-	-	-	-	-	-
PbO	-	-	-	-	2.48e-03	-	-	-	-
SO ₄	-	-	-	-	0.04	-	-	-	-
SeO	-	-	-	-	1.20e-04	-	-	-	-
SiO ₂	4.80	25.00	54.00	95.98	57.76	-	53.50	0.90	50.00
SrO	-	0.01	-	-	-	-	-	-	-
TiO ₂	10.40	0.13	-	0.01	0.43	-	-	95.80	0.05
V ₂ O ₅	0.70	-	-	-	-	-	-	0.70	-
ZnO	-	-	-	-	0.01	-	-	-	-
ZrO ₂	-	-	-	-	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 G-1-1 (b). Compositions of feed mixture additives.

Species	Additive Component									
	Aluminum Shot	Copper Powder	Electrolytic Iron	Lead Shot	Stainless Powder	Zinc Powder	Limestone	Pebble Lime	Mill Scale (a)	Mill Scale (b)
Al ₂ O ₃	-	-	-	-	-	-	-	0.35	-	-
CaCO ₃	-	-	-	-	-	-	98.00	1.64	-	-
CaO	-	-	-	-	-	-	-	93.00	-	-
Cr ₂ O ₃	-	-	-	-	-	-	-	-	-	0.13
CuO	-	-	-	-	-	-	-	-	-	0.33
Fe ₂ O ₃	-	-	-	-	-	-	-	0.08	-	-
Fe ₃ O ₄	-	-	-	-	-	-	-	-	-	99.09
H ₂ O (1)	-	-	-	-	-	-	0.30	3.45	-	-
MgCO ₃	-	-	-	-	-	-	1.00	-	-	-
MgO	-	-	-	-	-	-	-	0.40	-	-
MnO ₂	-	-	-	-	-	-	-	0.05	-	0.85
Na ₂ O	-	-	-	-	-	-	-	0.03	-	-
NiO	-	-	-	-	-	-	-	-	-	0.19
PO ₄	-	-	-	-	-	-	-	-	-	0.04
P ₂ O ₅	-	-	-	-	-	-	-	0.02	-	-
SO ₃	-	-	-	-	-	-	-	0.15	-	-
SiO ₂	-	-	-	-	-	-	-	0.75	-	0.21
TiO ₂	-	-	-	-	-	-	-	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	-	-	-	-	-
O ₂	-	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 G-1-1(c). Compositions of feed mixture additives.

Species	Additive Component							
	Cerium Oxide Conc.	Gypsum	Ilmenite	Potash	Salt	Soda Ash	Zircon	Zirconia
Al ₂ O ₃	-	-	0.70	-	-	-	-	0.43
CaO	3.80	-	0.03	-	-	-	-	0.03
CaSO ₄	-	0.80	-	-	-	-	-	-
CaSO ₄ *2H ₂ O	-	95.70	-	-	-	-	-	-
CeO ₂	65.50	-	-	-	-	-	-	-
Cr ₂ O ₃	-	-	0.17	-	-	-	-	-
Fe ₂ O ₃	-	-	29.97	-	-	1.00e-03	-	0.03
H ₂ O (1)	4.04	3.50	2.25	0.12	0.03	0.17	-	-
HfO ₂	-	-	-	-	-	-	-	1.82
KCl	-	-	-	5.00e-03	-	-	-	-
K ₂ CO ₃	-	-	-	99.80	-	-	-	-
KOH	-	-	-	0.07	-	-	-	-
K ₂ SO ₄	-	-	-	6.00e-03	-	-	-	-
MgO	-	-	0.22	-	-	-	-	0.01
MnO	-	-	1.24	-	-	-	-	-
NaCl	-	-	-	-	99.70	0.08	-	-
Na ₂ CO ₃	-	-	-	-	-	99.60	-	-
Na ₂ O	-	-	-	-	-	-	-	0.06
Na ₂ SO ₄	-	-	-	-	-	0.15	-	-
P ₂ O ₅	-	-	0.09	-	-	-	-	-
SO ₄	6.00	-	-	-	0.08	-	-	-
SiO ₂	4.00	-	0.26	-	-	-	-	1.95
ThO ₂	0.26	-	-	-	-	-	-	-
TiO ₂	-	-	64.80	-	-	-	-	0.27
V ₂ O ₃	-	-	0.23	-	-	-	-	-
Y ₂ O ₃	-	-	-	-	-	-	-	0.15
ZrO ₂	-	-	0.04	-	-	-	-	95.21
BaO+SrO	7.20	-	-	-	-	-	-	-
ZrO ₂ +HfO ₂	-	-	-	-	-	-	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	-	-	1.42e-14	0.10	-1.00e-03	33.92	-
Total	100.00	100.00	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.

Appendix G-2

Feed Mixture Additives and Compositions

Table G-2-1. S60 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.	Gypsum	Magnetite	Pollucite	Salt	Silica	Soil	Talc	Wollastonit		
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 G-2-2. S60-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 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 G-2-3. N80 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.	Magnetite	Potash	Soda Ash	Soil		
Al ₂ O ₃	-	60.65	-	-	969.18	1,029.83	8.22
Ag ₂ O	-	-	-	-	0.08	0.08	6.39e-04
As ₂ O	-	-	-	-	0.11	0.11	9.05e-04
BaO	-	-	-	-	1.04	1.04	8.30e-03
CaCO ₃	-	-	-	-	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
CeO ₂	52.50	-	-	-	0.51	53.01	0.42
Cr ₂ O ₃	-	2.02	-	-	2.72	4.74	0.04
Cs ₂ O	-	-	-	-	0.49	0.49	3.94e-03
CuO	-	-	-	-	0.52	0.52	4.19e-03
Fe ₂ O ₃	-	-	-	0.01	-	0.01	1.07e-04
Fe ₃ O ₄	-	762.14	-	-	393.65	1,155.80	9.23
H ₂ O	3.24	-	0.93	2.28	940.19	946.63	7.56
HgO	-	-	-	-	1.01e-03	1.01e-03	8.02e-06
K ₂ CO ₃	-	-	784.63	-	-	784.63	6.26
KCl	-	-	0.04	-	-	0.04	3.14e-04
K ₂ O	-	-	-	-	225.49	225.49	1.80
KOH	-	-	0.55	-	-	0.55	4.39e-03
K ₂ SO ₄	-	-	0.05	-	-	0.05	3.77e-04
MgO	-	13.14	-	-	211.50	224.64	1.79
MnO	-	2.02	-	-	-	2.02	0.02
Na ₂ CO ₃	-	-	-	1,334.04	-	1,334.04	10.65
NaCl	-	-	-	1.07	-	1.07	8.55e-03
Na ₂ O	-	-	-	-	119.19	119.19	0.95
Na ₂ SO ₄	-	-	-	2.01	-	2.01	0.02
NiO	-	-	-	-	0.40	0.40	3.22e-03
PO ₄	-	-	-	-	27.12	27.12	0.22
P ₂ O ₅	-	0.40	-	-	-	0.40	3.23e-03
PbO	-	-	-	-	0.23	0.23	1.84e-03
SO ₄	4.81	-	-	-	3.91	8.72	0.07
SeO	-	-	-	-	0.01	0.01	8.94e-05
SiO ₂	3.21	48.52	-	-	5,376.60	5,428.33	43.34
ThO ₂	0.21	-	-	-	-	0.21	1.66e-03
TiO ₂	-	105.12	-	-	40.37	145.50	1.16
V ₂ O ₅	-	7.08	-	-	-	7.08	0.06
ZnO	-	-	-	-	1.27	1.27	0.01
ZrO ₂	-	-	-	-	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 G-2-4. N80-Mod surrogate waste mixture composition.

Species	Amount of each species provided by the listed additives (lb)									
	Cement					Oxide Conc. Magnetic Potash Soda Ash Soil Limestone Mill Scale				
	Total amt. of ea. species (lb)					Total wt. % of ea. species				
Al ₂ O ₃	-	60.65	-	-	969.18	-	1,029.83	6.78	5.26e-04	100.00
Ag ₂ O	-	-	-	-	0.08	-	0.08	0.11	7.46e-04	-1.47e+00
As ₂ O	-	-	-	-	0.11	-	0.11	0.14	6.84e-03	15,198.48
BaO	-	-	-	-	1.04	-	1.04	1.07	19.07	-2.23e+02
CaCO ₃	-	-	-	-	1,210.14	1,687.93	2,898.07	19.07	7.46e-04	15,198.48
CaO	3.05	7.08	-	-	10.43	-	20.55	0.14	6.84e-03	15,198.48
CD	-	-	-	-	5.32e-03	-	5.32e-03	3.50e-05	5.26e-04	15,198.48
CeO ₂	52.50	-	-	-	0.51	-	53.01	0.35	5.26e-04	15,198.48
C ₂ O ₃	-	2.02	-	-	2.72	-	5.94	0.04	5.26e-04	15,198.48
Cs ₂ O	-	-	-	-	0.49	-	0.49	3.25e-03	5.26e-04	15,198.48
CuO	-	-	-	-	0.52	-	3.62	0.02	5.26e-04	15,198.48
Fe ₂ O ₃	-	-	-	0.01	-	-	0.01	8.81e-05	5.26e-04	15,198.48
Fe ₃ O ₄	-	762.14	-	-	393.65	-	2,097.87	13.80	5.26e-04	15,198.48
H ₂ O	3.24	-	0.93	2.28	940.19	5.17	951.80	6.26	5.26e-04	15,198.48
HgO	-	-	-	-	1.01e-03	-	1.01e-03	6.61e-06	5.26e-04	15,198.48
K ₂ CO ₃	-	-	784.63	-	-	-	784.63	5.16	5.26e-04	15,198.48
KCl	-	-	0.04	-	-	-	0.04	2.59e-04	5.26e-04	15,198.48
K ₂ O	-	-	-	-	225.49	-	225.49	1.48	5.26e-04	15,198.48
KOH	-	-	0.55	-	-	-	0.55	3.62e-03	5.26e-04	15,198.48
K ₂ SO ₄	-	-	0.05	-	-	-	0.05	3.10e-04	5.26e-04	15,198.48
MgCO ₃	-	-	-	-	-	17.22	17.22	0.11	5.26e-04	15,198.48
MgO	-	13.14	-	-	211.50	-	224.64	1.48	5.26e-04	15,198.48
MnO	-	2.02	-	-	-	-	2.02	0.01	5.26e-04	15,198.48
MnO ₂	-	-	-	-	-	-	8.12	0.05	5.26e-04	15,198.48
Na ₂ CO ₃	-	-	-	1,334.04	-	-	1,334.04	8.78	5.26e-04	15,198.48
NaCl	-	-	-	1.07	-	-	1.07	7.05e-03	5.26e-04	15,198.48
Na ₂ O	-	-	-	-	119.19	-	119.19	0.78	5.26e-04	15,198.48
Na ₂ SO ₄	-	-	-	2.01	-	-	2.01	0.01	5.26e-04	15,198.48
NiO	-	-	-	-	0.40	-	0.40	0.01	5.26e-04	15,198.48
PO ₄	-	-	-	-	27.12	-	27.12	0.18	5.26e-04	15,198.48
P ₂ O ₅	-	0.40	-	-	-	-	0.40	2.66e-03	5.26e-04	15,198.48
PbO	-	-	-	-	0.23	-	0.23	1.52e-03	5.26e-04	15,198.48
SO ₄	4.81	-	-	-	3.91	-	8.72	0.06	5.26e-04	15,198.48
SeO	-	-	-	-	0.01	-	0.01	7.37e-05	5.26e-04	15,198.48
SiO ₂	3.21	48.52	-	-	5,430.60	-	5,430.60	35.73	5.26e-04	15,198.48
ThO ₂	0.21	-	-	-	-	-	0.21	1.37e-03	5.26e-04	15,198.48
TiO ₂	-	105.12	-	-	40.37	-	145.50	0.96	5.26e-04	15,198.48
V ₂ O ₅	-	7.08	-	-	-	-	7.08	0.05	5.26e-04	15,198.48
ZnO	-	-	-	-	1.27	-	1.27	8.39e-03	5.26e-04	15,198.48
ZrO ₂	-	-	-	-	1.26	-	1.26	8.27e-03	5.26e-04	15,198.48
BaO+SrO	5.77	-	-	-	-	-	5.77	0.04	5.26e-04	15,198.48
As	-	-	7.86e-04	-	-	-	7.86e-04	5.17e-06	5.26e-04	15,198.48
Cl	-	-	-	-	0.37	-	0.37	2.45e-03	5.26e-04	15,198.48
F	7.37	-	-	-	-	-	7.37	0.05	5.26e-04	15,198.48
Fe	-	-	9.43e-04	-	-	-	9.43e-04	6.21e-06	5.26e-04	15,198.48
Hg	-	-	3.14e-05	-	-	-	3.14e-05	2.07e-07	5.26e-04	15,198.48
Pb	-	-	7.08e-03	-	-	-	7.08e-03	4.66e-05	5.26e-04	15,198.48
S	2.02	-	-	-	-	-	2.02	0.01	5.26e-04	15,198.48
Other	-1.14e-14	0.61	1.12e-13	-1.34e-02	-2.28e+02	12.06	-8.00e+00	-1.47e+00	5.26e-04	15,198.48
Total	80.15	1,010.80	786.20	1,339.40	9,308.80	1,722.38	950.75	15,198.48	5.26e-04	15,198.48

Table G-2-5. 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		
Al ₂ O ₃	-	7.83	33.82	-	-	855.22	1.90	898.77	7.17
Ag ₂ O	-	-	-	-	-	0.07	-	0.07	5.63e-04
As ₂ O	-	-	-	-	-	0.10	-	0.10	7.97e-04
BaO	-	-	-	-	-	0.92	-	0.92	7.31e-03
CaCO ₃	-	-	-	-	-	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
CeO ₂	52.50	-	-	-	-	0.45	-	52.95	0.42
Cr ₂ O ₃	-	1.90	1.13	-	-	2.40	-	5.43	0.04
Cs ₂ O	-	-	-	-	-	0.44	-	0.44	3.47e-03
CuO	-	-	-	-	-	0.46	-	0.46	3.69e-03
Fe ₂ O ₃	-	335.30	-	-	0.01	-	0.13	335.45	2.67
Fe ₃ O ₄	-	-	425.03	-	-	347.37	-	772.40	6.16
H ₂ O	3.24	25.17	-	0.93	2.28	829.64	-	861.26	6.87
HfO ₂	-	-	-	-	-	-	8.03	8.03	0.06
HgO	-	-	-	-	-	8.87e-04	-	8.87e-04	7.07e-06
K ₂ CO ₃	-	-	-	784.63	-	-	-	784.63	6.26
KCl	-	-	-	0.04	-	-	-	0.04	3.13e-04
K ₂ O	-	-	-	-	-	198.98	-	198.98	1.59
KOH	-	-	-	0.55	-	-	-	0.55	4.39e-03
K ₂ SO ₄	-	-	-	0.05	-	-	-	0.05	3.76e-04
MgCO ₃	-	-	-	-	-	-	-	-	-
MgO	-	2.46	7.33	-	-	186.63	0.04	196.47	1.57
MnO	-	13.87	1.13	-	-	-	-	15.00	0.12
MnO ₂	-	-	-	-	-	-	-	-	-
Na ₂ CO ₃	-	-	-	-	1,334.04	-	-	1,334.04	10.64
NaCl	-	-	-	-	1.07	-	-	1.07	8.54e-03
Na ₂ O	-	-	-	-	-	105.18	0.26	105.44	0.84
Na ₂ SO ₄	-	-	-	-	2.01	-	-	2.01	0.02
NiO	-	-	-	-	-	0.36	-	0.36	2.83e-03
PO ₄	-	-	-	-	-	23.93	-	23.93	0.19
P ₂ O ₅	-	1.01	0.23	-	-	-	-	1.23	9.82e-03
PbO	-	-	-	-	-	0.20	-	0.20	1.62e-03
SO ₄	4.81	-	-	-	-	3.45	-	8.26	0.07
SeO	-	-	-	-	-	9.88e-03	-	9.88e-03	7.88e-05
SiO ₂	3.21	2.91	27.06	-	-	4,744.44	8.60	4,786.21	38.16
ThO ₂	0.21	-	-	-	-	-	-	0.21	1.66e-03
TiO ₂	-	724.98	58.62	-	-	35.63	1.19	820.42	6.54
V ₂ O ₃	-	2.57	-	-	-	-	-	2.57	0.02
V ₂ O ₅	-	-	3.95	-	-	-	-	3.95	0.03
Y ₂ O ₃	-	-	-	-	-	-	0.66	0.66	5.27e-03
ZnO	-	-	-	-	-	1.12	-	1.12	8.97e-03
ZrO ₂	-	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 G-2-6. N80-IV-Mod surrogate waste mixture 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	ebble Lim	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	-	-	-	-	-	-	-	-	-	-	0.00
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 G-2-7. M60 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
	CeO2 Conc.	Mullite	Soil	Wollastonite	Aluminum	Copper	Iron	Lead	Stainless	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 G-2-8. M60-Mod surrogate waste mixture 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.	Cerium Ingot	Ilmenite	Magnetite	Potash	Soda Ash	Soil	Zirconia	Pebble Lime	Mill Scale		
Al2O3	-	-	7.83	33.82	-	-	855.22	1.90	5.31	-	904.08	5.99
Ag2O	-	-	-	-	-	-	0.07	-	-	-	0.07	4.68e-04
As2O	-	-	-	-	-	-	0.10	-	-	-	0.10	6.62e-04
BaO	-	-	-	-	-	-	0.92	-	-	-	0.92	6.08e-03
CaCO3	-	-	-	-	-	-	1,067.86	-	24.84	-	1,092.70	7.24
CaO	3.05	-	0.34	3.95	-	-	9.20	0.13	1,410.68	-	1,427.34	9.46
CdO	-	-	-	-	-	-	4.69e-03	-	-	-	4.69e-03	3.11e-05
CeO2	52.50	-	-	-	-	-	0.45	-	-	-	52.95	0.35
Cr2O3	-	-	1.90	1.13	-	-	2.40	-	-	1.30	6.73	0.04
Cs2O	-	-	-	-	-	-	0.44	-	-	-	0.44	2.88e-03
CuO	-	-	-	-	-	-	0.46	-	-	3.36	3.82	0.03
Fe2O3	-	-	335.30	-	-	0.01	-	0.13	1.21	-	336.66	2.23
Fe3O4	-	-	-	425.03	-	-	347.37	-	-	1,022.69	1,795.09	11.89
H2O	3.24	-	25.17	-	0.93	2.28	829.64	-	52.36	-	913.62	6.05
HfO2	-	-	-	-	-	-	-	8.03	-	-	8.03	0.05
HgO	-	-	-	-	-	-	8.87e-04	-	-	-	8.87e-04	5.88e-06
K2CO3	-	-	-	-	784.63	-	-	-	-	-	784.63	5.20
KCl	-	-	-	-	0.04	-	-	-	-	-	0.04	2.60e-04
K2O	-	-	-	-	-	-	198.98	-	-	-	198.98	1.32
KOH	-	-	-	-	0.55	-	-	-	-	-	0.55	3.65e-03
K2SO4	-	-	-	-	0.05	-	-	-	-	-	0.05	3.12e-04
MgO	-	-	2.46	7.33	-	-	186.63	0.04	6.07	-	202.53	1.34
MnO	-	-	13.87	1.13	-	-	-	-	-	-	15.00	0.10
MnO2	-	-	-	-	-	-	-	-	0.76	8.82	9.58	0.06
Na2CO3	-	-	-	-	-	1,334.04	-	-	-	-	1,334.04	8.84
NaCl	-	-	-	-	-	1.07	-	-	-	-	1.07	7.10e-03
Na2O	-	-	-	-	-	-	105.18	0.26	0.46	-	105.90	0.70
Na2SO4	-	-	-	-	-	2.01	-	-	-	-	2.01	0.01
NiO	-	-	-	-	-	-	0.36	-	-	1.97	2.33	0.02
PO4	-	-	-	-	-	-	23.93	-	-	0.44	24.37	0.16
P2O5	-	-	1.01	0.23	-	-	-	-	0.30	-	1.54	0.01
PbO	-	-	-	-	-	-	0.20	-	-	-	0.20	1.35e-03
SO3	-	-	-	-	-	-	-	-	2.28	-	2.28	0.02
SO4	4.81	-	-	-	-	-	3.45	-	-	-	8.26	0.05
SeO	-	-	-	-	-	-	9.88e-03	-	-	-	9.88e-03	6.54e-05
SiO2	3.21	-	2.91	27.06	-	-	4,744.44	8.60	11.38	2.21	4,799.80	31.80
ThO2	0.21	-	-	-	-	-	-	-	-	-	0.21	1.38e-03
TiO2	-	-	724.98	58.62	-	-	35.63	1.19	0.76	-	821.18	5.44
V2O3	-	-	2.57	-	-	-	-	-	-	-	2.57	0.02
V2O5	-	-	-	3.95	-	-	-	-	-	-	3.95	0.03
Y2O3	-	-	-	-	-	-	-	0.66	-	-	0.66	4.38e-03
ZnO	-	-	-	-	-	-	1.12	-	-	-	1.12	7.45e-03
ZrO2	-	-	0.45	-	-	-	1.11	419.97	-	-	421.53	2.79
BaO+SrO	5.77	-	-	-	-	-	-	-	-	-	5.77	0.04
As	-	-	-	-	7.86e-04	-	-	-	3.03e-03	-	3.82e-03	2.53e-05
Ce	-	1.50	-	-	-	-	-	-	-	-	1.50	9.94e-03
Cl	-	-	-	-	-	-	0.33	-	-	-	0.33	2.18e-03
F	7.37	-	-	-	-	-	-	-	0.46	-	7.83	0.05
Fe	-	1.50	-	-	9.43e-04	-	-	-	-	-	1.50	9.94e-03
Hg	-	-	-	-	3.14e-05	-	-	-	-	-	3.14e-05	2.08e-07
Pb	-	-	-	-	7.08e-03	-	-	-	7.58e-03	-	0.01	9.71e-05
S	-	-	-	1.13	-	-	-	-	-	-	1.13	7.47e-03
Th	-	-	-	-	-	-	-	0.07	-	-	0.07	4.68e-04
U	-	-	-	-	-	-	-	0.11	-	-	0.11	7.01e-04
Other	-1.14e-14	-	-	0.34	1.12e-13	-1.34e-02	-2.01e+02	-	4.14e-04	-8.68e+00	-2.10e+02	-1.39e+00
Total	80.15	3.00	1,118.80	563.70	786.20	1,339.40	8,214.30	441.10	1,516.86	1,032.10	15,095.62	100.00

Appendix H

Chemical Composition of Individual Slag Molds

Table H-1. Melting test of the RWMC soil and mill scale.

	Slag ingots							Subtotal
	RWMC-S1	RWMC-S2	RWMC-S3	RWMC-S4	RWMC-S5	RWMC-S6	RWMC-S7	
wt, lb	770	730	768	696	506	790	1770	6030
wt, pct	12.77	12.11	12.74	11.54	8.39	13.10	29.35	100
Component	Concentration, mg/kg							wt. mean
Ag ₂ O	<1	<1	<1	<1	<1	<1	<1	<1
Al ₂ O ₃	104000	104000	97300	86500	89700	74600	76500	88000
As ₂ O ₃	8	8	8	12	12	9	12	10
BaO	834	1030	952	1000	958	969	903	940
CaO	36100	30800	30800	30500	32800	33600	31100	32100
CdO	<1	<1	<1	<1	<1	<1	<1	<1
CeO ₂	NA	NA	NA	NA	NA	NA	NA	NC
Cl	<100	<100	<100	<100	<100	<100	<100	<100
CO ₂	180	170	160	210	710	240	230	247
CrO ₂	807	1170	1110	1040	1130	1180	1240	1120
Cs ₂ O	11	11	8	13	8	10	8	10
CuO	422	687	647	677	766	761	863	715
Fe ₃ O ₄	201000	213000	214000	204000	228000	229000	265000	229000
HgO	<0.1	<0.1	<0.1	0.1	0.1	1	<0.1	<0.1
K ₂ O	21000	20500	20700	20800	20500	20200	19400	20300
MgO	26200	22700	22500	18700	18200	19800	17800	20500
Na ₂ O	20757	14300	18300	17000	12300	15100	19400	17400
NiO	192	306	304	295	329	324	362	311
P ₂ O ₅	1120	137	69	1170	160	115	1280	708
PbO	20	19	18	19	20	20	23	20
SO ₃	30	15	15	15	15	15	15	17
SeO ₂	<1	<1	<1	<1	<1	<1	<1	<1
SiO ₂	540000	456000	471000	450000	452000	506000	401000	458000
TiO ₂	7210	9650	9350	9700	9150	9220	8510	8870
ZnO	130	184	164	182	178	194	194	178
ZrO ₂	392	560	530	557	541	542	546	526
Total	959000	876000	888000	844000	868000	912000	844000	879000

Table H-2. Melting test of the S60 waste mixture.

	Slag ingot									Total
	S60-S1	S60-S2	S60-S3	S60-S4	S60-S5	S60-S6	S60-S7	S60-S8	S60-L1	
wt, lb	888	865	843	876	870	848	754	1001	2095	9040
wt, pct	9.82	9.57	9.33	9.69	9.62	9.38	8.34	11.07	23.17	100.00
Component	Concentration, mg/kg									wt. mean
Ag ₂ O	<1	<1	2	2	1	5	9	8	6	4
Al ₂ O ₃	66700	68400	71600	71000	76900	73700	74300	73700	75800	72892
As ₂ O ₃	3	3	4	3	3	3	4	3	4	3
BaO	660	622	615	723	702	704	691	656	717	682
CaO	175000	148000	116000	101000	91400	89600	79100	78400	79100	102767
CdO	<1	<1	<1	<1	<1	<1	<1	<1	2	<1
CeO ₂	2740	2580	2300	2950	2750	2570	2780	2870	2870	2737
Cl	100	180	210	190	180	170	170	160	140	163
CO ₂	660	660	697	697	660	880	1250	807	1280	897
CrO ₂	420	570	664	751	591	753	897	872	1000	761
Cs ₂ O	1060	1380	1440	1510	1620	1660	1590	1610	1550	1499
CuO	66	115	374	456	319	595	734	623	634	460
Fe ₃ O ₄	162000	156000	159000	167000	171000	166000	192000	164000	171000	167681
HgO	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
K ₂ O	7830	7950	8070	8070	9040	8190	7830	7590	7350	7900
MgO	51700	85700	124000	133000	97700	143000	162000	161000	166000	130356
Na ₂ O	15900	15100	13600	10800	15800	11100	9570	9300	3100	10430
NiO	66	69	70	85	72	84	93	89	90	81
P ₂ O ₅	46	115	321	275	183	527	389	344	664	364
PbO	5	14	27	27	22	44	53	55	51	36
SO ₃	120	<10	15	<10	<10	<10	<10	<10	15	17
SeO ₂	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
SiO ₂	510000	491000	474000	471000	499000	474000	456000	469000	461000	476211
TiO ₂	18200	17300	17000	18200	18600	18000	18300	17400	17200	17710
ZnO	130	150	140	155	133	151	155	142	150	146
ZrO ₂	292	226	203	257	219	214	220	226	211	228
Total	1014000	996000	990000	988000	988000	994000	1008000	989000	990000	993000

Table H-3. Melting test of the S60-IV waste mixture.

Slag ingot	Slag Ingot								Total
	S60-IV-S1	S60-IV-S2	S60-IV-S3	S60-IV-S4	S60-IV-S5	S60-IV-S6	S60-IV-S7	S60-IV-L1	
wt, lb	436	882	866	883	794	814	545	1799	7019
wt, pct	6.21	12.57	12.34	12.58	11.31	11.60	7.76	25.63	100
Component	Concentration, mg/kg								wt. mean
	<1	<1	<1	<1	<1	<1	<1	<1	
Ag ₂ O	<1	<1	<1	<1	<1	<1	<1	<1	<1
Al ₂ O ₃	73900	75000	73100	74800	69900	71000	69500	71400	72282
As ₂ O ₃	4	4	4	3	3	4	3	3	3
BaO	685	733	678	758	719	731	745	796	742
CaO	97900	101000	102000	103000	102000	102000	104000	112000	104464
CdO	<1	<1	<1	<1	<1	<1	<1	<1	<1
CeO ₂	3970	4430	4200	5040	4450	4430	4750	4770	4564
Cl	120	110	130	100	100	110	120	90	106
CO ₂	623	550	843	1140	1250	4660	1650	1800	1627
CrO ₂	506	552	523	543	540	523	554	871	622
Cs ₂ O	2410	2320	2510	2260	2160	2160	2260	2190	2267
CuO	70	66	59	61	53	49	53	73	62
Fe ₃ O ₄	213000	186000	191000	184000	188000	214000	184000	170000	187260
HgO	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
K ₂ O	10000	9640	9400	9040	9040	8920	9400	9880	9449
MgO	44300	41800	37800	34700	36200	34200	34300	33300	36293
Na ₂ O	21400	16600	18700	19500	17900	16600	19800	22000	19302
NiO	62	65	64	71	70	71	67	78	70
P ₂ O ₅	344	412	366	275	183	275	137	46	228
PbO	15	16	16	13	14	12	12	9	13
SO ₃	<10	<10	15	15	15	15	45	180	57
SeO ₂	<1	<1	<1	<1	<1	<1	<1	<1	<1
SiO ₂	484000	476000	467000	478000	465000	467000	476000	495000	478220
TiO ₂	39400	45400	46400	47300	48300	48600	49400	41300	45349
ZnO	141	155	142	135	147	130	131	110	133
ZrO ₂	19300	22200	23000	22900	24400	24700	24800	20300	22460
Total	1011000	983000	978000	984000	969000	1001000	982000	985000	983000

Table H-4. Melting test of the N80 and N80-Mod waste mixtures.

	Slag ingot								Total
	N80-S1	N80-S2	N80-S3	N80-Mod-S4	N80-Mod-S5	N80-Mod-S6	N80-Mod-S7	N80-Mod-L1	
wt, lb	952	678	667	758	749	804	734	2068	7410
pct	12.85	9.15	9.00	10.23	10.11	10.85	9.91	27.91	100
Component	Concentration, mg/kg								wt. mean
Ag ₂ O	<1	<1	<1	<1	<1	<1	<1	<1	<1
Al ₂ O ₃	87700	91800	92200	86000	79200	72000	69000	68400	78500
As ₂ O ₃	3	3	3	3	4	6	7	7	5
BaO	891	988	873	810	699	658	661	628	749
CaO	85000	83300	80200	102000	122000	141000	154000	167000	126000
CdO	<1	<1	<1	<1	<1	<1	<1	<1	<1
CeO ₂	2800	2610	2260	2270	2250	2220	2160	2130	2310
Cl	40	20	30	30	30	30	30	30	30
CO ₂	2710	1280	2090	880	880	770	620	510	1120
CrO ₂	355	373	326	320	393	396	506	573	435
Cs ₂ O	488	403	329	456	424	509	519	551	479
CuO	46	50	48	95	148	203	246	249	155
Fe ₃ O ₄	127000	112000	182000	141000	168000	233000	239000	215000	183000
HgO	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
K ₂ O	61300	59900	61500	54100	50000	42100	40000	39200	49000
MgO	24500	24500	25200	24800	23500	24200	24200	28200	25500
Na ₂ O	78600	74400	76600	68300	67800	57600	55500	52800	64100
NiO	93	95	74	72	127	121	161	137	115
P ₂ O ₅	847	573	779	1490	1490	1510	1370	1400	1220
PbO	10	10	11	10	11	11	10	10	10
SO ₃	435	390	390	420	390	330	255	180	320
SeO ₂	<1	<1	<1	<1	<1	<1	<1	<1	<1
SiO ₂	501000	512000	506000	482000	435000	414000	369000	388000	440000
TiO ₂	15900	17000	13800	14000	13100	14400	14300	13300	14300
ZnO	102	121	108	101	106	106	148	107	111
ZrO ₂	1770	1910	1520	2180	2150	3390	3420	3100	2550
Total	992000	983000	1040000	979000	966000	1008000	975000	981000	989000

Table H-5. Melting test of the N80-IV and N80-IV-Mod waste mixtures.

	Slag ingot											Total
	N80-IV-S1	N80-IV-S2	N80-IV-S3	N80-IV-S4	N80M-IV-S5	N80M-IV-S6	N80M-IV-S7	N80M-IV-S8	N80M-IV-S9	N80M-IV-S10	N80M-IV-L1	
wt, lb	762	721	717	347	739	842	788	818	732	317	1997	8780
pct	8.68	8.21	8.17	3.95	8.42	9.59	8.97	9.32	8.34	3.61	22.74	100
Component	Concentration, mg/kg											wt. mean
Ag ₂ O	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Al ₂ O ₃	77500	76000	69500	69300	69900	65000	63700	57800	53800	59000	61400	51200
As ₂ O ₃	3	4	3	4	5	8	9	9	11	9	11	5
BaO	902	817	1030	873	806	755	723	659	656	670	695	14570
CaO	79800	75000	71000	72500	97900	127800	147000	154000	176400	189000	186200	91000
CdO	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CeO ₂	4810	4510	4060	3980	4000	3660	3490	3280	3100	3130	3540	45300
Cl	12	11	9	7	19	10	19	3	7	7	8	8
CO ₂	660	1060	660	1030	990	1870	1030	953	1250	770	1210	1620
CrO ₂	498	422	489	344	465	491	519	509	674	567	564	390
Cs ₂ O	148	99	69	48	72	67	57	46	48	29	67	331
CuO	81	64	54	61	111	180	236	261	291	305	303	255
Fe ₃ O ₄	118000	116000	113000	122000	134000	166000	185000	200000	213000	264000	204000	124000
HgO	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
K ₂ O	61900	59500	61100	58700	54600	52700	50400	49000	46600	45600	46200	88200
MgO	25300	25700	24200	23000	22200	20800	19500	18300	17500	17800	18000	16600
Na ₂ O	84800	81300	79000	80500	69700	67900	66600	68100	62900	61200	60900	66300
NiO	52	48	64	48	99	102	119	142	191	173	154	4170
P ₂ O ₅	<1	9	5	27	<1	366	481	298	618	252	847	14020
PbO	23	28	25	29	26	25	22	23	23	23	23	54
SO ₃	495	390	255	180	270	195	165	180	180	150	225	389
SeO	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
SiO ₂	424000	435000	441000	435000	411000	377000	356000	339000	315000	317000	259000	298000
TiO ₂	71600	65600	87600	66400	58900	54200	54000	50000	49500	52100	50700	47000
ZnO	106	199	112	107	110	106	103	117	102	107	110	59000
ZrO ₂	31300	28700	32900	28200	27500	26300	25300	23800	23400	22400	25900	32500
Total	982000	971000	986000	962000	953000	965000	974000	966000	966000	1034000	920000	954000

Table H-6. Melting test of the M60 and M60-Mod waste mixtures.

Component	Slag ingot							Total
	M60	M60-Mod-S1	M60-Mod-S2	M60-Mod-S3	M60-Mod-S4	M60-Mod-S5	M60-Mod-L1	
wt, lb	0	817	770	734	792	372	1739	5224
pct	0.00	15.64	14.74	14.05	15.16	7.12	33.29	100
Component	Concentration, mg/kg							wt. mean
Ag ₂ O	<1	<1	<1	<1	<1	<1	<1	<1
Al ₂ O ₃	140000	132000	112000	92600	82600	74400	76100	93300
As ₂ O	2	<1	<1	<1	<1	<1	<1	<1
BaO	1080	1180	895	728	639	634	664	782
CaO	114000	153000	195000	224000	220000	242000	252000	219000
CdO	<1	<1	<1	<1	<1	<1	<1	<1
CeO ₂	4830	5500	4750	3770	3870	3370	2790	3850
Cl	60	10	15	15	10	19	21	16
CO ₂	953	2310	843	843	5350	2050	3040	2570
CrO ₂	21000	22000	13300	6700	2800	3160	3780	8300
Cs ₂ O	66	66	64	54	39	148	170	100
CuO	413	91	129	189	224	266	289	209
Fe ₃ O ₄	81500	33600	104000	132000	167000	257000	163000	137000
HgO	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
K ₂ O	24100	23600	27600	30500	35200	34100	33900	31100
MgO	24300	24200	21700	19300	18000	17300	18300	19700
Na ₂ O	17800	17800	26700	34500	42300	39900	39900	34100
NiO	842	72	130	183	186	253	258	188
P ₂ O ₅	<1	<1	<1	<1	<1	<1	<1	<1
PbO	1220	81	377	280	237	452	474	333
SO ₃	450	375	405	285	240	450	495	392
SeO ₂	<1	<1	<1	<1	<1	<1	<1	<1
SiO ₂	551000	527000	450000	386000	356000	341000	339000	394000
TiO ₂	11400	12200	17400	24100	29300	28200	29800	24200
ZnO	3310	634	1970	1370	910	2540	2660	1790
ZrO ₂	4590	5140	7690	10700	13600	14500	15070	11550
Total	1002000	961000	985000	969000	978000	1060000	981000	982000

Appendix I

Variation of Slag Composition During Melting Tests

I-1.a. Concentrations of slag forming oxides in the RWMC slag.

I-1.b. Concentrations of heavy metal and cesium oxides in the RWMC slag.

Figure I-2.a. Concentrations of slag forming oxides in the S60 slag.

Figure I-2.b. Concentrations of heavy metal and cesium oxides in the S60 slag.

I-3.a. Concentrations of slag forming oxides in the S60-IV slag.

I-3.b. Concentrations of heavy metal and cesium oxides in the S60-IV slag.

I-4.a. Concentrations of slag forming oxides in the N80 slag.

I-4.b. Concentrations of heavy metal and cesium oxides in the N80 slag.

I-5.a. Concentrations of slag forming oxides in the S60 slag.

I-5.b. Concentrations of heavy metal and cesium oxides in the N80-IV slag.

I-6.a. Concentrations of slag forming oxides in the M60 slag.

I-6.b. Concentrations of heavy metal and cesium oxides in the M60 slag.

Appendix J

X-Ray Diffraction Analysis of Furnace Products

Table J-1. X-Ray diffraction analysis of the S60 furnace products.

Phase	Slag		Fume Solids		
	S60-S1	S60-S7	Fume Trap 1	Fume Trap 2	Baghouse
Primary	non-crystalline	non-crystalline	ND	ND	ND
Secondary	ND	ND	ND	ND	NaCl (Halite) KCl (Sylvite)
Minor	ND	[(Mg,Fe)2SiO4] Forsterite	SiO2 (Quartz) NaCl (Halite) KCl (Sylvite)	SiO2 (Quartz) NaCl (Halite) KCl (Sylvite)	ND
Trace	may contain Alpha Fe	unidentified compounds	Fe3O4 (Magnetite) CaSiO3 (Wollastonite) NaAlSi3O8 (Albite) Mg3Si4O10(OH)2 (Talc)	Fe3O4 (Magnetite) CaSiO3 (Wollastonite) NaAlSi3O8 (Albite) Mg3Si4O10(OH)2 (Talc)	unidentified compounds
Primary Phase: 40 to 100% Secondary Phase: 20 to 60% Minor Phase: 5 to 30% Trace: 1 to 10% ND: Not detected					

Table J-2. X-Ray diffraction analysis of the S60-IV furnace products.

Phase	Slag		Fume Solids		
	S60-IV-S1	S60-IV-S6	Fume Trap 1	Fume Trap 2	Baghouse
Primary	only non-crystalline material detected	only non-crystalline material detected	ND	ND	ND
Secondary	ND	ND	ND	NaCl (Halite) KCl (Sylvite)	NaCl (Halite) KCl (Sylvite)
Minor	ND	ND	NaCl (Halite) KCl (Sylvite) Fe3O4 (Magnetite) SiO2 (Quartz) CaSiO3 (Wollastonite)	SiO2 (Quartz) CaSiO3 (Wollastonite)	water soluble Cs-Fe-Cl compound
Trace	ND	ND	Mg3Si4O10(OH)2 (Talc)	Mg3Si4O10(OH)2 (Talc) NaAlSi3O8-CaAl2Si2O8 (plagioclase) unidentified compounds	Fe3O4 (Magnetite) Ca4(CaOH)(PO4)3 (hydroxylapatite) non-crystalline
Primary Phase: 40 to 100% Secondary Phase: 20 to 60% Minor Phase: 5 to 30% Trace: 1 to 10% ND: Not detected					

Table J-3. X-Ray diffraction analysis of N80 furnace products.

Phase	Slag		Fume Solids		
	S60-IV-S1	S60-IV-S6	Fume Trap 1	Fume Trap 2	Baghouse
Primary	only non-crystalline material detected	only non-crystalline material detected	ND	ND	ND
Secondary	ND	ND	ND	NaCl (Halite) KCl (Sylvite)	NaCl (Halite) KCl (Sylvite)
Minor	ND	ND	NaCl (Halite) KCl (Sylvite) Fe3O4 (Magnetite) SiO2 (Quartz) CaSiO3 (Wollastonite)	SiO2 (Quartz) CaSiO3 (Wollastonite)	water soluble Cs-Fe-Cl compound
Trace	ND	ND	Mg3Si4O10(OH)2 (Talc)	Mg3Si4O10(OH)2 (Talc) NaAlSi3O8-CaAl2Si2O8 (plagioclase) unidentified compounds	Fe3O4 (Magnetite) Ca4(CaOH)(PO4)3 (hydroxylapatite) non-crystalline
Primary Phase: 40 to 100% Secondary Phase: 20 to 60% Minor Phase: 5 to 30% Trace: 1 to 10% ND: Not detected					

Table J-4. X-Ray diffraction analysis of the N80-Mod furnace products.

Phase	Slag		Fume Solids		
	N80-Mod-S6	N80-Mod-S7	Fume Trap 1	Fume Trap 2	Baghouse
Primary	only non-crystalline material detected	only non-crystalline material detected	ND	ND	ND
Secondary	ND	ND	ND	CaCO ₃ (Calcite)	ND
Minor	ND	ND	CaCO ₃ (Calcite) SiO ₂ (Quartz) CaO (Lime)	SiO ₂ (Quartz) CaO (Lime)	CaCO ₃ (Calcite) NaCl (Halite) KCl (Sylvite)
Trace	unidentified compounds	unidentified compounds	NaCl (Halite) KCl (Sylvite) NaAlSi ₃ O ₈ (Albite) Fe ₃ O ₄ (Magnetite)	NaCl (Halite) KCl (Sylvite) NaAlSi ₃ O ₈ (Albite) Fe ₃ O ₄ (Magnetite)	SiO ₂ (Quartz) unidentified compound
Primary Phase: 40 to 100% Secondary Phase: 20 to 60% Minor Phase: 5 to 30% Trace: 1 to 10%					
ND: Not detected					

Table J-5. X-Ray diffraction analysis of the N80-IV furnace products.

Phase	Slag	Fume Solids		
	N80-IV-S4	Fume Trap 1	Fume Trap 2	Baghouse
Primary	only non-crystalline material detected	ZrO ₂ (Zirconia)	ND	ND
Secondary	ND	ND	ZrO ₂ (Zirconia)	KCl (Sylvite)
Minor	ND	SiO ₂ (Quartz)	SiO ₂ (Quartz) CaCO ₃ (Calcite)	NaCl (Halite) ZrO ₂ (Zirconia) CaCO ₃ (Calcite)
Trace	ND	CaCO ₃ (Calcite) Fe ₃ O ₄ (Magnetite) Na ₂ CO ₃ unidentified compounds	Na ₂ CO ₃ CaO (Lime) unidentified compounds	unidentified compounds
Primary Phase: 40 to 100% Secondary Phase: 20 to 60% Minor Phase: 5 to 30%				
Trace: 1 to 10% ND: Not detected				

Table J-6. X-Ray diffraction analysis of the N80-IV-Mod furnace products.

Phase	Slag	Fume Solids		
	N80-IV-Mod-S10	Fume Trap 1	Fume Trap 2	Baghouse
Primary	non-crystalline material	ND	ND	non-crystalline material
Secondary	ND	ND	ND	ND
Minor	ND	ZrO ₂ (Zirconia) CaO (Lime) SiO ₂ (Quartz)	ZrO ₂ (Zirconia) SiO ₂ (Quartz) CaO (Lime)	ND
Trace	MgO (Periclase)	CaCO ₃ (Calcite) Na ₂ CO ₃ K ₂ CO ₃ KCl (Sylvite) NaCl (Halite) CeO ₂ unidentified compounds	CaCO ₃ (Calcite) Na ₂ CO ₃ K ₂ CO ₃ KCl (Sylvite) NaCl (Halite) possible CeO ₂	KCl (Sylvite) ZrO ₂ (Zirconia) NaCl (Halite) SiO ₂ (Quartz)
Primary Phase: 40 to 100% Secondary Phase: 20 to 60% Minor Phase: 5 to 30%				
Trace: 1 to 10% ND: Not detected				

Table J-7. X-Ray diffraction analysis of the M60 furnace products.

Phase	Slag	Fume Solids		
	M60-S1	Fume Trap 1	Fume Trap 2	Baghouse
Primary	non-crystalline material detected	non-crystalline material detected	ND	ND
Secondary	ND	ND	ND	ZnO (Zincite) non-crystalline material detected
Minor	ND	SiO ₂ (Quartz) CaSiO ₃ (Wollastonite) NaAlSi ₃ O ₈ -CaAl ₂ Si ₂ O ₈ (plagioclase) ZnO (Zincite)	ZnO (Zincite) SiO ₂ (Quartz) CaSiO ₃ (Wollastonite) non-crystalline material detected	Pb (Lead)
Trace	alpha Fe unidentified compounds	Pb (Lead) Fe ₃ O ₄ (Magnetite)	Pb (Lead) NaAlSi ₃ O ₈ -CaAl ₂ Si ₂ O ₈ (plagioclase) CaO (Lime) ZrO ₂ (Zirconia) CaCO ₃ (Calcite) unidentified compounds	may contain Zn(OH) ₂ unidentified compounds
Primary Phase: 40 to 100% Secondary Phase: 20 to 60% Minor Phase: 5 to 30% Trace: 1 to 10% ND: Not detected				

Table J-8. X-Ray diffraction analysis of the M60-Mod furnace products.

Phase	Slag		Fume Solids		
	M60-Mod-S2	M60-Mod-S5	Fume Trap 1	Fume Trap 2	Baghouse
Primary	non-crystalline material	non-crystalline material	ND	ND	ND
Secondary	ND	ND	ND	ND	ZnO (Zincite)
Minor	ND	ND	CaO (Lime) CaCO ₃ (Calcite) ZrO ₂ (Zirconia) SiO ₂ (Quartz)	CaO (Lime) SiO ₂ (Quartz) ZnO (Zincite) ZrO ₂ (Zirconia)	ND
Trace	Fe ₃ O ₄ (Magnetite)	Fe ₃ O ₄ (Magnetite) unidentified compounds	Fe ₃ O ₄ (Magnetite) ZnO (Zincite) CaSiO ₃ (Wollastonite) unidentified compounds	Fe ₃ O ₄ (Magnetite) CaCO ₃ (Calcite) Pb (Lead) Na ₂ CO ₃ K ₂ CO ₃ CaSiO ₃ (Wollastonite) NaAlSi ₃ O ₈ -CaAl ₂ Si ₂ O ₈ (plagioclase)	Pb (Lead) KCl (Sylvite) CaCO ₃ (Calcite) ZrO ₂ (Zirconia) may contain Zn(OH) ₂ unidentified compound
Primary Phase: 40 to 100% Secondary Phase: 20 to 60% Minor Phase: 5 to 30% Trace: 1 to 10% ND: Not detected					

Appendix K

Chemical Composition of Furnace Products

Table K-1. Masses and chemical composition of furnace products from the melting test of RWMC soil and mill scale.

	RWMC Slag	APCS solid			Total APCS Solids	Volatilized bag house catch components
		SD-T1	SD-T2	SD-BH		
wt, lb	6,030	1	29	35	65	
wt, %	100	1.54	44.62	53.85	100	
Component	Concentration, mg/kg					
Ag ₂ O	<1	2	20	15	17	15
Al ₂ O ₃	88,003	78,800	86,500	38,900	60,751	
As ₂ O ₃	10	49	238	647	455	
BaO	940	539	622	205	396	
CaO	32,065	41,000	51,500	23,000	35,992	
CdO	<1	3	51	54	52	54
CeO ₂	NC	NA	NA	NA	NC	
Cl	<100	980	17,200	10,100	13,127	
CO ₂	247	8,800	3,990	2,640	3,337	
CrO ₂	1,120	414	543	352	438	
Cs ₂ O	10	24	27	63	46	
CuO	715	362	611	1,500	1,086	
Fe ₃ O ₄	229,175	93,000	78,000	72,000	75,000	
HgO	<0.1	1	14	17	15	
K ₂ O	20,262	26,600	34,900	40,900	38,003	40,900
MgO	20,464	18,200	19,800	8,830	13,868	
Na ₂ O	17,380	25,500	27,800	29,700	28,788	29,700
NiO	311	118	132	226	182	226
P ₂ O ₅	708	4,560	13,700	25,400	19,859	25,400
PbO	20	119	3,090	1,370	2,118	1,370
SO ₃	17	1,040	4,880	6,980	5,952	6,980
SeO ₂	<1	3	13	22	18	22
SiO ₂	458,015	639,000	568,000	651,000	613,785	
TiO ₂	8,873	3,480	5,820	1,310	3,356	
ZnO	178	292	6,590	3,530	4,845	3,530
ZrO ₂	526	135	127	39	80	
Total	879,000	943,000	927,000	919,000	920,000	108,197
Portion of baghouse catch assumed to be from volatilization (%)						12

Notes:

1. The slag composition is the most representative slag composition for the RWMC soil + mill scale.
(weighted mean composition of all slag molds)
2. The composition of the total APCS solids is from the weighted average composition for the combined fume traps and bag house.
3. Components in the baghouse catch that increased in concentration from the fume trap 1 to the fume trap 2 to the baghouse were assumed to be volatilized.

Table K-2. Masses and chemical composition of furnace products from the melting test of S60 waste mixture.

	S60 Slag	APCS solid			Total APCS Solids	Volatilized bag house catch components
		S60-T1	S60-T2	S60-BH		
wt, lb	9,040	8	49	84	141	
wt, %	100	5.67	34.75	59.57	100	
Component	Concentration, mg/kg					
Ag ₂ O	7	15	16	24	21	24
Al ₂ O ₃	74,960	68,600	60,800	13,000	32,766	
As ₂ O ₃	4	28	59	127	98	127
BaO	696	1,370	1,690	737	1,104	
CaO	78,918	101,000	99,100	36,300	61,795	
CdO	<1	2	8	19	14	19
CeO ₂	2,852	3,800	6,500	568	2,813	
Cl	151	20,900	127,000	361,000	260,384	
CO ₂	1,151	17,100	7,700	1,760	4,695	
CrO ₂	947	443	246	246	257	
Cs ₂ O	1,573	15,500	28,800	87,100	62,777	87,100
CuO	651	719	1,210	4,080	2,892	4,080
Fe ₃ O ₄	173,293	96,700	78,200	64,600	71,148	
HgO	<0.1	0	3	12	8	12
K ₂ O	7,506	41,800	59,300	142,000	107,575	142,000
MgO	163,917	25,500	22,800	11,200	16,043	
Na ₂ O	5,979	39,000	51,800	127,000	95,874	127,000
NiO	90	149	109	107	110	
P ₂ O ₅	527	4,210	4,370	8,610	6,887	8,610
PbO	52	116	539	1,480	1,076	1,480
SO ₃	8	8,580	8,970	18,800	14,804	18,800
SeO ₂	<1	1	4	10	7	10
SiO ₂	462,101	469,000	394,000	160,000	258,851	
TiO ₂	17,467	7,870	5,470	1,170	3,044	
ZnO	149	683	1,690	3,380	2,640	3,380
ZrO ₂	217	115	95	15	48	
Total	994,000	925,000	961,000	1,043,000	1,009,000	392,642
Portion of baghouse catch assumed to be from volatilization (%)						38

Notes:

1. The slag composition is the most representative slag composition for the S60 waste mixture.
(weighted mean composition of last 3 slag molds)
2. The composition of the total APCS solids is from the weighted average composition for the combined fume traps and bag house.
3. Components in the baghouse catch that increased in concentration from the fume trap 1 to the fume trap 2 to the baghouse were assumed to be volatilized.

Table K-3. Masses and chemical composition of furnace products from the melting test of S60-IV waste mixture.

	S60-IV Slag	APCS solid			Total APCS Solids	Volatilized baghouse catch components
		S60-IV-T1	S60-IV-T2	S60-IV-BH		
wt, lb	7,019	11	43	110	164	
wt, %	100	6.71	26.22	67.07	100	
Component	Concentration, mg/kg					
Ag ₂ O	<1	3	6	14	11	14
Al ₂ O ₃	70,969	57,100	47,200	8,300	21,773	
As ₂ O ₃	3	37	63	67	64	67
BaO	770	1,700	1,820	672	1,042	
CaO	108,042	107,000	108,000	35,600	59,372	
CdO	<1	3	8	26	20	26
CeO ₂	4,679	6,960	5,130	472	2,128	
Cl	100	94,000	154,000	387,000	306,256	
CO ₂	2,511	11,500	10,000	1,760	4,574	
CrO ₂	727	381	275	231	253	231
Cs ₂ O	2,194	21,100	38,600	97,100	76,664	97,100
CuO	63	203	300	1,260	937	
Fe ₃ O ₄	183,757	115,000	92,400	64,900	75,471	
HgO	<0.1	0	1	11	8	11
K ₂ O	9,550	45,600	70,600	169,000	134,923	169,000
MgO	33,705	30,700	24,700	7,330	13,452	
Na ₂ O	20,228	41,200	60,800	164,000	128,705	164,000
NiO	74	90	104	92	95	
P ₂ O ₅	121	4,030	5,430	13,800	10,950	13,800
PbO	10	140	354	1,450	1,075	1,450
SO ₃	114	13,400	13,200	29,700	24,280	29,700
SeO ₂	<1	4	8	8	8	8
SiO ₂	484,504	405,000	347,000	136,000	209,366	
TiO ₂	44,580	11,700	5,810	1,140	3,073	
ZnO	119	961	1,390	4,050	3,145	4,050
ZrO ₂	22,211	264	158	120	140	
Total	991,000	968,000	986,000	1,120,000	1,080,000	479,457
Portion of baghouse catch assumed to be from volatilization (%)						43

Notes:

1. For ease of use, all analyzed elements are reported as oxides, even though many of the elements such as C, Ca, Cl, Mg, and other metals may be present (especially in the fume traps and baghouse) as carbonates, chlorides, and sulfates.
2. The slag composition is the most representative slag composition for the S60-IV waste mixture. (weighted mean composition of last 3 slag molds).
3. The composition of the total APCS solids is from the weighted average composition for the combined fume traps and baghouse.
4. Components in the baghouse catch that increased in concentration from the fume trap 1 to the fume trap 2 to the baghouse were assumed to be volatilized.

Table K-4. Masses and chemical composition of furnace products from the melting test of N80 waste mixture.

	N80 Slag	APCS solid			Total APCS Solids	Volatilized bag house catch components
		N80-T1	N80-T2	N80-BH		
wt, lb	4,069	15	14	80	109	
wt, %	100	13.82	12.44	73.73	100	
Component	Concentration, mg/kg					
Ag ₂ O	<1	2	11	45	35	45
Al ₂ O ₃	91,998	79,500	69,500	12,300	28,894	
As ₂ O ₃	3	59	131	110	106	110
BaO	931	1,129	1,606	746	909	
CaO	81,763	70,100	81,900	29,500	41,817	
CdO	<1	7	18	24	21	24
CeO ₂	2,436	2,450	4,850	434	1,279	
Cl	25	8,700	57,200	375,000	283,773	
CO ₂	1,682	28,500	33,900	3,150	10,588	
CrO ₂	350	289	494	249	286	
Cs ₂ O	366	1,660	9,490	85,600	64,273	85,600
CuO	49	56	216	1,530	1,158	1,530
Fe ₃ O ₄	146,714	72,800	75,000	62,000	65,156	
HgO	<0.1	0	4	13	10	13
K ₂ O	60,693	58,300	70,900	145,000	123,551	145,000
MgO	24,847	22,800	21,800	8,830	12,418	
Na ₂ O	75,491	62,100	72,200	147,000	125,709	147,000
NiO	85	498	2,430	4,490	3,676	4,490
P ₂ O ₅	675	3,640	6,940	13,400	11,227	13,400
PbO	10	147	957	1,410	1,178	1,410
SO ₃	390	12,200	23,600	32,000	28,196	32,000
SeO ₂	<1	1	8	8	7	8
SiO ₂	509,025	508,000	399,000	149,000	230,514	
TiO ₂	15,413	5,720	4,880	1,200	2,295	
ZnO	115	488	2,380	4,400	3,602	4,400
ZrO ₂	1,717	120	151	82	96	
Total	1,014,777	939,000	939,000	1,070,000	1,040,776	435,030
Portion of baghouse catch assumed to be from volatilization (%)						41

Notes:

1. The slag composition is the most representative slag composition for the N80 waste mixture.
(weighted mean composition of last 2 slag molds)
2. The composition of the total APCS solids is from the weighted average composition for the combined fume traps and bag house.
3. Components in the baghouse catch that increased in concentration from the fume trap 1 to the fume trap 2 to the baghouse were assumed to be volatilized.
4. The N80 slag weight was calculated from total slag(N80+N80-Mod)/total feed(N80+n80-Mod) • N80 feed.

Table K-5. Masses and chemical composition of furnace products from the melting test of N80-Mod waste mixture.

	N80-Mod Slag	APCS solid			Total APCS Solids	Volatilized bag house catch components
		N80-Mod-T1	N80-Mod-T2	N80-Mod-BH		
wt, lb	3,341	13	47	62	122	
pct	100	10.66	38.52	50.82	100	
Component	Concentration, mg/kg					
Ag ₂ O	<1	2	4	13	8	13
Al ₂ O ₃	68,557	41,800	37,600	19,100	28,646	
As ₂ O ₃	8	104	145	247	192	247
BaO	637	726	799	79	425	
CaO	163,595	295,000	330,000	160,000	239,877	
CdO	<1	6	10	27	19	27
CeO ₂	2,138	2,360	2,900	2,060	2,416	
Cl	30	25,800	22,100	108,000	66,148	
CO ₂	539	132,000	179,000	106,000	136,893	
CrO ₂	555	911	254	517	458	
Cs ₂ O	543	3,180	3,060	17,810	10,569	17,810
CuO	248	233	208	909	567	909
Fe ₃ O ₄	221,287	68,900	45,000	41,400	45,717	
HgO	<0.1	1	3	7	5	7
K ₂ O	39,410	39,400	38,800	123,000	81,654	123,000
MgO	27,152	19,200	20,300	12,300	16,117	
Na ₂ O	53,507	43,700	37,200	115,000	77,430	115,000
NiO	143	318	107	160	156	
P ₂ O ₅	1,392	3,780	3,990	15,400	9,766	15,400
PbO	10	106	357	813	562	813
SO ₃	200	14,600	14,200	58,400	36,705	58,400
SeO ₂	<1	4	3	8	6	8
SiO ₂	383,023	264,000	209,000	150,000	184,877	
TiO ₂	13,562	3,400	2,530	1,610	2,155	
ZnO	118	417	1,020	3,620	2,277	3,620
ZrO ₂	3,184	91	73	82	79	
Total	979,837	959,000	948,000	936,000	943,726	335,254
Portion of baghouse catch assumed to be from volatilization (%)						36

Notes:

1. The slag composition is the most representative slag composition for the N80-Mod waste mixture.
(weighted mean composition of last 2 slag molds)
2. The composition of the total APCS solids is from the weighted average composition for the combined fume traps and bag house.
3. Components in the baghouse catch that increased in concentration from the fume trap 1 to the fume trap 2 to the baghouse were assumed to be volatilized.
4. The N80-Mod slag weight was calculated from: total slag(N80+N80-Mod)-N80 slag.

Table K-6. Masses and chemical composition of furnace products from the melting test of N80-IV waste mixture.

	N80-IV Slag	APCS solid			Total APCS Solids	Volatilized bag house catch components
		N80-IV-T1	N80-IV-T2	N80-IV-BH		
wt, lb	4,613	26	39	47	112	
wt, %	100	23.21	34.82	41.96	100	
Component	Concentration, mg/kg					
Ag ₂ O	<1	2	11	45	23	45
Al ₂ O ₃	69,435	79,500	69,500	12,300	47,818	
As ₂ O ₃	3	59	131	110	105	110
BaO	979	1,129	1,606	746	1,134	
CaO	71,489	70,100	81,900	29,500	57,171	
CdO	<1	7	18	24	18	24
CeO ₂	4,034	2,450	4,850	434	2,440	
Cl	8	8,700	57,200	375,000	179,304	
CO ₂	781	28,500	33,900	3,150	19,742	
CrO ₂	442	289	494	249	344	
Cs ₂ O	62	1,660	9,490	85,600	39,611	85,600
CuO	56	56	216	1,530	730	1,530
Fe ₃ O ₄	115,935	72,800	75,000	62,000	69,034	
HgO	<0.1	0	4	13	7	13
K ₂ O	60,317	58,300	70,900	145,000	99,071	145,000
MgO	23,809	22,800	21,800	8,830	16,589	
Na ₂ O	79,489	62,100	72,200	147,000	101,245	147,000
NiO	59	498	2,430	4,490	2,846	4,490
P ₂ O ₅	12	3,640	6,940	13,400	8,885	13,400
PbO	26	147	957	1,410	959	1,410
SO ₃	231	12,200	23,600	32,000	24,479	32,000
SeO ₂	<1	1	8	8	6	8
SiO ₂	439,043	508,000	399,000	149,000	319,393	
TiO ₂	80,686	5,720	4,880	1,200	3,531	
ZnO	110	488	2,380	4,400	2,788	4,400
ZrO ₂	31,367	120	151	82	115	
Total	976,000	939,000	939,000	1,070,000	1,040,776	435,030
Portion of baghouse catch assumed to be from volatilization (%)						41

Notes:

1. The slag composition is the most representative slag composition for the N80-IV waste mixture.
(weighted mean composition of last 2 slag molds)
2. The composition of the total APCS solids is from the weighted average composition for the combined fume traps and bag house.
3. Components in the baghouse catch that increased in concentration from the fume trap 1 to the fume trap 2 to the baghouse were assumed to be volatilized.
4. The N80-IV slag weight was calculated from: total slag(N80-IV+N80-IV-Mod)/total feed(N80-IV+N80-IV-Mod) • N80-IV feed.

Table K-7. Masses and chemical composition of furnace products from the melting test of N80-IV-Mod waste mixture.

	N80-IV-Mod Slag	APCS solid			Total APCS Solids	Volatilized bag house catch components
		N80-IV-Mod-T1	N80-IV-Mod-T2	N80-IV-Mod-BH		
wt, lb	4,167	14	45	67	126	
wt, %	100	11.11	35.71	53.17	100	
Component	wt. mean"	Concentration, mg/kg			wt. mean	
Ag ₂ O	<1	2	5	8	6	8
Al ₂ O ₃	59,324	53,800	56,900	14,500	34,010	
As ₂ O ₃	11	145	251	198	211	198
BaO	683	1,320	1,680	1,620	1,608	
CaO	184,136	196,000	196,000	77,700	133,094	
CdO	<1	3	8	46	28	46
CeO ₂	3,392	9,990	10,400	10,400	10,354	
Cl	8	3,100	8,800	42,400	26,033	
CO ₂	1,174	29,800	45,500	61,200	52,104	
CrO ₂	591	265	325	964	658	964
Cs ₂ O	58	329	1,060	4,160	2,627	4,160
CuO	300	325	376	1,030	718	1,030
Fe ₃ O ₄	212,407	58,700	52,500	59,700	57,017	
HgO	<0.1	0	1	5	3	5
K ₂ O	46,234	78,500	81,200	131,000	107,381	131,000
MgO	17,859	16,700	18,200	9,830	13,583	
Na ₂ O	61,412	70,200	79,000	174,000	128,538	174,000
NiO	165	65	88	145	116	145
P ₂ O ₅	730	<1	5	1,260	672	1,260
PbO	23	101	280	1,770	1,052	1,770
SO ₃	206	12,000	14,600	50,000	33,135	50,000
SeO	<1	4	6	20	13	20
SiO ₂	278,494	313,000	296,000	257,000	277,151	
TiO ₂	50,557	4,800	4,100	4,200	4,231	
ZnO	108	492	880	2,256	1,569	2,256
ZrO ₂	24,935	98,800	57,800	18,100	41,245	
Total	942,806	948,441	925,965	923,512	927,158	366,862
Portion of baghouse catch assumed to be from volatilization (%)						40

Notes:

1. The slag composition is the most representative slag composition for the N80-IV-Mod waste mixture.
(weighted mean composition of last 3 slag molds)
2. The composition of the total APCS solids is from the weighted average composition for the combined fume traps and bag house.
3. Components in the baghouse catch that increased in concentration from the fume trap 1 to the fume trap 2 to the baghouse were assumed to be volatilized.
4. The N80-IV-Mod slag weight was calculated from: total slag(N80_IV+N80-IV-Mod) - N80-IV slag.

Table K-8. Masses and chemical composition of furnace products from melting test of M60 waste mixture.

	M60 Slag	M60 Metal	APCS Solid			Total APCS Solids	Volatilized baghouse catch components
			M60-T1	M60-T2	M60-BH		
wt, lb	2,119	865	5	20	28	53	
wt, %	100	100.00	9.43	37.74	52.83	100	
Component	Concentration, mg/kg						
Ag	<1	<1	2	13	9	10	9
Al	74,000	1,100	40,300	31,100	5,100	18,232	
As	2	99	15	69	47	52	47
Ba	969	18	1,720	1,980	527	1,188	
Ca	81,300	690	80,600	87,900	15,800	49,121	
Cd	<1	<1	5	16	18	16	18
Ce	3,928	<10	7,530	8,120	1,750	4,699	
Cl	60	<1	7,640	14,900	27,300	20,766	
C	260	1,490	4,480	6,370	2,650	4,226	
Cr	13,002	17,053	601	1,070	526	738	
Cs	62	<3	740	1,530	1,610	1,498	1,610
Cu	330	17,949	255	441	822	625	822
Fe	59,000	902,000	33,100	32,000	15,100	23,175	
Hg	<0.1	<0.1	0	4	8	6	8
K	20,000	59	26,500	36,000	30,100	31,987	
Mg	14,600	170	11,400	9,500	2,000	5,717	
Na	13,200	210	17,600	29,200	27,900	27,419	
Ni	662	17,681	400	401	189	289	
P	15	2,100	720	360	1,760	1,134	1,760
Pb	1,130	2,020	22,500	42,300	1,700	18,983	
S	300	500	2,020	5,050	8,940	6,819	8,940
Se	<1	3	<1	4	8	6	8
Si	257,000	25,100	222,000	153,000	67,200	114,181	
Ti	6,820	178	2,370	1,780	358	1,084	
Zn	2,650	979	62,300	107,000	210,000	157,198	210,000
Zr	3,400	33	4,560	12,100	2,270	6,195	
Total	553,000	947,000	549,000	582,000	424,000	495,365	223,222
Portion of baghouse catch assumed to be from volatilization (%)							53

Notes:

1. For ease of use, all analyzed elements are reported as oxides, even though many of the elements such as C, Ca, Cl, Mg, and other metals may be present (especially in the fume traps and baghouse) as carbonates, chlorides, and sulfates.
2. The slag composition is from the M60 rod sample.
3. The composition of the total APCS solids is from the weighted average composition for the combined fume traps and baghouse.
4. Components in the baghouse catch that increased in concentration from the fume trap 1 to the fume trap 2 to the baghouse were assumed to be volatilized.
5. The M60 slag weight is the weight of the M60 slag remaining in the furnace before feeding the modified composition [total M60 mixture fed-volatiles in M60 feed (including Cu, Fe, and Ni) which partitioned to the metal phase]
6. The M60 metal weight is the M60 remaining in the furnace before feeding the modified composition [Cu, Fe, Ni in feed].

Table K-9. Masses and chemical composition of furnace products from melting test of M60-Mod waste mixture.

	Slag	Metal	APCS Solid			Total APCS Solids	Volatilized baghouse catch components
			T1	T2	BH		
wt, lb	3105	0	12	26	32	70	
wt, %	100.00	0.00	17.14	37.14	45.71	100	
Component	Concentration, mg/kg						
Ag	<1	<1	2	7	12	9	12
Al	49,400	1,100	33,925	33,502	5,102	20,591	
As	3	99	39	80	101	83	101
Ba	700	18	1,182	1,738	637	1,139	
Ca	156,000	690	134,364	127,931	22,299	80,745	
Cd	<1	<1	2	9	35	20	35
Ce	3,130	10	7,555	8,955	966	5,063	
Cl	16	<1	3,480	8,730	50,900	27,108	
C	702	1,490	5,431	7,232	4,094	5,489	
Cr	5,100	17,053	496	842	1,430	1,051	1,430
Cs	95	<3	370	930	4,980	2,685	4,980
Cu	167	17,949	224	360	748	514	748
Fe	99,000	902,000	42,982	37,989	22,070	31,568	
Hg	<0.1	<0.1	0.1	3	8	5	8
K	25,800	59	42,338	48,813	69,401	57,115	69,401
Mg	11,900	170	10,373	10,373	2,412	6,734	
Na	25,300	210	33,087	48,963	52,524	47,869	52,524
Ni	148	17,681	131	217	193	191	
P	181	2,100	10	3	2,610	1,196	2,610
Pb	310	2,020	9,283	21,908	129,964	69,141	129,964
S	261	500	1,282	2,867	12,135	6,832	12,135
Se	<1	3	1	3	11	6	11
Si	184,000	25,100	168,278	154,255	81,334	123,324	
Ti	14,500	178	2,482	1,978	611	1,440	
Zn	1,430	979	22,414	46,033	159,068	93,657	159,068
Zr	8,500	33	46,491	29,316	3,613	20,510	
Total	586,643	989,442	926,000	949,000	861,000	907,000	433,026
Portion of baghouse catch assumed to be from volatilization (%)							50

Appendix L

Distribution of Components Among Furnace Products

Table L-1. Distribution of components among furnace products during the shakedown test of the RWMC soil and mill scale.

	APCS solid						APCS solid		Slag		Total	
	SD-T1		SD-T2		SD-BH		Subtotal		Subtotal			
wt, lb	1		29		35		65		6030		6095	
wt, pct	0.02		0.48		0.57		1.07		98.93		100	
Component	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct
Ag ₂ O	0.000002	0.18	0.0006	52.39	0.0005	47.43	0.0011	100.00	NC	NC	0.0011	100.00
Al ₂ O ₃	0.08	0.01	2.51	0.47	1.36	0.25	3.95	0.74	530.66	99.26	534.61	100.00
As ₂ O ₃	0.000	0.05	0.007	7.63	0.02	25.02	0.03	32.70	0.06	67.30	0.09	100.00
BaO	0.0005	0.01	0.02	0.32	0.01	0.13	0.03	0.45	5.67	99.55	5.70	100.00
CaO	0.04	0.02	1.49	0.76	0.81	0.41	2.34	1.20	193.35	98.80	195.69	100.00
CdO	0.00000	0.09	0.0015	43.86	0.002	56.05	0.0034	100.00	NC	NC	0.003	100.00
CeO ₂	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Cl	0.00	0.11	0.50	58.46	0.35	41.43	0.85	100.00	NC	NC	0.85	100.00
CO ₂	0.009	0.52	0.12	6.79	0.09	5.42	0.22	12.72	1.49	87.28	1.70	100.00
CrO ₂	0.0004	0.01	0.02	0.23	0.01	0.18	0.03	0.42	6.75	99.58	6.78	100.00
Cs ₂ O	0.00002	0.04	0.0008	1.29	0.002	3.63	0.003	4.95	0.06	95.05	0.06	100.00
CuO	0.0004	0.01	0.02	0.40	0.05	1.20	0.07	1.61	4.31	98.39	4.38	100.00
Fe ₃ O ₄	0.09	0.01	2.26	0.16	2.52	0.18	4.88	0.35	1381.92	99.65	1386.80	100.00
HgO	0.000001	0.10	0.00041	40.52	0.001	59.38	0.0010	100.00	NC	NC	0.0010	100.00
K ₂ O	0.03	0.02	1.01	0.81	1.43	1.15	2.47	1.98	122.18	98.02	124.65	100.00
MgO	0.02	0.01	0.57	0.46	0.31	0.25	0.90	0.73	123.40	99.27	124.30	100.00
Na ₂ O	0.03	0.02	0.81	0.76	1.04	0.97	1.87	1.75	104.80	98.25	106.67	100.00
NiO	0.0001	0.01	0.004	0.20	0.008	0.42	0.012	0.63	1.87	99.37	1.89	100.00
P ₂ O ₅	0.005	0.08	0.40	7.15	0.89	15.99	1.29	23.23	4.27	76.77	5.56	100.00
PbO	0.0001	0.05	0.090	34.38	0.05	18.40	0.14	52.83	0.12	47.17	0.26	100.00
SO ₃	0.001	0.21	0.14	28.95	0.24	49.97	0.39	79.14	0.10	20.86	0.49	100.00
SeO ₂	0.000003	0.26	0.00038	32.78	0.0008	66.96	0.0012	100.00	0.00	NC	0.0012	100.00
SiO ₂	0.64	0.02	16.47	0.59	22.79	0.81	39.90	1.42	2761.83	98.58	2801.73	100.00
TiO ₂	0.003	0.01	0.17	0.31	0.05	0.09	0.22	0.41	53.50	99.59	53.72	100.00
ZnO	0.0003	0.02	0.19	13.76	0.12	8.90	0.31	22.68	1.07	77.32	1.39	100.00
ZrO ₂	0.00014	0.004	0.004	0.12	0.001	0.04	0.005	0.16	3.17	99.84	3.18	100.00
Total	1		27		32		60		5301		5360	

Table L-2. Distribution of components among furnace products in the melting test of the S60 waste mixture.

	APCS solid						APCS solid		Slag		Total	
	S60-T1		S60-T2		S60-BH		Subtotal		Subtotal			
wt, lb	8		49		84		141		9040		9181	
wt, pct	0.09		0.53		0.91		1.54		98.46		100	
Component	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct
Ag ₂ O	0.0001	0.18	0.0008	1.17	0.002	3.00	0.003	4.35	0.06	95.65	0.07	100.00
Al ₂ O ₃	0.5488	0.08	2.9792	0.44	1.092	0.16	4.62	0.68	677.64	99.32	682.26	100.00
As ₂ O ₃	0.0002	0.47	0.0029	6.07	0.011	22.42	0.01	28.96	0.03	71.04	0.05	100.00
BaO	0.0110	0.17	0.0828	1.28	0.062	0.96	0.16	2.41	6.29	97.59	6.45	100.00
CaO	0.8080	0.11	4.8559	0.67	3.049	0.42	8.71	1.21	713.42	98.79	722.13	100.00
CdO	0.0000	0.80	0.0004	19.56	0.002	79.64	0.002	100.00	NC	NC	0.002	100.00
CeO ₂	0.0304	0.12	0.3185	1.22	0.048	0.18	0.40	1.51	25.79	98.49	26.18	100.00
Cl	0.1672	0.44	6.2230	16.34	30.324	79.63	36.71	96.41	1.37	3.59	38.08	100.00
CO ₂	0.1368	1.24	0.3773	3.41	0.148	1.34	0.66	5.98	10.41	94.02	11.07	100.00
CrO ₂	0.0035	0.04	0.0121	0.14	0.021	0.24	0.04	0.42	8.56	99.58	8.59	100.00
Cs ₂ O	0.1240	0.54	1.4112	6.12	7.316	31.71	8.85	38.36	14.22	61.64	23.08	100.00
CuO	0.0058	0.09	0.0593	0.94	0.343	5.45	0.41	6.48	5.88	93.52	6.29	100.00
Fe ₃ O ₄	0.7736	0.05	3.8318	0.24	5.426	0.34	10.03	0.64	1566.57	99.36	1576.60	100.00
HgO	0.0000	0.14	0.0001	12.71	0.001	87.15	0.001	100.00	NC	NC	0.001	100.00
K ₂ O	0.3344	0.40	2.9057	3.50	11.928	14.37	15.17	18.27	67.86	81.73	83.03	100.00
MgO	0.2040	0.01	1.1172	0.08	0.941	0.06	2.26	0.15	1481.81	99.85	1484.07	100.00
Na ₂ O	0.3120	0.46	2.5382	3.76	10.668	15.79	13.52	20.01	54.05	79.99	67.57	100.00
NiO	0.0012	0.14	0.0053	0.64	0.009	1.08	0.02	1.87	0.82	98.13	0.83	100.00
P ₂ O ₅	0.0337	0.59	0.2141	3.73	0.723	12.61	0.97	16.93	4.76	83.07	5.73	100.00
PbO	0.0009	0.15	0.0264	4.22	0.124	19.87	0.15	24.24	0.47	75.76	0.63	100.00
SO ₃	0.0686	3.18	0.4395	20.34	1.579	73.07	2.09	96.59	0.07	3.41	2.16	100.00
SeO ₂	0.0000	0.77	0.0002	18.77	0.001	80.46	0.0010	100.00	NC	NC	0.0010	100.00
SiO ₂	3.7520	0.09	19.3060	0.46	13.440	0.32	36.50	0.87	4177.39	99.13	4213.89	100.00
TiO ₂	0.0630	0.04	0.2680	0.17	0.098	0.06	0.43	0.27	157.91	99.73	158.33	100.00
ZnO	0.0055	0.32	0.0828	4.82	0.284	16.52	0.37	21.66	1.35	78.34	1.72	100.00
ZrO ₂	0.0009	0.05	0.0047	0.24	0.001	0.06	0.007	0.35	1.96	99.65	1.97	100.00
Total	7		47		88		142		8979		9121	

Table L-3. Distribution of components among furnace products in the melting test of the S60-IV waste mixture.

	APCS solid						APCS solid		Slag		Total	
	S60-IV-T1		S60-IV-T2		S60-IV-BH		Subtotal		Subtotal			
wt, lb	11		43		110		164		7019		7183	
wt, pct	0.15		0.60		1.53		2.28		97.72		100	
Component	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct
Ag ₂ O	0.00003	1.80	0.0003	14.09	0.002	84.11	0.002	100.00	NC	NC	0.002	100.00
Al ₂ O ₃	0.62810	0.13	2.0296	0.40	0.913	0.18	3.571	0.71	498.13	99.29	501.70	100.00
As ₂ O ₃	0.00041	1.22	0.0027	8.12	0.007	22.10	0.010	31.44	0.02	68.56	0.03	100.00
BaO	0.01870	0.34	0.0783	1.40	0.074	1.33	0.171	3.06	5.41	96.94	5.58	100.00
CaO	1.17700	0.15	4.6440	0.60	3.916	0.51	9.737	1.27	758.35	98.73	768.08	100.00
CdO	0.00003	1.02	0.0003	10.63	0.003	88.35	0.003	100.00	NC	NC	0.003	100.00
CeO ₂	0.07656	0.23	0.2206	0.66	0.052	0.16	0.349	1.05	32.84	98.95	33.19	100.00
Cl	1.03400	2.03	6.6220	13.00	42.570	83.58	50.226	98.62	0.70	1.38	50.93	100.00
CO ₂	0.12650	0.69	0.4300	2.34	0.194	1.05	0.751	4.08	17.63	95.92	18.38	100.00
CrO ₂	0.00419	0.08	0.0118	0.23	0.025	0.49	0.041	0.81	5.10	99.19	5.14	100.00
Cs ₂ O	0.23210	0.83	1.6598	5.93	10.681	38.18	12.573	44.94	15.40	55.06	27.98	100.00
CuO	0.00223	0.37	0.0129	2.16	0.139	23.16	0.154	25.69	0.44	74.31	0.60	100.00
Fe ₃ O ₄	1.26500	0.10	3.9732	0.31	7.139	0.55	12.377	0.95	1289.79	99.05	1302.17	100.00
HgO	0.00000	0.18	0.0000	3.43	0.001	96.40	0.001	100.00	NC	NC	0.001	100.00
K ₂ O	0.50160	0.56	3.0358	3.41	18.590	20.85	22.127	24.82	67.03	75.18	89.16	100.00
MgO	0.33770	0.14	1.0621	0.44	0.806	0.34	2.206	0.92	236.57	99.08	238.78	100.00
Na ₂ O	0.45320	0.28	2.6144	1.60	18.040	11.06	21.108	12.94	141.98	87.06	163.09	100.00
NiO	0.00099	0.18	0.0045	0.83	0.010	1.88	0.015	2.90	0.52	97.10	0.54	100.00
P ₂ O ₅	0.04433	1.68	0.2335	8.83	1.518	57.43	1.796	67.94	0.85	32.06	2.64	100.00
PbO	0.00154	0.62	0.0152	6.13	0.160	64.19	0.177	70.93	0.07	29.07	0.25	100.00
SO ₃	0.14740	3.08	0.5676	11.87	3.267	68.30	3.982	83.25	0.80	16.75	4.78	100.00
SeO ₂	0.00004	3.47	0.0003	27.13	0.001	69.40	0.001	100.00	NC	NC	0.001	100.00
SiO ₂	4.45500	0.13	14.9210	0.43	14.960	0.44	34.336	1.00	3400.73	99.00	3435.07	100.00
TiO ₂	0.12870	0.04	0.2498	0.08	0.125	0.04	0.504	0.16	312.90	99.84	313.41	100.00
ZnO	0.01057	0.78	0.0598	4.43	0.446	33.01	0.516	38.22	0.83	61.78	1.35	100.00
ZrO ₂	0.00290	0.002	0.0068	0.004	0.013	0.01	0.023	0.01	155.90	99.99	155.92	100.00
Total	11		42		124		177		6942		7119	

Table L-4. Distribution of components among furnace products in the melting test of the N80 waste mixture.

	APCS solid						APCS solid		Slag		Total	
	N80-T1		N80-T2		N80-BH		Subtotal		Subtotal			
wt, lb	15		14		80		109		4069		4178	
wt, pct	0.36		0.34		1.91		2.61		97.39		100	
Component	wt, lb	pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct
Ag ₂ O	0.00003	0.79	0.0002	4.07	0.004	95.14	0.004	100.00	NC	NC	0.004	100.00
Al ₂ O ₃	1.19250	0.32	0.97	0.26	0.98	0.26	3.15	0.83	374.34	99.17	377.49	100.00
As ₂ O ₃	0.0009	3.73	0.002	7.73	0.009	37.09	0.01	48.55	0.01	51.45	0.02	100.00
BaO	0.02	0.44	0.02	0.58	0.06	1.54	0.10	2.55	3.79	97.45	3.89	100.00
CaO	1.05	0.31	1.15	0.34	2.36	0.70	4.56	1.35	332.69	98.65	337.25	100.00
CdO	0.0001	4.61	0.0003	11.07	0.002	84.32	0.002	100.00	NC	NC	0.002	100.00
CeO ₂	0.04	0.37	0.07	0.68	0.04	0.35	0.14	1.39	9.91	98.61	10.05	100.00
Cl	0.13	0.42	0.80	2.58	30.00	96.67	30.93	99.67	0.10	0.33	31.03	100.00
CO ₂	0.43	5.35	0.47	5.93	0.25	3.15	1.15	14.43	6.84	85.57	8.00	100.00
CrO ₂	0.004	0.30	0.007	0.48	0.02	1.37	0.03	2.14	1.42	97.86	1.45	100.00
Cs ₂ O	0.02	0.29	0.13	1.56	6.85	80.60	7.01	82.46	1.49	17.54	8.50	100.00
CuO	0.0008	0.26	0.003	0.93	0.12	37.58	0.13	38.77	0.20	61.23	0.33	100.00
Fe ₃ O ₄	1.09	0.18	1.05	0.17	4.96	0.82	7.10	1.18	596.98	98.82	604.08	100.00
HgO	0.000002	0.14	0.0001	5.10	0.001	94.76	0.001	100.00	NC	NC	0.001	100.00
K ₂ O	0.87	0.34	0.99	0.38	11.60	4.45	13.47	5.17	246.96	94.83	260.43	100.00
MgO	0.34	0.33	0.31	0.30	0.71	0.69	1.35	1.32	101.10	98.68	102.46	100.00
Na ₂ O	0.93	0.29	1.01	0.32	11.76	3.66	13.70	4.27	307.17	95.73	320.88	100.00
NiO	0.007	1.00	0.03	4.57	0.36	48.22	0.40	53.79	0.34	46.21	0.74	100.00
P ₂ O ₅	0.05	1.37	0.10	2.45	1.07	27.00	1.22	30.82	2.75	69.18	3.97	100.00
PbO	0.002	1.29	0.01	7.83	0.11	65.92	0.13	75.04	0.04	24.96	0.17	100.00
SO ₃	0.18	3.93	0.33	7.09	2.56	54.93	3.07	65.95	1.59	34.05	4.66	100.00
SeO ₂	0.00002	1.96	0.0001	14.60	0.001	83.44	0.001	100.00	NC	NC	0.001	100.00
SiO ₂	7.620	0.36	5.59	0.27	11.92	0.57	25.13	1.20	2071.22	98.80	2096.35	100.00
TiO ₂	0.086	0.14	0.07	0.11	0.10	0.15	0.25	0.40	62.72	99.60	62.97	100.00
ZnO	0.007	0.85	0.03	3.88	0.35	40.99	0.39	45.72	0.47	54.28	0.86	100.00
ZrO ₂	0.002	0.03	0.002	0.03	0.007	0.09	0.01	0.15	6.98	99.85	7.00	100.00
Total	14		13		86		113		4129		4243	

Table L-5. Distribution of components among furnace products in the melting test of the N80-Mod waste mixture.

	APCS solid						APCS solid		Slag		Total	
	N80-Mod-T1		N80-Mod-T2		N80-Mod-BH		Subtotal		Subtotal			
wt, lb	13		47		62		122		3341		3463	
wt, pct	0.38		1.36		1.79		3.52		96.48		100	
Component	wt, lb	pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct
Ag ₂ O	0.00003	2.71	0.0002	19.62	0.001	77.66	0.001	100.00	NC	NC	0.001	100.00
Al ₂ O ₃	0.54	0.23	1.77	0.76	1.18	0.51	3.49	1.50	229.05	98.50	232.54	100.00
As ₂ O ₃	0.001	2.69	0.01	13.57	0.02	30.50	0.02	46.77	0.03	53.23	0.05	100.00
BaO	0.009	0.43	0.04	1.72	0.005	0.22	0.05	2.38	2.13	97.62	2.18	100.00
CaO	3.84	0.67	15.51	2.69	9.92	1.72	29.27	5.08	546.57	94.92	575.83	100.00
CdO	0.00007	3.29	0.0005	21.41	0.002	75.30	0.003	100.00	NC	NC	0.003	100.00
CeO ₂	0.03	0.41	0.14	1.83	0.13	1.72	0.29	3.96	7.14	96.04	7.44	100.00
Cl	0.34	4.11	1.04	12.71	6.70	81.96	8.07	98.77	0.10	1.23	8.17	100.00
CO ₂	1.72	9.28	8.41	45.47	6.57	35.52	16.70	90.27	1.80	9.73	18.50	100.00
CrO ₂	0.01	0.62	0.01	0.62	0.03	1.68	0.06	2.92	1.86	97.08	1.91	100.00
Cs ₂ O	0.04	1.33	0.14	4.64	1.10	35.59	1.29	41.56	1.81	58.44	3.10	100.00
CuO	0.003	0.34	0.01	1.09	0.06	6.27	0.07	7.70	0.83	92.30	0.90	100.00
Fe ₃ O ₄	0.90	0.12	2.12	0.28	2.57	0.34	5.58	0.75	739.32	99.25	744.90	100.00
HgO	0.00001	2.21	0.0001	23.98	0.0004	73.81	0.0005	100.00	NC	NC	0.001	100.00
K ₂ O	0.51	0.36	1.82	1.29	7.63	5.38	9.96	7.03	131.67	92.97	141.63	100.00
MgO	0.25	0.27	0.95	1.03	0.76	0.82	1.97	2.12	90.72	97.88	92.68	100.00
Na ₂ O	0.57	0.30	1.75	0.93	7.13	3.79	9.45	5.02	178.77	94.98	188.21	100.00
NiO	0.004	0.83	0.005	1.01	0.01	1.99	0.02	3.83	0.48	96.17	0.50	100.00
P ₂ O ₅	0.05	0.84	0.19	3.21	0.96	16.34	1.19	20.39	4.65	79.61	5.84	100.00
PbO	0.001	1.35	0.02	16.45	0.05	49.43	0.07	67.24	0.03	32.76	0.10	100.00
SO ₃	0.19	3.69	0.67	12.97	3.62	70.37	4.48	87.04	0.67	12.96	5.15	100.00
SeO ₂	0.00005	7.55	0.0001	20.46	0.001	71.99	0.0007	100.00	NC	NC	0.001	100.00
SiO ₂	3.43	0.26	9.82	0.75	9.30	0.71	22.56	1.73	1279.68	98.27	1302.23	100.00
TiO ₂	0.04	0.10	0.12	0.26	0.10	0.22	0.26	0.58	45.31	99.42	45.57	100.00
ZnO	0.005	0.81	0.05	7.14	0.22	33.44	0.28	41.39	0.39	58.61	0.67	100.00
ZrO ₂	0.001	0.01	0.003	0.03	0.005	0.05	0.01	0.09	10.64	99.91	10.65	100.00
Total	12		45		58		115		3274		3389	

Table L-6. Distribution of components among furnace products in the melting test of the N80-IV waste mixture.

	APCS solid						APCS solid		Slag		Total	
	N80-IV-T1		N80-IV-T2		N80-IV-BH		Subtotal		Subtotal			
wt, lb	26		39		47		112		4613		4725	
wt, pct	0.55		0.83		0.99		2.37		97.63		100	
Component	wt, lb	pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct
Ag ₂ O	0.00005	2.00	0.0004	16.53	0.002	81.47	0.003	100.00	NC	NC	0.003	100.00
Al ₂ O ₃	2.06700	0.63	2.7105	0.83	0.578	0.18	5.36	1.64	320.30	98.36	325.66	100.00
As ₂ O ₃	0.00153	5.65	0.0051	18.81	0.005	19.04	0.01	43.50	0.02	56.50	0.03	100.00
BaO	0.02935	0.63	0.0626	1.35	0.035	0.76	0.13	2.74	4.52	97.26	4.64	100.00
CaO	1.82260	0.54	3.1941	0.95	1.387	0.41	6.40	1.90	329.78	98.10	336.18	100.00
CdO	0.00018	9.05	0.0007	34.89	0.001	56.06	0.002	100.00	NC	NC	0.002	100.00
CeO ₂	0.06370	0.34	0.1892	1.00	0.020	0.11	0.27	1.45	18.61	98.55	18.88	100.00
Cl	0.22620	1.12	2.2308	11.09	17.625	87.60	20.08	99.81	0.04	0.19	20.12	100.00
CO ₂	0.74100	12.75	1.3221	22.75	0.148	2.55	2.21	38.04	3.60	61.96	5.81	100.00
CrO ₂	0.00751	0.36	0.0193	0.93	0.012	0.56	0.04	1.85	2.04	98.15	2.08	100.00
Cs ₂ O	0.04316	0.91	0.3701	7.84	4.023	85.18	4.44	93.93	0.29	6.07	4.72	100.00
CuO	0.00146	0.43	0.0084	2.47	0.072	21.06	0.08	23.96	0.26	76.04	0.34	100.00
Fe ₃ O ₄	1.89280	0.35	2.9250	0.54	2.914	0.54	7.73	1.43	534.81	98.57	542.54	100.00
HgO	0.00000	0.34	0.0002	20.27	0.001	79.39	0.001	100.00	NC	NC	0.001	100.00
K ₂ O	1.51580	0.52	2.7651	0.96	6.815	2.36	11.10	3.83	278.24	96.17	289.34	100.00
MgO	0.59280	0.53	0.8502	0.76	0.415	0.37	1.86	1.66	109.83	98.34	111.69	100.00
Na ₂ O	1.61460	0.43	2.8158	0.74	6.909	1.83	11.34	3.00	366.68	97.00	378.02	100.00
NiO	0.01295	2.19	0.0948	16.07	0.211	35.77	0.32	54.03	0.27	45.97	0.59	100.00
P ₂ O ₅	0.09464	9.00	0.2707	25.75	0.630	59.91	1.00	94.66	0.06	5.34	1.05	100.00
PbO	0.00382	1.67	0.0373	16.32	0.066	28.97	0.11	46.96	0.12	53.04	0.23	100.00
SO ₃	0.31720	8.34	0.9204	24.19	1.504	39.53	2.74	72.05	1.06	27.95	3.81	100.00
SeO ₂	0.00003	3.64	0.0003	43.70	0.000	52.66	0.001	100.00	NC	NC	0.001	100.00
SiO ₂	13.20800	0.64	15.5610	0.75	7.003	0.34	35.77	1.74	2025.31	98.26	2061.08	100.00
TiO ₂	0.14872	0.04	0.1903	0.05	0.056	0.02	0.40	0.11	372.20	99.89	372.60	100.00
ZnO	0.01269	1.54	0.0928	11.30	0.207	25.18	0.31	38.02	0.51	61.98	0.82	100.00
ZrO ₂	0.00312	0.002	0.0059	0.004	0.004	0.003	0.01	0.01	144.70	99.99	144.71	100.00
Total	24		37		51		112		4513		4625	

Table L-7. Distribution of components among furnace products in the melting test of the N80-IV-Mod waste mixture.

	APCS solid						APCS solid		Slag		Total	
	N80-T1		N80-T2		N80-BH		Subtotal		Subtotal			
wt, lb	14		45		67		126		4167		4293	
wt, pct	0.33		1.05		1.56		2.94		97.06		100	
Component	wt, lb	pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct	wt, lb	wt, pct
Ag ₂ O	0.00003	3.55	0.0002	28.52	0.001	67.93	0.001	100.00	NC	NC	0.001	100.00
Al ₂ O ₃	0.75320	0.30	2.5605	1.02	0.972	0.39	4.29	1.70	247.20	98.30	251.49	100.00
As ₂ O ₃	0.00203	2.84	0.0113	15.78	0.013	18.54	0.03	37.16	0.04	62.84	0.07	100.00
BaO	0.01848	0.61	0.0756	2.48	0.109	3.56	0.20	6.65	2.85	93.35	3.05	100.00
CaO	2.74400	0.35	8.8200	1.12	5.206	0.66	16.77	2.14	767.30	97.86	784.07	100.00
CdO	0.00004	1.21	0.0004	10.33	0.003	88.46	0.003	100.00	NC	NC	0.003	100.00
CeO ₂	0.13986	0.91	0.4680	3.03	0.697	4.51	1.30	8.45	14.13	91.55	15.44	100.00
Cl	0.04340	1.31	0.3960	11.96	2.841	85.77	3.28	99.04	0.03	0.96	3.31	100.00
CO ₂	0.41720	3.64	2.0475	17.87	4.100	35.79	6.57	57.31	4.89	42.69	11.46	100.00
CrO ₂	0.00371	0.15	0.0146	0.57	0.065	2.54	0.08	3.26	2.46	96.74	2.54	100.00
Cs ₂ O	0.00461	0.80	0.0477	8.30	0.279	48.50	0.33	57.60	0.24	42.40	0.57	100.00
CuO	0.00455	0.34	0.0169	1.26	0.069	5.14	0.09	6.74	1.25	93.26	1.34	100.00
Fe ₃ O ₄	0.82180	0.09	2.3625	0.26	4.000	0.45	7.18	0.81	885.10	99.19	892.28	100.00
HgO	0.00000	0.37	0.0000	11.80	0.000	87.83	0.0004	100.00	NC	NC	0.000	100.00
K ₂ O	1.09900	0.53	3.6540	1.77	8.777	4.26	13.53	6.56	192.66	93.44	206.19	100.00
MgO	0.23380	0.31	0.8190	1.08	0.659	0.87	1.71	2.25	74.42	97.75	76.13	100.00
Na ₂ O	0.98280	0.36	3.5550	1.31	11.658	4.28	16.20	5.95	255.90	94.05	272.10	100.00
NiO	0.00091	0.13	0.0040	0.56	0.010	1.38	0.01	2.08	0.69	97.92	0.70	100.00
P ₂ O ₅	0.00000	0.00	0.0002	0.01	0.084	2.70	0.08	2.71	3.04	97.29	3.13	100.00
PbO	0.00141	0.62	0.0126	5.52	0.119	51.91	0.13	58.05	0.10	41.95	0.23	100.00
SO ₃	0.16800	3.34	0.6570	13.05	3.350	66.53	4.18	82.92	0.86	17.08	5.03	100.00
SeO ₂	0.00006	3.36	0.0003	16.21	0.001	80.43	0.0017	100.00	NC	NC	0.002	100.00
SiO ₂	4.38200	0.37	13.3200	1.11	17.219	1.44	34.92	2.92	1160.48	97.08	1195.40	100.00
TiO ₂	0.06720	0.03	0.1845	0.09	0.281	0.13	0.53	0.25	210.67	99.75	211.21	100.00
ZnO	0.00689	1.07	0.0396	6.12	0.151	23.37	0.20	30.56	0.45	69.44	0.65	100.00
ZrO ₂	1.38320	1.27	2.6010	2.38	1.213	1.11	5.20	4.76	103.90	95.24	109.10	100.00
Total	13		42		62		117		3929		4045	

Table L-8. Distribution of components among furnace products in the melting test of the M60 waste mixture.

	APCS solid						APCS solid Subtotal		Slag Subtotal		Metal Subtotal		Total	
	M60-T1		M60-T2		M60-BH									
	wt, lb		wt, lb		wt, lb		wt, lb		wt, lb		wt, lb		wt, lb	
wt, lb	5		20		28		53		2119		865		3037	
wt, pct	0.16		0.66		0.92		1.75		69.77		28.48		100	
Component	wt, lb	pct	wt, lb	pct	wt, lb	pct	wt, lb	pct	wt, lb	pct	wt, lb	pct	wt, lb	pct
Ag	0.00001	1.92	0.0003	49.81	0.0003	48.28	0.001	100.00	NC	NC	NC	NC	0.001	100.00
Al	0.20150	0.13	0.6220	0.39	0.1428	0.09	0.97	0.61	156.81	98.79	0.95	0.60	158.72	100.00
As	0.00008	0.08	0.0014	1.49	0.0013	1.42	0.003	2.99	0.00	4.57	0.09	92.43	0.09	100.00
Ba	0.00860	0.40	0.0396	1.86	0.0148	0.69	0.06	2.95	2.05	96.32	0.02	0.73	2.13	100.00
Ca	0.40300	0.23	1.7580	1.00	0.4424	0.25	2.60	1.48	172.27	98.18	0.60	0.34	175.47	100.00
Cd	0.00003	2.94	0.0003	37.69	0.0005	59.36	0.001	100.00	NC	NC	NC	NC	0.001	100.00
Ce	0.03765	0.44	0.1624	1.89	0.0490	0.57	0.25	2.91	8.32	97.09	NC	NC	8.57	100.00
Cl	0.03820	3.11	0.2980	24.27	0.7644	62.26	1.10	89.64	0.13	10.36	NC	NC	1.23	100.00
C	0.02240	1.09	0.1274	6.17	0.0742	3.60	0.22	10.85	0.55	26.70	1.29	62.45	2.06	100.00
Cr	0.00301	0.01	0.0214	0.05	0.0147	0.03	0.04	0.09	27.55	65.07	14.75	34.84	42.34	100.00
Cs	0.00370	1.76	0.0306	14.52	0.0451	21.39	0.08	37.66	0.13	62.34	NC	NC	0.21	100.00
Cu	0.00128	0.01	0.0088	0.05	0.0230	0.14	0.03	0.20	0.70	4.30	15.53	95.50	16.26	100.00
Fe	0.16550	0.02	0.6400	0.07	0.4228	0.05	1.23	0.14	125.02	13.79	780.23	86.07	906.48	100.00
Hg	0.00000	0.32	0.0001	27.90	0.0002	71.77	0.0003	100.00	NC	NC	NC	NC	0.0003	100.00
K	0.13250	0.30	0.7200	1.63	0.8428	1.91	1.70	3.84	42.38	96.04	0.05	0.12	44.13	100.00
Mg	0.05700	0.18	0.1900	0.61	0.0560	0.18	0.30	0.97	30.94	98.57	0.15	0.47	31.39	100.00
Na	0.08800	0.30	0.5840	1.97	0.7812	2.64	1.45	4.91	27.97	94.48	0.18	0.61	29.61	100.00
Ni	0.00200	0.01	0.0080	0.05	0.0053	0.03	0.02	0.09	1.40	8.39	15.29	91.51	16.71	100.00
P	0.00360	0.19	0.0072	0.38	0.0493	2.58	0.06	3.15	0.03	1.67	1.82	95.19	1.91	100.00
Pb	0.11250	2.19	0.8460	16.43	0.0476	0.92	1.01	19.54	2.39	46.51	1.75	33.94	5.15	100.00
S	0.01010	0.71	0.1010	7.06	0.2503	17.51	0.36	25.28	0.64	44.47	0.43	30.25	1.43	100.00
Se	NC	NC	0.0001	2.76	0.0002	7.73	0.0003	10.49	NC	NC	0.003	89.51	0.0029	100.00
Si	1.11000	0.19	3.0600	0.53	1.8816	0.33	6.05	1.06	544.58	95.15	21.71	3.79	572.35	100.00
Ti	0.01185	0.08	0.0356	0.24	0.0100	0.07	0.06	0.39	14.45	98.56	0.15	1.05	14.66	100.00
Zn	0.31150	2.11	2.1400	14.47	5.8800	39.75	8.33	56.32	5.62	37.96	0.85	5.72	14.79	100.00
Zr	0.02280	0.30	0.2420	3.20	0.0636	0.84	0.33	4.34	7.20	95.28	0.03	0.38	7.56	100.00
Total	3		12		12		26		1171		856		2053	

Appendix M

Distribution of Ce and Toxic Metals Among Furnace Products

Figure M-1. Toxic metal partitioning for the RWMC soil and mill scale.

Figure M-2. Cerium and toxic metal partitioning for the S60 waste mixture.

Figure M-3. Cerium and toxic metal partitioning for the S60-IV waste mixture.

Figure M-4. Cerium and toxic metal partitioning for the N80 waste mixture.

Figure M-5. Cerium and toxic metal partitioning for the N80-Mod waste mixture.

Figure M-6. Cerium and toxic metal partitioning for the N80-IV waste mixture.

Figure M-7. Cerium and toxic metal partitioning for the N80-IV-Mod waste mixture.

Figure M-8. Cerium and toxic metal partitioning for the M60 waste mixture.

Appendix N

Toxic Characteristic Leaching Procedure (TCLP) Analysis of Furnace Products

Table N-1. TCLP test results for slag samples.

Analyte	Analyte Concentration												
	S60-S1				S60-S7			S60-IV-S1			S60-IV-S6		
	TCLP Limits (mg/L)	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved
Arsenic	5.0	<0.2	2	< 100	<0.2	3	< 100	<0.2	3	< 100	<0.2	3	< 100
Barium	100.0	<0.2	591	< 6.77	<0.2	587	< 6.81	<0.2	613	< 6.53	<0.2	655	< 6.11
Cadmium	1.0	<0.1	<1	NC	<0.1	<1	NC	<0.1	<1	NC	<0.1	<1	NC
Chromium	5.0	0.2	260	15.4	0.3	555	10.8	0.2	313	12.8	<0.1	324	< 6.17
Lead	5.0	<0.1	5	< 100	<0.1	49	< 40.8	<0.1	14	< 100	<0.1	11	< 100
Mercury	0.2	<0.1	<0.1	NC	<0.1	<0.1	NC	<0.1	<0.1	NC	<0.1	<0.1	NC
Selenium	1.0	<0.1	<1	NC	<0.1	<1	NC	<0.1	<1	NC	<0.1	<1	NC
Silver	5.0	<0.1	<1	NC	<0.1	8	< 100	<0.1	<1	NC	<0.1	<1	NC
Cerium	---	0.17	2227	1.53	0.17	2264	1.50	0.06	3232	0.37	0.07	3608	0.39
Basicity			0.64			0.82			0.52			0.50	

Analyte	Analyte Concentration												
	N80-S3				N80-Mod-S6			N80-Mod-S7			N80-IV-S4		
	TCLP Limits (mg/L)	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved
Arsenic	5.0	<0.2	2	< 100	<0.2	5	< 100	<0.2	6	< 100	<0.2	3	< 100
Barium	100.0	<0.2	782	< 5.12	<0.2	589	< 6.79	<0.2	592	< 6.76	<0.2	782	< 5.12
Cadmium	1.0	<0.1	<1	NC	<0.1	<1	NC	<0.1	<1	NC	<0.1	<1	NC
Chromium	5.0	<0.1	202	< 9.90	0.1	245	8.16	0.1	313	< 6.39	0.1	213	9.39
Lead	5.0	<0.1	10	< 100	<0.1	10	< 100	<0.1	9	< 100	<0.1	27	< 74.1
Mercury	0.2	<0.1	<0.1	NC	<0.1	<0.1	NC	<0.1	<0.1	NC	<0.1	<0.1	NC
Selenium	1.0	<0.1	<1	NC	<0.1	<1	NC	<0.1	<1	NC	<0.1	<1	NC
Silver	5.0	<0.1	<1	NC	<0.1	<1	NC	<0.1	<1	NC	<0.1	<1	NC
Cerium	---	0.35	1838	3.81	0.36	1808	3.98	0.58	1760	6.59	0.13	3240	0.80
Basicity			0.56			0.79			0.90			0.52	

- Notes: 1. Percent dissolved was based on 1 gram of slag put into 0.2 liters of solvent.
2. NC = Not calculated due to uncertainty in data.

Table N-1. TCLP test results for slag samples (continued).

Analyte	Analyte Concentration												
	N80-IV-Mod-S10				M60-RS			M60-Mod-S2			M60-Mod-S5		
	TCLP Limits (mg/L)	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved
Arsenic	5.0	<0.2	7	< 100	<0.2	2	< 100	<0.2	1	< 100	<0.2	5	< 100
Barium	100.0	<0.2	600	< 6.67	<0.2	969	< 4.13	<0.2	801	< 4.99	<0.2	568	< 7.04
Cadmium	1.0	<0.1	<1	NC	<0.1	<1	< 100	<0.1	<1	NC	<0.1	<1	NC
Chromium	5.0	0.2	210	19.0	0.5	13002	0.77	0.1	8219	0.24	<0.1	1958	< 1.02
Lead	5.0	<0.1	21	< 95.2	<0.1	1130	< 1.77	<0.1	350	< 5.71	<0.1	420	< 4.76
Mercury	0.2	<0.1	<0.1	NC	<0.1	<0.1	< 100	<0.1	<0.1	NC	<0.1	<0.1	NC
Selenium	1.0	<0.1	<1	NC	<0.1	<1	< 100	0.3	<1	NC	0.2	<1	NC
Silver	5.0	<0.1	<1	NC	<0.1	<1	< 100	<0.1	<1	NC	<0.1	<1	NC
Cerium	---	0.32	2545	2.51	0.18	3928	0.92	0.3	3864	1.55	1.75	2739	12.8
Basicity			NC			NC			0.61			1.08	

- Notes: 1. Percent dissolved was based on 1 gram of slag put into 0.2 liters of solvent.
2. NC = Not calculated due to uncertainty in data.

Table N-2. TCLP test results for APCS solids.

Analyte	Analyte Concentration												
	S60				S60-IV			N80			N80-Mod		
	TCLP Limits (mg/L)	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved
Arsenic	5.0	<0.2	74	< 54.1	<0.2	49	< 81.6	<0.2	80	< 50	<0.2	146	< 27.4
Barium	100.0	<0.2	989	< 4.04	<0.2	933	< 4.29	<0.2	810	< 4.94	<0.2	381	< 10.5
Cadmium	1.0	0.7	13	100	0.8	17	100	0.7	18	100	<0.1	16	< 100
Chromium	5.0	<0.1	159	< 12.6	<0.1	156	< 12.8	<0.1	176	< 11.4	0.1	283	7.07
Lead	5.0	12.2	994	100	13.8	1001	100	4.1	1094	75.0	0.2	522	7.66
Mercury	0.2	<0.1	8	< 100	<0.1	7	< 100	<0.1	9	< 100	<0.1	4	< 100
Selenium	1.0	0.2	5	100	0.2	6	100	0.1	5	100	0.4	4	100
Silver	5.0	0.1	19	100	<0.1	10	< 100	<0.1	32	< 62.5	<0.1	8	< 100
Cerium	—	8.44	2297	73.5	7.41	1732	85.6	3.65	1025	71.2	0.03	1965	3.05
Basicity			NC			NC			NC			NC	

Analyte	Analyte Concentration												
	N80-IV				N80-IV-Mod			M60			M60-Mod		
	TCLP Limits (mg/L)	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved	Leachate Conc. (mg/L)	Element Conc. in slag (mg/kg)	Percent Dissolved
Arsenic	5.0	<0.2	136	< 29.4	<0.2	160	< 25	<0.2	52	< 76.9	<0.2	99	< 40.4
Barium	100.0	<0.2	1278	< 3.13	<0.2	1441	< 2.78	<0.2	1178	< 3.40	<0.2	1136	< 3.52
Cadmium	1.0	<0.1	17	< 100	<0.1	24	< 83.3	0.4	16	100	0.4	20	100
Chromium	5.0	0.1	239	8.37	<0.1	408	< 4.90	<0.1	736	< 2.72	<0.1	1056	< 1.89
Lead	5.0	<0.1	769	< 2.60	<0.1	978	< 2.04	164	18743	100	3.9	69953	1.1
Mercury	0.2	<0.1	3	< 100	<0.1	3	< 100	<0.1	6	< 100	<0.1	5	< 100
Selenium	1.0	0.5	9	100	0.2	11	100	<0.1	6	< 100	0.3	6	100
Silver	5.0	<0.1	6	< 100	<0.1	6	< 100	<0.1	10	< 100	<0.1	8	< 100
Cerium	—	0.01	6364	0.03	<0.01	8454	0.02	0.02	4653	0.09	0.02	5027	0.08
Basicity			NC			NC			NC			NC	

- Notes: 1. Percent dissolved was based on 1 gram of slag put into 0.2 liters of solvent.
2. NC = Not calculated due to uncertainty in data.

Appendix O

Offgas CEMS Reduced Data

Table O-1 Calculated furnace outlet offgas compositions for S60.

TIME (a)	Quench Outlet Dry vol. % / ppm (a)					Wet (b) H2O (%)	Quench Outlet (c)	Quench Outlet	Quench Air (d)	Quench Air	Temp. Quench	Dilution	Dilution	Furnace Outlet Offgas Composition (wet basis %) (g)					
	NOx (ppm)	O2 (%)	CO2 (%)	CO (ppm)	SO2 (ppm)		Flowrate (dscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Air (C) (e)	Factor	Factor (f)	NOx (ppm)	O2 (h)	CO2	CO (ppm)	SO2 (ppm)	H2O
10:13	17.3	19.8	2.9	3654	1038	6.05	457.00	486.43	492.36	308.00	24.70	0.21	4.77	77.5	14.39	13.00	16375.1	4651.7	28.86
10:14	19.5	19.8	2.93	3654	1038	6.05	457.00	486.43	492.36	308.00	24.70	0.21	4.77	87.4	14.39	13.13	16375.1	4651.7	28.86
10:15	20.2	19.9	2.74	3654	1038	6.05	457.00	486.43	492.36	308.00	24.70	0.21	4.77	90.5	14.75	12.28	16375.1	4651.7	28.86
10:16	22	19.9	2.71	3654	1038	6.05	457.00	486.43	492.36	308.00	24.70	0.21	4.77	98.6	14.80	12.14	16375.1	4651.7	28.86
10:17	23.1	19.9	2.63	3654	1038	6.05	457.00	486.43	489.32	308.00	25.30	0.21	4.77	103.5	15.02	11.79	16375.1	4651.7	28.86
10:18	24.5	19.9	2.63	3654	1038	6.05	457.00	486.43	489.32	308.00	25.30	0.21	4.77	109.8	15.02	11.79	16375.1	4651.7	28.86
10:19	27.9	20	2.49	3654	1038	6.05	457.00	486.43	489.32	308.00	25.30	0.21	4.77	125.0	15.25	11.16	16375.1	4651.7	28.86
10:20	31	19.9	2.62	3924	1048	6.05	457.00	486.43	489.32	308.00	25.30	0.21	4.77	138.9	14.98	11.74	17585.1	4696.5	28.86
10:21	35.5	19.9	2.55	3924	1048	6.05	457.00	486.43	489.32	308.00	25.30	0.21	4.77	159.1	14.93	11.43	17585.1	4696.5	28.86
10:22	30.2	19.9	2.52	3604	1048	6.05	457.00	486.43	489.32	308.00	25.30	0.21	4.77	135.3	14.98	11.29	16151.0	4696.5	28.86
10:23	38.7	19.8	2.82	3604	1048	6.05	457.00	486.43	471.77	308.00	25.30	0.21	4.77	173.4	14.44	12.64	16151.0	4696.5	28.86
10:24	39.3	19.8	2.72	3542	1049	6.05	457.00	486.43	471.77	308.00	25.30	0.21	4.77	176.1	14.57	12.19	15873.2	4701.0	28.86
10:25	39.1	19.8	2.76	3542	1049	6.05	457.00	486.43	471.77	308.00	25.30	0.21	4.77	175.2	14.53	12.37	15873.2	4701.0	28.86
10:26	39	19.8	2.88	3467	1051	6.05	457.00	486.43	471.77	308.00	25.30	0.21	4.77	174.8	14.35	12.91	15537.1	4710.0	28.86
10:27	35.6	19.8	2.78	3467	1051	6.05	457.00	486.43	471.77	308.00	25.30	0.21	4.77	159.5	14.53	12.46	15537.1	4710.0	28.86
10:28	44.8	19.7	2.97	3825	1044	6.05	457.00	486.43	471.77	308.00	25.30	0.21	4.77	200.8	14.22	13.31	17141.4	4678.6	28.86
10:29	40.6	19.8	2.66	3825	1044	6.05	457.00	486.43	498.37	308.00	26.00	0.21	4.77	181.9	14.62	11.92	17141.4	4678.6	28.86
10:30	37.5	19.8	2.65	4045	1047	6.05	457.00	486.43	498.37	308.00	26.00	0.21	4.77	168.1	14.62	11.88	18127.3	4692.0	28.86
10:31	32.5	19.9	2.46	4045	1047	6.05	457.00	486.43	498.37	308.00	26.00	0.21	4.77	145.6	14.89	11.02	18127.3	4692.0	28.86
10:32	38.3	19.8	2.64	4665	1052	6.05	457.00	486.43	498.37	308.00	26.00	0.21	4.77	171.6	14.57	11.83	20905.8	4714.4	28.86
10:33	49	19.1	2.64	4665	1052	6.05	457.00	486.43	498.37	308.00	26.00	0.21	4.77	219.6	11.57	11.83	20905.8	4714.4	28.86
10:57	34.8	20	1.94	4665	1052	6.05	457.00	486.43	487.69	308.00	23.60	0.21	4.77	156.0	15.51	8.69	20905.8	4714.4	28.86
10:58	41.2	20	2.08	4665	1052	6.05	457.00	486.43	487.69	308.00	23.60	0.21	4.77	184.6	15.29	9.32	20905.8	4714.4	28.86
10:59	41.2	20	2.01	4665	1052	6.05	457.00	486.43	461.01	308.00	23.60	0.21	4.77	184.6	15.25	9.01	20905.8	4714.4	28.86
11:00	37.1	20	1.92	3006	1043	6.05	457.00	486.43	461.01	308.00	23.60	0.21	4.77	166.3	15.51	8.60	13471.1	4674.1	28.86
11:01	34.6	20	1.9	3006	1043	6.05	457.00	486.43	461.01	308.00	23.60	0.21	4.77	155.1	15.51	8.51	13471.1	4674.1	28.86
11:02	34.8	19.9	2.1	5713	1045	6.05	457.00	486.43	461.01	308.00	23.60	0.21	4.77	156.0	15.16	9.41	25602.3	4683.1	28.86
11:03	45.1	19.9	2.27	5713	1045	6.05	457.00	486.43	461.01	308.00	23.60	0.21	4.77	202.1	14.75	10.17	25602.3	4683.1	28.86
11:04	34.5	20	1.93	2677	1039	6.05	457.00	486.43	461.01	308.00	23.60	0.21	4.77	154.6	15.38	8.65	11996.7	4656.2	28.86
11:05	32.3	20	1.91	2677	1039	6.05	457.00	486.43	509.91	308.00	25.40	0.21	4.77	144.7	15.43	8.56	11996.7	4656.2	28.86
11:06	39	19.9	2.04	3437	1045	6.05	457.00	486.43	509.91	308.00	25.40	0.21	4.77	174.8	15.16	9.14	15402.6	4683.1	28.86
11:07	38.8	20	1.9	3437	1045	6.05	457.00	486.43	509.91	308.00	25.40	0.21	4.77	173.9	15.38	8.51	15402.6	4683.1	28.86
11:08	38.5	20	1.93	2586	1045	6.05	457.00	486.43	509.91	308.00	25.40	0.21	4.77	172.5	15.20	8.65	11588.9	4683.1	28.86
11:09	38.9	20	1.88	2586	1045	6.05	457.00	486.43	509.91	308.00	25.40	0.21	4.77	174.3	15.29	8.43	11588.9	4683.1	28.86
11:10	36.4	20	1.8	2371	1043	6.05	457.00	486.43	509.91	308.00	25.40	0.21	4.77	163.1	15.43	8.07	10625.4	4674.1	28.86
11:11	34.5	20	1.7	2371	1043	6.05	457.00	486.43	510.19	308.00	26.50	0.21	4.77	154.6	15.51	7.62	10625.4	4674.1	28.86
11:12	36.7	20	1.86	2787	1050	6.05	457.00	486.43	510.19	308.00	26.50	0.21	4.77	164.5	15.25	8.34	12489.7	4705.5	28.86
11:13	38.4	20	1.82	2787	1050	6.05	457.00	486.43	510.19	308.00	26.50	0.21	4.77	172.1	15.29	8.16	12489.7	4705.5	28.86
11:14	37.9	19.9	1.93	3982	1048	6.05	457.00	486.43	510.19	308.00	26.50	0.21	4.77	169.8	15.11	8.65	17845.0	4696.5	28.86
11:15	39.9	20	1.94	3982	1048	6.05	457.00	486.43	510.19	308.00	26.50	0.21	4.77	178.8	15.20	8.69	17845.0	4696.5	28.86
11:16	37.7	20	1.87	2292	1046	6.05	457.00	486.43	510.19	308.00	26.50	0.21	4.77	168.9	15.29	8.38	10271.4	4687.6	28.86
11:17	36.4	20	1.74	2292	1046	6.05	457.00	486.43	506.37	308.00	26.60	0.21	4.77	163.1	15.43	7.80	10271.4	4687.6	28.86
11:18	35.9	20	1.76	2686	1040	6.05	457.00	486.43	506.37	308.00	26.60	0.21	4.77	160.9	15.34	7.89	12037.1	4660.7	28.86
11:19	35.5	20	1.69	2686	1040	6.05	457.00	486.43	506.37	308.00	26.60	0.21	4.77	159.1	15.51	7.57	12037.1	4660.7	28.86
11:20	37.6	20	1.75	2694	1051	6.05	457.00	486.43	506.37	308.00	26.60	0.21	4.77	168.5	15.34	7.84	12072.9	4710.0	28.86
11:21	42.8	20	1.8	2694	1051	6.05	457.00	486.43	506.37	308.00	26.60	0.21	4.77	191.8	15.29	8.07	12072.9	4710.0	28.86
11:22	33.7	20	1.65	2293	1044	6.05	457.00	486.43	506.37	308.00	26.60	0.21	4.77	151.0	15.51	7.39	10275.9	4678.6	28.86
11:23	37.4	20	1.72	2293	1044	6.05	457.00	486.43	463.49	308.00	26.80	0.21	4.77	167.6	15.34	7.71	10275.9	4678.6	28.86
11:24	36.4	19.9	1.86	3185	1060	6.05	457.00	486.43	463.49	308.00	26.80	0.21	4.77	163.1	15.11	8.34	14273.3		

Table O-1 Calculated furnace outlet offgas compositions for S60 (continued).

TIME (a)	Quench Outlet Dry vol. % / ppm (a)					Wet (b) H2O (%)	Quench Outlet (c) Flowrate (dscfm)	Quench Outlet Flowrate (wscfm)	Quench Air (d) Flowrate (wacfm)	Quench Air Flowrate (wscfm)	Temp. Quench Air (C) (e)	Dilution Factor	Dilution Factor (f)	Furnace Outlet Offgas Composition (wet basis %) (g)							
	NOx (ppm)	O2 (%)	CO2 (%)	CO (ppm)	SO2 (ppm)									NOx (ppm)	O2 (h)	CO2	CO (ppm)	SO2 (ppm)	H2O		
14:04	21.6	20.5	1.41	1708.2	4510																
14:05	21.1	20.5	1.32	1401.2	4510																
14:06	22.3	20.5	1.38	1216.6	4510	6.45	446	476.75	521.94	308.00	31.00	0.24	4.16	86.8	17.89	5.37	4734.6	17551.5	26.83		
14:07	28.6	20.4	1.66	1951.4	4510	6.45	446	476.75	521.94	308.00	31.00	0.24	4.16	111.3	17.58	6.46	7594.2	17551.5	26.83		
14:08	22.2	20.5	1.48	2298.4	4950	6.45	446	476.75	521.94	308.00	31.00	0.24	4.16	86.4	17.73	5.76	8944.6	19263.8	26.83		
14:09	23.2	20.4	1.64	2065.3	4950	6.45	446	476.75	521.94	308.00	31.00	0.24	4.16	90.3	17.54	6.38	8037.5	19263.8	26.83		
14:10	19.9	20.5	1.58	1887.7	5370	6.45	446	476.75	521.94	308.00	31.00	0.24	4.16	77.4	17.65	6.15	7346.3	20898.3	26.83		
14:11	22.4	20.4	1.69	1831.3	5370	6.45	446	476.75	521.94	308.00	29.70	0.24	4.16	87.2	17.50	6.58	7126.8	20898.3	26.83		
14:12	19	20.5	1.54	1683	4600	6.45	446	476.75	521.94	308.00	29.70	0.24	4.16	73.9	17.65	5.99	6549.7	17901.7	26.83		
14:13	18.2	20.5	1.57	1524.2	4600	6.45	446	476.75	521.94	308.00	29.70	0.24	4.16	70.8	17.65	6.11	5931.7	17901.7	26.83		
14:14	17.7	20.5	1.55	1641.4	4780	6.45	446	476.75	521.94	308.00	29.70	0.24	4.16	68.9	17.69	6.03	6387.8	18602.2	26.83		
14:15	22	20.4	1.73	1709.1	4780	6.45	446	476.75	521.94	308.00	29.70	0.24	4.16	85.6	17.42	6.73	6651.3	18602.2	26.83		
14:16	19	20.4	1.58	1719.7	5970	6.45	446	476.75	521.94	308.00	29.70	0.24	4.16	73.9	17.58	6.15	6692.5	23233.3	26.83		
14:17	22	20.4	1.67	1738.6	5970	6.45	446	476.75	500.21	308.00	30.30	0.24	4.16	85.6	17.46	6.50	6766.1	23233.3	26.83		
14:18	20	20.4	1.61	1556.8	5340	6.45	446	476.75	500.21	308.00	30.30	0.24	4.16	77.8	17.61	6.27	6058.6	20781.6	26.83		
14:19	17.8	20.4	1.61	1514.3	5340	6.45	446	476.75	500.21	308.00	30.30	0.24	4.16	69.3	17.58	6.27	5893.2	20781.6	26.83		
14:20	17.8	20.5	1.55	1435.1	4240	6.45	446	476.75	500.21	308.00	30.30	0.24	4.16	69.3	17.65	6.03	5584.9	16500.7	26.83		
14:21	15.5	20.5	1.33	1109.1	4240	6.45	446	476.75	500.21	308.00	30.30	0.24	4.16	60.3	17.96	5.18	4316.3	16500.7	26.83		
14:22	17.1	20.4	1.55	1342.9	4830	6.45	446	476.75	500.21	308.00	30.30	0.24	4.16	66.5	17.61	6.03	5226.1	18796.8	26.83		
14:23	16.3	20.4	1.63	1427.1	4830	6.45	446	476.75	538.57	308.00	31.50	0.24	4.16	63.4	17.54	6.34	5553.8	18796.8	26.83		
14:24	16.7	20.4	1.62	1825.9	4510	6.45	446	476.75	538.57	308.00	31.50	0.24	4.16	65.0	17.54	6.30	7105.8	17551.5	26.83		
14:25	16.9	20.4	1.73	1746.4	4510	6.45	446	476.75	538.57	308.00	31.50	0.24	4.16	65.8	17.46	6.73	6796.4	17551.5	26.83		
14:26	16.7	20.4	1.67	1765.1	4620	6.45	446	476.75	538.57	308.00	31.50	0.24	4.16	65.0	17.46	6.50	6869.2	17979.6	26.83		
14:27	17.2	20.4	1.59	1660.1	4620	6.45	446	476.75	538.57	308.00	31.50	0.24	4.16	66.9	17.54	6.19	6460.6	17979.6	26.83		
14:28	16.7	20.5	1.51	1585.2	4330	6.45	446	476.75	538.57	308.00	31.50	0.24	4.16	65.0	17.65	5.88	6169.1	16851.0	26.83		
14:29	24.6	20.4	1.7	2236.5	4330	6.45	446	476.75	465.25	308.00	31.10	0.24	4.16	95.7	17.38	6.62	8703.7	16851.0	26.83		
14:30	19.6	20.4	1.59	2260.9	4940	6.45	446	476.75	465.25	308.00	31.10	0.24	4.16	76.3	17.42	6.19	8798.7	19224.9	26.83		
14:31	20.1	20.4	1.57	1614.1	4940	6.45	446	476.75	465.25	308.00	31.10	0.24	4.16	78.2	17.38	6.11	6281.6	19224.9	26.83		
14:32	21.1	20.3	1.69	1768.8	5240	6.45	446	476.75	465.25	308.00	31.10	0.24	4.16	82.1	17.15	6.58	6883.6	20392.4	26.83		
14:33	24.8	20.4	1.54	2043	5240	6.45	446	476.75	465.25	308.00	31.10	0.24	4.16	96.5	17.38	5.99	7950.7	20392.4	26.83		
14:34	14.6	20.4	1.48	1252.4	4570	6.45	446	476.75	465.25	308.00	31.10	0.24	4.16	56.8	17.50	5.76	4873.9	17785.0	26.83		
14:35	16	20.3	1.6	1522.9	4570	6.45	446	476.75	533.47	308.00	31.40	0.24	4.16	62.3	17.19	6.23	5926.6	17785.0	26.83		
14:36	15.3	20.4	1.54	1436.6	4450	6.45	446	476.75	533.47	308.00	31.40	0.24	4.16	59.5	17.34	5.99	5590.8	17318.0	26.83		
14:37	13.6	20.4	1.41	1310.8	4450	6.45	446	476.75	533.47	308.00	31.40	0.24	4.16	52.9	17.46	5.49	5101.2	17318.0	26.83		
14:38	13.9	20.4	1.34	1188.5	4300	6.45	446	476.75	533.47	308.00	31.40	0.24	4.16	54.1	17.54	5.21	4625.3	16734.2	26.83		
14:39	16.1	20.4	1.48	1447.5	4300	6.45	446	476.75	533.47	308.00	31.40	0.24	4.16	62.7	17.30	5.76	5633.2	16734.2	26.83		
14:40	14.3	20.4	1.38	1328.5	4750	6.45	446	476.75	533.47	308.00	31.40	0.24	4.16	55.7	17.38	5.37	5170.1	18485.5	26.83		
14:41	17.9	20.4	1.47	1323.3	4750	6.45	446	476.75	517.69	308.00	31.10	0.24	4.16	69.7	17.38	5.72	5149.9	18485.5	26.83		
14:42	17.6	20.4	1.48	1583.4	4950	6.45	446	476.75	517.69	308.00	31.10	0.24	4.16	68.5	17.34	5.76	6162.1	19263.8	26.83		
14:43	14.3	20.4	1.47	1320.6	4950	6.45	446	476.75	517.69	308.00	31.10	0.24	4.16	55.7	17.30	5.72	5139.4	19263.8	26.83		
14:44	18	20.3	1.61	1464.4	5520	6.45	446	476.75	517.69	308.00	31.10	0.24	4.16	70.1	17.19	6.27	5699.0	21482.1	26.83		
14:45	17.1	20.3	1.57	1282.4	5520	6.45	446	476.75	517.69	308.00	31.10	0.24	4.16	66.5	17.11	6.11	4990.7	21482.1	26.83		
14:46	16.3	20.3	1.6	1435	5060	6.45	446	476.75	517.69	308.00	31.10	0.24	4.16	63.4	17.03	6.23	5584.6	19691.9	26.83		
14:47	12.5	20.3	1.58	987.2	5060	6.45	446	476.75	505.24	308.00	31.10	0.24	4.16	48.6	17.07	6.15	3841.9	19691.9	26.83		
14:48	16.7	20.3	1.71	1399.3	5360	6.45	446	476.75	505.24	308.00	31.10	0.24	4.16	65.0	16.87	6.65	5445.6	20859.4	26.83		
14:49	11.9	20.2	1.65	1200.6	5360	6.45	446	476.75	505.24	308.00	31.10	0.24	4.16	46.3	16.84	6.42	4672.4	20859.4	26.83		
14:50	11	20.2	1.68	1037.7	5790	6.45	446	476.75	505.24	308.00	31.10	0.24	4.16	42.8	16.76	6.54	4038.4	22532.8	26.83		
14:51	8.7	20.2	1.63	936.2	5790	6.45	446	476.75	505.24	308.00	31.10	0.24	4.16	33.9	16.84	6.					

Table O-1 Calculated furnace outlet offgas compositions for S60 (continued)

TIME (a)	Quench Outlet Dry vol. % / ppm (a)					Wet (b)		Quench Outlet (c)	Quench Outlet	Quench Air (d)	Quench Air	Temp. Quench	Dilution	Dilution	Furnace Outlet Offgas Composition (wet basis %) (g)					
	NOx (ppm)	O2 (%)	CO2 (%)	CO (ppm)	SO2 (ppm)	H2O (%)	Flowrate (dscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Air (C) (e)	Factor	Factor (f)	NOx (ppm)	O2 (h)	CO2	CO (ppm)	SO2 (ppm)	H2O	
15:03	9.8	20.2	1.75	1129.8	5240	6.45	446	476.75	529.51	308.00	31.20	0.24	4.16	38.1	16.76	6.81	4396.8	20392.4	26.83	
15:04	10.3	20.3	1.7	1266.9	5180	6.45	446	476.75	529.51	308.00	31.20	0.24	4.16	40.1	16.87	6.62	4930.4	20158.9	26.83	
15:05	11.8	20.2	1.76	1340.4	5180	6.45	446	476.75	555.98	308.00	32.00	0.24	4.16	45.9	16.84	6.85	5216.4	20158.9	26.83	
15:06	14.1	20.2	1.82	1456.2	5310	6.45	446	476.75	555.98	308.00	32.00	0.24	4.16	54.9	16.80	7.08	5667.1	20664.8	26.83	
15:07	14.2	20.2	1.76	1528.9	5310	6.45	446	476.75	555.98	308.00	32.00	0.24	4.16	55.3	16.80	6.85	5950.0	20664.8	26.83	
15:08	11.7	20.3	1.65	1412.8	4900	6.45	446	476.75	555.98	308.00	32.00	0.24	4.16	45.5	16.95	6.42	5498.2	19069.2	26.83	
15:09	12.3	20.2	1.76	1424	4900	6.45	446	476.75	555.98	308.00	32.00	0.24	4.16	47.9	16.80	6.85	5541.8	19069.2	26.83	
15:10	9	20.2	1.64	1230.9	4430	6.45	446	476.75	555.98	308.00	32.00	0.24	4.16	35.0	16.84	6.38	4790.3	17240.1	26.83	
15:11	9.4	20.3	1.63	1184.3	4430	6.45	446	476.75	520.1	308.00	32.90	0.24	4.16	36.6	16.95	6.34	4608.9	17240.1	26.83	
15:12	9.1	20.3	1.65	1155.8	4620	6.45	446	476.75	520.1	308.00	32.90	0.24	4.16	35.4	16.91	6.42	4498.0	17979.6	26.83	
15:13	13.2	20.2	1.75	1389.5	4620	6.45	446	476.75	520.1	308.00	32.90	0.24	4.16	51.4	16.76	6.81	5407.5	17979.6	26.83	
15:14	9.6	20.3	1.56	1111.8	4470	6.45	446	476.75	520.1	308.00	32.90	0.24	4.16	37.4	17.07	6.07	4326.8	17395.8	26.83	
15:15	7.8	20.3	1.63	975.8	4470	6.45	446	476.75	520.1	308.00	32.90	0.24	4.16	30.4	17.03	6.34	3797.5	17395.8	26.83	
15:16	7.2	20.3	1.64	1060.8	4520	6.45	446	476.75	520.1	308.00	32.90	0.24	4.16	28.0	16.95	6.38	4128.3	17590.4	26.83	
15:17	6.4	20.3	1.61	1030.6	4520	6.45	446	476.75	520.1	308.00	32.90	0.24	4.16	24.9	16.87	6.27	4010.8	17590.4	26.83	
15:18	5.2	20.3	1.54	855.9	3820	6.45	446	476.75	520.1	308.00	32.90	0.24	4.16	20.2	16.91	5.99	3330.9	14866.2	26.83	
15:19	5.3	20.3	1.39	848.9	3820	6.45	446	476.75	520.1	308.00	32.90	0.24	4.16	20.6	17.11	5.41	3303.6	14866.2	26.83	
15:20	5.3	20.3	1.48	872	4500	6.45	446	476.75	520.1	308.00	32.90	0.24	4.16	20.6	17.11	5.76	3393.5	17512.6	26.83	
15:21	6.6	20.3	1.43	1107.9	4500	6.45	446	476.75	520.1	308.00	32.90	0.24	4.16	25.7	17.11	5.57	4311.6	17512.6	26.83	
15:22	6.5	20.3	1.39	1098.7	3590	6.45	446	476.75	520.1	308.00	32.90	0.24	4.16	25.3	17.15	5.41	4275.8	13971.1	26.83	
	14.06829	19.8	1.513	1342.9	4718.4	6.2081						0.231	4.16	54.0408	16.80203	5.97742	5205.097	18383	26.1527	

a. Data obtained from Continuous Emissions Monitoring Systems (CEMS) data provided by Entropy personnel.

b. Moisture content, percent by volume, as shown in analysis from particulate/metals sampling period (MMT).

c. Source gas volumetric flowrate from MMT data.

d. Quench air flowrate, channel 15 from Data Acquisition System (DAS).

e. Quench air temperature, channel 1 from DAS.

f. Calculated from mass and energy balances at the quench section as the quench outlet flowrate divided by the furnace outlet flowrate.

g. Calculated from the quench outlet composition and the dilution factor, making the necessary conversions from a dry to a wet basis.

h. Calculated from the quench outlet composition and the dilution factor, taking into account the amount of oxygen added by the quench air.

Table O-2 Calculated furnace outlet offgas compositions for S60-IV.

TIME (a)	Quench Outlet Dry vol. % / ppm (a)					Wet (b) H2O (%)	Quench Outlet (c) Flowrate (dscfm)	Quench Outlet Flowrate (wscfm)	Quench Air (d) Flowrate (wacfm)	Quench Air Flowrate (wscfm)	Temp. Quenc Air (C) (e)	Dilution Factor	Dilution Factor (f)	Furnace Outlet Offgas Composition (wet basis %) (g)					
	NOx (ppm)	O2 (%)	CO2 (%)	CO (ppm)	SO2 (ppm)									NOx (ppm)	O2 (h)	CO2	CO (ppm)	SO2 (ppm)	H2O
12:29	24.2	19.9	2.1	2836.0	5470.0	8.2	450.0	490.4	300.1	280.2	41.2	0.2	4.2	92.8	15.3	8.2	10878.9	20982.8	34.4
12:30	24.3	19.9	2.3	2546.8	5470.0	8.2	450.0	490.4	300.1	280.2	41.2	0.2	4.2	93.2	15.1	8.8	9769.5	20982.8	34.4
12:31	24.4	19.9	2.3	2789.3	5470.0	8.2	450.0	490.4	300.1	280.2	41.2	0.2	4.2	93.6	15.3	8.7	10699.7	20982.8	34.4
12:32	23.7	20.0	2.2	3130.1	5070.0	8.2	450.0	490.4	294.3	280.4	34.9	0.2	4.2	90.9	15.4	8.6	12007.0	19448.4	34.4
12:33	17.7	20.0	2.2	2927.1	5070.0	8.2	450.0	490.4	294.3	280.4	34.9	0.2	4.2	67.9	15.4	8.4	11228.3	19448.4	34.4
12:34	13.9	19.9	2.3	2593.3	5070.0	8.2	450.0	490.4	294.3	280.4	34.9	0.2	4.2	53.3	15.2	8.6	9947.9	19448.4	34.4
12:35	14.7	19.9	2.4	2239.8	5070.0	8.2	450.0	490.4	294.3	280.4	34.9	0.2	4.2	56.4	15.1	9.1	8591.8	19448.4	34.4
12:36	12.0	19.9	2.3	2305.4	5640.0	8.2	450.0	490.4	294.3	280.4	34.9	0.2	4.2	46.0	15.1	9.0	8843.5	21635.0	34.4
12:37	29.7	19.8	2.8	3180.6	5640.0	8.2	450.0	490.4	294.3	280.4	34.9	0.2	4.2	113.9	14.7	10.7	12200.7	21635.0	34.4
12:38	24.3	19.9	2.5	4024.8	5150.0	8.2	450.0	490.4	287.5	275.4	33.3	0.2	4.2	93.2	15.2	9.4	15439.1	19755.3	34.4
12:44	32.0	19.9	2.5	4762.6	5760.0	8.2	450.0	490.4	306.9	293.8	33.5	0.2	4.2	122.8	15.2	9.6	18269.3	22095.3	34.4
12:45	28.1	19.7	3.0	3871.9	5760.0	8.2	450.0	490.4	306.9	293.8	33.5	0.2	4.2	107.8	14.5	11.5	14852.6	22095.3	34.4
12:46	47.8	19.8	2.8	4634.8	6940.0	8.2	450.0	490.4	306.9	293.8	33.5	0.2	4.2	183.4	14.7	10.9	17779.0	26621.7	34.4
12:47	30.3	19.8	2.7	4406.4	6940.0	8.2	450.0	490.4	306.9	293.8	33.5	0.2	4.2	116.2	14.8	10.4	16902.9	26621.7	34.4
12:48	31.3	19.7	2.8	3818.8	6430.0	8.2	450.0	490.4	306.9	293.8	33.5	0.2	4.2	120.1	14.5	10.7	14648.9	24665.4	34.4
12:49	34.0	19.7	2.7	4100.0	6430.0	8.2	450.0	490.4	306.9	293.8	33.5	0.2	4.2	130.4	14.6	10.3	15727.5	24665.4	34.4
12:50	37.8	19.6	2.9	4228.9	7600.0	8.2	450.0	490.4	324.9	310.0	34.4	0.2	4.2	145.0	14.1	11.1	16222.0	29153.5	34.4
12:51	41.2	19.6	2.7	4859.6	7600.0	8.2	450.0	490.4	324.9	310.0	34.4	0.2	4.2	158.0	14.1	10.5	18641.4	29153.5	34.4
12:52	39.4	19.6	2.7	4933.2	7420.0	8.2	450.0	490.4	324.9	310.0	34.4	0.2	4.2	151.1	14.2	10.3	18923.7	28463.0	34.4
12:53	33.6	19.7	2.7	4321.5	7420.0	8.2	450.0	490.4	324.9	310.0	34.4	0.2	4.2	128.9	14.3	10.2	16577.2	28463.0	34.4
12:54	28.6	19.8	2.5	4046.4	6240.0	8.2	450.0	490.4	324.9	310.0	34.4	0.2	4.2	109.7	14.7	9.4	15521.9	23936.6	34.4
12:55	29.3	19.8	2.4	4437.9	6240.0	8.2	450.0	490.4	324.9	310.0	34.4	0.2	4.2	112.4	14.8	9.2	17023.7	23936.6	34.4
12:56	29.0	19.7	2.6	4614.5	7660.0	8.2	450.0	490.4	301.5	288.1	34.0	0.2	4.2	111.2	14.6	9.9	17701.2	29383.7	34.4
12:57	37.2	19.7	2.7	4913.6	7660.0	8.2	450.0	490.4	301.5	288.1	34.0	0.2	4.2	142.7	14.6	10.3	18848.5	29383.7	34.4
12:58	40.2	19.7	2.8	5411.0	7270.0	8.2	450.0	490.4	301.5	288.1	34.0	0.2	4.2	154.2	14.4	10.8	20756.5	27887.6	34.4
12:59	36.0	19.7	2.8	4942.4	7270.0	8.2	450.0	490.4	301.5	288.1	34.0	0.2	4.2	138.1	14.4	10.6	18959.0	27887.6	34.4
13:00	29.6	19.8	2.6	4824.8	7060.0	8.2	450.0	490.4	301.5	288.1	34.0	0.2	4.2	113.5	14.8	10.1	18507.9	27082.1	34.4
13:01	31.0	19.7	2.7	4719.3	7060.0	8.2	450.0	490.4	301.5	288.1	34.0	0.2	4.2	118.9	14.6	10.5	18103.2	27082.1	34.4
13:02	28.2	19.8	2.6	4952.3	5720.0	8.2	450.0	490.4	309.9	294.0	36.3	0.2	4.2	108.2	14.8	10.0	18997.0	21941.8	34.4
13:03	32.6	19.8	2.8	4982.0	5720.0	8.2	450.0	490.4	309.9	294.0	36.3	0.2	4.2	125.1	14.6	10.6	19110.9	21941.8	34.4
13:04	32.8	19.8	2.6	4982.1	6360.0	8.2	450.0	490.4	309.9	294.0	36.3	0.2	4.2	125.8	14.9	9.9	19111.3	24396.9	34.4
13:05	26.6	19.8	2.5	4671.1	6360.0	8.2	450.0	490.4	309.9	294.0	36.3	0.2	4.2	102.0	14.8	9.7	17918.3	24396.9	34.4
13:06	26.1	19.9	2.3	5758.0	5800.0	8.2	450.0	490.4	309.9	294.0	36.3	0.2	4.2	100.1	15.3	8.9	22087.6	22248.7	34.4
13:07	30.5	19.8	2.7	5758.0	5800.0	8.2	450.0	490.4	309.9	294.0	36.3	0.2	4.2	117.0	15.0	10.2	22087.6	22248.7	34.4
13:08	29.1	19.8	2.6	5649.0	5740.0	8.2	450.0	490.4	309.9	294.0	36.3	0.2	4.2	111.6	14.8	10.1	21669.5	22018.6	34.4
13:09	22.7	19.8	2.6	5649.0	5740.0	8.2	450.0	490.4	292.0	277.8	35.4	0.2	4.2	87.1	14.9	9.8	21669.5	22018.6	34.4
13:10	30.5	19.7	2.9	7590.0	6930.0	8.2	450.0	490.4	292.0	277.8	35.4	0.2	4.2	117.0	14.3	11.0	29115.1	26583.4	34.4
13:11	43.8	19.7	2.8	7590.0	6930.0	8.2	450.0	490.4	292.0	277.8	35.4	0.2	4.2	168.0	14.5	10.7	29115.1	26583.4	34.4
13:12	26.0	19.7	2.6	5399.0	5850.0	8.2	450.0	490.4	292.0	277.8	35.4	0.2	4.2	99.7	14.6	10.1	20710.5	22440.5	34.4
13:13	21.3	19.6	2.8	5399.0	5850.0	8.2	450.0	490.4	292.0	277.8	35.4	0.2	4.2	81.7	14.2	10.7	20710.5	22440.5	34.4
13:14	35.8	19.7	2.7	7202.0	7210.0	8.2	450.0	490.4	292.0	277.8	35.4	0.2	4.2	137.3	14.4	10.5	27626.8	27657.5	34.4
13:15	32.4	19.7	2.7	7202.0	7210.0	8.2	450.0	490.4	301.2	285.8	36.1	0.2	4.2	124.3	14.4	10.3	27626.8	27657.5	34.4
13:16	28.6	19.7	2.6	7019.0	5860.0	8.2	450.0	490.4	301.2	285.8	36.1	0.2	4.2	109.7	14.6	10.0	26924.8	22478.9	34.4
13:17	29.1	19.7	2.8	7019.0	5860.0	8.2	450.0	490.4	301.2	285.8	36.1	0.2	4.2	111.6	14.4	10.6	26924.8	22478.9	34.4
13:18	30.3	19.7	2.8	7856.0	6780.0	8.2	450.0	490.4	301.2	285.8	36.1	0.2	4.2	116.2	14.3	10.7	30135.5	26008.0	34.4
13:19	37.0	19.6	2.9	7856.0	6780.0	8.2	450.0	490.4	301.2	285.8	36.1	0.2	4.2	141.9	14.2	10.9	30135.5	26008.0	34.4
13:20	32.4	19.7	2.7	7704.0	6310.0	8.2	450.0	490.4	301.2	285.8	36.1	0.2	4.2	124.3	14.4	10.2	29552.4	24205.1	34.4
13:21	44.2	19.6	3.0	7704.0	6310.0	8.2	450.0	490.4	293.7	279.0	35.9	0.2	4.2	169.6	13.9	11.5	29552.4	24205.1	34.4
13:22	47.4	19.6	3.1	9994.0	7450.0	8.2	450.0	490.4	293.7	279.0	35.9	0.2	4.2	181.8	13.9	11.7	38336.8	28578.1	34.4
13:23	36.7	19.7	2.7	9994.0	7450.0	8.2	450.0	490.4	293.7	279.0	35.9	0.2	4.2	140.8	14.2	10.3	38336.8	28578.1	34.4
13:24	31.3	19.7	2.6	9893.0	6710.0	8.2	450.0	490.4	293.7	279.0	35.9	0.2	4.2	120.1	14.3	9.9	37949.4	25739.5	34.4
13:25	35.8	19.6	2.8	9893.0	6710.0	8.2	450.0	490.4	293.7	279.0	35.9	0.2	4.2						

Table O-2 Calculated furnace outlet offgas compositions for S60-IV (continued).

TIME (a)	Quench Outlet Dry vol. % / ppm (a)					Wet (b) Quench Outlet (c)		Quench Outlet	Quench Air (d)	Quench Air	Temp. Quench	Dilution	Dilution	Furnace Outlet Offgas Composition (wet basis %) (g)					
	NOx (ppm)	O ₂ (%)	CO ₂ (%)	CO (ppm)	SO ₂ (ppm)	H ₂ O (%)	Flowrate (dscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Air (C) (e)	Factor	Factor (f)	NOx (ppm)	O ₂ (h)	CO ₂	CO (ppm)	SO ₂ (ppm)	H ₂ O
13:33	30.4	19.6	2.8	7291.0	4540.0	8.2	450.0	490.4	300.8	291.9	29.3	0.2	4.2	116.6	14.1	10.8	27968.2	17415.4	34.4
13:34	32.4	19.5	3.0	10841.0	7360.0	8.2	450.0	490.4	300.8	291.9	29.3	0.2	4.2	124.3	13.8	11.4	41585.9	28232.9	34.4
13:35	49.1	19.5	3.3	10841.0	7360.0	8.2	450.0	490.4	300.8	291.9	29.3	0.2	4.2	188.3	13.5	12.5	41585.9	28232.9	34.4
13:36	63.7	19.5	3.5	10841.0	7360.0	8.2	450.0	490.4	300.8	291.9	29.3	0.2	4.2	244.4	13.5	13.2	41585.9	28232.9	34.4
13:37	32.0	19.6	2.8	10841.0	7360.0	8.2	450.0	490.4	300.8	291.9	29.3	0.2	4.2	122.8	14.0	10.7	41585.9	28232.9	34.4
13:38	35.9	19.6	2.9	8352.0	5970.0	8.2	450.0	490.4	300.8	291.9	29.3	0.2	4.2	137.7	13.9	11.1	32038.2	22900.8	34.4
13:39	30.4	19.6	2.8	8352.0	5970.0	8.2	450.0	490.4	274.3	266.2	29.4	0.2	4.2	116.6	14.0	10.6	32038.2	22900.8	34.4
13:40	38.8	19.5	2.9	7333.0	5570.0	8.2	450.0	490.4	274.3	266.2	29.4	0.2	4.2	148.8	13.7	11.0	28129.3	21366.4	34.4
15:23	14.1	20.6	1.7	2297.4	3740.0	6.2	462.0	492.5	340.7	323.4	36.1	0.2	4.2	56.1	18.2	6.9	9138.0	14876.0	26.2
15:24	15.7	20.5	1.8	2522.3	3470.0	6.2	462.0	492.5	340.7	323.4	36.1	0.2	4.2	62.4	18.0	7.2	10032.6	13802.1	26.2
15:25	17.3	20.6	1.7	2915.3	3470.0	6.2	462.0	492.5	340.7	323.4	36.1	0.2	4.2	68.8	18.1	6.8	11595.7	13802.1	26.2
15:26	16.8	20.6	1.7	3045.0	3290.0	6.2	462.0	492.5	340.7	323.4	36.1	0.2	4.2	66.8	18.1	6.7	12111.6	13086.1	26.2
15:27	15.9	20.6	1.6	2748.8	3290.0	6.2	462.0	492.5	340.7	323.4	36.1	0.2	4.2	63.2	18.2	6.5	10933.5	13086.1	26.2
15:28	14.7	20.6	1.6	2494.3	3240.0	6.2	462.0	492.5	331.4	314.7	36.0	0.2	4.2	58.5	18.1	6.4	9921.2	12887.2	26.2
15:29	13.2	20.6	1.6	2476.1	3078.4	6.2	462.0	492.5	331.4	314.7	36.0	0.2	4.2	52.5	18.1	6.3	9848.8	12244.5	26.2
15:30	12.7	20.6	1.6	2543.7	3010.4	6.2	462.0	492.5	331.4	314.7	36.0	0.2	4.2	50.5	18.1	6.3	10117.7	11974.0	26.2
15:31	12.8	20.5	1.6	2816.2	3040.7	6.2	462.0	492.5	331.4	314.7	36.0	0.2	4.2	50.9	18.0	6.4	11201.6	12094.5	26.2
15:32	12.0	20.6	1.6	2584.3	3009.4	6.2	462.0	492.5	331.4	314.7	36.0	0.2	4.2	47.7	18.1	6.3	10279.2	11970.0	26.2
15:33	11.7	20.5	1.6	2485.3	3057.0	6.2	462.0	492.5	331.4	314.7	36.0	0.2	4.2	46.5	18.0	6.4	9885.4	12159.4	26.2
15:34	12.2	20.6	1.6	2501.0	3029.2	6.2	462.0	492.5	350.5	327.6	40.9	0.2	4.2	48.5	18.1	6.5	9947.8	12048.8	26.2
15:35	12.3	20.5	1.7	2877.0	3124.6	6.2	462.0	492.5	350.5	327.6	40.9	0.2	4.2	48.9	18.0	6.6	11443.4	12428.2	26.2
15:36	11.1	20.5	1.7	2969.4	3105.9	6.2	462.0	492.5	350.5	327.6	40.9	0.2	4.2	44.2	18.0	6.8	11810.9	12353.9	26.2
15:37	10.0	20.6	1.7	2989.9	2960.8	6.2	462.0	492.5	350.5	327.6	40.9	0.2	4.2	39.8	18.1	6.7	11892.5	11776.7	26.2
15:38	10.1	20.5	1.8	3261.8	3079.5	6.2	462.0	492.5	350.5	327.6	40.9	0.2	4.2	40.2	17.9	7.0	12974.0	12248.8	26.2
15:39	9.2	20.5	1.7	2966.9	3058.3	6.2	462.0	492.5	350.5	327.6	40.9	0.2	4.2	36.6	17.9	6.8	11801.0	12164.5	26.2
15:40	8.4	20.5	1.7	2700.9	3054.1	6.2	462.0	492.5	364.3	340.9	40.6	0.2	4.2	33.4	17.9	6.9	10742.9	12147.8	26.2
15:41	9.3	20.5	1.7	2515.8	3054.1	6.2	462.0	492.5	364.3	340.9	40.6	0.2	4.2	37.0	17.9	6.9	10006.7	12147.8	26.2
15:42	10.1	20.5	1.7	2641.3	3520.0	6.2	462.0	492.5	364.3	340.9	40.6	0.2	4.2	40.2	17.8	6.8	10505.9	14001.0	26.2
15:43	10.9	20.5	1.7	2576.4	3520.0	6.2	462.0	492.5	364.3	340.9	40.6	0.2	4.2	43.4	17.9	6.6	10247.7	14001.0	26.2
15:44	11.0	20.5	1.7	2734.8	3450.0	6.2	462.0	492.5	364.3	340.9	40.6	0.2	4.2	43.8	17.8	6.9	10877.8	13722.5	26.2
15:45	9.5	20.5	1.7	2654.0	3450.0	6.2	462.0	492.5	364.3	340.9	40.6	0.2	4.2	37.8	17.8	6.8	10556.4	13722.5	26.2
15:46	10.5	20.5	1.7	2952.7	3480.0	6.2	462.0	492.5	354.7	336.6	36.2	0.2	4.2	41.8	17.8	6.8	11744.5	13841.9	26.2
15:47	11.8	20.5	1.8	2887.5	3480.0	6.2	462.0	492.5	354.7	336.6	36.2	0.2	4.2	46.9	17.8	7.0	11485.2	13841.9	26.2
15:48	10.9	20.5	1.7	2834.4	3540.0	6.2	462.0	492.5	354.7	336.6	36.2	0.2	4.2	43.4	17.8	6.7	11274.0	14080.5	26.2
15:49	10.9	20.5	1.6	2913.2	3540.0	6.2	462.0	492.5	354.7	336.6	36.2	0.2	4.2	43.4	17.8	6.5	11587.4	14080.5	26.2
15:50	10.2	20.5	1.6	2749.1	3460.0	6.2	462.0	492.5	354.7	336.6	36.2	0.2	4.2	40.6	17.9	6.3	10934.7	13762.3	26.2
15:51	10.1	20.5	1.6	2819.2	3460.0	6.2	462.0	492.5	354.7	336.6	36.2	0.2	4.2	40.2	17.9	6.4	11213.5	13762.3	26.2
15:52	11.3	20.5	1.6	2744.3	3620.0	6.2	462.0	492.5	337.9	325.2	31.8	0.2	4.2	44.9	17.9	6.2	10915.6	14398.7	26.2
15:53	11.4	20.6	1.6	2869.4	3620.0	6.2	462.0	492.5	337.9	325.2	31.8	0.2	4.2	45.3	18.1	6.4	11413.2	14398.7	26.2
15:54	11.1	20.6	1.6	2994.3	3390.0	6.2	462.0	492.5	337.9	325.2	31.8	0.2	4.2	44.2	18.2	6.4	11910.0	13483.9	26.2
15:55	11.9	20.6	1.6	3277.6	3066.8	6.2	462.0	492.5	337.9	325.2	31.8	0.2	4.2	47.3	18.4	6.4	13036.8	12198.3	26.2
15:56	11.5	20.6	1.8	4361.7	3097.9	6.2	462.0	492.5	337.9	325.2	31.8	0.2	4.2	45.7	18.2	7.0	17348.9	12322.0	26.2
15:57	9.9	20.6	1.7	4254.4	2815.4	6.2	462.0	492.5	337.9	325.2	31.8	0.2	4.2	39.4	18.3	6.8	16922.1	11198.4	26.2
15:58	9.2	20.6	1.7	4197.3	2758.1	6.2	462.0	492.5	342.3	329.0	32.2	0.2	4.2	36.6	18.3	6.8	16694.9	10970.5	26.2
15:59	10.3	20.6	1.7	4088.9	2889.2	6.2	462.0	492.5	342.3	329.0	32.2	0.2	4.2	41.0	18.2	6.9	16263.8	11491.9	26.2
16:00	12.3	20.6	1.6	4090.5	3078.7	6.2	462.0	492.5	342.3	329.0	32.2	0.2	4.2	48.9	18.3	6.3	16270.1	12245.7	26.2
16:01	12.9	20.6	1.6	4227.8	3107.4	6.2	462.0	492.5	342.3	329.0	32.2	0.2	4.2	51.3	18.4	6.3	16816.3	12359.8	26.2
16:02	11.2	20.7	1.6	4103.1	2999.4	6.2	462.0	492.5	342.3	329.0	32.2	0.2	4.2	44.5	18.5	6.4	16320.3	11930.2	26.2
16:03	9.7	20.6	1.8	3950.1	2982.6	6.2	462.0	492.5	342.3	329.0	32.2	0.2	4.2	38.6	18.3	7.0	15711.7	11863.4	26.2
16:04	9.6	20.6	1.7	3878.2	2860.1	6.2	462.0	492.5	371.7	357.8	31.8	0.2	4.2	38.2	18.4	6.6	15425.7	11376.2	26.2
16:05	7.3	20.7	1.6	3558.4	2357.2	6.2	462.0	492.5	371.7	357.8	31.8	0.2	4.2	29.0	18.6	6.4	14153.7	9375.9	26.2
16:06	6.5	20.7	1.6	3015.0	2109.8	6.2	462.0	492.5	371.7	357.8	31.8	0.2	4.2	25.9	18.7	6.3	11992.3	8391.8	26.2
16:07	7.3	20.7	1.8	3518.6	2122.7	6.2	462.0	492.5	371.7	357.8	31.8	0.2	4.2	29.0	18.5	7.2	13995.4	8443.1	26.2
16:08	8.0	20.7	1.8	3716.2	2104.2	6.2	462.0	492.5	371.7	357.8	31.8	0.2	4.2	31.8	18.5	7.3	14781.3	8369.5	26.2
16:09	8.2	20.7	1.7	3225.4	2371.6	6.2	462.0	492.5	371.7	357.8	31.8	0.2	4.2	32.6	18.6	6.8	12829.2	9433.1	26.2
16:10	8.8	20.7	1.8	3312.3	2608.3	6.2	462.0	492.5	342.6	329.6	31.9	0.2	4.2	35.0	18.5	7.1	13174.8	10374.6	26.2
16:11	7.9	20.7	1.7	3398.0	2386.5	6.2	462.0	492.5	342.6	329.6	31.9	0.2	4.2	31.4	18.5	6.8	13515.7	9492.4	26.2
16:12	8.8	20.7	1.7	3051.9	2595.7	6.2	462.0	492.5	342.6	329.6	31.9	0.2	4.2	35.0	18.7	6.7	12139.1	10324.5	26.2
16:13	7.9	20.7	1.7	3404.2	2657.1	6.2	462.0	492.5	342.6	329.6	31.9	0.2	4.2	31.4	18.5	6.8	13540.4	10568.7	26.2

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Table O-2 Calculated furnace outlet offgas compositions for S60-IV (continued).

TABLE 9-2. Calculated furnace outlet offgas compositions for 2001 (continued)																									
Quench Outlet Dry vol. % / ppm (a)						Wet (b)	Quench Outlet (c)	Quench Outlet	Quench Air (d)	Quench Air	Temp. Quench	Dilution	Dilution	Furnace Outlet Offgas Composition (wet basis %) (g)											
TIME (a)	NOx (ppm)	O2 (%)	CO2 (%)	CO (ppm)	SO2 (ppm)	H2O (%)	Flowrate (dscfm)	Flowrate (wscfm)	Flowrate (wacfm)	Flowrate (wscfm)	Air (C) (e)	Factor	Factor (f)	NOx (ppm)	O2 (h)	CO2	CO (ppm)	SO2 (ppm)	H2O	NOx (ppm)	O2 (h)	CO2	CO (ppm)	SO2 (ppm)	H2O
16:14	8.3	20.6	1.8	3460.0	2616.8	6.2	462.0	492.5	342.6	329.6	31.9	0.2	4.2	33.0	18.3	7.1	13762.3	10408.4	26.2						
16:15	31.3	20.5	2.3	4832.4	2616.8	6.2	462.0	492.5	342.6	329.6	31.9	0.2	4.2	124.5	17.7	9.1	19221.1	10408.4	26.2						
16:16	17.4	20.6	1.8	4518.6	2616.8	6.2	462.0	492.5	323.6	315.8	27.6	0.2	4.2	69.2	18.4	7.2	17972.9	10408.4	26.2						
16:17	9.6	20.6	1.8	4191.8	2807.2	6.2	462.0	492.5	323.6	315.8	27.6	0.2	4.2	38.2	18.3	7.1	16673.1	11165.8	26.2						
16:18	8.1	20.7	1.3	3474.7	2358.6	6.2	462.0	492.5	323.6	315.8	27.6	0.2	4.2	32.2	18.6	5.0	13820.8	9381.4	26.2						
16:19	6.3	20.7	1.5	3178.2	2097.7	6.2	462.0	492.5	323.6	315.8	27.6	0.2	4.2	25.1	18.7	6.0	12641.4	8343.7	26.2						
16:20	6.0	20.5	1.9	2853.8	2889.0	6.2	462.0	492.5	323.6	315.8	27.6	0.2	4.2	23.9	17.9	7.5	11351.1	11491.1	26.2						
16:21	5.8	20.5	1.6	1768.9	2889.0	6.2	462.0	492.5	323.6	315.8	27.6	0.2	4.2	23.1	17.9	6.2	7035.9	11491.1	26.2						
16:22	5.9	20.6	1.6	2054.7	2889.0	6.2	462.0	492.5	330.2	323.3	26.7	0.2	4.2	23.5	18.1	6.5	8172.7	11491.1	26.2						
16:23	6.7	20.6	1.6	1608.2	2889.0	6.2	462.0	492.5	330.2	323.3	26.7	0.2	4.2	26.6	18.1	6.2	6396.7	11491.1	26.2						
16:24	8.8	20.7	1.4	2219.1	3810.0	6.2	462.0	492.5	330.2	323.3	26.7	0.2	4.2	35.0	18.7	5.7	8826.6	15154.4	26.2						
16:25	5.0	20.7	1.4	1553.6	3810.0	6.2	462.0	492.5	330.2	323.3	26.7	0.2	4.2	19.9	18.7	5.4	6179.5	15154.4	26.2						
16:26	2.5	20.8	1.3	850.1	3052.3	6.2	462.0	492.5	330.2	323.3	26.7	0.2	4.2	9.9	19.1	5.1	3381.3	12140.7	26.2						
16:27	2.5	20.8	1.4	696.8	3098.6	6.2	462.0	492.5	330.2	323.3	26.7	0.2	4.2	9.9	19.0	5.6	2771.6	12324.8	26.2						
16:28	2.2	20.8	1.4	772.0	3300.0	6.2	462.0	492.5	316.6	310.8	25.8	0.2	4.2	8.8	18.9	5.7	3070.7	13125.9	26.2						
16:29	1.6	20.8	1.3	625.8	3300.0	6.2	462.0	492.5	316.6	310.8	25.8	0.2	4.2	6.4	19.1	5.3	2489.1	13125.9	26.2						
16:30	1.5	20.8	1.4	563.7	3460.0	6.2	462.0	492.5	316.6	310.8	25.8	0.2	4.2	6.0	19.1	5.5	2242.1	13762.3	26.2						
16:31	1.4	20.8	1.4	564.4	3460.0	6.2	462.0	492.5	316.6	310.8	25.8	0.2	4.2	5.6	19.1	5.6	2244.9	13762.3	26.2						
16:32	1.7	20.8	1.4	714.4	3260.0	6.2	462.0	492.5	316.6	310.8	25.8	0.2	4.2	6.8	19.0	5.7	2841.6	12966.8	26.2						
16:33	2.0	20.8	1.4	947.5	3000.5	6.2	462.0	492.5	316.6	310.8	25.8	0.2	4.2	8.0	19.1	5.5	3768.7	11934.6	26.2						
16:34	1.9	20.8	1.5	1232.7	2841.8	6.2	462.0	492.5	342.3	331.6	29.8	0.2	4.2	7.6	19.1	6.0	4903.1	11303.4	26.2						
16:35	1.6	20.8	1.5	1167.2	2960.8	6.2	462.0	492.5	342.3	331.6	29.8	0.2	4.2	6.4	19.0	5.8	4642.6	11776.7	26.2						
16:36	2.6	20.8	1.5	1273.5	2733.6	6.2	462.0	492.5	342.3	331.6	29.8	0.2	4.2	10.3	19.2	5.9	5065.4	10873.0	26.2						
16:37	5.1	20.8	1.7	1906.4	2932.2	6.2	462.0	492.5	342.3	331.6	29.8	0.2	4.2	20.3	19.1	6.6	7582.8	11663.0	26.2						
16:38	5.4	20.8	1.8	2464.2	3310.0	6.2	462.0	492.5	342.3	331.6	29.8	0.2	4.2	21.5	19.0	7.2	9801.5	13165.7	26.2						
16:39	5.7	20.8	1.8	2319.3	3310.0	6.2	462.0	492.5	342.3	331.6	29.8	0.2	4.2	22.7	18.9	7.2	9225.1	13165.7	26.2						
16:40	6.1	20.8	1.7	2402.0	3280.0	6.2	462.0	492.5	351.5	338.0	32.1	0.2	4.2	24.3	19.0	6.7	9554.1	13046.3	26.2						
16:41	5.7	20.8	1.6	2209.9	3280.0	6.2	462.0	492.5	351.5	338.0	32.1	0.2	4.2	22.7	19.2	6.5	8790.0	13046.3	26.2						
16:42	6.3	20.8	1.6	2180.4	3120.0	6.2	462.0	492.5	351.5	338.0	32.1	0.2	4.2	25.1	19.2	6.2	8672.6	12409.9	26.2						
16:43	5.8	20.9	1.5	2080.4	3120.0	6.2	462.0	492.5	351.5	338.0	32.1	0.2	4.2	23.1	19.3	6.0	8274.9	12409.9	26.2						
16:44	5.1	20.8	1.5	1909.4	3095.8	6.2	462.0	492.5	351.5	338.0	32.1	0.2	4.2	20.3	19.2	5.9	7594.7	12313.7	26.2						
16:45	5.8	20.8	1.5	1852.5	3095.8	6.2	462.0	492.5	351.5	338.0	32.1	0.2	4.2	23.1	19.1	6.0	7368.4	12313.7	26.2						
Avg. #2	9.0	20.6	1.6	2688.7	3059.8	6.2				328.9			0.2	4.2	35.9	18.4	6.5	10694.2	12170.4	26.2					

a. Data obtained from Continuous Emissions Monitoring Systems (CEMS) data provided by Entropy personnel.

b. Moisture content, percent by volume, as shown in analysis from particulate/metals sampling period (MMT).

c. Source gas volumetric flowrate from MMT data.

d. Quench air flowrate, channel 15 from Data Acquisition System (DAS).

e. Quench air temperature, channel 1 from DAS.

f. Calculated from mass and energy balances at the quench section as the quench outlet flowrate divided by the furnace outlet flowrate.

g. Calculated from the quench outlet composition and the dilution factor, making the necessary conversions from a dry to a wet basis.

h. Calculated from the quench outlet composition and the dilution factor, taking into account the amount of oxygen added by the quench air.

Table O-3 Calculated furnace outlet offgas compositions for N80 and N80-Mod.

TIME (a)	Quench Outlet Dry vol. % / ppm (a)					Wet (b)		Quench Outlet (c)		Quench Outlet		Quench Air (d)		Quench Air		emp. Quenc		Dilution		Dilution		Furnace Outlet Offgas Composition (wet basis %) (g)				
	NOx (ppm)	O ₂ (%)	CO ₂ (%)	CO (ppm)	SO ₂ (ppm)	H ₂ O (%)	Flowrate (dscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Air (C) (e)	Factor	Factor (f)	Factor (f)	Factor (f)	Factor (f)	Factor (f)	Factor (f)	NOx (ppm)	O ₂ (h)	CO ₂	CO (ppm)	SO ₂ (ppm)
10:50	0.2	20.15	0.61	839.2	11.9	5.49	511.00	540.68	531.35	516.89	28.60	0.30	3.29	0.62	17.31	1.90	2,609.39	37.00	18.06							
10:51	0.2	20.16	0.6	783.5	10.9	5.49	511.00	540.68	531.35	516.89	28.60	0.30	3.29	0.62	17.34	1.87	2,436.20	33.89	18.06							
10:52	0.2	20.17	0.59	800.3	9.4	5.49	511.00	540.68	531.35	516.89	28.60	0.30	3.29	0.62	17.37	1.83	2,488.44	29.23	18.06							
10:53	0.2	20.18	0.59	789.1	7.9	5.49	511.00	540.68	531.35	516.89	28.60	0.30	3.29	0.62	17.41	1.83	2,453.61	24.56	18.06							
10:54	0.2	20.18	0.58	807.8	8.1	5.49	511.00	540.68	531.35	516.89	28.60	0.30	3.29	0.62	17.41	1.80	2,511.76	25.19	18.06							
10:55	0.2	20.19	0.53	764.7	7.2	5.49	511.00	540.68	531.35	516.89	28.60	0.30	3.29	0.62	17.44	1.65	2,377.74	22.39	18.06							
10:56	0.2	20.22	0.54	749	8.3	5.49	511.00	540.68	509.13	493.15	29.90	0.30	3.29	0.62	17.53	1.68	2,328.92	25.81	18.06							
10:57	0.3	20.2	0.56	892.1	6.5	5.49	511.00	540.68	509.13	493.15	29.90	0.30	3.29	0.93	17.47	1.74	2,773.88	20.21	18.06							
10:58	0.4	20.21	0.55	801	4.2	5.49	511.00	540.68	509.13	493.15	29.90	0.30	3.29	1.24	17.50	1.71	2,490.61	13.06	18.06							
10:59	0.4	20.21	0.56	710.5	2.5	5.49	511.00	540.68	509.13	493.15	29.90	0.30	3.29	1.24	17.50	1.74	2,209.21	7.77	18.06							
11:00	0.4	20.2	0.53	700.8	2.6	5.49	511.00	540.68	509.13	493.15	29.90	0.30	3.29	1.24	17.47	1.65	2,179.05	8.08	18.06							
11:01	0.5	20.22	0.49	605.6	0.6	5.49	511.00	540.68	509.13	493.15	29.90	0.30	3.29	1.55	17.53	1.52	1,883.04	1.87	18.06							
11:02	0.5	20.21	0.48	600.4	0.6	5.49	511.00	540.68	488.25	471.06	31.10	0.30	3.29	1.55	17.50	1.49	1,866.87	1.87	18.06							
11:03	0.5	20.22	0.51	651.6	0.9	5.49	511.00	540.68	488.25	471.06	31.10	0.30	3.29	1.55	17.53	1.59	2,026.07	2.80	18.06							
11:04	0.5	20.21	0.52	715.9	1.5	5.49	511.00	540.68	488.25	471.06	31.10	0.30	3.29	1.55	17.50	1.62	2,226.00	4.66	18.06							
11:05	0.5	20.21	0.52	780.1	1.6	5.49	511.00	540.68	488.25	471.06	31.10	0.30	3.29	1.55	17.50	1.62	2,425.63	4.98	18.06							
11:06	0.5	20.22	0.5	747.3	1.1	5.49	511.00	540.68	488.25	471.06	31.10	0.30	3.29	1.55	17.53	1.55	2,323.64	3.42	18.06							
11:07	0.5	20.22	0.54	846.5	1.8	5.49	511.00	540.68	488.25	471.06	31.10	0.30	3.29	1.55	17.53	1.68	2,632.09	5.60	18.06							
11:08	0.5	20.21	0.51	866.7	2	5.49	511.00	540.68	566.59	543.25	33.00	0.30	3.29	1.55	17.50	1.59	2,694.90	6.22	18.06							
11:09	0.6	20.21	0.56	892.4	1.2	5.49	511.00	540.68	566.59	543.25	33.00	0.30	3.29	1.87	17.50	1.74	2,774.81	3.73	18.06							
11:10	0.7	20.2	0.52	833.9	0.6	5.49	511.00	540.68	566.59	543.25	33.00	0.30	3.29	2.18	17.47	1.62	2,592.91	1.87	18.06							
11:11	0.6	20.19	0.52	746.7	0.6	5.49	511.00	540.68	566.59	543.25	33.00	0.30	3.29	1.87	17.44	1.62	2,321.77	1.87	18.06							
11:12	0.7	20.2	0.49	730.6	0.2	5.49	511.00	540.68	566.59	543.25	33.00	0.30	3.29	2.18	17.47	1.52	2,271.71	0.62	18.06							
11:13	0.7	20.21	0.48	690.3	0.2	5.49	511.00	540.68	566.59	543.25	33.00	0.30	3.29	2.18	17.50	1.49	2,146.40	0.62	18.06							
11:14	0.8	20.2	0.5	703.1	0.1	5.49	511.00	540.68	513.45	496.02	30.70	0.30	3.29	2.49	17.47	1.55	2,186.20	0.31	18.06							
11:15	0.7	20.19	0.5	744.8	0.2	5.49	511.00	540.68	513.45	496.02	30.70	0.30	3.29	2.18	17.44	1.55	2,315.87	0.62	18.06							
11:16	0.7	20.19	0.5	712.9	0.2	5.49	511.00	540.68	513.45	496.02	30.70	0.30	3.29	2.18	17.44	1.55	2,216.68	0.62	18.06							
11:17	0.6	20.17	0.49	683.6	0.2	5.49	511.00	540.68	513.45	496.02	30.70	0.30	3.29	1.87	17.37	1.52	2,125.57	0.62	18.06							
11:18	0.6	20.19	0.45	644.1	0.3	5.49	511.00	540.68	513.45	496.02	30.70	0.30	3.29	1.87	17.44	1.40	2,002.75	0.93	18.06							
11:19	0.6	20.19	0.44	626.9	0.4	5.49	511.00	540.68	513.45	496.02	30.70	0.30	3.29	1.87	17.44	1.37	1,949.27	1.24	18.06							
11:20	0.6	20.19	0.46	627.2	0.2	5.49	511.00	540.68	517.27	497.42	32.10	0.30	3.29	1.87	17.44	1.43	1,950.20	0.62	18.06							
11:21	0.7	20.18	0.47	652	0.1	5.49	511.00	540.68	517.27	497.42	32.10	0.30	3.29	2.18	17.41	1.46	2,027.32	0.31	18.06							
11:22	0.6	20.18	0.46	628.5	0.1	5.49	511.00	540.68	517.27	497.42	32.10	0.30	3.29	1.87	17.41	1.43	1,954.24	0.31	18.06							
11:23	0.7	20.18	0.49	669.6	0.1	5.49	511.00	540.68	517.27	497.42	32.10	0.30	3.29	2.18	17.41	1.52	2,082.04	0.31	18.06							
11:24	0.6	20.19	0.47	646.3	0.1	5.49	511.00	540.68	517.27	497.42	32.10	0.30	3.29	1.87	17.44	1.46	2,009.59	0.31	18.06							
11:25	0.6	20.17	0.53	767.7	0.8	5.49	511.00	540.68	517.27	497.42	32.10	0.30	3.29	1.87	17.37	1.65	2,387.07	2.49	18.06							
11:26	0.7	20.17	0.52	746.8	0.4	5.49	511.00	540.68	514.51	494.60	32.20	0.30	3.29	2.18	17.37	1.62	2,322.08	1.24	18.06							
11:27	0.8	20.17	0.55	806.8	0.5	5.49	511.00	540.68	514.51	494.60	32.20	0.30	3.29	2.49	17.37	1.71	2,508.65	1.55	18.06							
11:28	0.8	20.17	0.55	826.5	0.3	5.49	511.00	540.68	514.51	494.60	32.20	0.30	3.29	2.49	17.37	1.71	2,569.90	0.93	18.06							
11:29	0.7	20.17	0.57	821.9	0.4	5.49	511.00	540.68	514.51	494.60	32.20	0.30	3.29	2.18	17.37	1.77	2,555.60	1.24	18.06							
11:30	0.8	20.15	0.61	978.3	1	5.49	511.00	540.68	514.51	494.60	32.20	0.30	3.29	2.49	17.31	1.90	3,041.91	3.11	18.06							
11:31	0.8	20.16	0.57	937.6	0.5	5.49	511.00	540.68	514.51	494.60	32.20	0.30	3.29	2.49	17.34	1.77	2,915.35	1.55	18.06							
11:32	0.8	20.15	0.6	930.2	0.7	5.49	511.00	540.68	518.26	495.45	33.90	0.30	3.29	2.49	17.31	1.87	2,892.34	2.18	18.06							
11:33	0.7	20.17	0.53	851.8	1.5	5.49	511.00	540.68	518.26	495.45	33.90	0.30	3.29	2.18	17.37	1.65	2,648.57	4.66	18.06							
11:34	0.8	20.16	0.53	760.8	1	5.49	511.00	540.68	518.26	495.45	33.90	0.30	3.29	2.49	17.34	1.65	2,365.62	3.11	18.06							
11:35	0.7	20.17	0.54	902.3	4.6	5.49	511.00	540.68	518.26	495.45	33.90	0.30	3.29	2.18	17.37	1.68	2,805.59	14.30	18.06							
11:36	0.6	20.15	0.59	1142.9	4.4	5.49	511.00	540.68	518.26	495.45	33.90	0.30	3.29	1.87	17.31	1.83	3,553.71	13.68	18.06							
11:37	0.7	20.15	0.59	1212.6	3.1	5.49	511.00	540.68	518.26	495.45	33.90	0.30	3.29	2.18	17.31	1.83	3,770.43	9.64	18.06							
11:38	0.8	20.15	0.58	1188.3	1.9	5.49	511.00	540.68	540.48	515.85	34.40	0.30	3.29	2.49	17.31	1.80	3,694.88	5.91	18.06							
11:39	0.7	20.16	0.58	1158.8	1.9	5.49	511.00	540.68	540.48	515.85	34.40	0.30	3.29	2.18	17.34	1.80	3,603.15	5.91	18.06							
11:40	0.8	20.15	0.61	1268.6	2.5	5.49	511.00	540.68	540.48	515.85	34.40	0.30	3.29	2.49	17.31	1.90	3,944.56	7.77	18.06							

Table O-3 Calculated furnace outlet offgas compositions for N80 and N80-Mod (continued).

TIME (a)	Quench Outlet Dry vol. % / ppm (a)					Wet (b)		Quench Outlet (c)	Quench Outlet	Quench Air (d)	Quench Air	emp Quenc	Dilution	Dilution	Furnace Outlet Offgas Composition (wet basis %) (g)					
	NOx (ppm)	O ₂ (%)	CO ₂ (%)	CO (ppm)	SO ₂ (ppm)	H ₂ O (%)	Flowrate (dscfm)	Flowrate (wscfm)	Flowrate (wacfm)	Flowrate (wscfm)	Air (C) (e)	Factor	Factor (f)	Factor (f)	NOx (ppm)	O ₂ (h)	CO ₂	CO (ppm)	SO ₂ (ppm)	H ₂ O
11:53	1.3	20.07	0.69	1407.8	3.2	5.49	511.00	540.68	530.29	504.65	35.30	0.30	3.29	4.04	17.06	2.15	4,377.38	9.95	18.06	
11:54	1.4	20.08	0.69	1428.6	3.9	5.49	511.00	540.68	530.29	504.65	35.30	0.30	3.29	4.35	17.09	2.15	4,442.06	12.13	18.06	
11:55	1.3	20.08	0.7	1325.8	3.2	5.49	511.00	540.68	530.29	504.65	35.30	0.30	3.29	4.04	17.09	2.18	4,122.41	9.95	18.06	
11:56	1.2	20.07	0.7	1370.5	2.7	5.49	511.00	540.68	512.46	492.80	32.10	0.30	3.29	3.73	17.06	2.18	4,261.40	8.40	18.06	
11:57	1.3	20.06	0.71	1325.7	2.2	5.49	511.00	540.68	512.46	492.80	32.10	0.30	3.29	4.04	17.03	2.21	4,122.10	6.84	18.06	
11:58	1.4	20.06	0.73	1394.1	2.6	5.49	511.00	540.68	512.46	492.80	32.10	0.30	3.29	4.35	17.03	2.27	4,334.79	8.08	18.06	
11:59	1.6	20.06	0.72	1413.4	3	5.49	511.00	540.68	512.46	492.80	32.10	0.30	3.29	4.98	17.03	2.24	4,394.80	9.33	18.06	
12:00	1.5	20.09	0.67	1373.1	2.3	5.49	511.00	540.68	512.46	492.80	32.10	0.30	3.29	4.66	17.13	2.08	4,269.49	7.15	18.06	
12:01	1.5	20.08	0.69	1391	2.5	5.49	511.00	540.68	512.46	492.80	32.10	0.30	3.29	4.66	17.09	2.15	4,325.15	7.77	18.06	
12:02	1.4	20.08	0.66	1427.1	2.2	5.49	511.00	540.68	496.60	475.83	33.20	0.30	3.29	4.35	17.09	2.05	4,437.39	6.84	18.06	
12:03	1.3	20.06	0.68	1431.7	1.8	5.49	511.00	540.68	496.60	475.83	33.20	0.30	3.29	4.04	17.03	2.11	4,451.70	5.60	18.06	
12:04	1.3	20.07	0.69	1467.9	1.9	5.49	511.00	540.68	496.60	475.83	33.20	0.30	3.29	4.04	17.06	2.15	4,564.26	5.91	18.06	
12:05	1.4	20.08	0.71	1429.5	2.2	5.49	511.00	540.68	496.60	475.83	33.20	0.30	3.29	4.35	17.09	2.21	4,444.86	6.84	18.06	
12:06	1.5	20.09	0.7	1450.6	2.2	5.49	511.00	540.68	496.60	475.83	33.20	0.30	3.29	4.66	17.13	2.18	4,510.47	6.84	18.06	
12:07	1.5	20.1	0.68	1445	2.9	5.49	511.00	540.68	496.60	475.83	33.20	0.30	3.29	4.66	17.16	2.11	4,493.05	9.02	18.06	
12:08	1.5	20.08	0.69	1461.6	3	5.49	511.00	540.68	509.48	483.90	35.90	0.30	3.29	4.66	17.09	2.15	4,544.67	9.33	18.06	
12:09	0.80	19.90	0.57	999.66	2.51	5.35	#REF!	527.33	509.48	488.73	31.98	0.30	3.21	2.56	16.64	1.82	3,191.57	8.02		
15:20	3.1	20.39	2.38	3884.1	9.9	4.58	474.00	496.75	491.72	476.44	29.80	0.14	7.33	21.68	16.07	16.65	27,166.51	69.24	33.57	
15:21	3.2	20.26	2.69	5814.7	8.8	4.58	474.00	496.75	491.72	476.44	29.80	0.14	7.33	22.38	15.16	18.81	40,669.67	61.55	33.57	
15:22	3.1	20.33	2.34	4736.7	7.2	4.58	474.00	496.75	491.72	476.44	29.80	0.14	7.33	21.68	15.65	16.37	33,129.83	50.36	33.57	
15:23	3.2	20.35	2.32	4138.1	6.7	4.58	474.00	496.75	491.72	476.44	29.80	0.14	7.33	22.38	15.79	16.23	28,943.05	46.86	33.57	
15:24	3.3	20.28	2.52	4514.6	7.8	4.58	474.00	496.75	500.57	484.70	30.00	0.14	7.33	23.08	15.30	17.63	31,576.40	54.56	33.57	
15:25	3.2	20.29	2.47	4379.5	6.4	4.58	474.00	496.75	500.57	484.70	30.00	0.14	7.33	22.38	15.37	17.28	30,631.48	44.76	33.57	
15:26	3.4	20.29	2.45	4236.2	6.8	4.58	474.00	496.75	500.57	484.70	30.00	0.14	7.33	23.78	15.37	17.14	29,629.19	47.56	33.57	
15:27	3	20.31	2.35	3974.2	6.5	4.58	474.00	496.75	500.57	484.70	30.00	0.14	7.33	20.98	15.51	16.44	27,796.69	45.46	33.57	
15:28	2.8	20.28	2.39	4179.9	7.7	4.58	474.00	496.75	500.57	484.70	30.00	0.14	7.33	19.58	15.30	16.72	29,235.42	53.86	33.57	
15:29	2.7	20.33	2.22	4114	6.4	4.58	474.00	496.75	500.57	484.70	30.00	0.14	7.33	18.88	15.65	15.53	28,774.49	44.76	33.57	
15:30	2.9	20.3	2.24	3796.9	6.2	4.58	474.00	496.75	506.72	491.30	29.60	0.14	7.33	20.28	15.44	15.67	26,556.60	43.36	33.57	
15:31	2.9	20.32	2.19	3659	5.5	4.58	474.00	496.75	506.72	491.30	29.60	0.14	7.33	20.28	15.58	15.32	25,592.09	38.47	33.57	
15:32	2.9	20.25	2.61	3928	7.6	4.58	474.00	496.75	506.72	491.30	29.60	0.14	7.33	20.28	15.09	18.26	27,473.56	53.16	33.57	
15:33	3.3	19.96	3.36	6040.6	8.6	4.58	474.00	496.75	506.72	491.30	29.60	0.14	7.33	23.08	13.07	23.50	42,249.68	60.15	33.57	
15:34	6.5	19.66	4.91	6479.3	47.2	4.58	474.00	496.75	506.72	491.30	29.60	0.14	7.33	45.46	10.97	34.34	45,318.08	330.13	33.57	
15:35	6.8	19.87	3.85	8125.9	39.9	4.58	474.00	496.75	506.72	491.30	29.60	0.14	7.33	47.56	12.44	26.93	56,834.87	279.07	33.57	
15:36	3.8	19.94	3.59	6774.2	14.4	4.58	474.00	496.75	454.22	440.54	29.50	0.14	7.33	26.58	12.93	25.11	47,380.69	100.72	33.57	
15:37	3.6	20	3	6882.4	11.5	4.58	474.00	496.75	454.22	440.54	29.50	0.14	7.33	25.18	13.35	20.98	48,137.47	80.43	33.57	
15:38	3.3	20.08	2.8	4703.8	8.3	4.58	474.00	496.75	454.22	440.54	29.50	0.14	7.33	23.08	13.91	19.58	32,899.72	58.05	33.57	
15:39	2.5	20.16	2.71	4371.1	10.5	4.58	474.00	496.75	454.22	440.54	29.50	0.14	7.33	17.49	14.47	18.95	30,572.72	73.44	33.57	
15:40	2.5	19.98	3.27	5213.1	11.1	4.58	474.00	496.75	454.22	440.54	29.50	0.14	7.33	17.49	13.21	22.87	36,461.91	77.64	33.57	
15:41	3	19.96	3.3	6423.4	8.7	4.58	474.00	496.75	454.22	440.54	29.50	0.14	7.33	20.98	13.07	23.08	44,927.10	60.85	33.57	
15:42	1.9	20.07	2.96	5146.4	6.7	4.58	474.00	496.75	493.35	482.48	27.00	0.14	7.33	13.29	13.84	20.70	35,995.39	46.86	33.57	
15:43	3	20.08	2.89	4823.9	9	4.58	474.00	496.75	493.35	482.48	27.00	0.14	7.33	20.98	13.91	20.21	33,739.74	62.95	33.57	
15:44	4.3	20.06	2.93	5181.2	7	4.58	474.00	496.75	493.35	482.48	27.00	0.14	7.33	30.08	13.77	20.49	36,238.79	48.96	33.57	
15:45	6.2	20.05	2.94	5190.7	6	4.58	474.00	496.75	493.35	482.48	27.00	0.14	7.33	43.36	13.70	20.56	36,305.24	41.97	33.57	
15:46	4.2	20.09	2.92	4934.4	6.3	4.58	474.00	496.75	493.35	482.48	27.00	0.14	7.33	29.38	13.98	20.42	34,512.60	44.06	33.57	
15:47	5.4	20.1	2.87	5253.1	6.5	4.58	474.00	496.75	493.35	482.48	27.00	0.14	7.33	37.77	14.05	20.07	36,741.68	45.46	33.57	
15:48	4.9	20.06	3.04	5322.9	7.4	4.58	474.00	496.75	504.25	486.33	31.20	0.14	7.33	34.27	13.77	21.26	37,229.88	51.76	33.57	
15:49	5	20.03	3.07	5453.2	6.8	4.58	474.00	496.75	504.25	486.33	31.20	0.14	7.33	34.97	13.56	21.47	38,141.24	47.56	33.57	
15:50	4.6	20.03	3.02	5164.9	6.7	4.58	474.00	496.75	504.25	486.33	31.20	0.14	7.33	32.17	13.56	21.12	36,124.79	46.86	33.57	
15:51	6.1	20.06	2.92	5138.9	6.9	4.58	474.00	496.75	504.25	486.33	31.20	0.14	7.33	42.67	13.77	20.42	35,942.94	48.26	33.57	
15:52	4.3	20.02	3.11	5446	8	4.58	474.00	496.75	504.25	486.33	31.20	0.14	7.33	30.08	13.49	21.75	38,090.88	55.95	33.57	
15:53	3.7	20.06	3.02	5652.4	8.1	4.58	474.00	496.75	504.25	486.33	31.20	0.14	7.33	25.88	13.77	21.12	39,534.50	56.65	33.57	
15:54	4.2	20.03	3.14	5932.9	9.9	4.58	474.00	496.75	539.77	518.38	32.50	0.14	7.33	29.38	13.56	21.96	41,496.40	69.24	33.57	
15:55	4	20.04	3.18	5907	11.6	4.58	474.00	496.75	539.77	518.38	32.50	0.14	7.33	27.98	13.63	22.24	41,315.25	81.13	33.57	
15:56	4	19.96	3.36	6558	17.8	4.58	474.00	496.75	539.77	518.38	32.50	0.14	7.33	27.98	13.07	23.50	45,868.53	124.50	33.57	
15:57	3.5	20.05	3.11	5838.7	10.9	4.58	474.00	496.75	539.77	518.38	32.50	0.14	7.33	24.48	13.70	21.75	40,837.54	76.24	33.57	
15:58	3.7	19.97	3.34	6522.6	11.3	4.58	474.00	496.75	539.77	518.38	32.50	0.14	7.33	25.88	13.14	23.36	45,620.93	79.04	33.57	
15:59	4	19.93	3.5	6571.5	11.2	4.58	474.00	496.75	539.77	518.38	32.50	0.14	7.33	27.98	12.86	24.48	45,962.95	78.34	33.57	
16:00	4.5	19.97	3.35	6277.6	11	4.58	474.00	496.75	496.96	474.62	34.20	0.14	7.33	31.47	13.14	23.43	43,			

Table O-3 Calculated furnace outlet offgas compositions for N80 and N80-Mod (continued).

TIME (a)	Quench Outlet Dry vol. % / ppm (a)					Wet (b) H2O (%)	Quench Outlet (c)	Quench Outlet	Quench Air (d)	Quench Air	emp. Quenc	Diluton	Diluton	Furnace Outlet Offgas Composition (wet basis %) (g)					
	NOx (ppm)	O2 (%)	CO2 (%)	CO (ppm)	SO2 (ppm)		Flowrate (dscfm)	Flowrate (wscfm)	Flowrate (wacfm)	Flowrate (wscfm)	Air (C) (e)	Factor	Factor (f)	NOx (ppm)	O2 (h)	CO2	CO (ppm)	SO2 (ppm)	H2O
16:06	5	19.93	3.65	6694.9	11.6	4.58	474.00	496.75	557.18	537.03	31.40	0.14	7.33	34.97	12.86	25.53	46,826.05	81.13	33.57
16:07	5.2	19.98	3.57	6673.1	11.7	4.58	474.00	496.75	557.18	537.03	31.40	0.14	7.33	36.37	13.21	24.97	46,673.57	81.83	33.57
16:08	5.2	19.95	3.66	6194	12.2	4.58	474.00	496.75	557.18	537.03	31.40	0.14	7.33	36.37	13.00	25.60	43,322.61	85.33	33.57
16:09	5.4	19.94	3.66	6569.8	12.3	4.58	474.00	496.75	557.18	537.03	31.40	0.14	7.33	37.77	12.93	25.60	45,951.06	86.03	33.57
16:10	5	19.96	3.66	6434.1	11.8	4.58	474.00	496.75	557.18	537.03	31.40	0.14	7.33	34.97	13.07	25.60	45,001.94	82.53	33.57
16:11	5.1	19.94	3.67	6748.8	12.7	4.58	474.00	496.75	557.18	537.03	31.40	0.14	7.33	35.67	12.93	25.67	47,203.04	88.83	33.57
16:12	6.2	19.92	3.72	6548	12.9	4.58	474.00	496.75	573.95	554.84	30.50	0.14	7.33	43.36	12.79	26.02	45,798.58	90.23	33.57
16:13	5.2	19.94	3.73	6917.5	15.9	4.58	474.00	496.75	573.95	554.84	30.50	0.14	7.33	36.37	12.93	26.09	48,382.97	111.21	33.57
16:14	5	19.92	3.76	6852.3	13	4.58	474.00	496.75	573.95	554.84	30.50	0.14	7.33	34.97	12.79	26.30	47,926.95	90.93	33.57
16:15	5.7	19.79	4.25	6499.2	10.9	4.58	474.00	496.75	573.95	554.84	30.50	0.14	7.33	39.87	11.88	29.73	45,457.26	76.24	33.57
16:16	7.7	19.55	4.98	8630	12	4.58	474.00	496.75	573.95	554.84	30.50	0.14	7.33	53.86	10.20	34.83	60,360.69	83.93	33.57
16:17	8.1	20.04	3.14	5416.2	6.6	4.58	474.00	496.75	573.95	554.84	30.50	0.14	7.33	56.65	13.63	21.96	37,882.45	46.16	33.57
16:18	5.6	20.01	3.35	5334.1	9.2	4.58	474.00	496.75	525.26	507.27	30.80	0.14	7.33	39.17	13.42	23.43	37,308.22	64.35	33.57
16:19	7	20.02	3.34	5044.9	7.4	4.58	474.00	496.75	525.26	507.27	30.80	0.14	7.33	48.96	13.49	23.36	35,285.47	51.76	33.57
16:20	5.2	19.93	3.6	6382.3	10.8	4.58	474.00	496.75	525.26	507.27	30.80	0.14	7.33	36.37	12.86	25.18	44,639.63	75.54	33.57
16:21	4.9	19.9	3.77	6749.1	12.9	4.58	474.00	496.75	525.26	507.27	30.80	0.14	7.33	34.27	12.65	26.37	47,205.14	90.23	33.57
16:22	5.7	19.97	3.53	6668	10.2	4.58	474.00	496.75	525.26	507.27	30.80	0.14	7.33	39.87	13.14	24.69	46,637.90	71.34	33.57
16:23	8.9	19.99	3.39	5775.7	8.2	4.58	474.00	496.75	525.26	507.27	30.80	0.14	7.33	62.25	13.28	23.71	40,396.90	57.35	33.57
16:24	11.5	20.02	3.26	4677.9	6.4	4.58	474.00	496.75	522.65	505.58	30.30	0.14	7.33	80.43	13.49	22.80	32,718.57	44.76	33.57
16:25	6.8	19.98	3.46	4884.1	6.7	4.58	474.00	496.75	522.65	505.58	30.30	0.14	7.33	47.56	13.21	24.20	34,160.79	46.86	33.57
Avg. #2	4.4808824	19.73791	3.1182	5596.9448	10.362687	4.4453		482.1408756		482.0865339	29.7058824	0.132	7.114411765	31.34057	13.4	22.1	39146.63	72.47959	33.07

a. Data obtained from Continuous Emissions Monitoring Systems (CEMS) data provided by Entropy personnel.

b. Moisture content, percent by volume, as shown in analysis from particulate/metals sampling period (MMT).

c. Source gas volumetric flowrate from MMT data

d. Quench air flowrate, channel 15 from Data Acquisition System (DAS).

e. Quench air temperature, channel 1 from DAS.

f. Calculated from mass and energy balances at the quench section as the quench outlet flowrate divided by the furnace outlet flowrate.

g. Calculated from the quench outlet composition and the dilution factor, making the necessary conversions from a dry to a wet basis.

h. Calculated from the quench outlet composition and the dilution factor, taking into account the amount of oxygen added by the quench air.

Table O-4 Calculated furnace outlet offgas compositions for N80-IV and N80-IV-Mod

TIME (a)	Quench Outlet Dry vol. % / ppm (a)					Wet (b)		Quench Outlet (c)		Quench Air (d)		Quench Air		Temp. Quench		Temp. at		Dilution	Dilution	Furnace Outlet Offgas Composition (wet basis %) (g)				
	NOx (ppm)	O ₂ (%)	CO ₂ (%)	CO (ppm)	SO ₂ (ppm)	H ₂ O (%)	Flowrate (dscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Flowrate (wscfm)	Air (C) (e)	Furnace outlet	Factor	Factor (f)	NOx (ppm)	O ₂ (h)	CO ₂	CO (ppm)	SO ₂ (ppm)	H ₂ O			
12:20	11.2	19.4	4.13	5869.3	100	6.5	477	510.16	450.54	423.53	39.10	71.40	0.17	5.86	61.37	11.10	22.63	32,158.48	547.91	38.09				
12:21	11.5	19.4	4.17	6655.5	94.2	6.5	477	510.16	450.54	423.53	39.10	71.40	0.17	5.86	63.01	11.10	22.85	36,466.15	516.13	38.09				
12:22	11.3	19.39	4.2	6023.4	91.6	6.5	477	510.16	450.54	423.53	39.10	71.40	0.17	5.86	61.91	11.04	23.01	33,002.81	501.89	38.09				
12:23	10.1	19.41	4.2	5985.2	90	6.5	477	510.16	454.43	430.64	36.60	71.50	0.17	5.86	55.34	11.15	23.01	32,793.51	493.12	38.09				
12:24	9.8	19.41	4.21	6609.5	87.7	6.5	477	510.16	454.43	430.64	36.60	71.50	0.17	5.86	53.70	11.15	23.07	36,214.11	480.52	38.09				
12:25	9	19.43	4.26	5953.4	85.8	6.5	477	510.16	454.43	430.64	36.60	71.50	0.17	5.86	49.31	11.26	23.34	32,619.27	470.11	38.09				
12:26	8.1	19.45	4.14	6204.2	80.4	6.5	477	510.16	438.72	418.05	34.90	70.10	0.17	5.86	44.38	11.37	22.68	33,993.43	440.52	38.09				
12:27	7.1	19.47	4.22	6388.4	80	6.5	477	510.16	438.72	418.05	34.90	70.10	0.17	5.86	38.90	11.48	23.12	35,002.68	438.33	38.09				
12:28	5.9	19.47	4.26	5831.5	78.8	6.5	477	510.16	438.72	418.05	34.90	70.10	0.17	5.86	32.33	11.48	23.34	31,951.37	431.75	38.09				
12:29	5.4	19.52	3.98	5492.7	77	6.5	477	510.16	443.39	423.46	34.20	69.00	0.17	5.86	29.59	11.75	21.81	30,095.05	421.89	38.09				
12:30	4	19.61	3.86	5472	72.5	6.5	477	510.16	443.39	423.46	34.20	69.00	0.17	5.86	21.92	12.25	21.15	29,981.64	397.23	38.09				
12:31	3.5	19.61	3.79	5169.8	64.3	6.5	477	510.16	443.39	423.46	34.20	69.00	0.17	5.86	19.18	12.25	20.77	28,325.85	352.31	38.09				
12:32	3.5	19.57	3.87	4811	64.1	6.5	477	510.16	441.69	422.52	33.70	67.60	0.17	5.86	19.18	12.03	21.20	26,359.95	351.21	38.09				
12:33	3.3	19.55	3.97	5925.8	63.9	6.5	477	510.16	441.69	422.52	33.70	67.60	0.17	5.86	18.08	11.92	21.75	32,468.05	350.11	38.09				
12:34	3	19.55	3.99	5751.1	60.4	6.5	477	510.16	441.69	422.52	33.70	67.60	0.17	5.86	16.44	11.92	21.86	31,510.85	330.94	38.09				
12:35	3.3	19.54	4.03	5884.4	58.8	6.5	477	510.16	399.16	381.34	34.10	65.40	0.17	5.86	18.08	11.86	22.08	32,241.22	322.17	38.09				
12:36	3.5	19.54	4.04	5259.5	59.9	6.5	477	510.16	399.16	381.34	34.10	65.40	0.17	5.86	19.18	11.86	22.14	28,817.33	328.20	38.09				
12:37	3.1	19.57	3.98	4983.5	58	6.5	477	510.16	399.16	381.34	34.10	65.40	0.17	5.86	16.99	12.03	21.81	27,305.09	317.79	38.09				
12:38	3.2	19.61	3.88	1135.7	56.7	6.5	477	510.16	472.4	452.05	33.60	64.20	0.17	5.86	17.53	12.25	21.26	6,222.61	310.66	38.09				
12:39	3.4	19.61	3.82	5937.7	54.3	6.5	477	510.16	472.4	452.05	33.60	64.20	0.17	5.86	18.63	12.25	20.93	32,533.25	297.52	38.09				
12:40	3.4	19.62	3.73	5069.5	57.7	6.5	477	510.16	472.4	452.05	33.60	64.20	0.17	5.86	18.63	12.30	20.44	27,776.30	316.14	38.09				
12:41	3.3	19.63	3.72	5560.6	58.2	6.5	477	510.16	435.04	415.62	34.10	62.70	0.17	5.86	18.08	12.36	20.38	30,467.08	318.88	38.09				
12:42	3.5	19.6	3.77	5610.7	62.4	6.5	477	510.16	435.04	415.62	34.10	62.70	0.17	5.86	19.18	12.19	20.66	30,741.59	341.90	38.09				
12:43	3.8	19.57	3.88	5256.2	61.8	6.5	477	510.16	435.04	415.62	34.10	62.70	0.17	5.86	20.82	12.03	21.26	28,799.25	338.61	38.09				
12:44	3.3	19.55	4.04	6056.7	63.2	6.5	477	510.16	436.31	415.75	34.90	61.80	0.17	5.86	18.08	11.92	22.14	33,185.26	346.28	38.09				
12:45	3.1	19.52	4.18	6714.6	66.6	6.5	477	510.16	436.31	415.75	34.90	61.80	0.17	5.86	16.99	11.75	22.90	36,789.96	364.91	38.09				
12:46	3.1	19.57	4.02	5797.8	66.6	6.5	477	510.16	436.31	415.75	34.90	61.80	0.17	5.86	16.99	12.03	22.03	31,766.73	364.91	38.09				
12:47	3.1	19.55	4.2	6186.3	65.8	6.5	477	510.16	431.36	411.70	34.40	60.60	0.17	5.86	16.99	11.92	23.01	33,895.36	360.52	38.09				
12:48	3.1	19.58	4.1	5474.2	72.2	6.5	477	510.16	431.36	411.70	34.40	60.60	0.17	5.86	16.99	12.08	22.46	29,993.69	395.59	38.09				
12:49	3.3	19.6	4.05	6341.3	74.8	6.5	477	510.16	431.36	411.70	34.40	60.60	0.17	5.86	18.08	12.19	22.19	34,744.62	409.84	38.09				
12:50	3.5	19.59	4.09	5908.7	74.3	6.5	477	510.16	440.63	416.49	37.40	60.40	0.17	5.86	19.18	12.14	22.41	32,374.36	407.10	38.09				
12:51	3.7	19.57	4.14	5584.7	70.3	6.5	477	510.16	440.63	416.49	37.40	60.40	0.17	5.86	20.27	12.03	22.68	30,599.13	385.18	38.09				
12:52	3.7	19.62	3.98	5645.5	65.6	6.5	477	510.16	440.63	416.49	37.40	60.40	0.17	5.86	20.27	12.30	21.81	30,932.26	359.43	38.09				
12:53	3.6	19.68	3.89	6192	67.1	6.5	477	510.16	432.49	409.06	37.20	59.60	0.17	5.86	19.72	12.63	21.31	33,926.59	367.65	38.09				
12:54	3.7	19.66	3.84	5986.5	64.2	6.5	477	510.16	432.49	409.06	37.20	59.60	0.17	5.86	20.27	12.52	21.04	32,800.63	351.76	38.09				
12:55	3.1	20.24	1.67	4102.5	44	6.5	477	510.16	432.49	409.06	37.20	59.60	0.17	5.86	16.99	15.70	9.15	22,478.01	241.08	38.09				
12:56	3	20.94	0.1	62.2	21.5	6.5	477	510.16	512.03	487.11	35.40	59.10	0.17	5.86	16.44	19.53	0.55	340.80	117.80	38.09				
12:57	6.9	20.96	0.09	3.5	22.3	6.5	477	510.16	512.03	487.11	35.40	59.10	0.17	5.86	37.81	19.64	0.49	19.18	122.18	38.09				
12:58	17.3	20.88	0.12	19.7	24.3	6.5	477	510.16	512.03	487.11	35.40	59.10	0.17	5.86	94.79	19.20	0.66	107.94	133.14	38.09				
12:59	15.7	20.83	0.12	60.6	23.7	6.5	477	510.16	478.84	453.48	36.80	58.80	0.17	5.86	86.02	18.93	0.66	332.03	129.85	38.09				
13:00	10.4	20.82	0.13	44	24.9	6.5	477	510.16	478.84	453.48	36.80	58.80	0.17	5.86	56.98	18.88	0.71	241.08	136.43	38.09				
13:01	8.2	20.79	0.14	43.9	26.2	6.5	477	510.16	478.84	453.48	36.80	58.80	0.17	5.86	44.93	18.71	0.77	240.53	143.55	38.09				
13:02	6.9	20.78	0.16	42.4	26.8	6.5	477	510.16	445.09	421.38	36.90	58.40	0.17	5.86	37.81	18.66	0.88	232.31	146.84	38.09				
13:03	6	20.78	0.13	33.8	26.9	6.5	477	510.16	445.09	421.38	36.90	58.40	0.17	5.86	32.87	18.66	0.71	185.19	147.39	38.09				
13:04	5.6	20.77	0.11	34	26.9	6.5	477	510.16	445.09	421.38	36.90	58.40	0.17	5.86	30.68	18.60	0.60	186.29	147.39	38.09				
13:05	5.3	20.76	0.11	33.3	26.9	6.5	477	510.16	453.65	430.04	36.50	57.50	0.17	5.86	29.04	18.55	0.60	182.45	147.39	38.09				
13:06	5.2	20.75	0.11	33.5	26.8	6.5	477	510.16	453.65	430.04	36.50	57.50	0.17	5.86	28.49	18.49	0.60	183.55	146.84	38.09				
13:07	5.2	20.73	0.11	36.9	26.9	6.5	477	510.16	453.65	430.04	36.50	57.50	0.17	5.86	28.49	18.38	0.60	202.18	147.39	38.09				
13:08	4.4	20.53	1.45	238.9	33.6	6.5	477	510.16	428.6	407.08	35.90	56.60	0.17	5.86	24.11	17.29	7.94	1,308.96	184.10	38.09				
13:09	2.3	19.61	4.08	4472.5	50.4	6.5	477	510.16	428.6	407.08	35.90	56.60	0.17	5.86	12.60	12.25	22.35	24,505.27	276.15	38.09				
13:10	2.4	19.58	4.23	5825	49.1	6.5	477	510.16	428.6	407.08	35.90	56.60	0.17	5.86	13.15	12.08	23.18	31,915.76	269.02	38.09				
13:11	3.5	19.56	4.09	5426.2	51.5	6.5	477	510.16	416.36	394.95	36.30	62.70	0.17	5.86	19.18	11.97	22.41	29,730.69	282.17	38.09				
13:12	4.2	19.65	3.85	4619.9	50.3	6.5	477	510.16	416.36	394.95	36.30	62.70	0.17	5.86	23.01	12.47	21.09	25,312.89	275.60	38.09				
13:13	5.3	19.66	3.81	5277	43.4	6.5	477	510.16	416.36	394.95	36.30	62.70	0.17	5.86	29.04	12.52	20.88	28,913.21	237.79	38.09				
13:14	6.4	19.59	3.99	5181.4	48.4	6.5	477	510.16	419.26	397.83	36.20	67.70	0.17	5.86	35.07	12.14	21.86	28,389.41	265.19	38.09				
13:15	7.3	19.59	3.94	5245.2	44.5	6.5																		

Table O-4 Calculated furnace outlet offgas compositions for N80-IV and N80-IV-Mod (continued).

Table G-4. Calculated sulfur dioxide and sulfur trioxide emissions for 100% sulfur recovery																					
TIME (a)	Quench Outlet Dry vol. % / ppm (a)					Wet (b) H2O (%)	Quench Outlet (c) Flowrate (dscfm)	Quench Outlet Flowrate (wscfm)	Quench Air (d) Flowrate (wscfm)	Quench Air Flowrate (wscfm)	Temp. Quench Air (C) (e)	Temp. at Furnace outlet	Dilution Factor	Dilution Factor (f)	Furnace Outlet Offgas Composition (wet basis %) (g)						
	NOx (ppm)	O2 (%)	CO2 (%)	CO (ppm)	SO2 (ppm)										NOx (ppm)	O2 (h)	CO2	CO (ppm)	SO2 (ppm)	H2O	
13:28	14.1	19.76	3.57	4023	51.9	6.5	477	510.16	510.55	482.58	37.40	73.90	0.17	5.86	77.26	13.07	19.56	22,042.42	284.37	38.09	
13:29	15.7	19.8	3.46	3990.9	54.5	6.5	477	510.16	445.58	418.74	39.20	72.50	0.17	5.86	86.02	13.29	18.96	21,866.54	298.61	38.09	
13:30	17.7	19.82	3.34	3939.7	51.6	6.5	477	510.16	445.58	418.74	39.20	72.50	0.17	5.86	96.98	13.40	18.30	21,586.01	282.72	38.09	
13:31	17.9	19.87	3.23	3580.1	52.9	6.5	477	510.16	445.58	418.74	39.20	72.50	0.17	5.86	98.08	13.67	17.70	19,615.73	289.84	38.09	
13:32	18.1	19.88	3.26	3784.3	56.8	6.5	477	510.16	425.41	400.42	38.70	71.00	0.17	5.86	99.17	13.73	17.86	20,734.56	311.21	38.09	
13:33	19.1	19.86	3.41	3743.6	57.7	6.5	477	510.16	425.41	400.42	38.70	71.00	0.17	5.86	104.65	13.62	18.68	20,511.56	316.14	38.09	
13:34	22.1	19.89	3.09	2860.9	36.8	6.5	477	510.16	425.41	400.42	38.70	71.00	0.17	5.86	121.09	13.78	16.93	15,675.16	201.63	38.09	
16:31	0.6	19.83	3.15	4904.3	36.8	5.74	447	474.22	374.96	356.83	35.30	83.20	0.28	3.59	2.03	15.96	10.66	16,595.83	124.53	20.61	
16:32	0.7	19.87	3.12	4390.1	36.6	5.74	447	474.22	394.28	373.52	36.70	81.40	0.28	3.59	2.37	16.09	10.56	14,855.81	123.85	20.61	
16:33	0.8	19.87	3.14	4127	37	5.74	447	474.22	394.28	373.52	36.70	81.40	0.28	3.59	2.71	16.09	10.63	13,965.50	125.21	20.61	
16:34	0.9	19.86	3.14	4093.1	36.6	5.74	447	474.22	394.28	373.52	36.70	81.40	0.28	3.59	3.05	16.06	10.63	13,850.78	123.85	20.61	
16:35	1	19.87	3.12	4521.4	35.1	5.74	447	474.22	359.11	342.41	34.70	79.30	0.28	3.59	3.38	16.09	10.56	15,300.12	118.78	20.61	
16:36	1.1	19.86	3.14	4082.4	34	5.74	447	474.22	359.11	342.41	34.70	79.30	0.28	3.59	3.72	16.06	10.63	13,814.57	115.05	20.61	
16:37	1.2	19.86	3.11	3915.3	33.2	5.74	447	474.22	359.11	342.41	34.70	79.30	0.28	3.59	4.06	16.06	10.52	13,249.12	112.35	20.61	
16:38	1.3	19.87	3.09	3767.4	32.6	5.74	447	474.22	346.93	329.41	36.00	78.50	0.28	3.59	4.40	16.09	10.46	12,748.63	110.32	20.61	
16:39	1.5	19.87	3.11	3806.2	32.5	5.74	447	474.22	346.93	329.41	36.00	78.50	0.28	3.59	5.08	16.09	10.52	12,879.93	109.98	20.61	
16:40	2	19.85	3.14	4049	33	5.74	447	474.22	346.93	329.41	36.00	78.50	0.28	3.59	6.77	16.03	10.63	13,701.55	111.67	20.61	
16:41	2	19.9	3.05	4000.2	32.1	5.74	447	474.22	360.17	341.43	36.50	77.70	0.28	3.59	6.77	16.19	10.32	13,536.41	108.62	20.61	
16:42	2.2	19.88	3.09	4197	32.5	5.74	447	474.22	360.17	341.43	36.50	77.70	0.28	3.59	7.44	16.13	10.46	14,202.37	109.98	20.61	
16:43	2.6	19.88	3.06	3820.8	33.6	5.74	447	474.22	360.17	341.43	36.50	77.70	0.28	3.59	8.80	16.13	10.35	12,929.34	113.70	20.61	
16:44	2.4	19.9	2.97	3839.2	32.1	5.74	447	474.22	359.6	345.46	32.40	77.00	0.28	3.59	8.12	16.19	10.05	12,991.60	108.62	20.61	
16:45	2.4	19.95	2.87	3766.3	32.2	5.74	447	474.22	359.6	345.46	32.40	77.00	0.28	3.59	8.12	16.36	9.71	12,744.91	108.96	20.61	
16:46	1.5	19.97	2.81	3558.8	33	5.74	447	474.22	359.6	345.46	32.40	77.00	0.28	3.59	5.08	16.43	9.51	12,042.74	111.67	20.61	
16:47	1.6	19.99	2.71	3862.2	33.2	5.74	447	474.22	337.95	325.41	31.70	76.90	0.28	3.59	5.41	16.50	9.17	13,069.43	112.35	20.61	
16:48	1.3	20.01	2.59	4127.6	35.8	5.74	447	474.22	337.95	325.41	31.70	76.90	0.28	3.59	4.40	16.57	8.76	13,967.53	121.14	20.61	
16:49	0.9	20.03	2.51	4031.7	44.3	5.74	447	474.22	337.95	325.41	31.70	76.90	0.28	3.59	3.05	16.63	8.49	13,643.01	149.91	20.61	
16:50	1.3	20	2.56	3854.9	48.7	5.74	447	474.22	356.84	344.28	31.10	77.90	0.28	3.59	4.40	16.53	8.66	13,044.73	164.80	20.61	
16:51	1.7	19.96	2.73	4059.5	51.8	5.74	447	474.22	356.84	344.28	31.10	77.90	0.28	3.59	5.75	16.40	9.24	13,737.08	175.29	20.61	
16:52	1.8	19.88	3.05	5100.6	44.7	5.74	447	474.22	356.84	344.28	31.10	77.90	0.28	3.59	6.09	16.13	10.32	17,260.09	151.26	20.61	
16:53	1.6	19.86	3.22	4771.5	40	5.74	447	474.22	338.94	326.47	31.60	76.70	0.28	3.59	5.41	16.06	10.90	16,146.44	135.36	20.61	
16:54	1.8	19.85	3.27	5156	40.1	5.74	447	474.22	338.94	326.47	31.60	76.70	0.28	3.59	6.09	16.03	11.07	17,447.56	135.70	20.61	
16:55	2.1	19.83	3.39	5885.5	40	5.74	447	474.22	338.94	326.47	31.60	76.70	0.28	3.59	7.11	15.96	11.47	19,916.14	135.36	20.61	
Avg. #2	1.532	19.9	3.0056	4227.52	36.86	5.74		474.2202419		341.6781723	33.896			0.27855	3.59	5.184187	16.194339	10.170752	14305.649	124.73181	20.6066

a. Data obtained from Continuous Emissions Monitoring Systems (CEMS) data provided by Entropy personnel.

b. Moisture content, percent by volume, as shown in analysis from particulate/metals sampling period (MMT)

c. Source gas volumetric flowrate from MMT data.

d. Quench air flowrate, channel 15 from Data Acquisition System (DAS).

e. Quench air temperature, channel 1 from DAS.

f. Calculated from mass and energy balances at the quench section as the quench outlet flowrate divided by the furnace outlet flowrate.

g. Calculated from the quench outlet composition and the dilution factor, making the necessary conversions from a dry to a wet basis.

h. Calculated from the quench outlet composition and the dilution factor, taking into account the amount of oxygen added by the quench air.

Table O-5 Calculated furnace outlet offgas compositions for M60 and N80-IV-Mod-2.

TIME (a)	Quench Outlet Dry vol. % / ppm (a)					Wet (b) H2O (%)	Quench Outlet (c) Flowrate (dscfm)	Quench Outlet Flowrate (wscfm)	Quench Air (d) Flowrate (wacfm)	Quench Air Flowrate (wscfm)	Temp. Quench Air (C) (e)	Dilution Factor	Dilution Factor (f)	Furnace Outlet Offgas Composition (wet basis %) (g)					
	NOx (ppm)	O2 (%)	CO2 (%)	CO (ppm)	SO2 (ppm)									NOx (ppm)	O2 (h)	CO2	CO (ppm)	SO2 (ppm)	H2O
10:05	23.6	20.4	1.54	3060.8	3.3	4.64	513.00	537.96	425.27	423.38	21.70	0.18	5.55	124.90	17.07	8.15	16,199.22	17.47	25.75
10:06	27.6	20.24	1.7	3699.7	2.9	4.64	513.00	537.96	400.72	398.40	22.10	0.18	5.55	146.07	16.22	9.00	19,580.59	15.35	25.75
10:07	28.1	20.23	1.72	3659.3	2.9	4.64	513.00	537.96	400.72	398.40	22.10	0.18	5.55	148.72	16.17	9.10	19,366.77	15.35	25.75
10:08	28.7	20.22	1.75	3684.9	2.9	4.64	513.00	537.96	400.72	398.40	22.10	0.18	5.55	151.89	16.11	9.26	19,502.26	15.35	25.75
10:09	28	20.22	1.74	3993.2	3.1	4.64	513.00	537.96	419.26	416.83	22.10	0.18	5.55	148.19	16.11	9.21	21,133.93	16.41	25.75
10:10	24.1	20.27	1.64	4021.2	3.4	4.64	513.00	537.96	419.26	416.83	22.10	0.18	5.55	127.55	16.38	8.68	21,282.12	17.99	25.75
10:11	22.7	20.27	1.62	4770.9	4	4.64	513.00	537.96	419.26	416.83	22.10	0.18	5.55	120.14	16.38	8.57	25,249.89	21.17	25.75
10:12	24.6	20.25	1.67	4820.9	3.9	4.64	513.00	537.96	385.5	383.14	22.20	0.18	5.55	130.20	16.27	8.84	25,514.52	20.64	25.75
10:13	27.1	20.23	1.73	4465.6	3.6	4.64	513.00	537.96	385.5	383.14	22.20	0.18	5.55	143.43	16.17	9.16	23,634.10	19.05	25.75
10:14	28.2	20.22	1.75	3627.8	3.1	4.64	513.00	537.96	385.5	383.14	22.20	0.18	5.55	149.25	16.11	9.26	19,200.06	16.41	25.75
10:15	30.5	20.15	1.81	3028.7	2.7	4.64	513.00	537.96	397.6	395.03	22.30	0.18	5.55	161.42	15.74	9.58	16,029.33	14.29	25.75
10:16	30	20.16	1.77	2393.3	2	4.64	513.00	537.96	397.6	395.03	22.30	0.18	5.55	158.77	15.80	9.37	12,666.49	10.58	25.75
10:17	27.9	20.29	1.58	2222.7	1.9	4.64	513.00	537.96	397.6	395.03	22.30	0.18	5.55	147.66	16.48	8.36	11,763.60	10.06	25.75
10:18	35.1	20.15	1.9	1692.3	1.8	4.64	513.00	537.96	451.88	449.11	22.20	0.18	5.55	185.77	15.74	10.06	8,956.46	9.53	25.75
10:19	38.8	20.05	2.03	1661.5	2	4.64	513.00	537.96	451.88	449.11	22.20	0.18	5.55	205.35	15.21	10.74	8,793.46	10.58	25.75
10:20	39.4	20.02	2.07	1483.8	1.6	4.64	513.00	537.96	451.88	449.11	22.20	0.18	5.55	208.52	15.06	10.96	7,852.98	8.47	25.75
10:21	36.2	20.08	1.91	1390	1.5	4.64	513.00	537.96	501.56	497.65	22.70	0.18	5.55	191.59	15.37	10.11	7,356.55	7.94	25.75
10:22	35.6	20.09	1.97	1110.1	1.4	4.64	513.00	537.96	501.56	497.65	22.70	0.18	5.55	188.41	15.43	10.43	5,875.18	7.41	25.75
10:23	47.7	20.01	2.3	1966.9	3.2	4.64	513.00	537.96	501.56	497.65	22.70	0.18	5.55	252.45	15.00	12.17	10,409.78	16.94	25.75
10:24	76.7	19.55	2.63	4026.3	6.9	4.64	513.00	537.96	460.02	456.74	22.50	0.18	5.55	405.93	12.57	13.92	21,309.11	36.52	25.75
10:25	50.1	19.86	2.24	1617.7	2.6	4.64	513.00	537.96	460.02	456.74	22.50	0.18	5.55	265.15	14.21	11.86	8,561.64	13.76	25.75
10:26	46.3	19.87	2.22	1116.7	1.9	4.64	513.00	537.96	460.02	456.74	22.50	0.18	5.55	245.04	14.26	11.75	5,910.11	10.06	25.75
10:27	43.4	19.91	2.16	1099.3	1.8	4.64	513.00	537.96	405.6	402.30	22.80	0.18	5.55	229.69	14.47	11.43	5,818.02	9.53	25.75
10:28	41.6	19.88	2.2	1070.5	1.7	4.64	513.00	537.96	405.6	402.30	22.80	0.18	5.55	220.17	14.31	11.64	5,665.60	9.00	25.75
10:29	42.1	19.83	2.29	1148.6	1.4	4.64	513.00	537.96	405.6	402.30	22.80	0.18	5.55	222.81	14.05	12.12	6,078.94	7.41	25.75
10:30	53.7	19.73	2.41	1289	1.6	4.64	513.00	537.96	481.32	477.08	23.00	0.18	5.55	284.21	13.52	12.75	6,822.01	8.47	25.75
10:31	56.2	19.67	2.53	1317.4	1.8	4.64	513.00	537.96	481.32	477.08	23.00	0.18	5.55	297.44	13.20	13.39	6,972.31	9.53	25.75
10:32	62.5	19.58	2.65	1363.3	2	4.64	513.00	537.96	481.32	477.08	23.00	0.18	5.55	330.78	12.73	14.03	7,215.24	10.58	25.75
10:33	58.5	19.66	2.53	1527.2	1.8	4.64	513.00	537.96	444.45	440.39	23.10	0.18	5.55	309.61	13.15	13.39	8,082.68	9.53	25.75
10:34	50.9	19.74	2.4	1237.8	1.6	4.64	513.00	537.96	444.45	440.39	23.10	0.18	5.55	269.39	13.57	12.70	6,551.03	8.47	25.75
10:35	45.1	19.79	2.27	1100.4	1.5	4.64	513.00	537.96	444.45	440.39	23.10	0.18	5.55	238.69	13.84	12.01	5,823.84	7.94	25.75
10:36	38	19.86	2.07	1711.8	2	4.64	513.00	537.96	426.55	421.94	23.60	0.18	5.55	201.11	14.21	10.96	9,059.67	10.58	25.75
10:37	31.8	20.21	1.69	1497.4	1.6	4.64	513.00	537.96	426.55	421.94	23.60	0.18	5.55	168.30	16.06	8.94	7,924.96	8.47	25.75
10:38	40.3	19.97	2.07	1679.1	1.6	4.64	513.00	537.96	426.55	421.94	23.60	0.18	5.55	213.29	14.79	10.96	8,886.60	8.47	25.75
10:39	43.7	19.88	2.14	1601.2	1.5	4.64	513.00	537.96	453.58	448.83	23.50	0.18	5.55	231.28	14.31	11.33	8,474.32	7.94	25.75
10:40	45	19.85	2.15	1879.8	1.5	4.64	513.00	537.96	453.58	448.83	23.50	0.18	5.55	238.16	14.16	11.38	9,948.80	7.94	25.75
10:41	46.6	19.86	2.16	1937.5	1.6	4.64	513.00	537.96	453.58	448.83	23.50	0.18	5.55	246.63	14.21	11.43	10,254.18	8.47	25.75
10:42	40.2	19.91	2.02	1822.2	1.6	4.64	513.00	537.96	456.13	451.81	23.20	0.18	5.55	212.76	14.47	10.69	9,643.96	8.47	25.75
10:43	60.3	19.75	2.34	2232.4	3.5	4.64	513.00	537.96	456.13	451.81	23.20	0.18	5.55	319.14	13.63	12.38	11,814.93	18.52	25.75
10:44	45.3	19.92	2.04	2257.8	2.3	4.64	513.00	537.96	456.13	451.81	23.20	0.18	5.55	239.75	14.53	10.80	11,949.36	12.17	25.75
10:45	39.8	19.91	2.07	1451.1	1.6	4.64	513.00	537.96	471.06	466.44	23.30	0.18	5.55	210.64	14.47	10.96	7,679.92	8.47	25.75
10:46	47.5	19.81	2.21	1672.2	1.6	4.64	513.00	537.96	471.06	466.44	23.30	0.18	5.55	251.39	13.94	11.70	8,850.09	8.47	25.75
10:47	60.8	19.64	2.38	2103.8	1.9	4.64	513.00	537.96	471.06	466.44	23.30	0.18	5.55	321.78	13.04	12.60	11,134.32	10.06	25.75
10:48	47.9	19.8	2.22	1386.7	1.4	4.64	513.00	537.96	460.23	456.95	22.50	0.18	5.55	253.51	13.89	11.75	7,339.08	7.41	25.75
10:49	52.4	19.76	2.3	1148.4	1.4	4.64	513.00	537.96	460.23	456.95	22.50	0.18	5.55	277.33	13.68	12.17	6,077.88	7.41	25.75
10:50	54.2	19.71	2.33	1072.4	1.4	4.64	513.00	537.96	460.23	456.95	22.50	0.18	5.55	286.85	13.42	12.33	5,675.66	7.41	25.75
10:51	49.9	19.7	2.31	1249.8	1.3	4.64	513.00	537.96	434.54	431.59	22.40	0.18	5.55	264.09	13.36	12.23	6,614.54	6.88	25.75
10:52	57.5	19.64	2.44	1258.2	1.5	4.64	513.00	537.96	434.54	431.59	22.40	0.18	5.55	304.32	13.04	12.91	6,659.00	7.94	25.75
10:53	56.4	19.67	2.38	1360	1.5	4.64	513.00	537.96	434.54	431.59	22.40	0.18	5.55	298.50	13.20	12.60			

Table O-5 Calculated furnace outlet offgas compositions for M60 and N80-IV-Mod-2 (continued).

TIME (a)	Quench Outlet Dry vol. % / ppm (a)					Wet (b) Quench Outlet (c)		Quench Outlet	Quench Air (d)	Quench Air	Temp. Quench	Dilution	Dilution	Furnace Outlet Offgas Composition (wet basis %) (g)						
	NOx (ppm)	O2 (%)	CO2 (%)	CO (ppm)	SO2 (ppm)	H2O (%)	Flowrate (dscfm)	Flowrate (wscfm)	Flowrate (wacfm)	Flowrate (wscfm)	Air (C) (e)	Factor	Factor (f)	NOx (ppm)	O2 (h)	CO2	CO (ppm)	SO2 (ppm)	H2O	
11:10	42.3	20.01	1.93	865.4	2.1	4.64	513.00	537.96	445.79	442.46	22.60	0.18	5.55	223.87	15.00	10.21	4,580.11	11.11	25.75	
11:11	43.5	19.99	1.99	598.6	1.7	4.64	513.00	537.96	445.79	442.46	22.60	0.18	5.55	230.22	14.90	10.53	3,168.08	9.00	25.75	
11:12	43.8	19.99	1.99	516.1	1.7	4.64	513.00	537.96	432.28	429.05	22.60	0.18	5.55	231.81	14.90	10.53	2,731.45	9.00	25.75	
11:13	40.8	20.06	1.94	482.4	1.5	4.64	513.00	537.96	432.28	429.05	22.60	0.18	5.55	215.93	15.27	10.27	2,553.09	7.94	25.75	
11:14	42.1	20.03	2.01	547.1	1.5	4.64	513.00	537.96	432.28	429.05	22.60	0.18	5.55	222.81	15.11	10.64	2,895.52	7.94	25.75	
11:15	43	19.97	2.04	509.1	1.9	4.64	513.00	537.96	433.76	430.08	22.90	0.18	5.55	227.58	14.79	10.80	2,694.40	10.06	25.75	
11:16	42.1	19.88	2.12	476.9	2.3	4.64	513.00	537.96	433.76	430.08	22.90	0.18	5.55	222.81	14.31	11.22	2,523.98	12.17	25.75	
11:17	44.3	19.96	2.05	664.9	8.8	4.64	513.00	537.96	433.76	430.08	22.90	0.18	5.55	234.46	14.74	10.85	3,518.97	46.57	25.75	
11:18	43.4	19.88	2.1	693.9	16.9	4.64	513.00	537.96	442.04	438.29	22.90	0.18	5.55	229.69	14.31	11.11	3,672.45	89.44	25.75	
11:19	47.9	19.86	2.21	671.1	11.5	4.64	513.00	537.96	442.04	438.29	22.90	0.18	5.55	253.51	14.21	11.70	3,551.78	60.86	25.75	
11:20	49.2	19.76	2.3	559.2	7.5	4.64	513.00	537.96	442.04	438.29	22.90	0.18	5.55	260.39	13.68	12.17	2,959.55	39.69	25.75	
11:21	48.5	19.77	2.3	475.6	6.4	4.64	513.00	537.96	454.64	450.63	23.00	0.18	5.55	256.69	13.73	12.17	2,517.10	33.87	25.75	
11:22	44	19.85	2.18	399.4	3.7	4.64	513.00	537.96	454.64	450.63	23.00	0.18	5.55	232.87	14.16	11.54	2,113.82	19.58	25.75	
11:23	45.3	19.71	2.37	437.5	2.4	4.64	513.00	537.96	454.64	450.63	23.00	0.18	5.55	239.75	13.42	12.54	2,315.46	12.70	25.75	
11:24	46.5	19.82	2.16	630.6	2.3	4.64	513.00	537.96	469.85	464.93	23.50	0.18	5.55	246.10	14.00	11.43	3,337.44	12.17	25.75	
11:25	46.8	19.79	2.21	442.5	2.2	4.64	513.00	537.96	469.85	464.93	23.50	0.18	5.55	247.69	13.84	11.70	2,341.92	11.64	25.75	
14:12	3.3	20.46	1.73	2085.6	2.2	3.92	530	551.62	513.31	487.86	35.70	0.18	5.49	17.41	17.54	9.13	11,001.11	11.60	21.52	
14:13	2.2	20.5	1.97	2363	6.4	3.92	530	551.62	513.31	487.86	35.70	0.18	5.49	11.60	17.76	10.39	12,464.33	33.76	21.52	
14:14	7.2	20.27	2.59	4501.5	6.9	3.92	530	551.62	513.31	487.86	35.70	0.18	5.49	37.98	16.54	13.66	23,744.48	36.40	21.52	
14:15	16.5	20.18	2.68	3340.3	2.2	3.92	530	551.62	608.2	575.25	37.20	0.18	5.49	87.03	16.07	14.14	17,619.39	11.60	21.52	
14:16	17.6	20.2	2.54	1815.7	0.1	3.92	530	551.62	608.2	575.25	37.20	0.18	5.49	92.84	16.17	13.40	9,577.44	0.53	21.52	
14:17	18.9	20.17	2.5	1229.6	0.8	3.92	530	551.62	608.2	575.25	37.20	0.18	5.49	99.69	16.01	13.19	6,485.88	4.22	21.52	
14:18	21.5	20.19	2.41	1158.1	1.4	3.92	530	551.62	510.54	510.54	36.30	0.18	5.49	113.41	16.12	12.71	6,108.74	7.38	21.52	
14:19	26.1	20.31	1.93	712.2	2.6	3.92	530	551.62	538.22	510.54	36.30	0.18	5.49	137.67	16.75	10.18	3,756.71	13.71	21.52	
14:20	16.3	20.37	1.62	524.1	3.4	3.92	530	551.62	538.22	510.54	36.30	0.18	5.49	85.98	17.07	8.55	2,764.52	17.93	21.52	
14:21	7.9	20.36	1.56	808.4	3.7	3.92	530	551.62	496.6	471.52	36.00	0.18	5.49	41.67	17.02	8.23	4,264.14	19.52	21.52	
14:22	7.2	20.26	1.93	1297.9	3.3	3.92	530	551.62	496.6	471.52	36.00	0.18	5.49	37.98	16.49	10.18	6,846.15	17.41	21.52	
14:23	8.9	20.16	2.26	2102.6	2.5	3.92	530	551.62	496.6	471.52	36.00	0.18	5.49	46.95	15.96	11.92	11,090.78	13.19	21.52	
14:24	5.2	20.15	2.57	2815.6	0.8	3.92	530	551.62	496.89	472.25	35.70	0.18	5.49	27.43	15.91	13.56	14,851.70	4.22	21.52	
14:25	6.9	20.1	2.88	3744.5	0.4	3.92	530	551.62	496.89	472.25	35.70	0.18	5.49	36.40	15.65	15.19	19,751.46	2.11	21.52	
14:26	8.6	20.1	2.91	3392.8	1.3	3.92	530	551.62	496.89	472.25	35.70	0.18	5.49	45.36	15.65	15.35	17,896.31	6.86	21.52	
14:27	9.7	20.08	3.03	3532.8	1.1	3.92	530	551.62	536.8	510.02	35.80	0.18	5.49	51.17	15.54	15.98	18,634.79	5.80	21.52	
14:28	10.7	20.03	3.14	3272.9	1.3	3.92	530	551.62	536.8	510.02	35.80	0.18	5.49	56.44	15.28	16.56	17,263.87	6.86	21.52	
14:29	12.2	20.03	3.07	3003.8	1.4	3.92	530	551.62	536.8	510.02	35.80	0.18	5.49	64.35	15.28	16.19	15,844.42	7.38	21.52	
14:30	8.9	20.06	3.02	2651.8	2	3.92	530	551.62	543.66	513.54	37.60	0.18	5.49	46.95	15.43	15.93	13,987.69	10.55	21.52	
14:31	15.7	20.1	2.73	1240.9	3.2	3.92	530	551.62	543.66	513.54	37.60	0.18	5.49	82.81	15.65	14.40	6,545.49	16.88	21.52	
14:32	10.9	20.26	2.44	227.9	4.4	3.92	530	551.62	543.66	513.54	37.60	0.18	5.49	57.50	16.49	12.87	1,202.13	23.21	21.52	
14:33	15.9	20.14	2.69	299.3	4.5	3.92	530	551.62	503.89	474.29	38.70	0.18	5.49	83.87	15.86	14.19	1,578.75	23.74	21.52	
14:34	15.6	20.07	2.88	515	4.6	3.92	530	551.62	503.89	474.29	38.70	0.18	5.49	82.29	15.49	15.19	2,716.52	24.26	21.52	
14:35	13.2	20.07	3.02	1247.5	4.9	3.92	530	551.62	503.89	474.29	38.70	0.18	5.49	69.63	15.49	15.93	6,580.30	25.85	21.52	
14:36	20.3	20.02	3.08	1527.1	4.4	3.92	530	551.62	498.87	470.63	38.00	0.18	5.49	107.08	15.22	16.25	8,055.13	23.21	21.52	
14:37	17.5	20.02	3.01	1531.1	4.5	3.92	530	551.62	498.87	470.63	38.00	0.18	5.49	92.31	15.22	15.88	8,076.23	23.74	21.52	
14:38	12.5	20.1	2.8	1748.3	4.3	3.92	530	551.62	498.87	470.63	38.00	0.18	5.49	65.93	15.65	14.77	9,221.92	22.68	21.52	
14:39	21.5	20.11	2.85	785.1	5	3.92	530	551.62	500.85	469.92	39.70	0.18	5.49	113.41	15.70	15.03	4,141.24	26.37	21.52	
14:40	22.4	20.04	3.05	1203.2	4.7	3.92	530	551.62	500.85	469.92	39.70	0.18	5.49	118.16	15.33	16.09	6,346.63	24.79	21.52	
14:41	12.8	20.02	3.01	1697.3	4.7	3.92	530	551.62	500.85	469.92	39.70	0.18	5.49	67.52	15.22	15.88	8,952.90	24.79	21.52	
14:42	18.5	20.01	3.07	1523.2	5	3.92	530	551.62	581.24	545.87	39.40	0.18	5.49	97.58	15.17	16.19	8,034.56	26.37	21.52	
14:43	22.1	20.03	3.05	1170.9	4.9	3.92	530	551.62	581.24	545.87	39.40	0.18	5.49	116.57	15.28	16.09	6,176.25	25.85	21.52	
14:44	18.7	20.04	3.04	1272.9	5.2	3.92	530	551.62	581.24	545.87	39.40	0.18	5.49	98.64	15.33	16.04	6,714.28	27.43	21.52	
14:45	19.6	20.06	2.95	1080.3	5	3.92	530	551.62	506.09	475.45	39.30	0.18	5.49	103.39	15.43	15.56	5,698			

- a. Data obtained from Continuous Emissions Monitoring Systems (CEMS) data provided by Entropy personnel.
- b. Moisture content, percent by volume, as shown in analysis from particulate/methane sampling period (MMT).
- c. Source gas volumetric flowrate from MMT data.
- d. Quench air flowrate, channel 15 from Data Acquisition System (DAS).
- e. Quench air temperature, channel 1 from DAS.
- f. Calculated from mass and energy balances at the quench section as the quench outlet flowrate divided by the furnace outlet flowrate
- g. Calculated from the quench outlet composition and the dilution factor, making the necessary conversions from a dry to a wet basis
- h. Calculated from the quench outlet composition and the dilution factor, taking into account the amount of oxygen added by the quench air

Appendix P

Particulate/Metals Reduced Data

Appendix P-1

MMT Analysis for the S60 Feed Mixture

Table P-1-1. MMT analysis for the S60 feed mixture.

FIELD DATA	RUN1	RUN2
Enter Pathway	d:\11885\	d:\11885\
Enter File Name	mt-s60-1	mt-s60-2
Complete Path Is	d:\11885\mt-s60	d:\11885\mt-s60-2
Enter Number of Runs	2	
Plant Name, City, State	U.S. Bureau of Mines, Albany, Oregon	
Test Location	Arc Melter Exhaust	
Enter Operator Name(s)	Miguel Chavez	Miguel Chavez Miguel Chavez

Press <Alt> C To Combine The Data From The Laptop Files

Run Number	MMT-S60-1	MMT-S60-2
Date	7/19/93	7/19/93
Start	1156	1406
Stop	1321	1522
Points	12	12
Theta	60	60
Dia	0.259	0.215
Cp	0.99	0.99
Y	1.006	1.006
Pbar	29.88	29.88
Delta-H	2.383333333	1.698333333
Vm	46.871	39.843
tm	67.58333333	77
Vlc	64.8	57.9
CO2	1.9	1.8
O2	20	20
Pg	-1.6	-1.6
ts	154	172
Delta-p	0.634060963	0.626678522
Area	23.75829444	23.75829444
F-Factor		
Tstd	68	68
Pstd	29.92	29.92

< Indicates the value is below the detection limit.

LABORATORY DATA			RUN1		RUN2	
Compound	Fwt	Unit	FH	BH	FH	BH
1 Arsenic	74.92	mg <	3.82	0.15 <	2.40 <	0.10
2 Aluminum	26.98	mg	346.42	0.45	181.50	0.43
3 Barium	137.33	mg	20.20 <	0.03	11.64 <	0.03
4 Boron	10.81	mg	-	0.23	-	0.38
5 Cadmium	112.41	mg	0.19 <	0.00	0.13 <	0.00
6 Calcium	40.08	mg	820.86	1.55	368.70	3.57
7 Cerium	140.12	mg	64.66 <	0.05	17.25 <	0.05
8 Cesium	132.91	mg				
9 Chromium	52	mg	2.50 <	0.01	2.91 <	0.01
10 Copper	63.55	mg	11.97 <	0.05	48.77 <	0.05
11 Iron	55.85	mg	880.57 <	0.25	545.63 <	0.26
12 Lead	207.19	mg	7.56 <	0.05	12.82 <	0.05
13 Magnesium	24.31	mg	177.99 <	0.25	96.74 <	0.26
14 Manganese	54.94	mg	8.38 <	0.01	7.06 <	0.01
15 Mercury	200.59	mg <	3.82 <	0.10 <	2.40 <	0.10
16 Nickel	58.71	mg	1.09 <	0.03	0.84 <	0.03
17 Phosphorus	30.97	mg	71.24 <	0.10	164.25	0.10
18 Potassium	39.1	mg	1340.31 <	0.25	1093.25	0.33
19 Selenium	78.96	mg <	3.82 <	0.10 <	2.40 <	0.10
20 Silicon	28.09	mg	2118.97 <	0.10	1258.49 <	0.10
21 Silver	107.87	mg <	0.38 <	0.03	0.24 <	0.03
22 Sodium	22.99	mg	1295.78	2.50	1052.17	5.36
23 Strontium	87.62	mg	7.04 <	0.01	4.02 <	0.01
24 Titanium	47.9	mg	41.42 <	0.03	18.30 <	0.03
25 Vanadium	50.94	mg	4.54 <	0.01	3.20 <	0.01
26 Zinc	65.38	mg	33.60 <	0.25	30.35 <	0.26
27 Zirconium	91.22	mg	0.90 <	0.03	0.52 <	0.03
28 Particulate (Filter)		g	16.334		8.783	
29 Particulate (Nitric Acid)		g	1.074		0.941	
30 Particulate (Acetone)		g	1.682		2.261	

< Indicates the value is below the detection limit.

LABORATORY DATA

Particulate Total (g)	19.09		11.986	
Sample Volume (ml)	500		510	
Compound	FH (mg/kg)	BH (ug/L)	FH (mg/kg)	BH (ug/L)
Arsenic	< 200	300	< 200	< 200
Aluminum	18147	900	15143	850
Barium	1058	< 50	971	< 50
Boron	-	450	-	750
Cadmium	10	< 1	11	< 1
Calcium	43000	3100	30762	7000
Cerium	3387	< 100	1439	< 100
Cesium				
Chromium	131	< 20	243	< 20
Copper	627	< 100	4069	< 100
Iron	46128	< 500	45524	< 500
Lead	396	< 100	1070	< 100
Magnesium	9324	< 500	8071	< 500
Manganese	439	< 20	589	< 20
Mercury	< 200	< 200	< 200	< 200
Nickel	57	< 50	70	< 50
Phosphorus	3732	< 200	13704	200
Potassium	70211	< 500	91214	650
Selenium	< 200	< 200	< 200	< 200
Silicon	111000	< 200	105000	< 200
Silver	< 20	< 50	20	< 50
Sodium	67878	5000	87786	10500
Strontium	369	< 20	335	< 20
Titanium	2170	< 50	1527	< 50
Vanadium	238	< 20	267	< 20
Zinc	1760	< 500	2532	< 500
Zirconium	47	< 50	43	< 50

< Indicates the value is below the detection limit.

Plant: U.S. Bureau of Mines, Albany; Oregon
 Test Location: Arc Melter Exhaust

Run Number	Run Date	Operator
MMT-S60-1	7/19/93	Miguel Chavez
MMT-S60-2	7/19/93	Miguel Chavez

		MMT-S60-1	MMT-S60-2
	Run Start Time	1156	1406
	Run Stop Time	1321	1522
	Net Sampling/Traversing Points	12	12
	Net Run Time, Minutes	60	60
Dia	Nozzle Diameter, Inches	0.259	0.215
Cp	Pitot Tube Coefficient	0.99	0.99
Y	Dry Gas Meter Calibration Coefficient	1.0060	1.0060
Pbar	Barometric Pressure, Inches Hg	29.88	29.88
Delta-H	Orifice Average Pressure Differential, Inch	2.383	1.698
Vm	Sampled Volume of Source Gas, Dry ACF	46.871	39.843
Vmm	Sampled Volume of Source Gas, Dry ACM	1.33	1.13
tm	Dry Gas Meter Temperature, Degrees F	68	77
Vmstd	Sampled Volume of Source Gas, Dry SCF	47.403	39.522
Vmstdm	Sampled Volume of Source Gas, Dry SCM	1.342	1.119
Vlc	Volume of Condensed Liquid, mL	64.8	57.9
Vwstd	Volume of Water Vapor, SCF	3.050	2.725
%H2O	Moisture Content, Percent by Volume	6.05	6.45
%H2Osat	Saturated Moisture Content, Percent by Volu	28.0	42.8
Mfd	Source Gas Dry Mole Fraction	0.940	0.935
%CO2	Source Gas CO2 Content, Percent by Dry Volu	1.9	1.8
%O2	Source Gas O2 Content, Percent by Dry Volum	20.0	20.0
Md	Source Gas Dry Molecular Weight, Lb/Lb-Mole	29.10	29.09
Ms	Source Gas Wet Molecular Weight, Lb/Lb-Mole	28.43	28.37
Pg	Source Gas Static Pressure, Inches H2O	-1.60	-1.60
Ps	Source Gas Absolute Pressure, Inches Hg	29.76	29.76
ts	Source Gas Temperature, Degrees F	154	172
Delta-p	Source Gas Average Velocity Head, Inches H2	0.6341	0.6267
vs	Source Gas Velocity, Feet/Second	57.41	57.96
A	Source Cross Sectional Area, Square Inches	24	24
Qsd	Source Gas Volumetric Flow Rate, Dry SCFM	457	446
Qmsd	Source Gas Volumetric Flow Rate, Dry SCMM	13	13
Qaw	Source Gas Volumetric Flow Rate, Wet ACFM	568	574
Qmaw	Source Gas Volumetric Flow Rate, Wet ACMM	16	16
%I	Average Isokinetic Sampling Rate, Percent	78.0	96.6
%EA	Excess Air, Percent	3234	3102
Fo	Fuel Factor	0.474	0.500

Note:

All standard volumes and flow rates based on 68 Degrees F (20 Degrees C) -- 29.92 Inches of Mercury (Hg)
 The lesser of %H2O and %H2Osat was used for calculation purposes.

		MMT-S60-1	MMT-S60-2
Arsenic			
FWt	Formula Weight, Lb/Lb-Mole	74.92	74.92
mg	Catch Weight, Milligrams	< 4.0	< 2.5
ug/DSCM	Concentration, Micrograms per DSCM	< 2,956	< 2,233
ng/DSCM	Concentration, Nanograms per DSCM	< 2.96E+06	< 2.23E+06
lb/hr	Emission Rate, Pounds per Hour	< 5.06E-03	< 3.73E-03
Aluminum			
FWt	Formula Weight, Lb/Lb-Mole	26.98	26.98
mg	Catch Weight, Milligrams	346.9	181.9
ug/DSCM	Concentration, Micrograms per DSCM	258,416	162,563
ng/DSCM	Concentration, Nanograms per DSCM	2.58E+08	1.63E+08
lb/hr	Emission Rate, Pounds per Hour	4.42E-01	2.72E-01
Barium			
FWt	Formula Weight, Lb/Lb-Mole	137.33	137.33
mg	Catch Weight, Milligrams	< 20.2	< 11.7
ug/DSCM	Concentration, Micrograms per DSCM	< 15,065	< 10,422
ng/DSCM	Concentration, Nanograms per DSCM	< 1.51E+07	< 1.04E+07
lb/hr	Emission Rate, Pounds per Hour	< 2.58E-02	< 1.74E-02
Boron			
FWt	Formula Weight, Lb/Lb-Mole	10.81	10.81
mg	Catch Weight, Milligrams	0.2	0.4
ug/DSCM	Concentration, Micrograms per DSCM	168	342
ng/DSCM	Concentration, Nanograms per DSCM	1.68E+05	3.42E+05
lb/hr	Emission Rate, Pounds per Hour	2.87E-04	5.71E-04
Cadmium			
FWt	Formula Weight, Lb/Lb-Mole	112.41	112.41
mg	Catch Weight, Milligrams	< 0.2	< 0.1
ug/DSCM	Concentration, Micrograms per DSCM	< 143	< 118
ng/DSCM	Concentration, Nanograms per DSCM	< 1.43E+05	< 1.18E+05
lb/hr	Emission Rate, Pounds per Hour	< 2.44E-04	< 1.98E-04
Calcium			
FWt	Formula Weight, Lb/Lb-Mole	40.08	40.08
mg	Catch Weight, Milligrams	822.4	372.3
ug/DSCM	Concentration, Micrograms per DSCM	612,686	332,638
ng/DSCM	Concentration, Nanograms per DSCM	6.13E+08	3.33E+08
lb/hr	Emission Rate, Pounds per Hour	1.05E+00	5.56E-01

< Indicates the value is below the detection limit.

		MMT-S60-1	MMT-S60-2
Cerium			
FWt	Formula Weight, Lb/Lb-Mole	140.12	140.12
mg	Catch Weight, Milligrams	< 64.7	< 17.3
ug/DSCM	Concentration, Micrograms per DSCM	< 48,206	< 15,457
ng/DSCM	Concentration, Nanograms per DSCM	< 4.82E+07	< 1.55E+07
lb/hr	Emission Rate, Pounds per Hour	< 8.25E-02	< 2.58E-02
Cesium			
FWt	Formula Weight, Lb/Lb-Mole	132.91	132.91
mg	Catch Weight, Milligrams	0.0	0.0
ug/DSCM	Concentration, Micrograms per DSCM	0	0
ng/DSCM	Concentration, Nanograms per DSCM	0.00E+00	0.00E+00
lb/hr	Emission Rate, Pounds per Hour	0.00E+00	0.00E+00
Chromium			
FWt	Formula Weight, Lb/Lb-Mole	52.00	52.00
mg	Catch Weight, Milligrams	< 2.5	< 2.9
ug/DSCM	Concentration, Micrograms per DSCM	< 1,870	< 2,612
ng/DSCM	Concentration, Nanograms per DSCM	< 1.87E+06	< 2.61E+06
lb/hr	Emission Rate, Pounds per Hour	< 3.20E-03	< 4.36E-03
Copper			
FWt	Formula Weight, Lb/Lb-Mole	63.55	63.55
mg	Catch Weight, Milligrams	< 12.0	< 48.8
ug/DSCM	Concentration, Micrograms per DSCM	< 8,954	< 43,623
ng/DSCM	Concentration, Nanograms per DSCM	< 8.95E+06	< 4.36E+07
lb/hr	Emission Rate, Pounds per Hour	< 1.53E-02	< 7.29E-02
Iron			
FWt	Formula Weight, Lb/Lb-Mole	55.85	55.85
mg	Catch Weight, Milligrams	< 880.8	< 545.9
ug/DSCM	Concentration, Micrograms per DSCM	< 656,203	< 487,771
ng/DSCM	Concentration, Nanograms per DSCM	< 6.56E+08	< 4.88E+08
lb/hr	Emission Rate, Pounds per Hour	< 1.12E+00	< 8.15E-01
Lead			
FWt	Formula Weight, Lb/Lb-Mole	207.19	207.19
mg	Catch Weight, Milligrams	< 7.6	< 12.9
ug/DSCM	Concentration, Micrograms per DSCM	< 5,669	< 11,505
ng/DSCM	Concentration, Nanograms per DSCM	< 5.67E+06	< 1.15E+07
lb/hr	Emission Rate, Pounds per Hour	< 9.70E-03	< 1.92E-02

< Indicates the value is below the detection limit.

MMT-S60-1

MMT-S60-2

Magnesium

FWt	Formula Weight, Lb/Lb-Mole		24.31		24.31
mg	Catch Weight, Milligrams	<	178.2	<	97.0
ug/DSCM	Concentration, Micrograms per DSCM	<	132,789	<	86,665
ng/DSCM	Concentration, Nanograms per DSCM	<	1.33E+08	<	8.67E+07
lb/hr	Emission Rate, Pounds per Hour	<	2.27E-01	<	1.45E-01

Manganese

FWt	Formula Weight, Lb/Lb-Mole		54.94		54.94
mg	Catch Weight, Milligrams	<	8.4	<	7.1
ug/DSCM	Concentration, Micrograms per DSCM	<	6,251	<	6,317
ng/DSCM	Concentration, Nanograms per DSCM	<	6.25E+06	<	6.32E+06
lb/hr	Emission Rate, Pounds per Hour	<	1.07E-02	<	1.06E-02

Mercury

FWt	Formula Weight, Lb/Lb-Mole		200.59		200.59
mg	Catch Weight, Milligrams	<	3.9	<	2.5
ug/DSCM	Concentration, Micrograms per DSCM	<	2,919	<	2,233
ng/DSCM	Concentration, Nanograms per DSCM	<	2.92E+06	<	2.23E+06
lb/hr	Emission Rate, Pounds per Hour	<	4.99E-03	<	3.73E-03

Nickel

FWt	Formula Weight, Lb/Lb-Mole		58.71		58.71
mg	Catch Weight, Milligrams	<	1.1	<	0.9
ug/DSCM	Concentration, Micrograms per DSCM	<	829	<	772
ng/DSCM	Concentration, Nanograms per DSCM	<	8.29E+05	<	7.72E+05
lb/hr	Emission Rate, Pounds per Hour	<	1.42E-03	<	1.29E-03

Phosphorus

FWt	Formula Weight, Lb/Lb-Mole		30.97		30.97
mg	Catch Weight, Milligrams	<	71.3	<	164.4
ug/DSCM	Concentration, Micrograms per DSCM	<	53,150	<	146,855
ng/DSCM	Concentration, Nanograms per DSCM	<	5.31E+07	<	1.47E+08
lb/hr	Emission Rate, Pounds per Hour	<	9.09E-02	<	2.45E-01

Potassium

FWt	Formula Weight, Lb/Lb-Mole		39.10		39.10
mg	Catch Weight, Milligrams	<	1340.6		1093.6
ug/DSCM	Concentration, Micrograms per DSCM	<	998,703		977,160
ng/DSCM	Concentration, Nanograms per DSCM	<	9.99E+08		9.77E+08
lb/hr	Emission Rate, Pounds per Hour	<	1.71E+00		1.63E+00

< Indicates the value is below the detection limit.

		MMT-S60-1		MMT-S60-2	
Selenium					
FWt	Formula Weight, Lb/Lb-Mole		78.96		78.96
mg	Catch Weight, Milligrams	<	3.9	<	2.5
ug/DSCM	Concentration, Micrograms per DSCM	<	2,919	<	2,233
ng/DSCM	Concentration, Nanograms per DSCM	<	2.92E+06	<	2.23E+06
lb/hr	Emission Rate, Pounds per Hour	<	4.99E-03	<	3.73E-03
Silicon					
FWt	Formula Weight, Lb/Lb-Mole		28.09		28.09
mg	Catch Weight, Milligrams	<	2119.1	<	1258.6
ug/DSCM	Concentration, Micrograms per DSCM	<	1,578,679	<	1,124,598
ng/DSCM	Concentration, Nanograms per DSCM	<	1.58E+09	<	1.12E+09
lb/hr	Emission Rate, Pounds per Hour	<	2.70E+00	<	1.88E+00
Silver					
FWt	Formula Weight, Lb/Lb-Mole		107.87		107.87
mg	Catch Weight, Milligrams	<	0.4	<	0.3
ug/DSCM	Concentration, Micrograms per DSCM	<	303	<	237
ng/DSCM	Concentration, Nanograms per DSCM	<	3.03E+05	<	2.37E+05
lb/hr	Emission Rate, Pounds per Hour	<	5.18E-04	<	3.96E-04
Sodium					
FWt	Formula Weight, Lb/Lb-Mole		22.99		22.99
mg	Catch Weight, Milligrams		1298.3		1057.5
ug/DSCM	Concentration, Micrograms per DSCM		967,201		944,936
ng/DSCM	Concentration, Nanograms per DSCM		9.67E+08		9.45E+08
lb/hr	Emission Rate, Pounds per Hour		1.65E+00		1.58E+00
Strontium					
FWt	Formula Weight, Lb/Lb-Mole		87.62		87.62
mg	Catch Weight, Milligrams	<	7.1	<	4.0
ug/DSCM	Concentration, Micrograms per DSCM	<	5,255	<	3,597
ng/DSCM	Concentration, Nanograms per DSCM	<	5.26E+06	<	3.60E+06
lb/hr	Emission Rate, Pounds per Hour	<	8.99E-03	<	6.01E-03
Titanium					
FWt	Formula Weight, Lb/Lb-Mole		47.90		47.90
mg	Catch Weight, Milligrams	<	41.4	<	18.3
ug/DSCM	Concentration, Micrograms per DSCM	<	30,880	<	16,376
ng/DSCM	Concentration, Nanograms per DSCM	<	3.09E+07	<	1.64E+07
lb/hr	Emission Rate, Pounds per Hour	<	5.28E-02	<	2.74E-02

< Indicates the value is below the detection limit.

		MMT-S60-1	MMT-S60-2
Vanadium			
Fwt	Formula Weight, Lb/Lb-Mole	50.94	50.94
mg	Catch Weight, Milligrams	< 4.6	< 3.2
ug/DSCM	Concentration, Micrograms per DSCM	< 3,392	< 2,869
ng/DSCM	Concentration, Nanograms per DSCM	< 3.39E+06	< 2.87E+06
lb/hr	Emission Rate, Pounds per Hour	< 5.80E-03	< 4.79E-03
Zinc			
Fwt	Formula Weight, Lb/Lb-Mole	65.38	65.38
mg	Catch Weight, Milligrams	< 33.8	< 30.6
ug/DSCM	Concentration, Micrograms per DSCM	< 25,216	< 27,345
ng/DSCM	Concentration, Nanograms per DSCM	< 2.52E+07	< 2.73E+07
lb/hr	Emission Rate, Pounds per Hour	< 4.31E-02	< 4.57E-02
Zirconium			
Fwt	Formula Weight, Lb/Lb-Mole	91.22	91.22
mg	Catch Weight, Milligrams	< 0.9	< 0.5
ug/DSCM	Concentration, Micrograms per DSCM	< 687	< 483
ng/DSCM	Concentration, Nanograms per DSCM	< 6.87E+05	< 4.83E+05
lb/hr	Emission Rate, Pounds per Hour	< 1.18E-03	< 8.08E-04
Particulate			
g	Catch Weight, Grams (Filter)	16.3338	8.7834
%	Percent of Particulate in Filter	85.6	73.3
g	Catch Weight, Grams (HNO3)	1.0743	0.941
%	Percent of Particulate in HNO3 Rinse	5.6	7.9
g	Catch Weight, Grams (Acetone)	1.6817	2.2612
%	Percent of Particulate in Acetone Rinse	8.8	18.9
g	Catch Weight, Grams (Total)	19.0898	11.9856
g/DSCM	Concentration, Total Milligrams per DSCM	14.222	10.710
gr/DSCF	Concentration, Total Grains per DSCF	6.215	4.680
lb/hr	Emission Rate, Total Pounds per Hour	24.330	17.894

< Indicates the value is below the detection limit.

Appendix P-2

MMT Analysis for the S60-IV Feed Mixture

Table P-2-1. MMT analysis for the S60-IV feed mixture.

FIELD DATA	RUN1	RUN2
Enter Pathway	d:\11885\	d:\11885\
Enter File Name	s60-iv-1	s60-iv-2
Complete Path Is	d:\11885\s60-iv	d:\11885\s60-iv-2
Enter Number of Runs	2	
Plant Name, City, State	U.S. Bureau of Mines, Albany, Oregon	
Test Location	Arc Melter Exhaust	
Enter Operator Name(s)	Miguel Chavez	Miguel Chavez Miguel Chavez

Press <Alt> C To Combine The Data From The Laptop Files

Run Number	MMT-S60-IV-1	MMT-S60-IV-2
Date	7/20/93	7/20/93
Start	1214	1523
Stop	1340	1645
Points	12	12
Theta	60	60
Dia	0.194	0.194
Cp	0.99	0.99
Y	1.006	1.006
Pbar	29.88	29.88
Delta-H	1.083333333	1.108333333
Vm	33.24	34.115
tm	74.83333333	77.83333333
Vlc	63	47.3
CO2	1.8	1.8
O2	20.5	20.5
Pg	-1.6	-1.6
ts	174.0833333	174.6666667
Delta-p	0.66175825	0.67176598
Area	23.75829444	23.75829444
F-Factor		
Tstd	68	68
Pstd	29.92	29.92

< Indicates the value is below the detection limit.

LABORATORY DATA				RUN1				RUN2			
Compound		Fwt Unit		FH		BH		FH		BH	
1	Arsenic	74.92	mg <	2.77	<	0.10	<	1.92	<	0.10	
2	Aluminum	26.98	mg	181.84		0.73		136.48		0.43	
3	Barium	137.33	mg	17.30	<	0.03		5.75	<	0.02	
4	Boron	10.81	mg	-		0.28		-		0.17	
5	Cadmium	112.41	mg	0.17	<	0.00		0.12	<	0.00	
6	Calcium	40.08	mg	578.25		3.28		2278.94		2.74	
7	Cerium	140.12	mg	47.21	<	0.05		24.66	<	0.02	
8	Cesium	132.91	mg								
9	Chromium	52	mg	1.90		0.03		1.53	<	0.01	
10	Copper	63.55	mg	4.44	<	0.05		3.73	<	0.05	
11	Iron	55.85	mg	660.95		0.25		242.56	<	0.24	
12	Lead	207.19	mg	7.42	<	0.05		2.44	<	0.05	
13	Magnesium	24.31	mg	103.82	<	0.25		90.01	<	0.24	
14	Manganese	54.94	mg	7.51	<	0.01		2.88	<	0.01	
15	Mercury	200.59	mg <	2.77	<	0.10	<	1.92	<	0.10	
16	Nickel	58.71	mg	0.64	<	0.03		0.46	<	0.02	
17	Phosphorus	30.97	mg	48.28	<	0.10		33.66	<	0.05	
18	Potassium	39.1	mg	863.19		0.42		643.35	<	0.24	
19	Selenium	78.96	mg <	2.77	<	0.10	<	1.92	<	0.10	
20	Silicon	28.09	mg	1283.31	<	0.10		722.44	<	0.10	
21	Silver	107.87	mg <	0.28	<	0.03		0.19	<	0.02	
22	Sodium	22.99	mg	1124.99		5.68		437.10		4.18	
23	Strontium	87.62	mg	5.52		0.01		3.38	<	0.01	
24	Titanium	47.9	mg	33.13	<	0.03		11.42	<	0.02	
25	Vanadium	50.94	mg	3.47	<	0.01		1.56	<	0.01	
26	Zinc	65.38	mg	25.06	<	0.25		9.38	<	0.24	
27	Zirconium	91.22	mg	1.33	<	0.03		0.50	<	0.02	
28	Particulate (Filter)		g	12.53				7.15			
29	Particulate (Nitric Acid)		g	0.78				1.08			
30	Particulate (Acetone)		g	0.52				1.38			

< Indicates the value is below the detection limit.

LABORATORY DATA

Particulate Total (g)	13.837		9.6158	
Sample Volume (ml)		505		480
Compound	FH (mg/kg)	BH (ug/L)	FH (mg/kg)	BH (ug/L)
Arsenic	< 200 <	200 <	200 <	200
Aluminum	13142	1450	14193	900
Barium	1250 <	50	598 <	50
Boron	-	550	-	350
Cadmium	12 <	1	12 <	1
Calcium	41791	6500	237000	5700
Cerium	3412 <	100	2565 <	50
Cesium				
Chromium	137	51	159 <	20
Copper	321 <	100	388 <	100
Iron	47768	500	25225 <	500
Lead	536 <	100	254 <	100
Magnesium	7503 <	500	9361 <	500
Manganese	543 <	20	300 <	20
Mercury	< 200 <	200 <	200 <	200
Nickel	46 <	50	48 <	50
Phosphorus	3489 <	200	3500 <	100
Potassium	62384	825	66905 <	500
Selenium	< 200 <	200 <	200 <	200
Silicon	92747 <	200	75131 <	200
Silver	< 20 <	50	20 <	50
Sodium	81305	11250	45456	8700
Strontium	399	21	351 <	20
Titanium	2394 <	50	1188 <	50
Vanadium	251 <	20	162 <	20
Zinc	1811 <	500	975 <	500
Zirconium	96 <	50	52 <	50

< Indicates the value is below the detection limit.

Plant: U.S. Bureau of Mines, Albany, Oregon
 Test Location: Arc Melter Exhaust

Run Number	Run Date	Operator
MMT-S60-IV-1	7/20/93	Miguel Chavez
MMT-S60-IV-2	7/20/93	Miguel Chavez

		MMT-S60-IV-1	MMT-S60-IV-2
	Run Start Time	1214	1523
	Run Stop Time	1340	1645
	Net Sampling/Traversing Points	12	12
	Net Run Time, Minutes	60	60
Dia	Nozzle Diameter, Inches	0.194	0.194
Cp	Pitot Tube Coefficient	0.99	0.99
Y	Dry Gas Meter Calibration Coefficient	1.0060	1.0060
Pbar	Barometric Pressure, Inches Hg	29.88	29.88
Delta-H	Orifice Average Pressure Differential, Inch	1.083	1.108
Vm	Sampled Volume of Source Gas, Dry ACF	33.240	34.115
Vmm	Sampled Volume of Source Gas, Dry ACM	0.94	0.97
tm	Dry Gas Meter Temperature, Degrees F	75	78
Vmstd	Sampled Volume of Source Gas, Dry SCF	33.056	33.739
Vmstdm	Sampled Volume of Source Gas, Dry SCM	0.936	0.955
Vlc	Volume of Condensed Liquid, mL	63.0	47.3
Vwstd	Volume of Water Vapor, SCF	2.965	2.226
%H2O	Moisture Content, Percent by Volume	8.23	6.19
%H2Osat	Saturated Moisture Content, Percent by Volu	44.9	45.5
Mfd	Source Gas Dry Mole Fraction	0.918	0.938
%CO2	Source Gas CO2 Content, Percent by Dry Volu	1.8	1.8
%O2	Source Gas O2 Content, Percent by Dry Volum	20.5	20.5
Md	Source Gas Dry Molecular Weight, Lb/Lb-Mole	29.11	29.11
Ms	Source Gas Wet Molecular Weight, Lb/Lb-Mole	28.19	28.42
Pg	Source Gas Static Pressure, Inches H2O	-1.60	-1.60
Ps	Source Gas Absolute Pressure, Inches Hg	29.76	29.76
ts	Source Gas Temperature, Degrees F	174	175
Delta-p	Source Gas Average Velocity Head, Inches H2	0.6618	0.6718
vs	Source Gas Velocity, Feet/Second	59.85	60.09
A	Source Cross Sectional Area, Square Inches	24	24
Qsd	Source Gas Volumetric Flow Rate, Dry SCFM	450	462
Qmsd	Source Gas Volumetric Flow Rate, Dry SCMM	13	13
Qaw	Source Gas Volumetric Flow Rate, Wet ACFM	592	595
Qmaw	Source Gas Volumetric Flow Rate, Wet ACMM	17	17
%I	Average Isokinetic Sampling Rate, Percent	98.3	97.9
%EA	Excess Air, Percent	160156	160156
Fo	Fuel Factor	0.222	0.222

Note:

All standard volumes and flow rates based on 68 Degrees F (20 Degrees C) -- 29.92 Inches of Mercury (Hg)
 The lesser of %H2O and %H2Osat was used for calculation purposes

Arsenic

FWt	Formula Weight, Lb/Lb-Mole		74.92		74.92
mg	Catch Weight, Milligrams	<	2.9	<	2.0
ug/DSCM	Concentration, Micrograms per DSCM	<	3,064	<	2,113
ng/DSCM	Concentration, Nanograms per DSCM	<	3.06E+06	<	2.11E+06
lb/hr	Emission Rate, Pounds per Hour	<	5.17E-03	<	3.66E-03

Aluminum

FWt	Formula Weight, Lb/Lb-Mole		26.98		26.98
mg	Catch Weight, Milligrams		182.6		136.9
ug/DSCM	Concentration, Micrograms per DSCM		195,048		143,302
ng/DSCM	Concentration, Nanograms per DSCM		1.95E+08		1.43E+08
lb/hr	Emission Rate, Pounds per Hour		3.29E-01		2.48E-01

Barium

FWt	Formula Weight, Lb/Lb-Mole		137.33		137.33
mg	Catch Weight, Milligrams	<	17.3	<	5.8
ug/DSCM	Concentration, Micrograms per DSCM	<	18,505	<	6,044
ng/DSCM	Concentration, Nanograms per DSCM	<	1.85E+07	<	6.04E+06
lb/hr	Emission Rate, Pounds per Hour	<	3.12E-02	<	1.05E-02

Boron

FWt	Formula Weight, Lb/Lb-Mole		10.81		10.81
mg	Catch Weight, Milligrams		0.3		0.2
ug/DSCM	Concentration, Micrograms per DSCM		297		176
ng/DSCM	Concentration, Nanograms per DSCM		2.97E+05		1.76E+05
lb/hr	Emission Rate, Pounds per Hour		5.01E-04		3.04E-04

Cadmium

FWt	Formula Weight, Lb/Lb-Mole		112.41		112.41
mg	Catch Weight, Milligrams	<	0.2	<	0.1
ug/DSCM	Concentration, Micrograms per DSCM	<	178	<	121
ng/DSCM	Concentration, Nanograms per DSCM	<	1.78E+05	<	1.21E+05
lb/hr	Emission Rate, Pounds per Hour	<	3.00E-04	<	2.10E-04

Calcium

FWt	Formula Weight, Lb/Lb-Mole		40.08		40.08
mg	Catch Weight, Milligrams		581.5		2281.7
ug/DSCM	Concentration, Micrograms per DSCM		621,265		2,388,230
ng/DSCM	Concentration, Nanograms per DSCM		6.21E+08		2.39E+09
lb/hr	Emission Rate, Pounds per Hour		1.05E+00		4.13E+00

< Indicates the value is below the detection limit.

		MMT-S60-IV-1	MMT-S60-IV-2
Cerium			
FWt	Formula Weight, Lb/Lb-Mole	140.12	140.12
mg	Catch Weight, Milligrams	< 47.3	< 24.7
ug/DSCM	Concentration, Micrograms per DSCM	< 50,490	< 25,841
ng/DSCM	Concentration, Nanograms per DSCM	< 5.05E+07	< 2.58E+07
lb/hr	Emission Rate, Pounds per Hour	< 8.52E-02	< 4.47E-02
Cesium			
FWt	Formula Weight, Lb/Lb-Mole	132.91	132.91
mg	Catch Weight, Milligrams	0.0	0.0
ug/DSCM	Concentration, Micrograms per DSCM	0	0
ng/DSCM	Concentration, Nanograms per DSCM	0.00E+00	0.00E+00
lb/hr	Emission Rate, Pounds per Hour	0.00E+00	0.00E+00
Chromium			
FWt	Formula Weight, Lb/Lb-Mole	52.00	52.00
mg	Catch Weight, Milligrams	1.9	< 1.5
ug/DSCM	Concentration, Micrograms per DSCM	2,053	< 1,610
ng/DSCM	Concentration, Nanograms per DSCM	2.05E+06	< 1.61E+06
lb/hr	Emission Rate, Pounds per Hour	3.46E-03	< 2.79E-03
Copper			
FWt	Formula Weight, Lb/Lb-Mole	63.55	63.55
mg	Catch Weight, Milligrams	< 4.5	< 3.8
ug/DSCM	Concentration, Micrograms per DSCM	< 4,799	< 3,955
ng/DSCM	Concentration, Nanograms per DSCM	< 4.80E+06	< 3.96E+06
lb/hr	Emission Rate, Pounds per Hour	< 8.10E-03	< 6.84E-03
Iron			
FWt	Formula Weight, Lb/Lb-Mole	55.85	55.85
mg	Catch Weight, Milligrams	661.2	< 242.8
ug/DSCM	Concentration, Micrograms per DSCM	706,380	< 254,137
ng/DSCM	Concentration, Nanograms per DSCM	7.06E+08	< 2.54E+08
lb/hr	Emission Rate, Pounds per Hour	1.19E+00	< 4.40E-01
Lead			
FWt	Formula Weight, Lb/Lb-Mole	207.19	207.19
mg	Catch Weight, Milligrams	< 7.5	< 2.5
ug/DSCM	Concentration, Micrograms per DSCM	< 7,977	< 2,607
ng/DSCM	Concentration, Nanograms per DSCM	< 7.98E+06	< 2.61E+06
lb/hr	Emission Rate, Pounds per Hour	< 1.35E-02	< 4.51E-03

< Indicates the value is below the detection limit.

Magnesium

FWt	Formula Weight, Lb/Lb-Mole		24.31		24.31
mg	Catch Weight, Milligrams	<	104.1	<	90.3
ug/DSCM	Concentration, Micrograms per DSCM	<	111,180	<	94,468
ng/DSCM	Concentration, Nanograms per DSCM	<	1.11E+08	<	9.45E+07
lb/hr	Emission Rate, Pounds per Hour	<	1.88E-01	<	1.63E-01

Manganese

FWt	Formula Weight, Lb/Lb-Mole		54.94		54.94
mg	Catch Weight, Milligrams	<	7.5	<	2.9
ug/DSCM	Concentration, Micrograms per DSCM	<	8,037	<	3,029
ng/DSCM	Concentration, Nanograms per DSCM	<	8.04E+06	<	3.03E+06
lb/hr	Emission Rate, Pounds per Hour	<	1.36E-02	<	5.24E-03

Mercury

FWt	Formula Weight, Lb/Lb-Mole		200.59		200.59
mg	Catch Weight, Milligrams	<	2.9	<	2.0
ug/DSCM	Concentration, Micrograms per DSCM	<	3,064	<	2,113
ng/DSCM	Concentration, Nanograms per DSCM	<	3.06E+06	<	2.11E+06
lb/hr	Emission Rate, Pounds per Hour	<	5.17E-03	<	3.66E-03

Nickel

FWt	Formula Weight, Lb/Lb-Mole		58.71		58.71
mg	Catch Weight, Milligrams	<	0.7	<	0.5
ug/DSCM	Concentration, Micrograms per DSCM	<	707	<	508
ng/DSCM	Concentration, Nanograms per DSCM	<	7.07E+05	<	5.08E+05
lb/hr	Emission Rate, Pounds per Hour	<	1.19E-03	<	8.79E-04

Phosphorus

FWt	Formula Weight, Lb/Lb-Mole		30.97		30.97
mg	Catch Weight, Milligrams	<	48.4	<	33.7
ug/DSCM	Concentration, Micrograms per DSCM	<	51,683	<	35,277
ng/DSCM	Concentration, Nanograms per DSCM	<	5.17E+07	<	3.53E+07
lb/hr	Emission Rate, Pounds per Hour	<	8.72E-02	<	6.10E-02

Potassium

FWt	Formula Weight, Lb/Lb-Mole		39.10		39.10
mg	Catch Weight, Milligrams		863.6	<	643.6
ug/DSCM	Concentration, Micrograms per DSCM		922,610	<	673,639
ng/DSCM	Concentration, Nanograms per DSCM		9.23E+08	<	6.74E+08
lb/hr	Emission Rate, Pounds per Hour		1.56E+00	<	1.17E+00

< Indicates the value is below the detection limit.

Selenium

FWt	Formula Weight, Lb/Lb-Mole		78.96		78.96
mg	Catch Weight, Milligrams	<	2.9	<	2.0
ug/DSCM	Concentration, Micrograms per DSCM	<	3,064	<	2,113
ng/DSCM	Concentration, Nanograms per DSCM	<	3.06E+06	<	2.11E+06
lb/hr	Emission Rate, Pounds per Hour	<	5.17E-03	<	3.66E-03

Silicon

FWt	Formula Weight, Lb/Lb-Mole		28.09		28.09
mg	Catch Weight, Milligrams	<	1283.4	<	722.5
ug/DSCM	Concentration, Micrograms per DSCM	<	1,371,102	<	756,282
ng/DSCM	Concentration, Nanograms per DSCM	<	1.37E+09	<	7.56E+08
lb/hr	Emission Rate, Pounds per Hour	<	2.31E+00	<	1.31E+00

Silver

FWt	Formula Weight, Lb/Lb-Mole		107.87		107.87
mg	Catch Weight, Milligrams	<	0.3	<	0.2
ug/DSCM	Concentration, Micrograms per DSCM	<	323	<	226
ng/DSCM	Concentration, Nanograms per DSCM	<	3.23E+05	<	2.26E+05
lb/hr	Emission Rate, Pounds per Hour	<	5.44E-04	<	3.92E-04

Sodium

FWt	Formula Weight, Lb/Lb-Mole		22.99		22.99
mg	Catch Weight, Milligrams		1130.7		441.3
ug/DSCM	Concentration, Micrograms per DSCM		1,207,927		461,878
ng/DSCM	Concentration, Nanograms per DSCM		1.21E+09		4.62E+08
lb/hr	Emission Rate, Pounds per Hour		2.04E+00		7.99E-01

Strontium

FWt	Formula Weight, Lb/Lb-Mole		87.62		87.62
mg	Catch Weight, Milligrams		5.5	<	3.4
ug/DSCM	Concentration, Micrograms per DSCM		5,909	<	3,543
ng/DSCM	Concentration, Nanograms per DSCM		5.91E+06	<	3.54E+06
lb/hr	Emission Rate, Pounds per Hour		9.97E-03	<	6.13E-03

Titanium

FWt	Formula Weight, Lb/Lb-Mole		47.90		47.90
mg	Catch Weight, Milligrams	<	33.2	<	11.4
ug/DSCM	Concentration, Micrograms per DSCM	<	35,415	<	11,982
ng/DSCM	Concentration, Nanograms per DSCM	<	3.54E+07	<	1.20E+07
lb/hr	Emission Rate, Pounds per Hour	<	5.97E-02	<	2.07E-02

< Indicates the value is below the detection limit.

Vanadium

Fwt	Formula Weight, Lb/Lb-Mole		50.94		50.94
mg	Catch Weight, Milligrams	<	3.5	<	1.6
ug/DSCM	Concentration, Micrograms per DSCM	<	3,721	<	1,641
ng/DSCM	Concentration, Nanograms per DSCM	<	3.72E+06	<	1.64E+06
lb/hr	Emission Rate, Pounds per Hour	<	6.28E-03	<	2.84E-03

Zinc

Fwt	Formula Weight, Lb/Lb-Mole		65.38		65.38
mg	Catch Weight, Milligrams	<	25.3	<	9.6
ug/DSCM	Concentration, Micrograms per DSCM	<	27,040	<	10,064
ng/DSCM	Concentration, Nanograms per DSCM	<	2.70E+07	<	1.01E+07
lb/hr	Emission Rate, Pounds per Hour	<	4.56E-02	<	1.74E-02

Zirconium

Fwt	Formula Weight, Lb/Lb-Mole		91.22		91.22
mg	Catch Weight, Milligrams	<	1.4	<	0.5
ug/DSCM	Concentration, Micrograms per DSCM	<	1,446	<	548
ng/DSCM	Concentration, Nanograms per DSCM	<	1.45E+06	<	5.48E+05
lb/hr	Emission Rate, Pounds per Hour	<	2.44E-03	<	9.49E-04

Particulate

g	Catch Weight, Grams (Filter)		12.5337		7.1526
%	Percent of Particulate in Filter		90.6		74.4
g	Catch Weight, Grams (HNO3)		0.7809		1.08
%	Percent of Particulate in HNO3 Rinse		5.6		11.2
g	Catch Weight, Grams (Acetone)		0.5221		1.3832
%	Percent of Particulate in Acetone Rinse		3.8		14.4
g	Catch Weight, Grams (Total)		13.8367		9.6158
g/DSCM	Concentration, Total Milligrams per DSCM		14.782		10.065
gr/DSCF	Concentration, Total Grains per DSCF		6.460		4.398
lb/hr	Emission Rate, Total Pounds per Hour		24.936		17.409

< Indicates the value is below the detection limit.

Appendix P-3

MMT Analysis for the N80 and N80-Mod Feed Mixtures

Table P-3-1. MMT analysis for the N80 and N80-Mod feed mixtures.

FIELD DATA	RUN1	RUN2
Enter Pathway	d:\11885\	d:\11885\
Enter File Name	mt-n80-1	mt-n80-2
Complete Path Is	d:\11885\mt-n80	d:\11885\mt-n80-2
Enter Number of Runs	2	
Plant Name, City, State	U.S. Bureau of Mines, Albany, Oregon	
Test Location	Arc Melter Exhaust	
Enter Operator Name(s)	Miguel Chavez	Miguel Chavez Miguel Chavez

Press <Alt> C To Combine The Data From The Laptop Files

Run Number	MMT-N80-1	MMT-N80-2
Date	7\21\93	7\21\93
Start	1050	1520
Stop	1208	1625
Points	12	12
Theta	60	60
Dia	0.194	0.194
Cp	0.99	0.99
Y	1.006	1.006
Pbar	29.9	29.8
Delta-H	1.433333333	1.208333333
Vm	37.352	35.692
tm	73.41666667	74.75
Vlc	46	36.1
CO2	20.2	20.2
O2	3	3
Pg	-1.8	-1.8
ts	186	201.6666667
Delta-p	0.888518155	0.773897621
Area	23.75829444	23.75829444
F-Factor		
Tstd	68	68
Pstd	29.92	29.92

LABORATORY DATA				RUN1			RUN2				
	Compound	Fwt	Unit	FH	BH		FH	BH			
1	Arsenic	74.92	mg	2.77	<	0.10	<	2.36	<	0.11	
2	Aluminum	26.98	mg	409.77		0.03		138.86		0.04	
3	Barium	137.33	mg	11.48	<	0.03		12.60	<	0.03	
4	Boron	10.81	mg	-		0.26	-		<	0.11	
5	Cadmium	112.41	mg	0.21	<	0.00		0.13	<	0.00	
6	Calcium	40.08	mg	523.07	<	0.26		414.76	<	0.27	
7	Cerium	140.12	mg	32.03	<	0.03		23.32	<	0.03	
8	Cesium	132.91	mg								
9	Chromium	52	mg	3.26	<	0.01		1.40	<	0.01	
10	Copper	63.55	mg	2.07	<	0.05		3.56	<	0.05	
11	Iron	55.85	mg	455.20		0.21		645.55	<	0.27	
12	Lead	207.19	mg	5.62	<	0.05		6.61	<	0.05	
13	Magnesium	24.31	mg	106.94	<	0.26		78.00	<	0.27	
14	Manganese	54.94	mg	4.02	<	0.01		7.25	<	0.01	
15	Mercury	200.59	mg	<	2.10	<	0.10	<	2.36	<	0.11
16	Nickel	58.71	mg		1.34	<	0.03		0.73	<	0.03
17	Phosphorus	30.97	mg		132.11	<	0.05		60.61	<	0.05
18	Potassium	39.1	mg		812.08		0.26		879.00	<	0.27
19	Selenium	78.96	mg	<	2.10	<	0.10	<	2.36	<	0.11
20	Silicon	28.09	mg		1857.79	<	0.10		1165.79	<	0.11
21	Silver	107.87	mg	<	0.21	<	0.03	<	0.24	<	0.03
22	Sodium	22.99	mg		1022.57	<	0.26		1027.82	<	0.27
23	Strontium	87.62	mg		3.29	<	0.01		4.08	<	0.01
24	Titanium	47.9	mg		32.57	<	0.03		23.45	<	0.03
25	Vanadium	50.94	mg		3.04	<	0.01		3.35	<	0.01
26	Zinc	65.38	mg		26.60	<	0.26		27.47	<	0.27
27	Zirconium	91.22	mg		0.88	<	0.03		2.35	<	0.03
28	Particulate (Filter)			g	9.4504			11.3082			
29	Particulate (Nitric Acid)			g	0.5689			0.2095			
30	Particulate (Acetone)			g	0.4767			0.306			

> Indicates the value is below the detection limit.

LABORATORY DATA

Particulate Total (g)	10.496		11.8237	
Sample Volume (ml)		520		530
Compound	FH (mg/kg)	BH (ug/L)	FH (mg/kg)	BH (ug/L)
Arsenic	264 <	200 <	200 <	200
Aluminum	39041	50	11744	75
Barium	1094 <	50	1066 <	50
Boron	-	500	-	200
Cadmium	20 <	1	11 <	1
Calcium	49835 <	500	35079 <	500
Cerium	3052 <	50	1972 <	50
Cesium				
Chromium	311 <	20	118 <	20
Copper	197 <	100	301 <	100
Iron	43369	400	54598 <	500
Lead	535 <	100	559 <	100
Magnesium	10189 <	500	6597 <	500
Manganese	383 <	20	613 <	20
Mercury	< 200 <	200 <	200 <	200
Nickel	128 <	50	62 <	50
Phosphorus	12587 <	100	5126 <	100
Potassium	77370	500	74342 <	500
Selenium	< 200 <	200 <	200 <	200
Silicon	177000 <	200	98598 <	200
Silver	< 20 <	50 <	20 <	50
Sodium	97425 <	500	86929 <	500
Strontium	313 <	20	345 <	20
Titanium	3103 <	50	1983 <	50
Vanadium	290 <	20	283 <	20
Zinc	2534 <	500	2323 <	500
Zirconium	84 <	50	199 <	50

< Indicates the value is below the detection limit.

Plant: U.S. Bureau of Mines, Albany, Oregon
 Test Location: Arc Melter Exhaust

Run Number	Run Date	Operator
MMT-N80-1	7\21\93	Miguel Chavez
MMT-N80-2	7\21\93	Miguel Chavez

		MMT-N80-1	MMT-N80-2
	Run Start Time	1050	1520
	Run Stop Time	1208	1625
	Net Sampling/Traversing Points	12	12
	Net Run Time, Minutes	60	60
Dia	Nozzle Diameter, Inches	0.194	0.194
Cp	Pitot Tube Coefficient	0.99	0.99
Y	Dry Gas Meter Calibration Coefficient	1.0060	1.0060
Pbar	Barometric Pressure, Inches Hg	29.90	29.80
Delta-H	Orifice Average Pressure Differential, Inch	1.433	1.208
Vm	Sampled Volume of Source Gas, Dry ACF	37.352	35.692
Vmm	Sampled Volume of Source Gas, Dry ACM	1.06	1.01
tm	Dry Gas Meter Temperature, Degrees F	73	75
Vmstd	Sampled Volume of Source Gas, Dry SCF	37.301	35.416
Vmstdm	Sampled Volume of Source Gas, Dry SCM	1.056	1.003
Vlc	Volume of Condensed Liquid, mL	46.0	36.1
Vwstd	Volume of Water Vapor, SCF	2.165	1.699
%H2O	Moisture Content, Percent by Volume	5.49	4.58
%H2Osat	Saturated Moisture Content, Percent by Volu	58.5	81.8
Mfd	Source Gas Dry Mole Fraction	0.945	0.954
%CO2	Source Gas CO2 Content, Percent by Dry Volu	20.2	20.2
%O2	Source Gas O2 Content, Percent by Dry Volum	3.0	3.0
Md	Source Gas Dry Molecular Weight, Lb/Lb-Mole	31.35	31.35
Ms	Source Gas Wet Molecular Weight, Lb/Lb-Mole	30.62	30.74
Pg	Source Gas Static Pressure, Inches H2O	-1.80	-1.80
Ps	Source Gas Absolute Pressure, Inches Hg	29.77	29.67
ts	Source Gas Temperature, Degrees F	186	202
Delta-p	Source Gas Average Velocity Head, Inches H2	0.8885	0.7739
vs	Source Gas Velocity, Feet/Second	67.16	63.42
A	Source Cross Sectional Area, Square Inches	24	24
Qsd	Source Gas Volumetric Flow Rate, Dry SCFM	511	474
Qmsd	Source Gas Volumetric Flow Rate, Dry SCMM	14	13
Qaw	Source Gas Volumetric Flow Rate, Wet ACFM	665	628
Qmaw	Source Gas Volumetric Flow Rate, Wet ACMM	19	18
%I	Average Isokinetic Sampling Rate, Percent	97.8	100.1
%EA	Excess Air, Percent	17	17
Fo	Fuel Factor	0.886	0.886

Note:

All standard volumes and flow rates based on 68 Degrees F (20 Degrees C) -- 29.92 Inches of Mercury (Hg)
 The lesser of %H2O and %H2Osat was used for calculation purposes.

		MMT-N80-1	MMT-N80-2
Arsenic			
FWt	Formula Weight, Lb/Lb-Mole	74.92	74.92
mg	Catch Weight, Milligrams	< 2.9	< 2.5
ug/DSCM	Concentration, Micrograms per DSCM	< 2,722	< 2,464
ng/DSCM	Concentration, Nanograms per DSCM	< 2.72E+06	< 2.46E+06
lb/hr	Emission Rate, Pounds per Hour	< 5.21E-03	< 4.37E-03
Aluminum			
FWt	Formula Weight, Lb/Lb-Mole	26.98	26.98
mg	Catch Weight, Milligrams	409.8	138.9
ug/DSCM	Concentration, Micrograms per DSCM	387,979	138,499
ng/DSCM	Concentration, Nanograms per DSCM	3.88E+08	1.38E+08
lb/hr	Emission Rate, Pounds per Hour	7.43E-01	2.46E-01
Barium			
FWt	Formula Weight, Lb/Lb-Mole	137.33	137.33
mg	Catch Weight, Milligrams	< 11.5	< 12.6
ug/DSCM	Concentration, Micrograms per DSCM	< 10,896	< 12,594
ng/DSCM	Concentration, Nanograms per DSCM	< 1.09E+07	< 1.26E+07
lb/hr	Emission Rate, Pounds per Hour	< 2.09E-02	< 2.24E-02
Boron			
FWt	Formula Weight, Lb/Lb-Mole	10.81	10.81
mg	Catch Weight, Milligrams	0.3	< 0.1
ug/DSCM	Concentration, Micrograms per DSCM	246	< 106
ng/DSCM	Concentration, Nanograms per DSCM	2.46E+05	< 1.06E+05
lb/hr	Emission Rate, Pounds per Hour	4.71E-04	< 1.88E-04
Cadmium			
FWt	Formula Weight, Lb/Lb-Mole	112.41	112.41
mg	Catch Weight, Milligrams	< 0.2	< 0.1
ug/DSCM	Concentration, Micrograms per DSCM	< 199	< 130
ng/DSCM	Concentration, Nanograms per DSCM	< 1.99E+05	< 1.30E+05
lb/hr	Emission Rate, Pounds per Hour	< 3.81E-04	< 2.31E-04
Calcium			
FWt	Formula Weight, Lb/Lb-Mole	40.08	40.08
mg	Catch Weight, Milligrams	< 523.3	< 415.0
ug/DSCM	Concentration, Micrograms per DSCM	< 495,462	< 413,839
ng/DSCM	Concentration, Nanograms per DSCM	< 4.95E+08	< 4.14E+08
lb/hr	Emission Rate, Pounds per Hour	< 9.48E-01	< 7.35E-01

> Indicates the value is below the detection limit.

		MMT-N80-1	MMT-N80-2
Cerium			
FWt	Formula Weight, Lb/Lb-Mole	140.12	140.12
mg	Catch Weight, Milligrams	< 32.1	< 23.3
ug/DSCM	Concentration, Micrograms per DSCM	< 30,353	< 23,276
ng/DSCM	Concentration, Nanograms per DSCM	< 3.04E+07	< 2.33E+07
lb/hr	Emission Rate, Pounds per Hour	< 5.81E-02	< 4.13E-02
Cesium			
FWt	Formula Weight, Lb/Lb-Mole	132.91	132.91
mg	Catch Weight, Milligrams	0.0	0.0
ug/DSCM	Concentration, Micrograms per DSCM	0	0
ng/DSCM	Concentration, Nanograms per DSCM	0.00E+00	0.00E+00
lb/hr	Emission Rate, Pounds per Hour	0.00E+00	0.00E+00
Chromium			
FWt	Formula Weight, Lb/Lb-Mole	52.00	52.00
mg	Catch Weight, Milligrams	< 3.3	< 1.4
ug/DSCM	Concentration, Micrograms per DSCM	< 3,100	< 1,402
ng/DSCM	Concentration, Nanograms per DSCM	< 3.10E+06	< 1.40E+06
lb/hr	Emission Rate, Pounds per Hour	< 5.93E-03	< 2.49E-03
Copper			
FWt	Formula Weight, Lb/Lb-Mole	63.55	63.55
mg	Catch Weight, Milligrams	< 2.1	< 3.6
ug/DSCM	Concentration, Micrograms per DSCM	< 2,007	< 3,602
ng/DSCM	Concentration, Nanograms per DSCM	< 2.01E+06	< 3.60E+06
lb/hr	Emission Rate, Pounds per Hour	< 3.84E-03	< 6.39E-03
Iron			
FWt	Formula Weight, Lb/Lb-Mole	55.85	55.85
mg	Catch Weight, Milligrams	455.4	< 645.8
ug/DSCM	Concentration, Micrograms per DSCM	431,159	< 643,964
ng/DSCM	Concentration, Nanograms per DSCM	4.31E+08	< 6.44E+08
lb/hr	Emission Rate, Pounds per Hour	8.25E-01	< 1.14E+00
Lead			
FWt	Formula Weight, Lb/Lb-Mole	207.19	207.19
mg	Catch Weight, Milligrams	< 5.7	< 6.7
ug/DSCM	Concentration, Micrograms per DSCM	< 5,366	< 6,643
ng/DSCM	Concentration, Nanograms per DSCM	< 5.37E+06	< 6.64E+06
lb/hr	Emission Rate, Pounds per Hour	< 1.03E-02	< 1.18E-02

> Indicates the value is below the detection limit.

		MMT-N80-1	MMT-N80-2
Magnesium			
FWt	Formula Weight, Lb/Lb-Mole	24.31	24.31
mg	Catch Weight, Milligrams	< 107.2	< 78.3
ug/DSCM	Concentration, Micrograms per DSCM	< 101,495	< 78,042
ng/DSCM	Concentration, Nanograms per DSCM	< 1.01E+08	< 7.80E+07
lb/hr	Emission Rate, Pounds per Hour	< 1.94E-01	< 1.39E-01
Manganese			
FWt	Formula Weight, Lb/Lb-Mole	54.94	54.94
mg	Catch Weight, Milligrams	< 4.0	< 7.3
ug/DSCM	Concentration, Micrograms per DSCM	< 3,816	< 7,238
ng/DSCM	Concentration, Nanograms per DSCM	< 3.82E+06	< 7.24E+06
lb/hr	Emission Rate, Pounds per Hour	< 7.30E-03	< 1.29E-02
Mercury			
FWt	Formula Weight, Lb/Lb-Mole	200.59	200.59
mg	Catch Weight, Milligrams	< 2.2	< 2.5
ug/DSCM	Concentration, Micrograms per DSCM	< 2,086	< 2,464
ng/DSCM	Concentration, Nanograms per DSCM	< 2.09E+06	< 2.46E+06
lb/hr	Emission Rate, Pounds per Hour	< 3.99E-03	< 4.37E-03
Nickel			
FWt	Formula Weight, Lb/Lb-Mole	58.71	58.71
mg	Catch Weight, Milligrams	< 1.4	< 0.8
ug/DSCM	Concentration, Micrograms per DSCM	< 1,297	< 757
ng/DSCM	Concentration, Nanograms per DSCM	< 1.30E+06	< 7.57E+05
lb/hr	Emission Rate, Pounds per Hour	< 2.48E-03	< 1.34E-03
Phosphorus			
FWt	Formula Weight, Lb/Lb-Mole	30.97	30.97
mg	Catch Weight, Milligrams	< 132.2	< 60.7
ug/DSCM	Concentration, Micrograms per DSCM	< 125,128	< 60,487
ng/DSCM	Concentration, Nanograms per DSCM	< 1.25E+08	< 6.05E+07
lb/hr	Emission Rate, Pounds per Hour	< 2.39E-01	< 1.07E-01
Potassium			
FWt	Formula Weight, Lb/Lb-Mole	39.10	39.10
mg	Catch Weight, Milligrams	812.3	< 879.3
ug/DSCM	Concentration, Micrograms per DSCM	769,080	< 876,742
ng/DSCM	Concentration, Nanograms per DSCM	7.69E+08	< 8.77E+08
lb/hr	Emission Rate, Pounds per Hour	1.47E+00	< 1.56E+00

> Indicates the value is below the detection limit.

		MMT-N80-1	MMT-N80-2
Selenium			
FWt	Formula Weight, Lb/Lb-Mole	78.96	78.96
mg	Catch Weight, Milligrams	< 2.2	< 2.5
ug/DSCM	Concentration, Micrograms per DSCM	< 2,086	< 2,464
ng/DSCM	Concentration, Nanograms per DSCM	< 2.09E+06	< 2.46E+06
lb/hr	Emission Rate, Pounds per Hour	< 3.99E-03	< 4.37E-03
Silicon			
FWt	Formula Weight, Lb/Lb-Mole	28.09	28.09
mg	Catch Weight, Milligrams	< 1857.9	< 1165.9
ug/DSCM	Concentration, Micrograms per DSCM	< 1,758,965	< 1,162,557
ng/DSCM	Concentration, Nanograms per DSCM	< 1.76E+09	< 1.16E+09
lb/hr	Emission Rate, Pounds per Hour	< 3.37E+00	< 2.06E+00
Silver			
FWt	Formula Weight, Lb/Lb-Mole	107.87	107.87
mg	Catch Weight, Milligrams	< 0.2	< 0.3
ug/DSCM	Concentration, Micrograms per DSCM	< 223	< 262
ng/DSCM	Concentration, Nanograms per DSCM	< 2.23E+05	< 2.62E+05
lb/hr	Emission Rate, Pounds per Hour	< 4.28E-04	< 4.66E-04
Sodium			
FWt	Formula Weight, Lb/Lb-Mole	22.99	22.99
mg	Catch Weight, Milligrams	< 1022.8	< 1028.1
ug/DSCM	Concentration, Micrograms per DSCM	< 968,368	< 1,025,140
ng/DSCM	Concentration, Nanograms per DSCM	< 9.68E+08	< 1.03E+09
lb/hr	Emission Rate, Pounds per Hour	< 1.85E+00	< 1.82E+00
Strontium			
FWt	Formula Weight, Lb/Lb-Mole	87.62	87.62
mg	Catch Weight, Milligrams	< 3.3	< 4.1
ug/DSCM	Concentration, Micrograms per DSCM	< 3,120	< 4,078
ng/DSCM	Concentration, Nanograms per DSCM	< 3.12E+06	< 4.08E+06
lb/hr	Emission Rate, Pounds per Hour	< 5.97E-03	< 7.24E-03
Titanium			
FWt	Formula Weight, Lb/Lb-Mole	47.90	47.90
mg	Catch Weight, Milligrams	< 32.6	< 23.5
ug/DSCM	Concentration, Micrograms per DSCM	< 30,859	< 23,406
ng/DSCM	Concentration, Nanograms per DSCM	< 3.09E+07	< 2.34E+07
lb/hr	Emission Rate, Pounds per Hour	< 5.91E-02	< 4.16E-02

> Indicates the value is below the detection limit.

		MMT-N80-1		MMT-N80-2	
Vanadium					
FWt	Formula Weight, Lb/Lb-Mole		50.94		50.94
mg	Catch Weight, Milligrams	<	3.1	<	3.4
ug/DSCM	Concentration, Micrograms per DSCM	<	2,892	<	3,347
ng/DSCM	Concentration, Nanograms per DSCM	<	2.89E+06	<	3.35E+06
lb/hr	Emission Rate, Pounds per Hour	<	5.53E-03	<	5.94E-03
Zinc					
FWt	Formula Weight, Lb/Lb-Mole		65.38		65.38
mg	Catch Weight, Milligrams	<	26.9	<	27.7
ug/DSCM	Concentration, Micrograms per DSCM	<	25,427	<	27,652
ng/DSCM	Concentration, Nanograms per DSCM	<	2.54E+07	<	2.77E+07
lb/hr	Emission Rate, Pounds per Hour	<	4.87E-02	<	4.91E-02
Zirconium					
FWt	Formula Weight, Lb/Lb-Mole		91.22		91.22
mg	Catch Weight, Milligrams	<	0.9	<	2.4
ug/DSCM	Concentration, Micrograms per DSCM	<	859	<	2,373
ng/DSCM	Concentration, Nanograms per DSCM	<	8.59E+05	<	2.37E+06
lb/hr	Emission Rate, Pounds per Hour	<	1.64E-03	<	4.21E-03
Particulate					
g	Catch Weight, Grams (Filter)		9.4504		11.3082
%	Percent of Particulate in Filter		90.0		95.6
g	Catch Weight, Grams (HNO3)		0.5689		0.2095
%	Percent of Particulate in HNO3 Rinse		5.4		1.8
g	Catch Weight, Grams (Acetone)		0.4767		0.306
%	Percent of Particulate in Acetone Rinse		4.5		2.6
g	Catch Weight, Grams (Total)		10.496		11.8237
g/DSCM	Concentration, Total Milligrams per DSCM		9.937		11.790
gr/DSCF	Concentration, Total Grains per DSCF		4.342		5.152
lb/hr	Emission Rate, Total Pounds per Hour		19.020		20.932

> Indicates the value is below the detection limit.

Appendix P-4

MMT Analysis for the N80-IV and N80-IV-Mod Feed Mixtures

Table P-4-1. MMT analysis for the N80-IV and N80-IV-Mod feed mixtures.

FIELD DATA	RUN1	RUN2
Enter Pathway	d:\11885\	d:\11885\
Enter File Name	n80-iv-2	n80-iv-3
Complete Path Is	d:\11885\n80-iv	d:\11885\n80-iv-3
Enter Number of Runs	2	
Plant Name, City, State	U.S. Bureau of Mines, Albany, Oregon	
Test Location	Arc Melter Exhaust	
Enter Operator Name(s)	Miguel Chavez	Miguel Chavez Miguel Chavez

Press <Alt> C To Combine The Data From The Laptop Files

Run Number	MMT-N80-IV-2	MMT-N80-IV-3
Date	7/22/93	7/22/93
Start	1220	1545
Stop	1334	1655
Points	12	12
Theta	60	60
Dia	0.194	0.194
Cp	0.99	0.99
Y	1.006	1.006
Pbar	29.8	29.8
Delta-H	1.175	1.575
Vm	34.748	40.49
tm	72.58333333	74
Vlc	51.1	52.1
CO2	3.82	3.14
O2	19.6	20.04
Pg	-1.9	-1.9
ts	215.9166667	228.9166667
Delta-p	0.777456914	0.68604418
Area	23.75829444	23.75829444
F-Factor		
Tstd	68	68
Pstd	29.92	29.92

LABORATORY DATA			RUN1		RUN2	
Compound	Fwt	Unit	FH	BH	FH	BH
1 Arsenic	74.92	mg <	2.77 <	0.10	2.20 <	0.09
2 Aluminum	26.98	mg	319.07	0.05	207.58	0.07
3 Barium	137.33	mg	20.73 <	0.02	18.78 <	0.02
4 Boron	10.81	mg	- <	0.10	- <	0.09
5 Cadmium	112.41	mg	0.14 <	0.00	0.17 <	0.00
6 Calcium	40.08	mg	453.40 <	0.25	1213.40 <	0.24
7 Cerium	140.12	mg	105.09 <	0.02	85.75 <	0.02
8 Cesium	132.91	mg				
9 Chromium	52	mg	4.44 <	0.01	3.17 <	0.01
10 Copper	63.55	mg	1.77 <	0.05	5.93 <	0.05
11 Iron	55.85	mg	379.39 <	0.25	381.55	1.27
12 Lead	207.19	mg	6.42 <	0.05	5.67 <	0.05
13 Magnesium	24.31	mg	95.95 <	0.25	74.15 <	0.24
14 Manganese	54.94	mg	5.24 <	0.01	4.15 <	0.01
15 Mercury	200.59	mg <	2.77 <	0.10 <	1.85 <	0.09
16 Nickel	58.71	mg	0.65 <	0.02	0.76 <	0.02
17 Phosphorus	30.97	mg	114.24 <	0.05	44.05 <	0.05
18 Potassium	39.1	mg	1182.39 <	0.25	741.71 <	0.24
19 Selenium	78.96	mg <	2.77 <	0.10 <	1.85 <	0.09
20 Silicon	28.09	mg	2005.51 <	0.10	1213.40 <	0.09
21 Silver	107.87	mg	3.91 <	0.02	1.99 <	0.02
22 Sodium	22.99	mg	1311.73 <	0.25	659.77 <	0.24
23 Strontium	87.62	mg	5.68 <	0.01	6.09 <	0.01
24 Titanium	47.9	mg	47.72 <	0.02	28.33 <	0.02
25 Vanadium	50.94	mg	5.02 <	0.01	2.12 <	0.01
26 Zinc	65.38	mg	14.88 <	0.25	7.28 <	0.24
27 Zirconium	91.22	mg	648.72 <	0.02	343.14 <	0.02
28 Particulate (Filter)		g	11.204		6.646	
29 Particulate (Nitric Acid)		g	1.044		0.304	
30 Particulate (Acetone)		g	1.583		2.313	

< Indicates the value is below the detection limit.

LABORATORY DATA

Particulate Total (g)	13.8311		9.2626	
Sample Volume (ml)	495		470	
Compound	FH (mg/kg)	BH (ug/L)	FH (mg/kg)	BH (ug/L)
Arsenic	< 200	< 200	238	< 200
Aluminum	23069	100	22411	150
Barium	1499	< 50	2027	< 50
Boron	-	< 200	-	< 200
Cadmium	10	< 1	18	< 1
Calcium	32781	< 500	131000	< 500
Cerium	7598	< 50	9258	< 50
Cesium				
Chromium	321	< 20	342	< 20
Copper	128	< 100	640	< 100
Iron	27430	< 500	41192	2700
Lead	464	< 100	612	< 100
Magnesium	6937	< 500	8005	< 500
Manganese	379	< 20	448	< 20
Mercury	< 200	< 200	< 200	< 200
Nickel	47	< 50	82	< 50
Phosphorus	8260	< 100	4756	< 100
Potassium	85488	< 500	80076	< 500
Selenium	< 200	< 200	< 200	< 200
Silicon	145000	< 200	131000	< 200
Silver	283	< 50	215	< 50
Sodium	94839	< 500	71230	< 500
Strontium	411	< 20	658	< 20
Titanium	3450	< 50	3059	< 50
Vanadium	363	< 20	229	< 20
Zinc	1076	< 500	786	< 500
Zirconium	46903	< 50	37046	< 50

< Indicates the value is below the detection limit.

Plant: U.S. Bureau of Mines, Albany, Oregon
 Test Location: Arc Melter Exhaust

Run Number	Run Date	Operator
MMT-N80-IV-2	7/22/93	Miguel Chavez
MMT-N80-IV-3	7/22/93	Miguel Chavez

		MMT-N80-IV-2	MMT-N80-IV-3
	Run Start Time	1220	1545
	Run Stop Time	1334	1655
	Net Sampling/Traversing Points	12	12
	Net Run Time, Minutes	60	60
Dia	Nozzle Diameter, Inches	0.194	0.194
Cp	Pitot Tube Coefficient	0.99	0.99
Y	Dry Gas Meter Calibration Coefficient	1.0060	1.0060
Pbar	Barometric Pressure, Inches Hg	29.80	29.80
Delta-H	Orifice Average Pressure Differential, Inch	1.175	1.575
Vm	Sampled Volume of Source Gas, Dry ACF	34.748	40.490
Vmm	Sampled Volume of Source Gas, Dry ACM	0.98	1.15
tm	Dry Gas Meter Temperature, Degrees F	73	74
Vmstd	Sampled Volume of Source Gas, Dry SCF	34.617	40.270
Vmstdm	Sampled Volume of Source Gas, Dry SCM	0.980	1.140
Vlc	Volume of Condensed Liquid, mL	51.1	52.1
Vwstd	Volume of Water Vapor, SCF	2.405	2.452
%H2O	Moisture Content, Percent by Volume	6.50	5.74
%H2Osat	Saturated Moisture Content, Percent by Volu	100.0	100.0
Mfd	Source Gas Dry Mole Fraction	0.935	0.943
%CO2	Source Gas CO2 Content, Percent by Dry Volu	3.8	3.1
%O2	Source Gas O2 Content, Percent by Dry Volum	19.6	20.0
Md	Source Gas Dry Molecular Weight, Lb/Lb-Mole	29.40	29.30
Ms	Source Gas Wet Molecular Weight, Lb/Lb-Mole	28.65	28.66
Pg	Source Gas Static Pressure, Inches H2O	-1.90	-1.90
Ps	Source Gas Absolute Pressure, Inches Hg	29.66	29.66
ts	Source Gas Temperature, Degrees F	216	229
Delta-p	Source Gas Average Velocity Head, Inches H2	0.7775	0.6860
vs	Source Gas Velocity, Feet/Second	66.55	63.11
A	Source Cross Sectional Area, Square Inches	24	24
Qsd	Source Gas Volumetric Flow Rate, Dry SCFM	477	447
Qmsd	Source Gas Volumetric Flow Rate, Dry SCMM	14	13
Qaw	Source Gas Volumetric Flow Rate, Wet ACFM	659	625
Qmaw	Source Gas Volumetric Flow Rate, Wet ACMM	19	18
%I	Average Isokinetic Sampling Rate, Percent	97.2	120.6
%EA	Excess Air, Percent	3176	8333
Fo	Fuel Factor	0.340	0.274

Note:

All standard volumes and flow rates based on 68 Degrees F (20 Degrees C) -- 29.92 Inches of Mercury (Hg)
 The lesser of %H2O and %H2Osat was used for calculation purposes

		MMT-N80-IV-2	MMT-N80-IV-3
Arsenic			
Fwt	Formula Weight, Lb/Lb-Mole	74.92	74.92
mg	Catch Weight, Milligrams	< 2.9 <	2.3
ug/DSCM	Concentration, Micrograms per DSCM	< 2,923 <	2,016
ng/DSCM	Concentration, Nanograms per DSCM	< 2.92E+06 <	2.02E+06
lb/hr	Emission Rate, Pounds per Hour	< 5.22E-03 <	3.38E-03
Aluminum			
Fwt	Formula Weight, Lb/Lb-Mole	26.98	26.98
mg	Catch Weight, Milligrams	319.1	207.7
ug/DSCM	Concentration, Micrograms per DSCM	325,551	182,103
ng/DSCM	Concentration, Nanograms per DSCM	3.26E+08	1.82E+08
lb/hr	Emission Rate, Pounds per Hour	5.82E-01	3.05E-01
Barium			
Fwt	Formula Weight, Lb/Lb-Mole	137.33	137.33
mg	Catch Weight, Milligrams	< 20.8 <	18.8
ug/DSCM	Concentration, Micrograms per DSCM	< 21,176 <	16,486
ng/DSCM	Concentration, Nanograms per DSCM	< 2.12E+07 <	1.65E+07
lb/hr	Emission Rate, Pounds per Hour	< 3.78E-02 <	2.76E-02
Boron			
Fwt	Formula Weight, Lb/Lb-Mole	10.81	10.81
mg	Catch Weight, Milligrams	< 0.1 <	0.1
ug/DSCM	Concentration, Micrograms per DSCM	< 101 <	82
ng/DSCM	Concentration, Nanograms per DSCM	< 1.01E+05 <	8.24E+04
lb/hr	Emission Rate, Pounds per Hour	< 1.80E-04 <	1.38E-04
Cadmium			
Fwt	Formula Weight, Lb/Lb-Mole	112.41	112.41
mg	Catch Weight, Milligrams	< 0.1 <	0.2
ug/DSCM	Concentration, Micrograms per DSCM	< 142 <	147
ng/DSCM	Concentration, Nanograms per DSCM	< 1.42E+05 <	1.47E+05
lb/hr	Emission Rate, Pounds per Hour	< 2.53E-04 <	2.46E-04
Calcium			
Fwt	Formula Weight, Lb/Lb-Mole	40.08	40.08
mg	Catch Weight, Milligrams	< 453.6 <	1213.6
ug/DSCM	Concentration, Micrograms per DSCM	< 462,789 <	1,064,299
ng/DSCM	Concentration, Nanograms per DSCM	< 4.63E+08 <	1.06E+09
lb/hr	Emission Rate, Pounds per Hour	< 8.27E-01 <	1.78E+00

< Indicates the value is below the detection limit.

		MMT-N80-IV-2	MMT-N80-IV-3
Cerium			
FWt	Formula Weight, Lb/Lb-Mole	140.12	140.12
mg	Catch Weight, Milligrams	< 105.1	< 85.8
ug/DSCM	Concentration, Micrograms per DSCM	< 107,232	< 75,222
ng/DSCM	Concentration, Nanograms per DSCM	< 1.07E+08	< 7.52E+07
lb/hr	Emission Rate, Pounds per Hour	< 1.92E-01	< 1.26E-01
Cesium			
FWt	Formula Weight, Lb/Lb-Mole	132.91	132.91
mg	Catch Weight, Milligrams	0.0	0.0
ug/DSCM	Concentration, Micrograms per DSCM	0	0
ng/DSCM	Concentration, Nanograms per DSCM	0.00E+00	0.00E+00
lb/hr	Emission Rate, Pounds per Hour	0.00E+00	0.00E+00
Chromium			
FWt	Formula Weight, Lb/Lb-Mole	52.00	52.00
mg	Catch Weight, Milligrams	< 4.4	< 3.2
ug/DSCM	Concentration, Micrograms per DSCM	< 4,539	< 2,786
ng/DSCM	Concentration, Nanograms per DSCM	< 4.54E+06	< 2.79E+06
lb/hr	Emission Rate, Pounds per Hour	< 8.11E-03	< 4.67E-03
Copper			
FWt	Formula Weight, Lb/Lb-Mole	63.55	63.55
mg	Catch Weight, Milligrams	< 1.8	< 6.0
ug/DSCM	Concentration, Micrograms per DSCM	< 1,857	< 5,240
ng/DSCM	Concentration, Nanograms per DSCM	< 1.86E+06	< 5.24E+06
lb/hr	Emission Rate, Pounds per Hour	< 3.32E-03	< 8.78E-03
Iron			
FWt	Formula Weight, Lb/Lb-Mole	55.85	55.85
mg	Catch Weight, Milligrams	< 379.6	< 382.8
ug/DSCM	Concentration, Micrograms per DSCM	< 387,287	< 335,709
ng/DSCM	Concentration, Nanograms per DSCM	< 3.87E+08	< 3.36E+08
lb/hr	Emission Rate, Pounds per Hour	< 6.92E-01	< 5.63E-01
Lead			
FWt	Formula Weight, Lb/Lb-Mole	207.19	207.19
mg	Catch Weight, Milligrams	< 6.5	< 5.7
ug/DSCM	Concentration, Micrograms per DSCM	< 6,597	< 5,012
ng/DSCM	Concentration, Nanograms per DSCM	< 6.60E+06	< 5.01E+06
lb/hr	Emission Rate, Pounds per Hour	< 1.18E-02	< 8.40E-03

< Indicates the value is below the detection limit.

Magnesium

FWt	Formula Weight, Lb/Lb-Mole		24.31		24.31
mg	Catch Weight, Milligrams	<	96.2	<	74.4
ug/DSCM	Concentration, Micrograms per DSCM	<	98,133	<	65,229
ng/DSCM	Concentration, Nanograms per DSCM	<	9.81E+07	<	6.52E+07
lb/hr	Emission Rate, Pounds per Hour	<	1.75E-01	<	1.09E-01

Manganese

FWt	Formula Weight, Lb/Lb-Mole		54.94		54.94
mg	Catch Weight, Milligrams	<	5.3	<	4.2
ug/DSCM	Concentration, Micrograms per DSCM	<	5,358	<	3,647
ng/DSCM	Concentration, Nanograms per DSCM	<	5.36E+06	<	3.65E+06
lb/hr	Emission Rate, Pounds per Hour	<	9.57E-03	<	6.11E-03

Mercury

FWt	Formula Weight, Lb/Lb-Mole		200.59		200.59
mg	Catch Weight, Milligrams	<	2.9	<	1.9
ug/DSCM	Concentration, Micrograms per DSCM	<	2,923	<	1,707
ng/DSCM	Concentration, Nanograms per DSCM	<	2.92E+06	<	1.71E+06
lb/hr	Emission Rate, Pounds per Hour	<	5.22E-03	<	2.86E-03

Nickel

FWt	Formula Weight, Lb/Lb-Mole		58.71		58.71
mg	Catch Weight, Milligrams	<	0.7	<	0.8
ug/DSCM	Concentration, Micrograms per DSCM	<	688	<	687
ng/DSCM	Concentration, Nanograms per DSCM	<	6.88E+05	<	6.87E+05
lb/hr	Emission Rate, Pounds per Hour	<	1.23E-03	<	1.15E-03

Phosphorus

FWt	Formula Weight, Lb/Lb-Mole		30.97		30.97
mg	Catch Weight, Milligrams	<	114.3	<	44.1
ug/DSCM	Concentration, Micrograms per DSCM	<	116,598	<	38,673
ng/DSCM	Concentration, Nanograms per DSCM	<	1.17E+08	<	3.87E+07
lb/hr	Emission Rate, Pounds per Hour	<	2.08E-01	<	6.48E-02

Potassium

FWt	Formula Weight, Lb/Lb-Mole		39.10		39.10
mg	Catch Weight, Milligrams	<	1182.6	<	741.9
ug/DSCM	Concentration, Micrograms per DSCM	<	1,206,478	<	650,651
ng/DSCM	Concentration, Nanograms per DSCM	<	1.21E+09	<	6.51E+08
lb/hr	Emission Rate, Pounds per Hour	<	2.16E+00	<	1.09E+00

< Indicates the value is below the detection limit.

Selenium

FWt	Formula Weight, Lb/Lb-Mole		78.96		78.96
mg	Catch Weight, Milligrams	<	2.9	<	1.9
ug/DSCM	Concentration, Micrograms per DSCM	<	2,923	<	1,707
ng/DSCM	Concentration, Nanograms per DSCM	<	2.92E+06	<	1.71E+06
lb/hr	Emission Rate, Pounds per Hour	<	5.22E-03	<	2.86E-03

Silicon

FWt	Formula Weight, Lb/Lb-Mole		28.09		28.09
mg	Catch Weight, Milligrams	<	2005.6	<	1213.5
ug/DSCM	Concentration, Micrograms per DSCM	<	2,046,034	<	1,064,175
ng/DSCM	Concentration, Nanograms per DSCM	<	2.05E+09	<	1.06E+09
lb/hr	Emission Rate, Pounds per Hour	<	3.66E+00	<	1.78E+00

Silver

FWt	Formula Weight, Lb/Lb-Mole		107.87		107.87
mg	Catch Weight, Milligrams	<	3.9	<	2.0
ug/DSCM	Concentration, Micrograms per DSCM	<	4,018	<	1,767
ng/DSCM	Concentration, Nanograms per DSCM	<	4.02E+06	<	1.77E+06
lb/hr	Emission Rate, Pounds per Hour	<	7.18E-03	<	2.96E-03

Sodium

FWt	Formula Weight, Lb/Lb-Mole		22.99		22.99
mg	Catch Weight, Milligrams	<	1312.0	<	660.0
ug/DSCM	Concentration, Micrograms per DSCM	<	1,338,420	<	578,796
ng/DSCM	Concentration, Nanograms per DSCM	<	1.34E+09	<	5.79E+08
lb/hr	Emission Rate, Pounds per Hour	<	2.39E+00	<	9.70E-01

Strontium

FWt	Formula Weight, Lb/Lb-Mole		87.62		87.62
mg	Catch Weight, Milligrams	<	5.7	<	6.1
ug/DSCM	Concentration, Micrograms per DSCM	<	5,809	<	5,353
ng/DSCM	Concentration, Nanograms per DSCM	<	5.81E+06	<	5.35E+06
lb/hr	Emission Rate, Pounds per Hour	<	1.04E-02	<	8.97E-03

Titanium

FWt	Formula Weight, Lb/Lb-Mole		47.90		47.90
mg	Catch Weight, Milligrams	<	47.7	<	28.4
ug/DSCM	Concentration, Micrograms per DSCM	<	48,704	<	24,868
ng/DSCM	Concentration, Nanograms per DSCM	<	4.87E+07	<	2.49E+07
lb/hr	Emission Rate, Pounds per Hour	<	8.70E-02	<	4.17E-02

< Indicates the value is below the detection limit.

Vanadium

FWt	Formula Weight, Lb/Lb-Mole		50.94		50.94
mg	Catch Weight, Milligrams	<	5.0	<	2.1
ug/DSCM	Concentration, Micrograms per DSCM	<	5,132	<	1,868
ng/DSCM	Concentration, Nanograms per DSCM	<	5.13E+06	<	1.87E+06
lb/hr	Emission Rate, Pounds per Hour	<	9.17E-03	<	3.13E-03

Zinc

FWt	Formula Weight, Lb/Lb-Mole		65.38		65.38
mg	Catch Weight, Milligrams	<	15.1	<	7.5
ug/DSCM	Concentration, Micrograms per DSCM	<	15,435	<	6,591
ng/DSCM	Concentration, Nanograms per DSCM	<	1.54E+07	<	6.59E+06
lb/hr	Emission Rate, Pounds per Hour	<	2.76E-02	<	1.10E-02

Zirconium

FWt	Formula Weight, Lb/Lb-Mole		91.22		91.22
mg	Catch Weight, Milligrams	<	648.7	<	343.2
ug/DSCM	Concentration, Micrograms per DSCM	<	661,821	<	300,939
ng/DSCM	Concentration, Nanograms per DSCM	<	6.62E+08	<	3.01E+08
lb/hr	Emission Rate, Pounds per Hour	<	1.18E+00	<	5.04E-01

Particulate

g	Catch Weight, Grams (Filter)		11.2042		6.6459
%	Percent of Particulate in Filter		81.0		71.7
g	Catch Weight, Grams (HNO3)		1.0435		0.3039
%	Percent of Particulate in HNO3 Rinse		7.5		3.3
g	Catch Weight, Grams (Acetone)		1.5834		2.3128
%	Percent of Particulate in Acetone Rinse		11.4		25.0
g	Catch Weight, Grams (Total)		13.8311		9.2626
g/DSCM	Concentration, Total Milligrams per DSCM		14.110		8.123
gr/DSCF	Concentration, Total Grains per DSCF		6.166		3.550
lb/hr	Emission Rate, Total Pounds per Hour		25.211		13.614

< Indicates the value is below the detection limit.

Appendix P-5

MMT Analysis for the M60 and M60-Mod Feed Mixtures

Table P-5-1. MMT analysis for the M60 and N80-IV-Mod 2 feed mixtures.

FIELD DATA	RUN1	RUN2
Enter Pathway	d:\11885\	d:\11885\
Enter File Name	m60-1	m60-1
Complete Path Is	d:\11885\m60-1	d:\11885\m60-1
Enter Number of Runs	2	
Plant Name, City, State	U.S. Bureau of Mines, Albany, Oregon	
Test Location	Arc Melter Exhaust	
Enter Operator Name(s)	Miguel Chavez	Miguel Chavez Miguel Chavez

Press <Alt> C To Combine The Data From The Laptop Files

Run Number	MMT-M60-1	MMT-M60-2
Date	7\23\93	7\23\93
Start	1005	1412
Stop	1125	1522
Points	12	12
Theta	60	60
Dia	0.215	0.215
Cp	0.99	0.99
Y	1.006	1.006
Pbar	29.9	29.9
Delta-H	1.426666667	1.9
Vm	33.995	43.487
tm	70.33333333	78.41666667
Vlc	35.3	37.3
CO2	0	0
O2	0	0
Pg	-1.7	-1.7
ts	410.5833333	249.8333333
Delta-p	0.987218802	0.857133518
Area	23.75829444	23.75829444
F-Factor		
Tstd	68	68
Pstd	29.92	29.92

LABORATORY DATA				RUN1				RUN2	
	Compound	Fwt	Unit	FH	BH		FH	BH	
1	Arsenic	74.92	mg <	2.37 <	0.11 <		2.68 <	0.10	
2	Aluminum	26.98	mg	183.74	0.08		313.99	0.03	
3	Barium	137.33	mg	15.77 <	0.03		20.41 <	0.03	
4	Boron	10.81	mg	- <	0.11		- <	0.10	
5	Cadmium	112.41	mg	0.15 <	0.00		0.17 <	0.00	
6	Calcium	40.08	mg	355.09 <	0.27		1368.91 <	0.25	
7	Cerium	140.12	mg	20.12 <	0.03		90.98 <	0.03	
8	Cesium	132.91	mg						
9	Chromium	52	mg	5.48 <	0.01		25.19 <	0.01	
10	Copper	63.55	mg	4.97 <	0.05		10.52 <	0.05	
11	Iron	55.85	mg	153.07 <	0.27		571.13 <	0.25	
12	Lead	207.19	mg	1703.16 <	0.05		73.17 <	0.05	
13	Magnesium	24.31	mg	51.83 <	0.27		102.05 <	0.25	
14	Manganese	54.94	mg	4.75 <	0.01		6.67 <	0.01	
15	Mercury	200.59	mg <	2.37 <	0.11 <		2.68 <	0.10	
16	Nickel	58.71	mg	1.45 <	0.03		2.16 <	0.03	
17	Phosphorus	30.97	mg	18.24 <	0.05		69.28 <	0.05	
18	Potassium	39.1	mg	195.75 <	0.27		1083.36 <	0.25	
19	Selenium	78.96	mg <	2.37 <	0.11 <		2.68 <	0.10	
20	Silicon	28.09	mg	1395.65 <	0.11		1691.01 <	0.10	
21	Silver	107.87	mg	0.64 <	0.03		2.97 <	0.03	
22	Sodium	22.99	mg	122.91 <	0.27		972.50 <	0.25	
23	Strontium	87.62	mg	4.22 <	0.01		7.65 <	0.01	
24	Titanium	47.9	mg	10.89 <	0.03		37.69 <	0.03	
25	Vanadium	50.94	mg	0.33 <	0.01		2.52 <	0.01	
26	Zinc	65.38	mg	2602.05 <	0.27		188.10 <	0.25	
27	Zirconium	91.22	mg	6.40 <	0.03		511.33 <	0.03	
28	Particulate (Filter)		g	9.834			11.145		
29	Particulate (Nitric Acid)		g	0.247			0.363		
30	Particulate (Acetone)		g	1.746			1.913		

< Indicates the value is below the detection limit.

LABORATORY DATA

Particulate Total (g)	11.8275		13.4207	
Sample Volume (ml)		540		505
Compound	FH (mg/kg)	BH (ug/L)	FH (mg/kg)	BH (ug/L)
Arsenic	< 200	< 200	< 200	< 200
Aluminum	15535	150	23396	50
Barium	1333	50	1521	50
Boron	-	200	-	200
Cadmium	13	1	13	1
Calcium	30022	500	102000	500
Cerium	1701	50	6779	50
Cesium				
Chromium	463	20	1877	20
Copper	420	100	784	100
Iron	12942	500	42556	500
Lead	144000	100	5452	100
Magnesium	4382	500	7604	500
Manganese	402	20	497	20
Mercury	< 200	< 200	< 200	< 200
Nickel	123	50	161	50
Phosphorus	1542	100	5162	100
Potassium	16550	500	80723	500
Selenium	< 200	< 200	< 200	< 200
Silicon	118000	200	126000	200
Silver	54	50	221	50
Sodium	10392	500	72463	500
Strontium	357	20	570	20
Titanium	921	50	2808	50
Vanadium	28	20	188	20
Zinc	220000	500	14016	500
Zirconium	541	50	38100	50

Plant: U.S. Bureau of Mines, Albany, Oregon
 Test Location: Arc Melter Exhaust

Run Number	Run Date	Operator
MMT-M60-1	7\23\93	Miguel Chavez
MMT-M60-2	7\23\93	Miguel Chavez

		MMT-M60-1	MMT-M60-2
	Run Start Time	1005	1412
	Run Stop Time	1125	1522
	Net Sampling/Traversing Points	12	12
	Net Run Time, Minutes	60	60
Dia	Nozzle Diameter, Inches	0.215	0.215
Cp	Pitot Tube Coefficient	0.99	0.99
Y	Dry Gas Meter Calibration Coefficient	1.0060	1.0060
Pbar	Barometric Pressure, Inches Hg	29.90	29.90
Delta-H	Orifice Average Pressure Differential, Inch	1.427	1.900
Vm	Sampled Volume of Source Gas, Dry ACF	33.995	43.487
Vmm	Sampled Volume of Source Gas, Dry ACM	0.96	1.23
tm	Dry Gas Meter Temperature, Degrees F	70	78
Vmstd	Sampled Volume of Source Gas, Dry SCF	34.145	43.073
Vmstdm	Sampled Volume of Source Gas, Dry SCM	0.967	1.220
Vlc	Volume of Condensed Liquid, mL	35.3	37.3
Vwstd	Volume of Water Vapor, SCF	1.662	1.756
%H2O	Moisture Content, Percent by Volume	4.64	3.92
%H2Osat	Saturated Moisture Content, Percent by Volu	100.0	100.0
Mfd	Source Gas Dry Mole Fraction	0.954	0.961
%CO2	Source Gas CO2 Content, Percent by Dry Volu	0.0	0.0
%O2	Source Gas O2 Content, Percent by Dry Volum	0.0	0.0
Md	Source Gas Dry Molecular Weight, Lb/Lb-Mole	28.00	28.00
Ms	Source Gas Wet Molecular Weight, Lb/Lb-Mole	27.54	27.61
Pg	Source Gas Static Pressure, Inches H2O	-1.70	-1.70
Ps	Source Gas Absolute Pressure, Inches Hg	29.78	29.78
ts	Source Gas Temperature, Degrees F	411	250
Delta-p	Source Gas Average Velocity Head, Inches H2	0.9872	0.8571
vs	Source Gas Velocity, Feet/Second	86.65	72.81
A	Source Cross Sectional Area, Square Inches	24	24
Qsd	Source Gas Volumetric Flow Rate, Dry SCFM	494	513
Qmsd	Source Gas Volumetric Flow Rate, Dry SCMM	14	15
Qaw	Source Gas Volumetric Flow Rate, Wet ACFM	858	721
Qmaw	Source Gas Volumetric Flow Rate, Wet ACMM	24	20
%I	Average Isokinetic Sampling Rate, Percent	75.4	91.6
%EA	Excess Air, Percent	0	0
Fo	Fuel Factor	#DIV/0!	#DIV/0!

Note:

All standard volumes and flow rates based on 68 Degrees F (20 Degrees C) -- 29.92 Inches of Mercury (Hg)
 The lesser of %H2O and %H2Osat was used for calculation purposes

		MMT-M60-1	MMT-M60-2
Arsenic			
FWt	Formula Weight, Lb/Lb-Mole	74.92	74.92
mg	Catch Weight, Milligrams	< 2.5	< 2.8
ug/DSCM	Concentration, Micrograms per DSCM	< 2,558	< 2,283
ng/DSCM	Concentration, Nanograms per DSCM	< 2.56E+06	< 2.28E+06
lb/hr	Emission Rate, Pounds per Hour	< 4.73E-03	< 4.38E-03
Aluminum			
FWt	Formula Weight, Lb/Lb-Mole	26.98	26.98
mg	Catch Weight, Milligrams	183.8	314.0
ug/DSCM	Concentration, Micrograms per DSCM	190,116	257,453
ng/DSCM	Concentration, Nanograms per DSCM	1.90E+08	2.57E+08
lb/hr	Emission Rate, Pounds per Hour	3.52E-01	4.94E-01
Barium			
FWt	Formula Weight, Lb/Lb-Mole	137.33	137.33
mg	Catch Weight, Milligrams	< 15.8	< 20.4
ug/DSCM	Concentration, Micrograms per DSCM	< 16,334	< 16,757
ng/DSCM	Concentration, Nanograms per DSCM	< 1.63E+07	< 1.68E+07
lb/hr	Emission Rate, Pounds per Hour	< 3.02E-02	< 3.22E-02
Boron			
FWt	Formula Weight, Lb/Lb-Mole	10.81	10.81
mg	Catch Weight, Milligrams	< 0.1	< 0.1
ug/DSCM	Concentration, Micrograms per DSCM	< 112	< 83
ng/DSCM	Concentration, Nanograms per DSCM	< 1.12E+05	< 8.28E+04
lb/hr	Emission Rate, Pounds per Hour	< 2.07E-04	< 1.59E-04
Cadmium			
FWt	Formula Weight, Lb/Lb-Mole	112.41	112.41
mg	Catch Weight, Milligrams	< 0.2	< 0.2
ug/DSCM	Concentration, Micrograms per DSCM	< 160	< 143
ng/DSCM	Concentration, Nanograms per DSCM	< 1.60E+05	< 1.43E+05
lb/hr	Emission Rate, Pounds per Hour	< 2.95E-04	< 2.75E-04
Calcium			
FWt	Formula Weight, Lb/Lb-Mole	40.08	40.08
mg	Catch Weight, Milligrams	< 355.4	< 1369.2
ug/DSCM	Concentration, Micrograms per DSCM	< 367,525	< 1,122,539
ng/DSCM	Concentration, Nanograms per DSCM	< 3.68E+08	< 1.12E+09
lb/hr	Emission Rate, Pounds per Hour	< 6.80E-01	< 2.16E+00

< Indicates the value is below the detection limit.

		MMT-M60-1	MMT-M60-2
Cerium			
FWt	Formula Weight, Lb/Lb-Mole	140.12	140.12
mg	Catch Weight, Milligrams	< 20.1	< 91.0
ug/DSCM	Concentration, Micrograms per DSCM	< 20,835	< 74,612
ng/DSCM	Concentration, Nanograms per DSCM	< 2.08E+07	< 7.46E+07
lb/hr	Emission Rate, Pounds per Hour	< 3.85E-02	< 1.43E-01
Cesium			
FWt	Formula Weight, Lb/Lb-Mole	132.91	132.91
mg	Catch Weight, Milligrams	0.0	0.0
ug/DSCM	Concentration, Micrograms per DSCM	0	0
ng/DSCM	Concentration, Nanograms per DSCM	0.00E+00	0.00E+00
lb/hr	Emission Rate, Pounds per Hour	0.00E+00	0.00E+00
Chromium			
FWt	Formula Weight, Lb/Lb-Mole	52.00	52.00
mg	Catch Weight, Milligrams	< 5.5	< 25.2
ug/DSCM	Concentration, Micrograms per DSCM	< 5,675	< 20,661
ng/DSCM	Concentration, Nanograms per DSCM	< 5.67E+06	< 2.07E+07
lb/hr	Emission Rate, Pounds per Hour	< 1.05E-02	< 3.97E-02
Copper			
FWt	Formula Weight, Lb/Lb-Mole	63.55	63.55
mg	Catch Weight, Milligrams	< 5.0	< 10.6
ug/DSCM	Concentration, Micrograms per DSCM	< 5,194	< 8,668
ng/DSCM	Concentration, Nanograms per DSCM	< 5.19E+06	< 8.67E+06
lb/hr	Emission Rate, Pounds per Hour	< 9.60E-03	< 1.66E-02
Iron			
FWt	Formula Weight, Lb/Lb-Mole	55.85	55.85
mg	Catch Weight, Milligrams	< 153.3	< 571.4
ug/DSCM	Concentration, Micrograms per DSCM	< 158,593	< 468,461
ng/DSCM	Concentration, Nanograms per DSCM	< 1.59E+08	< 4.68E+08
lb/hr	Emission Rate, Pounds per Hour	< 2.93E-01	< 9.00E-01
Lead			
FWt	Formula Weight, Lb/Lb-Mole	207.19	207.19
mg	Catch Weight, Milligrams	< 1703.2	< 73.2
ug/DSCM	Concentration, Micrograms per DSCM	< 1,761,543	< 60,031
ng/DSCM	Concentration, Nanograms per DSCM	< 1.76E+09	< 6.00E+07
lb/hr	Emission Rate, Pounds per Hour	< 3.26E+00	< 1.15E-01

< Indicates the value is below the detection limit.

MMT-M60-1

MMT-M60-2

Magnesium

FWt	Formula Weight, Lb/Lb-Mole		24.31		24.31
mg	Catch Weight, Milligrams	<	52.1	<	102.3
ug/DSCM	Concentration, Micrograms per DSCM	<	53,882	<	83,876
ng/DSCM	Concentration, Nanograms per DSCM	<	5.39E+07	<	8.39E+07
lb/hr	Emission Rate, Pounds per Hour	<	9.96E-02	<	1.61E-01

Manganese

FWt	Formula Weight, Lb/Lb-Mole		54.94		54.94
mg	Catch Weight, Milligrams	<	4.8	<	6.7
ug/DSCM	Concentration, Micrograms per DSCM	<	4,929	<	5,477
ng/DSCM	Concentration, Nanograms per DSCM	<	4.93E+06	<	5.48E+06
lb/hr	Emission Rate, Pounds per Hour	<	9.11E-03	<	1.05E-02

Mercury

FWt	Formula Weight, Lb/Lb-Mole		200.59		200.59
mg	Catch Weight, Milligrams	<	2.5	<	2.8
ug/DSCM	Concentration, Micrograms per DSCM	<	2,558	<	2,283
ng/DSCM	Concentration, Nanograms per DSCM	<	2.56E+06	<	2.28E+06
lb/hr	Emission Rate, Pounds per Hour	<	4.73E-03	<	4.38E-03

Nickel

FWt	Formula Weight, Lb/Lb-Mole		58.71		58.71
mg	Catch Weight, Milligrams	<	1.5	<	2.2
ug/DSCM	Concentration, Micrograms per DSCM	<	1,533	<	1,792
ng/DSCM	Concentration, Nanograms per DSCM	<	1.53E+06	<	1.79E+06
lb/hr	Emission Rate, Pounds per Hour	<	2.83E-03	<	3.44E-03

Phosphorus

FWt	Formula Weight, Lb/Lb-Mole		30.97		30.97
mg	Catch Weight, Milligrams	<	18.3	<	69.3
ug/DSCM	Concentration, Micrograms per DSCM	<	18,918	<	56,840
ng/DSCM	Concentration, Nanograms per DSCM	<	1.89E+07	<	5.68E+07
lb/hr	Emission Rate, Pounds per Hour	<	3.50E-02	<	1.09E-01

Potassium

FWt	Formula Weight, Lb/Lb-Mole		39.10		39.10
mg	Catch Weight, Milligrams	<	196.0	<	1083.6
ug/DSCM	Concentration, Micrograms per DSCM	<	202,728	<	888,422
ng/DSCM	Concentration, Nanograms per DSCM	<	2.03E+08	<	8.88E+08
lb/hr	Emission Rate, Pounds per Hour	<	3.75E-01	<	1.71E+00

< Indicates the value is below the detection limit.

		MMT-M60-1	MMT-M60-2
Selenium			
FWt	Formula Weight, Lb/Lb-Mole	78.96	78.96
mg	Catch Weight, Milligrams	< 2.5	< 2.8
ug/DSCM	Concentration, Micrograms per DSCM	< 2,558	< 2,283
ng/DSCM	Concentration, Nanograms per DSCM	< 2.56E+06	< 2.28E+06
lb/hr	Emission Rate, Pounds per Hour	< 4.73E-03	< 4.38E-03
Silicon			
FWt	Formula Weight, Lb/Lb-Mole	28.09	28.09
mg	Catch Weight, Milligrams	< 1395.8	< 1691.1
ug/DSCM	Concentration, Micrograms per DSCM	< 1,443,553	< 1,386,492
ng/DSCM	Concentration, Nanograms per DSCM	< 1.44E+09	< 1.39E+09
lb/hr	Emission Rate, Pounds per Hour	< 2.67E+00	< 2.66E+00
Silver			
FWt	Formula Weight, Lb/Lb-Mole	107.87	107.87
mg	Catch Weight, Milligrams	< 0.7	< 3.0
ug/DSCM	Concentration, Micrograms per DSCM	< 688	< 2,452
ng/DSCM	Concentration, Nanograms per DSCM	< 6.88E+05	< 2.45E+06
lb/hr	Emission Rate, Pounds per Hour	< 1.27E-03	< 4.71E-03
Sodium			
FWt	Formula Weight, Lb/Lb-Mole	22.99	22.99
mg	Catch Weight, Milligrams	< 123.2	< 972.8
ug/DSCM	Concentration, Micrograms per DSCM	< 127,400	< 797,536
ng/DSCM	Concentration, Nanograms per DSCM	< 1.27E+08	< 7.98E+08
lb/hr	Emission Rate, Pounds per Hour	< 2.36E-01	< 1.53E+00
Strontium			
FWt	Formula Weight, Lb/Lb-Mole	87.62	87.62
mg	Catch Weight, Milligrams	< 4.2	< 7.7
ug/DSCM	Concentration, Micrograms per DSCM	< 4,378	< 6,280
ng/DSCM	Concentration, Nanograms per DSCM	< 4.38E+06	< 6.28E+06
lb/hr	Emission Rate, Pounds per Hour	< 8.10E-03	< 1.21E-02
Titanium			
FWt	Formula Weight, Lb/Lb-Mole	47.90	47.90
mg	Catch Weight, Milligrams	< 10.9	< 37.7
ug/DSCM	Concentration, Micrograms per DSCM	< 11,294	< 30,918
ng/DSCM	Concentration, Nanograms per DSCM	< 1.13E+07	< 3.09E+07
lb/hr	Emission Rate, Pounds per Hour	< 2.09E-02	< 5.94E-02

< Indicates the value is below the detection limit.

		MMT-M60-1		MMT-M60-2	
Vanadium					
Fwt	Formula Weight, Lb/Lb-Mole		50.94		50.94
mg	Catch Weight, Milligrams	<	0.3	<	2.5
ug/DSCM	Concentration, Micrograms per DSCM	<	354	<	2,077
ng/DSCM	Concentration, Nanograms per DSCM	<	3.54E+05	<	2.08E+06
lb/hr	Emission Rate, Pounds per Hour	<	6.54E-04	<	3.99E-03
Zinc					
Fwt	Formula Weight, Lb/Lb-Mole		65.38		65.38
mg	Catch Weight, Milligrams	<	2602.3	<	188.4
ug/DSCM	Concentration, Micrograms per DSCM	<	2,691,441	<	154,429
ng/DSCM	Concentration, Nanograms per DSCM	<	2.69E+09	<	1.54E+08
lb/hr	Emission Rate, Pounds per Hour	<	4.98E+00	<	2.97E-01
Zirconium					
Fwt	Formula Weight, Lb/Lb-Mole		91.22		91.22
mg	Catch Weight, Milligrams	<	6.4	<	511.4
ug/DSCM	Concentration, Micrograms per DSCM	<	6,646	<	419,245
ng/DSCM	Concentration, Nanograms per DSCM	<	6.65E+06	<	4.19E+08
lb/hr	Emission Rate, Pounds per Hour	<	1.23E-02	<	8.05E-01
Particulate					
g	Catch Weight, Grams (Filter)		9.8341		11.145
%	Percent of Particulate in Filter		83.1		83.0
g	Catch Weight, Grams (HNO3)		0.2471		0.3631
%	Percent of Particulate in HNO3 Rinse		2.1		2.7
g	Catch Weight, Grams (Acetone)		1.7463		1.9126
%	Percent of Particulate in Acetone Rinse		14.8		14.3
g	Catch Weight, Grams (Total)		11.8275		13.4207
g/DSCM	Concentration, Total Milligrams per DSCM		12.233		11.003
gr/DSCF	Concentration, Total Grains per DSCF		5.346		4.808
lb/hr	Emission Rate, Total Pounds per Hour		22.621		21.129

< Indicates the value is below the detection limit.

Appendix P-6

Partitioning of Feed Material, Toxic, and Structural Metals

Table P-6-1. Feed material partitioning.

	S60	S60-IV	N80 runs	N80-IV runs	M60 runs	Average of runs
From MMT	2.01	1.65	2.29	1.53	1.70	1.84
APCS solids	1.32	1.97	2.76	2.27	1.82	2.02
Entrained feed	1.01	1.40	2.10	1.84	1.36	1.42
Condensed volatiles	0.30	0.57	0.66	0.43	0.45	0.61

Table P-6-2. Partitioning of toxic metals into the slag.

Element	S60	S60-IV	Total N80 runs	Total N80-IV runs	M60	Total M60 runs
Arsenic	71.0	68.6	52.7	61.1	4.6	12.6
Barium	97.6	96.9	97.5	95.7	96.3	96.4
Cadmium	< 81.9	< 68.4	< 62.1	< 61.5	< 55.2	< 62.8
Cerium	98.5	98.9	97.5	95.4	97.0	96.7
Chromium	99.6	99.2	97.4	97.4	65.1	74.5
Copper	93.5	74.3	84.0	89.8	4.3	7.2
Lead	75.8	29.1	27.9	47.5	46.5	30.7
Nickel	98.1	97.1	66.3	74.2	8.4	10.8
Phosphorus	83.1	32.1	75.4	74.2	1.7	23.2
Silver	95.7	< 79.3	< 60.7	< 72.2	< 60.3	< 72.3
Zinc	78.3	61.8	56.2	65.3	37.9	39.0
Toxic metals	96.0	94.9	90.4	92.7	44.5	53.5

< Value below detection limit

Table P-6-3. Partitioning of metals in the M60 and M60-Mod feed mixtures.

	M60 (%)				M60 and M60-Mod (%)			
	Metal	Slag	Fume traps	Baghouse	Metal	Slag	Fume traps	Baghouse
Aluminum	0.60	98.8	0.52	0.09	0.30	98.9	0.67	0.10
Arsenic	92.9	4.60	1.32	1.20	79.8	12.6	3.52	4.03
Barium	0.73	96.3	2.26	0.69	0.36	96.4	2.45	0.80
Calcium	0.34	98.2	1.23	0.25	0.09	98.7	1.07	0.17
Carbon	62.4	26.7	7.27	3.60	27.8	59.0	8.71	4.44
Chromium	34.8	65.1	0.06	0.03	25.3	74.5	0.09	0.10
Copper	95.5	4.30	0.06	0.14	92.3	7.24	0.13	0.28
Iron	86.1	13.8	0.09	0.05	64.2	35.6	0.19	0.09
Lead	33.9	46.5	18.6	0.92	16.0	30.7	15.0	38.4
Magnesium	0.47	98.6	0.79	0.18	0.21	98.7	0.93	0.19
Nickel	91.5	8.39	0.06	0.03	89.0	10.8	0.10	0.07
Phosphorus	95.2	1.67	0.57	2.58	71.1	23.2	0.43	5.20
Potassium	0.12	96.0	1.93	1.91	0.04	95.5	2.05	2.39
Silicon	3.79	95.1	0.73	0.33	1.88	96.8	0.89	0.39
Sodium	0.61	94.5	2.27	2.64	0.16	95.5	2.10	2.21
Sulfur	33.7	49.5	5.20	11.7	16.8	56.2	6.09	20.9
Titanium	1.05	98.6	0.32	0.07	0.26	99.5	0.22	0.05
Zinc	5.72	37.9	16.5	39.8	3.28	39.0	15.2	42.6
Zirconium	0.38	95.3	3.51	0.84	0.08	94.9	4.48	0.51

Table P-6-4. Partitioning of toxic metals to the fume traps and the baghouse.

	S60	S60-IV	N80 runs	N80-IV runs	M60	M60 runs
Arsenic to baghouse	22.4	22.1	32.6	18.7	1.20	4.03
Arsenic to fume traps	6.55	9.34	14.6	20.2	1.32	3.52
Barium to baghouse	0.96	1.33	1.06	1.87	0.69	0.80
Barium to fume traps	1.45	1.74	1.41	2.42	2.26	2.45
Cadmium to baghouse	>14.45	>27.9	>30.3	>29.5	>13.4	>19.7
Cadmium to fume traps	>3.69	>3.68	>7.59	>9.01	>8.89	>7.10
Cerium to baghouse	0.18	0.16	0.93	2.09	0.57	0.43
Cerium to fume traps	1.33	0.90	1.54	2.51	2.33	2.81
Chromium to baghouse	0.24	0.49	1.54	1.65	0.03	0.10
Chromium to fume traps	0.18	0.31	1.03	0.98	0.06	0.09
Copper to baghouse	5.45	23.2	14.6	8.37	0.14	0.28
Copper to fume traps	1.03	2.53	1.35	1.86	0.06	0.13
Lead to baghouse	19.9	64.2	59.9	40.4	0.92	38.4
Lead to fume traps	4.37	6.75	12.2	12.1	18.6	15.0
Mercury to baghouse	>48.9	>61.8	>60.8	>46.6	>37.3	>39.2
Mercury to fume traps	>7.2	>2.3	>8.6	>10.1	>15.0	>13.1
Nickel to baghouse	1.08	1.88	29.7	17.1	0.03	0.07
Nickel to fume traps	0.79	1.02	3.98	8.72	0.06	0.10
Phosphorus to baghouse	12.6	57.4	20.7	17.1	2.58	5.20
Phosphorus to fume traps	4.32	10.5	3.92	8.75	0.57	0.43
Selenium to baghouse	>8.33	>10.6	>12.8	>15.4	>4.36	>6.56
Selenium to fume traps	>2.02	>4.68	>3.57	>5.95	>1.77	>2.01
Silver to baghouse	3.00	>17.4	>36.0	>21.8	>7.42	>8.97
Silver to fume traps	1.35	>3.29	>3.34	>6.03	>7.68	>6.73
Zinc to baghouse	16.5	33.0	37.7	24.4	39.8	42.6
Zinc to fume traps	5.14	5.21	6.07	10.4	16.5	15.2

Appendix Q

Overview of the Integrated Melting Facility

Q. 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.¹ A process schematic of the facility is shown in Figure Q-1.

Q.1 Feed System

Feed waste mixtures, received in 55 gal barrels, were either transferred directly by barrel-lift into the 60 ft³ 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 ft³ 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/ft³, could be operated manually or controlled automatically by a programmable controller. A detailed description of the feed system is provided in the operations manual.² The receiving bin and charge hopper are shown in Figure Q-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.

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

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

Q.2 Electric Arc Melting Furnace and Power Supply

Q.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 ft³. Figure Q-3 shows a 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.³

Figure Q-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 Q-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.

Q.2.2 Furnace Refractories

Refractory placement within the shell and roof is indicated in Figure Q-6. The bottom of the shell was lined with 5 in. (2 courses) of straight Ruby¹ 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

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

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

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

Figure Q-5. Photograph of furnace roof.

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

(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 ft³.

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.

Q.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.⁴ 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 Q-7 shows a circuit diagram for cooling water indicating maximum anticipated flowrates.

Figure Q-7. Cooling water circuit diagram.

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.

Q.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 Q-8 shows an electrical line drawing of the power supply beginning 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 Q-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.

Q.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,

Table Q-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 Q-8. Line drawing for electric arc melting furnace power supply.

with the 12.5 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 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 Q-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 Q-9. View of the furnace and the offgas system within the building.

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Appendix R

Molar Basicity and Slag Viscosity

MOLAR BASICITY AND SLAG VISCOSITY

The basicity ratio is the molar ratio of total basic oxides to total acidic oxides in the slag. The basicity ratio is a useful indicator of slag viscosity, melting temperature, and refractory compatibility. A slag with basicity ratio less than one is considered acidic, greater than one is basic, and a basicity of one is considered neutral. With high proportions of soil in the surrogate waste mixtures, the resultant slags had high silica (SiO_2) levels. Silica is a network or polymer former and largely determines the viscosity of the slag. Metals with a valence greater than or equal to three form acidic oxides (P_2O_5 , Al_2O_3 , Cr_2O_3 , TiO_2 , and ZrO_2), which tend to extend or incorporate into the silicate network. The alkali metal oxides (Na_2O , K_2O , Cs_2O) and the alkaline earth metal oxides (MgO , CaO , SrO , BaO) are basic oxides that terminate the Si-O-bonds and tend to break up the silicate network. The divalent oxides of the transition metals (FeO , MnO , NiO) are also basic. Fe_2O_3 is considered to be half basic and half acidic. Sulfur and chlorine in silicate slags are considered basic because they tend to break up the silicate network, in contrast to their acidic nature in aqueous systems.

The slag viscosity had to be sufficiently low to enable tapping through the slag tap hole. Slag viscosity depended on the slag temperature and the slag composition. Higher slag temperatures were required for continuous tapping when the slag basicity ratio deviated significantly from unity.

The following rules of thumb have been suggested for estimating the melting temperature, viscosity, and refractory compatibility of silicate slags in a rotary kiln slagging incinerator (Queneau⁵). These rules may also be applicable to silicate slags in an arc melting furnace:

1. Basic slags should be contained in basic refractories, and acidic slags in acidic refractories.
2. Basicity in excess of neutral tends to increase slag melting temperature but decrease liquid-phase viscosity. Viscosity in the range 25 poise is optimum, with viscosity less than 10 poise leading to refractory brick attack, and viscosity greater than 200 poise leading to slag buildup within the kiln.
3. Slag viscosity should be acceptable if the basicity ratio is between 0.9 and 1.3.
4. Slags with silica concentration greater than 45% usually have high viscosities.
5. Slags with high alumina content ($>10\%$) and high silica tend to be especially viscous.
6. Chemical interaction among Al_2O_3 , MgO , FeO , and Cr_2O_3 can lead to the formation of insoluble spinel-type precipitates and result in high slag viscosity.
7. Acidic slags tend to resist weathering better (and are less leachable) than basic slags. Similarly, oxidized slags tend to resist weathering better than reduced slags. Basalt, which contains 45 to 55% silica, is a good example of a naturally occurring weather-resistant slag.
8. The retention of volatile metals, metal oxides, chlorine, and sulfur in slags is inversely related to the melting temperature.

In light of the above rules and experience with weathering-resistant natural minerals, the ideal slag in the present investigation would be acidic, contain 45 to 50% SiO_2 , and be highly oxidized with low melting temperature and low viscosity. That combination of properties likely cannot be obtained, and if compromise is called for, resistance to weathering and long-term stability will be emphasized at the expense of viscosity and melting temperature. Table R-1 lists the calculated molar basicity for slags produced by melting the waste mixtures and the modified furnace feed compositions.

The viscosity of two natural mineral slags and product slags derived from the furnace feed mixtures were calculated by the method of R.W. Shaw⁶. By the standards of Queneau¹, the viscosity of soil slag should be about 25 poise at 1800°C and hence should tap from the furnace at that temperature. Slags derived from the waste mixtures and modified furnace feeds should tap at much lower temperatures.

Table R-1. Molar Basicity of Product Slags.

Furnace Feed Mixture	Basicity Ratio	Temperature Tapping was Achieved (C)	Calculated Slag Viscosity at Tapping Temperature (Poise)
RWMC soil	0.26		
100 lb soil:10 lb mill scale	0.31	>1600	<11
100 lb soil:20 lb mill scale	0.37		
Calcium silicate	1.00	1450-1700	1 - 7
S60	0.52	1550-1600	2 - 3
S60-IV	0.51	1550-1650	5 - 9
N80	0.48	1650-1800	1 - 3
N80-Mod	1.00	1450-1550	1 - 2
N80-IV	0.44	1650-1750	1
N80-IV-Mod	1.00	1550-1590	0.36 - 0.42
M60 (non-metal components)	0.28	No Tap	

One objective of the melting tests was to determine the relationship between the composition of furnace feed materials and the leaching characteristics of product slags including the influence of additives designed to improve melting and tapping conditions. Unadulterated soil produced a very acidic slag (molar basicity ratio 0.26) that proved to be very viscous at desired tapping temperatures (1,550°C). Other waste mixtures also produced very acidic and viscous slags owing to high silica content (67%) of the RWMC soil; therefore, additional materials including limestone (CaCO_3), pebble lime (CaO), and magnetite (Fe_3O_4) as mill scale from a local steel mill were obtained prior to the melting test to fluidize the melts if needed.

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Appendix S

Comparison of Offgas Flowrates, Temperatures, and Dilution Factors

Table S-1. Comparison of offgas flowrates, temperatures, and dilution factors.

Feed type	Barometric pressure (in. Hg)	Stack static pressure (in H2O)	Quench outlet		Quench air		Furnace outlet temperature			Mass balance	Energy balance
			Flowrate (wscfm)	Temp. (C)	Flowrate (wscfm)	Temp. (C)	Data Logger (C)	Manual measurements		Dilution factor	Dilution factor
								(C)	Clock time		
S60	29.88	-1.6	486	67.8	308	25	110	229	NM	2.73	4.77
S60	29.88	-1.6	477	77.8	308	30	62	229	NM	2.82	4.16
S60-IV	29.88	-1.6	490	78.9	286	35	69	218	1120	2.40	4.18
S60-IV	29.88	-1.6	493	79.4	329	30	60	239 202 277	Avg. 1515 1655	3.01	4.24
N80	29.9	-1.8	541	85.6	501	33	63	206 500 429	Avg. 1115 1200	13.53	3.29
N80-Mod	29.8	-1.8	497	94.4	497	31	60	496 485 499 504	Avg. 1535 1547 1635	-	7.33
N80-IV	29.8	-1.9	510	102	423	36	65	506 504 507	Avg. 1025 1342	5.86	7.10
N80-IV-Mod	29.8	-1.9	474	109	342	34	81	622 623 616 643 604	Avg. 1600 1730 1740 1750	3.59	7.79
M60	29.9	-1.7	538	211	441	23	120		NM	5.55	-
N80-IV-Mod-2	29.9	-1.7	552	121	496	37	68	499	1520	9.86	5.49

Notes:

1. NM = Not Measured.
2. The bolded numbers in the dilution factor columns are the values which have been chosen as most representative and subsequently used in making other calculations.
3. For the S60 feed type, the measured quench air flowrates were unreasonably high and the manually measured furnace outlet temperatures were not measured. Average values of these parameters from the S60-IV feed type were used for S60, since the same general offgas conditions existed for both feed types.
4. Dilution factors were calculated as the Quench outlet flowrate/Furnace outlet flowrate.
5. The Data Logger furnace outlet temperature measurement was made using a Type-K SS-sheathed TC installed through a port to the duct wall, but not penetrating into the offgas flow in order to prevent interference with the mechanical furnace outlet duct scraper.
6. Occasional manual furnace outlet offgas measurements were made using a Type-K SS-sheathed TC inserted through a port in the furnace outlet duct to the duct centerline, to minimize effects of the water-cooled outlet duct on the temperature measurements.

Appendix T

In-Furnace Velocity and Particle Size Entrainment Calculations

IN-FURNACE VELOCITY AND PARTICLE SIZE ENTRAINMENT CALCULATIONS

The furnace gas temperatures, flow rates and compositions were not directly measured during the baseline tests, but were estimated using mass and energy balances from offgas measurements made in the APCS. These estimates of furnace gas conditions may be used to get a semi-quantitative perspective of conditions in the furnace plenum and feed material entrainment from the furnace. From data in Table 6-1, the average furnace gas temperature was 511°C, and the average furnace offgas flow rate was 110 wscfm. The average gas velocity in the furnace just below the feed tubes may be estimated from the cross-section area of this section. For this estimate, an approximate furnace "equivalent inside diameter" of 3.5 feet (5 inches less than the nominal diameter of 3 ft 11 in. to account for the diameters of the electrodes and minimal skull on the refractory walls) was used. From the gas temperature, gas flowrate and inside diameter, an average gas velocity of 0.51 ft/sec was calculated. The actual gas velocity gradient (variation in local velocities) likely varied widely in this zone, with somewhat higher gas velocities near the feed tubes and the electrodes from feed tube air influx and from gas evolution from the melt, while gas recirculation (downward or negative velocities) was likely near the sidewalls. However, using the average gas velocity as the stagnation velocity (also known as terminal velocity, when the force of gravity on a particle equals the drag and buoyancy forces from the gas), the particle radius can be estimated for spherical particles using Stokes's Law:¹

$$\mu = 2R^2(\rho_s - \rho)g/9v_t$$

where μ is the fluid viscosity, R is the radius of the sphere, ρ_s is the density of the sphere, ρ is the density of fluid, and v_t is the terminal velocity. Solving for R we get

$$R = \left[\frac{9v_t\mu}{2g(\rho_s - \rho)} \right]^{\frac{1}{2}}$$

This result is valid only when the Reynolds number, $Dv_t \rho/\mu$, is less than about 0.1.

To solve for the radius of a sphere that will remain stagnate in the air flow of the furnace is as follows:

Assumed or estimated values:

Temperature = 511°C

$\mu = 3.55 \text{ E-5 (N*s)/m}^2$

(From White, Fluid Mechanics Second ed.; McGraw-Hill 1986 Table A.2.)

$\rho = 0.457 \text{ kg/m}^3$

(White, Fluid Mechanics Second ed.; McGraw-Hill 1986 Table A.2.)

$\rho_s = 2340 \text{ kg/m}^3$

Standard density used for particle sizing measurements from thermal processes.

1. From Bird, Stewart, Lightfoot; Transport Phenomena. Wiley 1960.

$$g = 9.81 \text{ m/s}^2$$

Calculations:

$$\text{Flow rate} = (110 \text{ wscfm}) * (784 \text{ K} / 293 \text{ K}) = 294.3 \text{ acfm}$$

$$\text{Furnace Area} = \pi D^2 / 4 = 9.6 \text{ ft}^2$$

$$v_i = 0.51 \text{ f/s} = 0.155 \text{ m/s}$$

$$R = \left[\frac{(9)(0.15 \text{ m/s})(3.55 \text{E-}5 \text{ N*s/m}^2)}{(2)(9.81 \text{ m/s}^2)(2,340 \text{ kg/m}^3 - 0.457 \text{ kg/m}^3)} \right]^{1/2}$$

$$\text{Radius} = 3.3 \text{ E-}5 \text{ m} = 33 \text{ } \mu.$$

$$\text{Diameter} = 2R = 66 \text{ } \mu = 0.066 \text{ mm.}$$

Check to verify solution is valid by showing $Dv_i \rho / \mu$ is less than 0.1:

$$Re = (6.6 \text{ E-}5 \text{ m})(0.155 \text{ m/s})(0.457 \text{ kg/m}^3) / 3.55 \text{ E-}5 \text{ N*s/m}^2 = 0.13, \text{ which is close.}$$

Results:

From the calculations any particle less than 66 μm in diameter should be entrained by the air flow of the furnace.

Appendix U

Mass Balances of Individual Elements

Table U-1. Mass balance closure for selected metals for the S60 feed mixture.

Element	Feed concentration (ppm)	Input amount (lb)	Slag product		Amount in APCS catches (solid)(a)		Total Particulate matter (b)		Mass balance closure (c)	
			MRSC Concentration (ppm)	Amount (lb)	Concentration (ppm)	Amount (lb)	Concentration (mg/dscm)	Amount (lb)	Using fume trap/baghouse data	Using MMT test data
Aluminum	39,927	392	39,672	359	17,341	2.43	210	3.65	0.922	0.925
Arsenic	6.21	0.061	2.83	0.026	74.0	0.010	< 2.59	< 0.045	0.591	< 1.16
Barium	463	4.54	623	5.64	989	0.138	12.7	0.220	1.27	1.29
Cadmium	0.282	0.003	< 1.00	< 0.009	13.0	0.002	0.130	0.002	< 3.92	< 4.08
Calcium	64,685	634	56,402	510	44,164	6.18	473	8.19	0.81	0.82
Cerium	3,384	33.2	2,322	21.0	2,300	0.322	31.8	0.553	0.642	0.649
Cesium	3,956	38.8	1,484	13.4	59,213	8.29		0.000	0.560	NC (d)
Chromium	359	3.52	586	5.30	159	0.022	2.24	0.039	1.51	1.51
Copper	25.4	0.249	520	4.70	2,310	0.323	26.3	0.450	20.2	20.7
Iron	116,317	1,141	125,393	1,134	51,483	7.21	572	9.88	1.000	1.002
Lead	13.0	0.127	48.7	0.440	994	0.139	8.59	0.148	4.55	4.61
Magnesium	14,790	145	98,857	894	9,676	1.35	110	1.90	6.17	6.18
Manganese	313	3.07					6.28	0.108		NC (d)
Mercury	0.056	0.001	< 0.100	< 0.001	8.00	0.001	< 2.58	< 0.045	< 3.66	NC (e)
Nickel	19.2	0.188	71.0	0.642	87.0	0.012	0.800	0.014	3.47	3.48
Phosphorous	573	5.62	229.96405	2.08	3,000	0.420	100	1.72	0.445	0.676
Potassium	11,708	115	6,231	56.3	89,305	12.5	988	17.1	0.600	0.639
Selenium	0.631	0.006	< 1.00	< 0.009	5.00	0.001	< 2.58	< 0.045	< 1.57	< 8.66
Silicon	207,759	2,037	216,000	1,953	120,997	16.9	1,352	23.4	0.97	0.97
Silver	4.52	0.044	6.62	0.060	19.0	0.003	< 0.270	< 0.005	1.411	< 1.457
Sodium	13,628	134	12,893	116.6	71,125	9.96	956	16.5	0.95	0.996
Titanium	12,706	125	10,472	94.7	1,825	0.256	23.6	0.410	0.76	0.763
Zinc	62.1	0.609	119.62077	1.08	2,110	0.295	26.3	0.453	2.26	2.52
Zirconium	56.5	0.554	160.39573	1.45	36.0	0.005	0.585	0.010	2.63	2.64
Total metals		4,812		5,172		66.8		84.8	1.09	1.09

a. From combined catches of fume trap 1, fume trap 2 and baghouse. This represents the solid entrained feed material and solid condensed materials.

b. The average of the particulate/metals test, proportioned over the S60 run. This represents all APCS solids plus any volatilized material that would condense at ambient conditions but which may not yet be condensed in the APCS.

c. Sum output elemental mass/Sum input elemental mass.

d. NC, incomplete output product measurements.

e. NC, measured levels below detection limits.

< Value below detection limit.

Table U-2. Mass balance closure for selected metals for the S60-IV feed mixture.

Element	Feed concentration (ppm)	Input amount (lb)	Slag product		Amount in APCS catches (solid) (a)		Total Particulate matter (b)		Mass balance closure (c)		
			MRSC Concentration (ppm)	Amount (lb)	Concentration (ppm)	Amount (lb)	Concentration (mg/dscm)	Amount (lb)	Using fume trap/baghouse data	Using MMT test data	
Aluminum	35,819	296	37,560	264	11,523	1.89	169	2.33	0.896		0.898
Arsenic	5.46	0.045	2.47	0.017	49.0	0.008	< 2.59	< 0.036	0.561	<	1.17
Barium	467	3.87	690	4.84	933	0.153	12.3	0.168	1.29		1.30
Cadmium	0.248	0.002	< 1.00	< 0.007	17.0	0.003	0.150	0.002	4.77	<	4.46
Calcium	62,164	514	77,217	542	42,433	6.96	1,505	20.9	1.07		1.09
Cerium	3,384	28.0	3,809	26.7	1,730	0.284	38.2	0.524	0.965		0.974
Cesium	4,063	33.6	2,070	14.5	72,311	11.9		0.000	0.785		NC (d)
Chromium	382	3.16	450	3.16	156	0.026	1.83	0.025	1.006		1.006
Copper	22.4	0.185	50.6	0.355	752	0.123	4.38	0.060	2.59		2.25
Iron	116,628	965	132,965	933	54,611	8.96	480	6.58	0.977		0.974
Lead	11.4	0.095	9.6	0.067	1,000	0.164	5.29	0.072	2.44		1.48
Magnesium	14,082	117	20,327	143	8,113	1.33	103	1.42	1.24		1.24
Manganese	755	6.24		0.000			5.53	0.076			NC (d)
Mercury	0.050	0.000	< 0.100	< 0.001	7.00	0.001	< 2.59	< 0.036	4.50		NC (e)
Nickel	16.9	0.140	58.4	0.410	75.0	0.012	0.610	0.008	3.02		2.99
Phosphorous	528	4.36	53	0.370	4,780	0.784	43.5	0.598	0.264		0.222
Potassium	10,299	85.2	7,928	55.6	112,008	18.4	798	11.0	0.869		0.782
Selenium	0.555	0.005	< 1.00	< 0.007	6.00	0.001	< 2.59	< 0.036	1.74	<	9.28
Silicon	185,066	1,531	226,472	1,590	97,866	16.1	1,064	14.6	1.05		1.05
Silver	3.97	0.033	< 1.00	< 0.007	10.0	0.002	< 0.270	< 0.004	0.263	<	0.327
Sodium	13,213	109	15,006	105	95,481	15.7	835	11.4	1.11		1.07
Titanium	30,368	251	26,725	188	1,842	0.302	23.7	0.324	0.748		0.748
Zinc	54.6	0.452	95	0.670	2,520	0.413	18.6	0.254	2.40		2.04
Zirconium	7,034	58.2	16,443	115	104	0.017	1.00	0.014	1.98		1.98
Total metals		4,007		3,986		83.4		70.5	1.02		1.01

a. From combined catches of fume trap 1, fume trap 2 and baghouse. This represents the solid entrained feed material and soild condensed materials.

b. The average of the particulate/metals test, proportioned over the S60-IV run. This represents all APCS solids plus any volatilized material that would condense at ambient conditions but which may not yet be condensed in the APCS.

c. Sum output elemental mass/Sum input element mass.

d. NC, incomplete output product measurements.

e. NC, measured levels below detection limits.

< Value below detection limit.

Table U-3. Mass balance closure for selected metals for the N80 and N80-Mod-1 feed mixtures.

Element	Feed concentration (ppm)	Input amount (lb)	Slag product		Amount in APCS catches (solid) (a)		Total Particulate matter (b)		Mass balance closure (c)	
			MRSC							
			Concentration (ppm) (d)	Amount (lb)	Concentration (ppm)	Amount (lb)	Concentration (mg/dscm) (d)	Amount (lb)	Using fume trap/baghouse data	Using MMT test data
Aluminum	40,062	335	43,096	270	15,223	3.51	287	4.84	0.817	0.821
Arsenic	7.58	0.063	3.98	0.033	115	0.026	2.62	0.047	0.939	1.26
Barium	295	2.47	715	5.25	583	0.134	11.6	0.213	2.18	2.21
Cadmium	0.342	0.003	< 1.00	< 0.007	16.9	0.004	0.172	0.003	3.95	< 3.61
Calcium	56,757	475	84,805	646	104,807	24.2	462	8.28	1.41	1.38
Cerium	3,172	26.5	1,874	18.1	1,528	0.352	27.5	0.489	0.694	0.699
Cesium	34.2	0.286	420	2.28	33,813	7.79			35.2	NC (e)
Chromium	263	2.20	274	2.31	233	0.054	2.42	0.041	1.077	1.071
Copper	104	0.871	111	0.957	678	0.156	2.65	0.051	1.28	1.16
Iron	81,700	683	130,490	932	39,702	9.15	517	9.72	1.38	1.38
Lead	16.3	0.136	10	0.119	789	0.182	5.88	0.109	2.22	1.68
Magnesium	10,106	84.5	15,612	115	8,670	2.00	91.8	1.64	1.38	1.38
Manganese	267	2.24					5.20			NC (e)
Mercury	0.071	0.001	< 0.100	< 0.001	6.35	0.001	< 2.24	< 0.041	3.73	NC (f)
Nickel	65.6	0.548	87.3	0.613	1,425	0.329	1.08	0.019	1.72	1.15
Phosphorous	669	5.60	436	2.49	4,562	1.05	99.1	1.70	0.633	0.75
Potassium	46,427	388	42,419	300	84,158	19.4	812	14.9	0.824	0.812
Selenium	0.765	0.006	< 1.00	< 0.007	4.47	0.001	< 2.24	< 0.041	1.32	< 7.60
Silicon	186,557	1,560	211,378	1,414	96,460	22.2	1,519	26.7	0.921	0.923
Silver	5.47	0.046	< 1.00	< 0.007	19.3	0.004	< 0.242	< 0.004	0.259	< 0.259
Sodium	49,134	411	48,650	359	74,301	17.1	991	18.1	0.914	0.916
Titanium	6,412	53.6	8,740	194.7	1,332	0.307	27.9	0.494	3.64	3.64
Zinc	75.3	0.630	93.2	0.681	2,329	0.537	26.3	0.482	1.93	1.85
Zirconium	68.4	0.572	1,761	87.2	64.1	0.015	1.47	0.029	152.3	152.4
Total metals		4,033		4,351		109		88.0	1.11	1.10

- a. From combined catches of fume trap 1, fume trap 2 and baghouse. This represents the solid entrained feed material and soild condensed materials.
- b. The average of the particulate/metals test, proportioned over the N80 and N80-Mod-1runs. This represents all APCS solids plus any volatilized material that would condense at ambient conditio but which may not yet be condensed in the APCS.
- c. Sum output elemental mass/Sum input element mass.
- d. Weighted average of the N80 and N80-Mod-1 runs.
- e. NC, incomplete output product measurements.
- f. NC, measured levels below detection limits.
- < Value below detection limit.

Table U-4. Mass balance closure for selected metals for the N80-IV and N80-IV-Mod-1 feed mixtures.

Element	Feed concentration (ppm)	Input amount (lb)	Slag product		Amount in APCS catches (solid)(a)		Total Particulate matter (b)		Mass balance closure (c)	
			MRSC Concentration (ppm) (d)	Amount (lb)	Concentration (ppm)	Amount (lb)	Concentration (mg/dscm) (d)	Amount (lb)	Using fume trap/baghouse data	Using MMT test data
Aluminum	35,354	371	34,207	300	21,447	5.07	290	4.94	0.822	0.822
Arsenic	6.83	0.072	5.20	0.046	149	0.035	2.69	0.047	1.13	1.30
Barium	290	3.04	751	6.59	1,365	0.323	20.0	0.358	2.27	2.28
Cadmium	0.305	0.003	< 1.00	< 0.009	20.7	0.005	0.142	0.003	4.27	< 3.60
Calcium	56,829	597	89,311	784	69,527	16.5	614	13.3	1.34	1.34
Cerium	3,198	33.6	3,036	26.7	7,464	1.77	99.2	1.75	0.846	0.845
Cesium	30.5	0.320	57.0	0.500	18,932	4.48			15.6	NC (e)
Chromium	304	3.20	317	2.79	328	0.078	4.10	0.071	0.896	0.894
Copper	114	1.20	138	1.21	385	0.091	2.71	0.061	1.08	1.06
Iron	82,798	870	117,028	1,028	45,359	10.7	374	6.81	1.19	1.19
Lead	14.7	0.155	23.0	0.202	879	0.208	6.20	0.111	2.65	2.02
Magnesium	8,877	93.2	12,656	111	9,047	2.14	89.8	1.57	1.21	1.21
Manganese	1,053	11.1					4.93		0.000	NC (e)
Mercury	0.063	0.001	< 0.10	< 0.001	3.00	0.001	< 2.61	< 0.045	2.39	NC (f)
Nickel	70.7	0.743	85.8	0.753	85.8	0.020	0.689	0.013	1.04	1.03
Phosphorous	634	6.66	154	1.35	1,863	0.441	97.0	1.56	0.269	0.438
Potassium	45,223	475	44,523	391	85,890	20.3	1,066	18.2	0.866	0.861
Selenium	0.681	0.007	< 1.00	< 0.009	10.1	0.002	< 2.61	< 0.045	1.56	< 7.52
Silicon	166,145	1,745	169,597	1,489	138,865	32.9	1,799	30.5	0.872	0.871
Silver	4.88	0.051	< 1.00	< 0.009	6.00	0.001	3.45	0.057	0.199	< 1.29
Sodium	48,840	513	52,603	462	85,806	20.3	1,147	19.0	0.940	0.937
Titanium	36,499	383	39,797	349	2,339	0.553	42.7	0.722	0.913	0.913
Zinc	67.0	0.704	87.7	0.770	1,425	0.337	13.2	0.219	1.57	1.40
Zirconium	23,151	243	20,961	184	16,172	3.83	571	9.51	0.773	0.796
Total metals		5,352		5,139		120		109	0.983	0.981

a. From combined catches of fume trap 1, fume trap 2 and baghouse. This represents the solid entrained feed material and solid condensed materials.

b. The average of the particulate/metals test, proportioned over the N80-IV and N80-IV-Mod-1 runs. This represents all APCS solids plus any volatilized material that would condense at ambient conditions but which may not yet be condensed in the APCS.

c. Sum output elemental mass/Sum input element mass.

d. Weighted average of the N80-IV and N80-IV-Mod-1 runs.

e. NC, incomplete output product measurements.

f. NC, measured levels below detection limits.

< Value below detection limit.

Table U-5. Mass balance closure for selected metals for the M60 and N80-IV-Mod-2 feed mixtures.

Element	Feed concentration (ppm)	Input amount (lb)	Slag product		Metal heel		Amount in APCS catches (solid) (a)		Total Particulate matter (b)		Mass balance closure (c)	
			MRSC Concentration (ppm) (d)	Amount (lb)	Concentration (ppm)	Amount (lb)	Concentration (ppm) (d)	Amount (lb)	Concentration (mg/dscm) (d)	Amount (lb)	Using fume trap/baghouse data	Using MMT test data
Aluminum	44,817	299	74,000	387	1,100	1.36	18,232	0.966	195	2.99	1.30	1.31
Arsenic	6.64	0.044	2.00	0.016	99.0	0.122	78.7	0.010	< 2.54	< 0.030	3.33	< 3.78
Barium	303	2.02	969	3.66	18.0	0.022	1,156	0.140	16.4	0.203	1.89	1.93
Cadmium	0.297	0.002	< 1.00	< 0.005	< 1.00	< 0.001	18.3	0.002	0.159	0.002	4.38	< 4.20
Calcium	69,878	466	81,300	425	690	0.852	49,121	2.60	424	9.80	0.92	0.935
Cerium	3,348	24.8	3,928	16.4	< 10.0	< 0.012	4,868	0.590	24.8	0.626	0.683	< 0.685
Cesium	29.3	0.195	62.0	0.324	< 3.00	0.004	1,498	0.079			2.08	NC (e)
Chromium	8,589	57.3	13,002	26.6	17,053	21.1	920	0.112	6.79	0.165	0.835	0.836
Copper	3,725	24.8	330	0.872	17,949	22.2	565	0.069	5.45	0.086	0.931	0.931
Iron	183,112	1,221	59,000	308	902,000	1,114	23,175	1.23	182	4.13	1.17	1.17
Lead	3,620	24.1	1,130	1.62	2,020	2.49	47,912	5.81	1,636	10.7	0.411	0.613
Magnesium	8,384	55.9	14,600	76.3	170	0.210	5,717	0.303	56.1	0.920	1.37	1.38
Manganese	620	4.13							50.3	0.350		NC (e)
Mercury	0.060	0.000	< 0.100	< 0.001	< 0.100	< 0.000	5.43	0.001	< 2.54	< 0.030	3.24	NC (f)
Nickel	4,761	31.7	662	0.773	17,681	21.8	233	0.028	1.56	0.020	0.713	0.713
Phosphorous	605	4.03	15	0.946	2,100	2.59	1,181	0.143	21.7	0.475	0.914	0.996
Potassium	26,859	179	20,000	104	59.0	0.073	31,987	1.70	254	7.13	0.593	0.624
Selenium	0.667	0.004	< 1.00	< 0.005	< 3.00	< 0.004	6.00	0.001	< 2.54	< 0.030	2.17	< 8.66
Silicon	163,314	1,089	257,000	1,343	25,100	31.0	114,181	6.05	1,440	19.1	1.27	1.28
Silver	4.80	0.032	< 1.00	< 0.005	1.00	0.001	8.86	0.001	0.821	0.020	0.235	< 0.818
Sodium	25,215	168	13,200	69.0	210	0.259	27,419	1.45	177	6.02	0.420	0.448
Titanium	17,459	116	6,820	35.6	178	0.220	1,084	0.057	12.8	0.278	0.309	0.310
Zinc	7,248	48.3	2,650	7.47	979	1.21	121,921	14.8	2,503	16.7	0.486	0.526
Zirconium	10,584	70.553	3,400	17.8	33.0	0.041	6,195	0.328	37.3	2.73	0.257	0.291
Total metals		3,885		2,824		1,220		36.5		82.6	1.05	1.06

a. From combined catches of fume trap 1, fume trap 2 and baghouse. This represents the solid entrained feed material and solid condensed materials.

b. The average of the particulate/metals test, proportioned over the M-60 and N80-IV-Mod-2 runs. This represents all APCS solids plus any volatilized material that would condense at ambient conditions but which may not yet be condensed in the APCS.

c. Sum output elemental mass/Sum input element mass.

d. Weighted average of the M60 and N80-IV-Mod-2 runs.

e. NC, incomplete output product measurements.

f. NC, measured levels below detection limits.

< Value below detection limit.