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Support for HLW Direct Feed- Phase 2, VSL-15R3440-1

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Final Report

Support for HLW Direct Feed– Phase 2

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Test Plan:	Support for HLW Direct Feed– Phase 2, VSL-14T3440-1, Rev. 0

This report describes the results of testing specified by the above Test Plan. The work was performed in compliance with the quality assurance requirements specified in the Test Plan. Results required by the Test Plan are reported. The test results and this report have been reviewed for correctness, technical adequacy, completeness, and accuracy.

I.L. Pegg: _____ **Date:** 9/28/15
VSL Program Director/Principal Investigator

I. Joseph: Innocent Joseph **Date:** 9/28/15
Energy*Solutions* Sub-Contract Manager

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List of Abbreviations

ASME	American Society of Mechanical Engineers
ANL-LRM	Argonne National Laboratory – Low Activity Waste Reference Material
BBI	Best Basis Inventory
DCP-AES	Direct Current Plasma Atomic Emission Spectroscopy
DF	Decontamination Factor
DM	DuraMelter
DOE	Department of Energy
DWPF	Defense Waste Processing Facility
EA	Environmental Assessment
EDS	Energy Dispersive X-Ray Spectroscopy
FTIR	Fourier Transform Infrared Spectroscopy
IC	Ion Chromatography
HEPA	High-Efficiency Particulate Air Filter
HLW	High Level Waste
HTWOS	Hanford Tank Waste Operations Simulator
LAW	Low Activity Waste
NIST	National Institute of Standards and Technology
ORP	Office of River Protection
PCT	Product Consistency Test
NQA	Nuclear Quality Assurance
QAPP	Quality Assurance Project Plan
QARD	Quality Assurance Requirements and Description
RCRA	Resource Conservation and Recovery Act
SEM	Scanning Electron Microscopy
SOP	Standard Operating Procedure
TCLP	Toxicity Characteristic Leaching Procedure
TOE	Total Operating Efficiency
UTS	Universal Treatment Standard
VGF	Vertical Gradient Furnace
VSL	Vitreous State Laboratory
WTP	Hanford Tank Waste Treatment and Immobilization Plant
XRF	X-Ray Fluorescence Spectroscopy

SECTION 1.0
INTRODUCTION

This report describes work performed to develop and test new glass and feed formulations originating from a potential flow-sheet for the direct vitrification of High Level Waste (HLW) with minimal or no pretreatment. In the HLW direct feed option that is under consideration for early operations at the Hanford Tank Waste Treatment and Immobilization Plant (WTP), the pretreatment facility would be bypassed in order to support an earlier start-up of the vitrification facility. For HLW, this would mean that the ultrafiltration and caustic leaching operations that would otherwise have been performed in the pretreatment facility would either not be performed or would be replaced by an interim pretreatment function (in-tank leaching and settling, for example). These changes would likely affect glass formulations and waste loadings and have impacts on the downstream vitrification operations. Modification of the pretreatment process may result in: (i) Higher aluminum contents if caustic leaching is not performed; (ii) Higher chromium contents if oxidative leaching is not performed; (iii) A higher fraction of supernate in the HLW feed resulting from the lower efficiency of in-tank washing; and (iv) A higher water content due to the likely lower effectiveness of in-tank settling compared to ultrafiltration. The HLW direct feed option has also been proposed as a potential route for treating HLW streams that contain the highest concentrations of fast-settling plutonium-containing particles, thereby avoiding some of the potential issues associated with such particles in the WTP Pretreatment facility [1]. In response, the work presented herein focuses on the impacts of increased supernate and water content on wastes from one of the candidate source tanks for the direct feed option that is high in plutonium.

A series of waste compositions was investigated that span the range of washing efficiencies between the baseline WTP full-wash case and the no-wash case. Crucible melts were formulated and tested to investigate the effects on glass compositions and waste loadings. Based on those results, the unwashed, the fully washed, and two intermediate-wash options were selected for subsequent testing on the DuraMelter 100 (DM100) melter system. These tests assessed impacts on processability and melt rates as well as the effects of incorporating increased amounts of the supernate fraction, which contains nitrates, halides, and sulfur which are typically not abundant in HLW streams. Off-gas data were collected to assess the potential for increased NOx generation which could have impacts on the WTP HLW facility. The DM100 tests were also conducted on representative HLW feeds at solids contents extending below the current WTP baseline, which are likely for the direct feed option. The effects on glass production rate, melter operations, and off-gas carryover were determined. In addition, the ability of increased bubbling to improve processing rates for slower melting feeds was investigated. These tests form the basis for subsequent larger-scale tests on the DM1200 HLW Pilot Melter, where the effects of enhanced bubbler configurations can also be investigated. This work built on previous work performed at the Vitreous State Laboratory (VSL) for the Department of Energy (DOE) to increase waste loadings in HLW glass formulations and processing rates [2-6] and to support the HLW direct feed option [7].

1.1 Background

Projections of the number of HLW canisters to be produced at the WTP (e.g., [8]) are based upon the inventory of the tank wastes, the anticipated performance of the sludge treatment processes, and current understanding of the capability of the borosilicate glass waste form. The WTP HLW melter design, unlike earlier DOE melter designs, incorporates an active glass pool bubbler system. The bubblers provide active glass pool mixing and thereby improve heat transfer and glass melting rate. The WTP HLW melters each have a glass pool surface area of 3.75 m^2 and depth of ~1.1 m. The two melters in the HLW facility together are designed to produce up to 7.5 MT of glass per day at 100% availability. Further increases in HLW processing rates can potentially be achieved by optimization of the feed and glass formulations, increasing the melter operating temperature above 1150°C, and by increasing the waste loading in the glass product. Increasing the waste loading also has the added benefit of decreasing the number of canisters for storage.

The baseline estimates and glass formulation efforts have been conservative in terms of achievable waste loadings. These baseline formulations have been specified to ensure that the glasses are homogenous, contain essentially no crystalline phases, are processable in joule-heated, ceramic lined melters and meet WTP Contract terms. The overall WTP mission will require the immobilization of tank waste compositions that are dominated by mixtures of aluminum, chromium, bismuth, iron, phosphorous, zirconium, and sulfur compounds as waste-loading-limiting components. Glass compositions for these waste mixtures have been developed based upon previous experience and current glass property models. In order to improve waste loadings, DOE has initiated a testing program to develop and characterize HLW glasses for wastes that are limited by Al, Al plus Na, Bi, and Cr [8, 9]. Results of that work have demonstrated the feasibility of increases in waste-loading from about 25 wt% to 33-50 wt% (based on oxide loading) in the glass, depending on the waste stream. It is expected that these higher waste loading glasses will reduce the HLW canister production requirement by about 25% or more [6]. Furthermore, it has been shown that a key technological risk area relates to the strong dependence of glass production rate on waste composition [6]. The extent of this variation across the full spectrum of HLW compositions needs to be quantified in order to accurately project waste treatment rates.

Under a separate contract with BNI to support the WTP, the VSL has developed and tested glass formulations for WTP HLW compositions to provide data to meet the WTP contract requirements and to support system design activities [10-15]. That work was based upon small-scale batch melts ("crucible melts") using waste simulants. Selected formulations were also tested in continuously fed, joule-heated melters (DM100 and DM1200) [16-21]. That testing was directed towards waste streams from the then-planned early feed tanks for the WTP (i.e., AZ-101, AZ-102, C-106/AY-102, and C-104/AY-101). These wastes are high in iron (AZ-101, AZ-102 and C-106/AY-102) or thorium (C-104/AY-101) and are significantly different than those used in more recent enhancement tests performed for ORP (i.e., wastes limited by Al, Al/Na, Bi, and Cr). Baseline glass formulations to treat these high-Fe wastes were developed under the BNI contract. During that time, the throughput requirement for the HLW melter was initially 400 kg/(m^2·day), which was subsequently increased to 800 kg/(m^2·day). As a result, the baseline high-Fe HLW glass formulations for WTP perform only slightly better than the

800 kg/(m^2·day) processing rate requirement. Furthermore, the baseline waste loadings for the Fe-limited HLW compositions are only slightly higher than the BNI contract minimum. Since that time, in work performed for ORP on other HLW compositions, VSL has developed small-scale test methods to assess processing rates of melter feeds and included them as an integral part of glass formulation development [3]. This methodology was used successfully to develop glass formulations for high-Al Hanford HLW that showed processing rates in excess of 2000 kg/(m^2·day) while achieving high waste loadings. The same methodology was applied in the development of improved glass formulations for high-Fe HLW [4] and can be applied to other Hanford HLW in order to provide ORP with a significantly more robust operating envelope with reduced risk of throughput shortfalls. These substantial increases in waste processing rates also have the potential to at least partially mitigate melt rate decreases caused by the likely lower solids contents in HLW feeds generated by the direct feed option.

1.2 Overview of Previous HLW Direct Feed Testing

The overall objective of the HLW direct feed testing work is to assess the potential impacts of various simplified HLW pretreatment options on glass volume and processing time for candidate HLW direct feed source tanks. Such data are essential inputs to assessments of the relative benefits (in terms of reduced glass volume and treatment time) of progressively more extensive HLW pretreatment, versus the associated increases in operational costs and supporting equipment costs. The results depend on the composition of both the HLW solids as well as the low activity waste (LAW) fraction (supernate, interstitial fluids, saltcake) in the respective candidate source tanks and therefore they are expected to vary from tank to tank. There is therefore a need to perform such evaluations over a representative set of candidate source tanks. The first such study of this type was focused on waste from Hanford tank AY-102 [7], which had been planned as one of the early WTP source tanks. In contrast, the present work is focused on a source tank that is high in plutonium since the HLW direct feed option has the potential to avoid some of the issues associated with fast-settling plutonium-containing particles in the WTP Pretreatment facility.

In previous work to support the HLW direct feed option [7], glass formulations were developed for four waste blends from Hanford tank AY-102 with varying amounts of LAW and HLW. As the number of wash cycles increases, the contribution of LAW to the overall waste composition decreases. Glass formulations for the waste blend with the highest LAW contribution contained high concentrations of alkali oxides and the waste loading was limited by K-3 refractory corrosion, whereas those for more extensively washed blends were limited by spinel formation. The test results showed that, in terms of HLW loading in the glass, there is clearly no advantage in conducting more than two wash cycles for AY-012 waste because the additional sodium that is removed from the waste is put back as a glass former additive in order to limit spinel crystallization in the glass formulation for the fully washed HLW solids.

A series of melter tests were conducted on the DM100-BL vitrification system with four blends of simulated HLW AY-102 waste solids and supernates processed with glass forming additives optimized for each blend. The five tests were distinguished by four different total waste compositions based on blending differing amounts of LAW supernate with HLW solids, four

different glass compositions corresponding to each of the four waste compositions, and five feed solids contents resulting from two different HLW solids contents.

The results from the glass formulation and melter testing demonstrated the viability of the HLW direct feed approach and provided valuable information on the relative merits for each waste pretreatment strategy in terms of mass of glass produced and processing time. The principal conclusions from the previous work were the rapidly diminishing benefits of multiple wash cycles, and, consequently, also of more complex and intensive washing facilities, and the importance of maintaining sufficiently high solids content in the HLW feed to the vitrification facility. Thus, of the pretreatment strategies for direct HLW feed evaluated, the first wash cycle was found to provide the vast majority of the overall benefit of washing in terms of HLW loading and HLW processing time; two wash cycles appears to be optimal in those respects since the second wash cycle provided further, though smaller, gains but that must be weighed against the operational cost of each successive wash cycle.

It should be noted that the A-104 supernate is relatively low in dissolved solids content, sulfate, and halides and therefore the primary benefit of washing on HLW loading is via removal of sodium. Consequently, excessive washing is counter-productive since sodium is a required additive for HLW vitrification. Conversely, for supernates with high levels of sulfur or halides, more extensive washing may be required, particularly in view of the fact that, unlike the WTP LAW melter systems, the WTP HLW melter systems are not designed to tolerate high levels of these species. Such compositions should be evaluated in future work.

1.3 Test Objectives

The primary objective of the work described herein was to develop and identify HLW glass compositions and glass forming additive blends for vitrification of a high-plutonium direct-feed HLW stream, which has undergone various degrees of washing with no other pretreatment, while maintaining high waste loadings, high processing rates (> 1000 kg glass per m^2 of melt surface area per day), and acceptable glass properties. High waste loadings refer to waste loading levels higher than those for the BNI baseline glasses and similar to those achieved in glass formulations developed for ORP by VSL and Energy*Solutions*. This was accomplished through a combination of crucible-scale tests, vertical gradient furnace tests, and confirmation tests on the DM100 melter system. The tests were performed according to the Test Plan that was developed for this work [22].

1.4 Quality Assurance

This work was conducted under a quality assurance program that is based on Nuclear Quality Assurance (NQA)-1 2004 and NQA-2a (1990) Part 2.7 that is in place at the VSL. The program is compliant with applicable criteria of 10 CFR 830.120; Office of Civilian Waste Management DOE/RW-0333P, Quality Assurance Requirements and Description (QARD) Revision 20; the American Society of Mechanical Engineers (ASME) Nuclear Quality Assurance (NQA-1), 2004; and DOE Order 414.1 C, Quality Assurance. This program is

supplemented by a Quality Assurance Project Plan (QAPP) for RPP-WTP work [23] that is conducted at VSL. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work [24].

1.5 DM100 Melter System

1.5.1 DM100 Feed System

A schematic diagram of the DM100 vitrification system is shown in Figure 1.1. The melter feed is introduced in batches into a feed container that is mounted on a load cell for weight monitoring. The feed is stirred with a variable speed mixer and constantly recirculated except for periodic, momentary interruptions during which the weight is recorded. A peristaltic pump is used in order to provide a uniform delivery of feed to the melt surface. Feed is directed from the recirculation loop that extends to the top of the melter and then diverted to the peristaltic pump, which regulates the flow of feed through a Teflon-lined feed line and water-cooled feed tube into the melter.

1.5.2 Melter System

Cross-sectional diagrams of the DM100-BL melter are shown in Figures 1.2.a-c. The DM100-BL unit is a ceramic refractory-lined melter fitted with five electrodes: two pairs of opposing Inconel 690 plate electrodes and a bottom electrode. Power can be supplied in either three-phase or single-phase configurations. All of the tests in the present work were performed with the upper and lower electrodes on each side connected together and powered by a single-phase supply; the bottom electrode was not powered. Melt pool agitation is achieved by either a removable lance entering from the top of the melter or a permanent bubbler installed through the bottom electrode. In these tests, the lance bubbler was used. The glass product is removed from the melter by means of an airlift discharge system. The melter has a melt surface area of 0.108 m^2 and a variable glass inventory of between 110 kg, when only the bottom pair of electrodes is used, and about 170 kg when both pairs of electrodes are used, which was the case in the present tests.

1.5.3 Off-Gas System

For operational simplicity, the DM100-BL is equipped with a dry off-gas treatment system involving gas filtration operations only. Exhaust gases leave the melter plenum through a film cooler device that minimizes the formation of solid deposits. The film-cooler air has constant flow rate and its temperature is thermostatically controlled. Consequently, under steady-state operating conditions, the exhaust gases passing through the transition line (between the melter and the first filtration device) can be sampled at constant temperature and airflow rate. The geometry of the transition line conforms to the requirements of the 40-CFR-60 air sampling techniques. Immediately downstream of the transition line are cyclonic filters followed by

conventional pre-filters and high efficiency particulate air (HEPA) filters. The temperature of the cyclonic filters is maintained above 150°C while the temperatures in the HEPAs are kept sufficiently high to prevent moisture condensation. The entire train of gas filtration operations is duplicated and each train is used alternately. An induced draft fan completes the system.

1.6 Experimental Procedures and Methods

1.6.1 Feed Conversion by Vertical Gradient Furnace (VGF) Testing

Figure 1.3 shows a schematic diagram of the VGF setup. The temperature gradient inside the VGF is maintained by two separate sets of heating elements, both of which are arranged in cylindrical form and aligned along their axes. The inner heater is set at 1150°C, which is the nominal temperature of the glass pool, and the ambient heater is set at 600°C, which is similar to the melter plenum temperature. A ceramic crucible (4 inches tall) is used to contain the reacting melter feed. The temperature gradient in the furnace is shown in Figure 1.4. For a typical feed conversion test, 10 grams of glass of identical chemical composition to the test feed (expressed on an oxide basis) is preheated in the ceramic crucible positioned in the inner heater before the dried melter feed (to yield 20 grams of glass) is introduced. Feed reactions under the controlled temperature gradient are allowed to continue for the designated test duration (typically, from 5 to 60 minutes) and then stopped by rapid cooling in room temperature air. The top surface of the reacted feed material is then inspected and photographed. The crucibles with their feed contents are then cross-sectioned to reveal the conversion progress of feed blends. The saw cuts of the crucibles are performed dry (without lubricant) to avoid loss of any soluble material.

To characterize the reacted feed material, visual inspection and digital imaging of the top (by photography) and cross section (using an optical scanner) of the reacted sample are performed. The results are assessed by comparison to results obtained previously from a wide range of other feeds that have known processing rates from continuous melter testing.

1.6.2 Feed Samples from Melter Tests

Feed samples were taken directly from as-received drums and the melter feed recirculation line during each test. Feed samples are poured into a platinum/gold crucible and placed into a programmed furnace for drying and fusion to form a glass. The glass produced from this fusion is ground to less than 200 mesh and sealed in 20-ml vials for subsequent analysis by X-ray fluorescence spectroscopy (XRF), or by acid digestion followed by direct-current plasma atomic emission spectroscopy (DCP-AES) on the resulting solution. The feed samples are also characterized for their density, pH, water content, and glass yield.

1.6.3 Glass Product

The glass product is discharged from the melter into 5-gallon steel pails periodically using an air-lift system. The discharged product glass is sampled at the end of each test by

removing sufficient glass from the top of the cans for compositional analysis and secondary phase determination. In addition, the Product Consistency Test (PCT, 7 days at 90°C) and Toxicity Characteristic Leaching Procedure (TCLP) were performed on samples of the glass product from the DM100 melter tests. Prior to those tests, the PCT and TCLP were also performed on the crucible melt compositions that were selected for the melter tests to ensure their compliance with the present WTP contract requirements. All of these procedures are routinely conducted at VSL and, therefore, standard operating procedures (SOPs) are in place.

Sample preparation for chemical analysis typically involves size reduction and sieving. All samples are subjected to XRF to determine the concentration of all elements except boron and lithium. A series of National Institute of Standards and Technology (NIST) reference materials are used for confirmation of the XRF data. Boron and lithium are determined by microwave-assisted total acid dissolution of ground glass samples in HF/HNO_3 and subjecting the resulting solutions to DCP-AES analysis.

1.6.3.1 Viscosity

The melt viscosity, η, is measured using a Brookfield viscometer. Measurements are performed in the temperature range of 950-1250ºC and the data are interpolated to standard temperatures using the Vogel-Fulcher equation: $\ln \eta = [A/(T-To)]+B$, where A, B, and To are fitting parameters. The equipment is calibrated at room temperature using standard oils of known viscosity and then checked at 950-1250ºC using a NIST standard reference glass (SRM 711). Both precision and accuracy of the viscosity measurements are estimated to be within ±15 relative%.

1.6.3.2 Electrical Conductivity

The electrical conductivity, σ, of each glass is determined by measuring the resistance of the glass melt as a function of frequency using a calibrated platinum/rhodium electrode probe attached to a Hewlett-Packard model 4194A impedance analyzer. Measurements are performed over similar temperature ranges to those employed for the melt viscosity measurements. The results are analyzed to obtain the DC electrical conductivity. The electrical conductivity data are then interpolated to standard temperatures using the Vogel-Fulcher equation: $\ln \sigma = [A/(T-To)] + B$, where A, B and To are fitting parameters. Estimated uncertainties in the electrical conductivity measurements are ± 20 relative%.

1.6.3.3 Product Consistency Test (PCT)

The product consistency test (PCT, ASTM C 1285) is used to evaluate the relative chemical durability of glasses by measuring the concentrations of the chemical species released from 100-200 mesh crushed glass (75-149 μm) to the test solution (de-ionized water in this case). PCT on the HLW glasses are performed at 90ºC, in accordance with the current WTP contract requirement. The ratio of the glass surface area to the solution volume for this test is about 2000

m^{-1} (typically, 4 g of 100-200 mesh glass is immersed in 40 ml of deionized water). All tests are conducted in triplicate, in 304L stainless steel vessels, and in parallel with a standard glass included in each test set. The internal standard is the Argonne National Laboratory Low Activity Waste Reference Material (ANL-LRM) glass [25] and/or the Defense Waste Processing Facility (DWPF)-Environmental Assessment (EA) glass, both of which have undergone round-robin testing. The leachates are sampled at seven days. One milliliter of sampled leachate is mixed with 20 ml of 1M HNO_3 and the resulting solution is analyzed by DCP-AES; another 3 ml of sampled leachate is used for pH measurement.

1.6.3.4 Toxicity Characteristic Leaching Procedure (TCLP)

The TCLP was performed at VSL using SW-846 Method 1311, which employs leaching of crushed glass (< 3/8") in a sodium acetate buffer solution for 18 hours at 22°C with constant end-over-end agitation. A mass of about 100 grams of glass is leached in 2 liters of TCLP extract, according to the extraction method for non-volatiles. The surface area to volume ratio for this test is about 20 m^{-1}, which is about two orders of magnitude lower than that in the PCT. The leachates are analyzed by DCP-AES according to VSL standard operating procedures.

1.6.3.5 Secondary Phases

Secondary phases in the glass samples are determined by optical microscopy and scanning electron microscopy coupled with energy dispersive x-ray spectroscopy (SEM-EDS). Secondary phases due to crystallization and phase separation can be identified using these methods. Quantitative determination of the amount of crystals in glass samples is made by SEM in conjunction with image analysis.

SECTION 2.0
WASTE SIMULANT AND GLASS FORMULATIONS

Per the WTP baseline, tank waste undergoes ultrafiltration in the WTP pretreatment facility to separate the dissolved and un-dissolved fractions. The dissolved fraction, combined with liquids generated from subsequent washing and leaching of the solids, is treated in the WTP LAW vitrification facility whereas the solids are treated in the WTP HLW vitrification facility. The objective of the present tests was to evaluate feed compositions that may arise as a result of bypassing the WTP pretreatment facility. In such "direct-feed" scenarios, some of the functions of the WTP ultrafiltration process would be replaced by interim alternatives such as in-tank settling and washing. Since these processes are likely to be less efficient than the WTP ultrafiltration process, the resulting HLW stream would retain larger amounts of the tank supernate and wash water. To evaluate these effects, tests were performed with blends of solids, supernate, and wash water that might be generated from direct-feed processing of wastes from tank A-104.

This section summarizes the compositions of the A-104 un-dissolved solids, dissolved solids, and mixtures of the two representing varying degrees of washing efficiency, and the glass formulations that were developed for each waste blend.

2.1 A-104 Tank Waste Simulants

The composition of the HLW simulant selected for testing is based on the inventory data for tank A-104 from the Best Basis Inventory (BBI) Hanford Tank Waste Operations Simulator (HTWOS) model run (April 17, 2012). Those data were used to identify source tanks with the highest concentrations of plutonium (≥ 0.1 mg of Pu (all isotopes) per gram of sludge) and appreciable volumes of sludge. This led to the selection of A-104 since although four tanks (C-102, SX-115, C-202 and AX-104) had somewhat higher plutonium concentrations, their combined volume was less than half that of A-104. The BBI information for A-104 gives a plutonium concentration of 0.12 mg/g sludge. After applying wash factors to the A-104 solids [26, 27], the calculated oxide mass of the fully washed solids was 76 MT. This waste has 17 component oxides, including radioactive oxides such as UO_3. In order to eliminate the use of radioactivity in melter testing, radioactive oxides are omitted in the definition of the HLW simulant; several minor components (i.e., < 0.01 wt%) were also omitted. The resulting HLW composition, which is given in Table 2.1, contains 97.26 wt% of the original oxides. The HLW simulant composition is obtained by normalization of the oxide composition, which is also given in Table 2.1. Although this waste is not leached, the composition of the HLW simulant listed in Table 2.1 remains typical of HLW simulants used in earlier melter tests in that it is high in Fe_2O_3 and Al_2O_3; these two oxides account for > 77 wt% of the waste. The other significant oxides in the HLW simulant include MnO, SiO_2, NiO, Na_2O, and CaO.

To complete the formulation of the fully washed HLW simulant for melter testing, the projected concentrations of volatile components were also included. Since the wash factors for nitrite and nitrate are both 1, the only volatile species found in tank A-104 washed solids is carbonate at 3.939 g/100 g oxide (total organic carbon is absent from the waste inventory).

2.2 Waste Compositions for Glass Formulation Development and Melter Testing

Four waste compositions were evaluated in the glass formulation development and melter testing work. These represent various blends of the solids and supernate fractions corresponding to various extents of washing of the solids to remove the soluble fraction. The end-members of this series of compositions are the fully washed solids and the pure supernate. Table 2.2 shows the compositions of the solution phase that is generated by adding water to the A-104 sludge (denoted as "Generated Supernate"). The soluble fraction in the A-104 tank waste is primarily a solution of alkali hydroxides, nitrites, and nitrates. On an oxide basis, this waste is greater than 90% sodium with the balance consisting primarily of sulfate, calcium, silicon, and chloride. This supernate solution is generally similar to other LAW streams previously addressed in high waste loading LAW formulation work and melter studies [28-32]. The other end-member of the series is the fully washed A-104 solids, whose composition is also included in Table 2.2.

Two intermediate blends are then produced by assuming one or two wash cycles, as described below. Table 2.2 summarizes the oxide compositions of the end-members together with intermediate blends selected for testing. Also shown in Table 2.2 are the solids and oxides contents of the various blends. These blends are based on the assumptions that the blended tank waste can be settled to achieve a slurry with 15 wt% un-dissolved solids and that each in-tank wash cycle results in a three-fold dilution of the soluble fraction followed by settling to achieve a slurry with 15 wt% un-dissolved solids. Thus, the four waste compositions in Table 2.2 selected for testing correspond to:

- Blend 1: A-104 solids in the supernate produced by dilution of the A-104 sludge with water to give 15 wt% un-dissolved solids.
- Blend 2: Blend 1 diluted three-fold with water and settled to 15 wt% un-dissolved solids (i.e., one in-tank wash/settle cycle).
- Blend 3: Blend 2 diluted three-fold with water and settled to 15 wt% un-dissolved solids (i.e., two in-tank wash/settle cycles).
- Solids: Fully washed solids (i.e., washed to the same extent as in the WTP baseline) and settled to 15 wt% un-dissolved solids.

All of the waste blends assume settling to 15 wt% un-dissolved solids, which corresponds to 13.3 wt% HLW oxides. The dissolved solids contribute the LAW oxide fraction. The changes in the solids content, waste oxide contribution, and chemical composition in response to the washing process are illustrated in Figures 2.1 and 2.2. The blend representing the unwashed waste (Blend 1) consists of the 15 wt% un-dissolved solids with the remaining 85 wt% being the

A-104 supernatant solution that is generated by adding water to the sludge. Therefore 37 wt% of the oxides in the unwashed waste originate from the supernatant (i.e., 7.94 wt% LAW oxides present in 21.24 wt% total oxides in Table 2.2), resulting in high alkali concentrations similar to LAW streams. The LAW contributions to the solids and oxides, and consequently the alkali content, decrease as the waste is washed. The fully washed waste is composed of only un-dissolved HLW solids with no LAW solids and therefore has a composition generally similar to HLW streams previously addressed in HLW glass formulation and melter studies [2-7, 12-21]. Table 2.3 gives the recipes to produce each of the four waste simulants. Since it was not possible to match exactly both the target total oxides and the target total solids in Table 2.2 (and in the simulant recipes in Table 2.3), preference was given to matching the target total oxides and therefore there are small deviations from target in the total solids.

The most abundant dissolved volatile constituents in the waste are nitrate and nitrite, which is typical of LAW streams. Sugar is added to LAW streams at the WTP to prevent melt pool foaming that results from high concentrations of these constituents. In the present tests, sugar was added to the waste at the ratio of 0.75 moles of carbon per mole of nitrogen oxide present in the waste, which is the same as in the WTP LAW baseline and previous tests with LAW streams [28-32]. As indicated above, the wash factors for nitrate and nitrite are both 1, resulting in A-104 fully washed solids that contain no nitrate or nitrite.

A primary formulation objective was to develop and evaluate glass compositions not only with high waste loadings and processing rates, but also acceptable durability and processing properties. Glass formulations were developed using an active design strategy in that characterization data from a set of crucible testing were fed back to design the next set of formulations. Additionally, glass property-composition models that have been developed for the WTP were used extensively in formulation development [33, 34]. Although the new glass compositions often resided outside the validity range of the models, the model predictions can be useful to provide guidance in selection of glasses to test when used judiciously. A new glass composition predicted by the models to have unacceptable properties might still be chosen for testing if past experience or literature information indicated benefits. Experience from previous work on WTP LAW and HLW was particularly valuable in formulation development for the unwashed and washed wastes. As seen in Table 2.2, Blend 1 waste is relatively high in sodium, suggesting that the new formulation will be similar to LAW glasses developed for the WTP in that Na_2O contents are expected to be higher than found in typical HLW glasses. Conversely, the other waste blends and the washed solids, as expected, are more similar to the HLW tested for the WTP, which are generally high in aluminum and iron.

2.3 Glass Formulations

As stated above, glass formulations for A-104 Blend 1 and Blend 2 wastes include high concentrations of Na_2O originating from the wastes, much like WTP LAW glasses. However, these wastes also contain high concentrations of Fe_2O_3 (e.g., 35.73 wt% Fe_2O_3 vs. 35.89 wt% Na_2O for Blend 1, see Table 2.2) such that waste loadings for the glass formulations are still expected to be limited by Fe_2O_3 instead of Na_2O. This is in contrast to the earlier HLW direct feed testing for AY-102 waste, where Na_2O is the waste loading-limiting component for Blend 1

and Blend 2 glasses due to its high concentrations in wastes when compared to Fe_2O_3 [7]. For example, the Na_2O content is 51.27 wt% in AY-102 Blend 1 waste while Fe_2O_3 is only 14.18 wt%. The Blend 1 glass formulation developed for melter testing (AY102D1-05), which has a waste loading of 39 wt%, consists of 20.00 wt% of Na_2O and only 5.53 wt% of Fe_2O_3. Glasses with waste loadings higher than 39 wt% showed K-3 corrosion above the recommended limit of 0.040" neck loss used in LAW glass formulation development for ORP and were deemed unacceptable [7]. By contrast, glass formulations for the A-104 Blend 1 waste would contain roughly equal amounts (wt%) of Na_2O and Fe_2O_3 if sodium is not used as an additive and, therefore, K-3 refractory corrosion was not a concern.

A review of the waste compositions in Table 2.2 and Figure 2.2 suggests that HLW glass formulations for all 4 wastes will likely be limited by Fe_2O_3 (spinel formation). Furthermore, Blend 2 and Blend 3 glasses will be very similar in composition to the "Washed Solids" glass. This is because the "Generated Supernate" in Table 2.2 is essentially a sodium solution (with minor amounts of SiO_2, SO_3, and CaO), while Na_2O will need to be added to suppress spinel formation in formulation of "Washed Solids" glasses. The sodium contribution from the LAW in the Blend 2 and Blend 3 wastes will therefore increase the overall waste loading for HLW glasses for these wastes even those these glasses can have a similar composition to that for the glass for the Fully Washed Solids. Development of glass formulations in this work therefore began with the Fully Washed Solids.

2.3.1 Glass Formulations for Fully Washed Solids

Previous development and characterization of HLW glass formulations at VSL to support melter testing covered various iron-rich waste streams. Glass formulations with increasingly higher waste loadings have been developed and tested for these wastes, with the Fe_2O_3 content in glass rising gradually from about 12.50 wt% (e.g., HLW98-86 for C-106/AY-102 waste with Sr/TRU pretreatment products [12]) to 16.02 wt% (e.g., HLW-NG-Fe2 for analyzed C-106/AY-102 waste [4]). Spinel crystallization was the principal waste loading limiting constraint in these formulation studies. In addition to Fe_2O_3, components that enhance the propensity for spinel formation include Cr_2O_3, MnO and NiO [35, 36]. While the Fe_2O_3 content in the A-104 solids is relatively high (see Table 2.2), the concentrations of these other oxides are only moderate, suggesting that Fe_2O_3 can be loaded to 16 wt% or higher in the A-104 glasses.

Eleven HLW glasses were tested for the A-104 washed solids (A104D4- series). The first four glasses have waste loadings of 25.50 wt%, which is equivalent to 14.55 wt% Fe_2O_3 in glass. Table 2.4 lists the waste loadings, glass forming additives and target compositions of these glasses. Table 2.5 gives the compositional data as analyzed by XRF. Both lithium and sodium were added in substantial quantities in these formulations to limit spinel formation. Heat treatments of A104D4-01 at 900°C and 950°C resulted in clear glass samples with no crystallization observed, while spinel was found in heat treated samples for all other glasses. Table 2.6 summarizes the heat treatment and other characterization data (viscosity, electrical conductivity and normalized PCT releases) for the A104D4 glasses. Table 2.6 also includes model predicted values for viscosity and electrical conductivity for all glasses (and PCT releases for glasses that were not leach tested). In general, the spinel crystals in the heat treated samples

are moderate in size (10 to 50 microns) and contain considerable amounts of Ni, Cr, and Mn in addition to Fe. The amount of crystallization after heat treatment at 950°C, however, is limited to 0.10 vol% in A104D4-04. Glasses with higher waste loadings therefore were formulated and tested.

Waste loadings for the next four members of the A104D4 series were increased, as shown in Table 2.4. The highest waste loading in these formulations (29.00 wt%) is found in A104D4-06, which incorporates 16.55 wt% of Fe_2O_3. Heat treatments of these glasses from 800°C to 950°C invariably resulted in crystallization of spinel crystals, the compositions of which were determined by EDS to be similar to that described above. The amounts of spinel crystals after heat treatment at 950°C are all below the WTP acceptance limit of 1 vol%. For example, only 0.22 vol% of spinel was found in A104D4-06. However, since the alkali concentrations are rather high in these glasses (e.g., 20.51 wt% Na_2O and 2.25 wt% Li_2O in A104D4-06), it was decided that additional formulations would be tested with lower alkalis in order to limit the corrosion of K-3 refractory.

Based on A104D4-06, another glass with 29.00 wt% waste loading was formulated with the substitution of 7 wt% of B_2O_3 for alkali oxides (5 wt%) and SiO_2 (2 wt%). Characterization data for the resulting glass, A104D4-11, are given in Table 2.6. Slightly more spinel crystals resulted (0.58 vol%) in this glass after heat treatment at 950°C. Regression of heat treatment data yielded an estimated spinel $T_{1\%}$ of 827°C (Table 2.7). The measured viscosity of A104D4-11 is within the 10 to 150 poise range in the current WTP requirement for HLW glass at 1100°C. Electrical conductivity values are also acceptable since they fall within the WTP range of 0.1 S/cm to 0.7 S/cm between 1100°C and 1200°C. The leaching performance of A104D4-11 was also found to be satisfactory: the PCT releases are well below those of the DWPF-EA reference glass and the TCLP releases of Resource Conservation and Recovery Act (RCRA) metals are all beneath the respective delisting limits (Table 2.8).

Evaluation of the feed processing rate was conducted through VGF screening tests. Two feed formulations were tested for A104D4-11: (i) boric acid and sodium carbonate provided the additive sources for B_2O_3 and Na_2O, respectively, and (ii) borax and sodium carbonate were the additive sources. No sugar was added to either feed since the A-104 washed solids contain no nitrite or nitrate (see Table 2.2). Results of the two small-scale melt rate screening tests are presented in Figure 2.3 and Table 2.9. At 30 minutes of testing, both feeds were essentially fully converted to glass with no bubbles or foam-like structure found on the surface. A numerical rank of 1-2 was assigned to both feed formulations, indicating a very high rate of feed conversion to glass.

The glass characterization and VGF data support the selection A104D4-11 as the target glass for the washed solids melter test. No HLW glass formulations have been developed previously for A-104 waste. However, the 16.55 wt% Fe_2O_3 content in A104D4-11 is among the highest tested in melter runs for the WTP.

2.3.2 Glass Formulations for A-104 Blend 2 and Blend 3 Wastes

The primary effect of washing the A-104 HLW solids is removal of sodium and sulfate, as seen in Table 2.2. Consequently, the major differences for non-volatile components among the four wastes in Table 2.2 are the progressively lower concentrations of Na_2O and SO_3 as the solids are washed and settled, which is graphically illustrated in Figure 2.2. Since Na_2O is added as a glass former in the glass formulations for washed solids, Blend 2 and Blend 3 glasses can be formulated with compositions that are very similar to those of the washed solids glasses but using a higher overall waste loading.

Table 2.10 shows that glasses with target compositions very similar to that of A104D4-11 can be formulated for both Blend 2 and Blend 3 wastes, with the addition of B_2O_3, Li_2O, Na_2O, and SiO_2. Compared to A104D4-11, which has a total waste loading of 29.00 wt%, the Blend 3 glass has an improved waste loading of 30.95 wt% while the waste loading of the Blend 2 glass is even higher at 34.78 wt%. Loadings of HLW oxides, however, are similar for all glasses at about 29.00 wt%. The two glasses in Table 2.10 are the target Blend 2 and Blend 3 glasses for melter testing.

Characterization of A104D4-11 is described in Section 2.3.1. No crucible melts were prepared and tested for the target glasses in Table 2.10 since there are only very minor differences in their compositions when compared to A104D4-11. Evaluation of feed processing rate was performed for these two formulations through VGF tests, with the addition of sugar in the amounts given in Table 2.2. Results of the two small-scale melt rate screening tests are shown in Table 2.9 and Figures 2.4-2.5. Conversion of both feeds took place relatively quickly and appeared to be complete after 60 minutes. A rank of 1 is assigned to feed-to-glass conversion for the Blend 2 feed. Conversion of the Blend 3 feed is only marginally slower and a rank of 1-2 is assigned.

2.3.3 Glass Formulations for A-104 Blend 1 Waste

Table 2.11 summarizes the four glasses formulated for A-104 Blend 1 waste, with waste loadings ranging from 44.50 wt% to 46.32 wt%. Table 2.5 gives the analyzed glass compositions. Blend 1 waste is closest to LAW in composition with its high sodium content, as noted above. However, sodium is not the waste-loading limiting component in the Blend 1 glass formulations and the glass formulations in Table 2.11 have Na_2O levels that are considerably lower than those found in typical LAW glass formulations (e.g., AY-102 Blend 1 glasses incorporated ≥ 20 wt% Na_2O).

As spinel crystallization was expected to limit waste loadings in Blend 1 glasses, lithium was used as an additive in both A104D1-01 and -D2 to suppress its formation. Glass samples were heat treated for 70 hours at 950°C and lower temperatures before evaluation for secondary phases by SEM. Table 2.12 presents these and other characterization data for the A104D1 glasses. A modest amount of spinel crystals was observed in all heat treated samples and regression of the heat treatment data provided estimates of spinel $T_{1\%}$ for these glasses, which are given in Table 2.7.

For the next round of Blend 1 formulations, waste loading was increased and the addition of lithium was eliminated. Increasing the waste loading resulted in higher concentrations of both Na_2O and Fe_2O_3. At a total waste loading of 46.32 wt%, the HLW loadings are 29.00 wt% and the Fe_2O_3 contents in these glasses are similar to those found in the target formulations for the Fully Washed Solids (and Blends 2 and 3). Heat treatment results of A104D1-03 and -04 are both acceptable (Table 2.12). In particular, both glasses showed < 0.5 wt% spinel after 70 hours at 950°C. The leaching performances of both glasses have been measured and found acceptable: Table 2.8 summarizes the TCLP results and Table 2.12 gives the PCT data. Both glasses outperform the WTP HLW PCT contract limits (of 16.70 g/L PCT-B and 13.35 g/L PCT-Na, based on the DWPF-EA glass) by wide margins. Formulation A104D1-04 was recommended as the Blend 1 target glass for melter testing since its measured viscosity is more favorable to processing.

Assessment of the feed processing rate was performed through VGF tests on the formulation A104D1-04. The feed was prepared for tests with addition of sugar to avoid melt pool foaming. The amount of sugar addition (see Table 2.2) was calculated based on the concentrations of nitrites and nitrates, which are the highest in Blend 1 waste. Results of VGF testing are shown in Figure 2.6 and the numerical ranking of feed conversion is given in Table 2.9. Figure 2.6 shows that a partially collapsed dome was present after 30 minutes and the foam layer persisted after 60 minutes, with only a slight reduction in the amount of bubbles observed. The assigned numerical ranking of 5 indicates the feed-to-glass conversion is relatively slow.

2.4 Glass and Feed Formulations Used in Melter Tests

Summaries of the glasses developed for melter testing illustrating the waste loadings of the HLW and LAW constituents are provided in Tables 2.13 – 2.16. The waste loading of undissolved solids remains essentially unchanged at about 29 wt% across the four wastes tested, as shown in Figure. 2.7. The constant HLW loadings arise from the fact that glasses formulated for all wastes are limited by iron (i.e., spinel formation). In contrast to the previous HLW direct feed testing with AY-102 waste, the alkali concentration in the A-104 supernate is not as high and its dilution is not required in formulating glasses for Blend 1 (or Blend 2) waste, which would otherwise lower HLW loadings. The maximum total waste oxide loadings therefore were achieved with no washing (see Figure 2.7). Total waste oxide loading progressively decreases with each wash cycle as LAW oxides (essentially Na_2O) are removed, which subsequently requires sodium to be added back as an additive. The amount of glass required to incorporate each of the waste oxides is illustrated for the waste blending scenarios in Figure 2.8. About 3.5 kilograms of glass is produced for each kilogram of HLW oxides, regardless of wash cycle. The number of canisters of HLW glass produced is therefore independent of washing of the solids. However, slightly more than 2 kilograms of glass is produced per kilogram of total waste oxides in the unwashed solids, which then increases with the number of wash cycles as the LAW fraction is removed.

Sufficient blended feed (glass formers plus waste simulant) was prepared by NOAH Technologies Corporation according to VSL specifications to make over 1.8 metric tons of glass

for melter testing. Glass forming additives for each of the four glass compositions are listed in Table 2.17. Upon receipt of the feed at VSL, analysis was performed to verify the oxide composition of the glass that would be produced from each feed and to measure the total solids content. Based on the feed analysis (see Section 4.1), each feed was modified as shown in Table 2.17. Sufficient water was added to each feed to achieve the water content consistent with 15 weight percent undissolved solids in the waste depending on the test. The overall solids content of the resultant feed also depends upon the amount and type of glass forming additives used in each formulation. Additions were made to three of the four feeds to achieve target concentrations of lithium, boron, and iron, as well as boron and iron to the feed used in Test 1. Sugar was added at the ratio of 0.75 moles of carbon per mole of nitrogen oxide present in the waste.

SECTION 3.0
DM100 MELTER OPERATIONS

Four melter tests were conducted on the DM100-BL vitrification system between 1/5/15 and 1/30/15 with four blends of simulated HLW A-104 waste solids and supernates processed with glass forming additives optimized for each blend. These tests produced about eighteen hundred kilograms of glass from over four metric tons of feed. In each test, the glass temperature and bubbling rate were held constant at 1150°C and 9 lpm per minute, respectively, while feeding to determine the effect of the test variables on production rate and processing properties as well as to facilitate comparison with previously conducted tests. Tests were conducted with the same A-104 simulated HLW solids, four different total waste compositions based on blending differing amounts of LAW supernate with HLW solids, and two different glass compositions: one corresponding to three of the waste compositions and one corresponding to the blend containing the highest proportion of LAW supernate. The feed solids content targeted a relatively narrow range from 0.316 to 0.346 kg glass per kg feed as a result of the concentration of HLW solids in the waste being the same for each feed. Testing with the Blend 2 waste and A104D4-11 glass composition was conducted in two segments of 25 and 34 hours due to the time required to repair and replace the film cooler air heaters. Summaries of the tests are provided in Tables 3.1-3.4. Attempts were made to replicate the melter configuration and operating conditions used for previous tests with HLW simulants [3-7, 17-21, 36-43]. These conditions include a near-complete cold cap, which is between 80-95% melt surface coverage for the DM100 since a 100% cold cap tends to lead to "bridging" in smaller melters. The bubbling rate was fixed at 9 lpm and the feed rate was adjusted to maintain a complete cold cap. Additional production rate data were collected for two of the feeds while optimizing bubbling by using feed remaining after the completion of the 50-hour test segments performed at a bubbling rate of 9 lpm per minute. This use of fixed bubbling is in contrast to some previous tests where the production rate was fixed between 1000 and 1050 kg/m^2/day and the bubbling rate was adjusted to maintain the complete cold cap [17-20]. This latter approach was also used for testing LAW feeds, where the bubbling rate was adjusted to maintain the complete cold cap at production rates between 2000 and 2500 kg/m^2/day [28-32].

The feed and glass were processed without significant difficulties throughout the majority of the tests. Cold cap conditions while processing feeds were largely similar to the range of conditions observed in previous tests with HLW feeds as opposed to LAW feeds. Some shelves formed along the walls of the melter, although not to the rate limiting extent observed while processing some high aluminum formulations [3, 5] or some high iron formulations [36]. On average, manual methods were used following glass discharges to dislodge these deposits without any interruptions in feeding. Most of these deposits were observed after discharging glass, which lowered the glass level in the melter leaving deposits adhering to the walls out of contact with the molten glass. The fully washed HLW solids did not leave any deposits on the melter walls after discharging feed whereas processing the feed with the highest proportion of LAW oxides required the use of manual methods for dislodging deposits after each discharge. The amount of deposits was observed to increase with the proportion of the LAW contribution to

the feed. The opposite trend was observed in the previous direct feed tests [7] which featured a far greater range of water contents, waste loadings, and target glass compositions, as well as far greater contributions of nitrogen oxides and added reductants from the LAW supernate. Short, routine interruptions of up to ten minutes were required during testing to transfer feed to the feed tank and to perform minor maintenance activities. No foamy glass was observed in the glass discharge and no foam was observed on the melt pool surface or cold cap.

Figures 3.1.a – 3.1.c illustrate the glass production rates as moving hourly and cumulative averages calculated from feed weights and target glass conversion ratios during the four tests. The cumulative average rates approximate the steady state processing rates as a result of consistent operation over the course of the majority of the tests. Steady state glass production rates ranged from 1200 to 1900 $kg/m^2/day$ for tests with fixed bubbling. Glass production rates increased with solids washing, and thus decreasing LAW solids loading, as shown in Figure 3.1.d. The opposite trend was observed in previous direct feed HLW tests with AY-102 wastes, as shown in Figure 3.1.e, due to the increases in water content and HLW oxide loading with washing of the AY-102 wastes [7]. The HLW oxide loading is constant in all of the A-104 formulations tested and the range of feed water content in the feeds tested was relatively narrow and exerted no effect on the measured production rates, as illustrated in Figure 3.1.f. Both VGF (see Table 2.9) and melter tests indicate that the feed with unwashed wastes processes slower than the other feeds in contrast to previous tests with AY-102 unwashed wastes in which the unwashed wastes processed more readily using both methods. A significant difference between the four feeds tested is the alkali source: lithium and sodium carbonates as additives in the fully washed waste versus sodium hydroxide and nitrite in the unwashed waste. The effect of the form of alkali on glass productions rates, depicted in Figure 3.1.g, shows the highest production rates at the minimum hydroxide and maximum carbonate concentrations, with the lowest rates at the minimum carbonate and maximum hydroxide concentrations. This result is in contrast to previous testing with HLW streams and carbonates, which showed decreasing glass production rates with increasing feed carbonate content [42]. Collectively, these studies suggest that the form of the carbonate, alkali, or alkaline earth, may affect whether carbonate enhances or reduces melter feed processing rates. Also of note is that the lowest production rate was obtained with feed containing sodium in place of lithium. Steady state production rates for the present tests are compared to those for previous tests [4, 17, 18, 21, 36, 37, 43] conducted at 9 lpm fixed bubbling with high-iron HLW streams and nominal solids content in Table 3.5. The production rates for the present tests with fully washed solids are comparable to the previously tested high iron wastes [4, 43] despite having higher iron content in the product glass. The production rates for the present tests with partially- and fully washed solids are higher than all other previously tested high iron wastes [17, 18, 21, 37] despite having considerably higher iron content in the product glass. Glass formulations with higher iron contents and with higher crystal contents [36] were processed at rates two to three times slower than the glasses in the present tests. It is also interesting to note that the unwashed waste in the initial HLW direct feed tests [7] processed at approximately the same rate as the unwashed waste in the present tests at a fixed bubbling rate of 9 lpm. In limited testing, glass production rates increased with optimized bubbling, consistent with previous tests conducted with HLW streams [4, 6, 7, 36, 40]; however, the extent of the increase while processing the unwashed solids was only about 10%.

For the direct feed HLW application, the rate of processing the HLW solids is more important than the overall glass production rate. Processing rates of the LAW oxides and HLW oxides are compared to glass production rates for each test segment in Table 3.6 and Figure 3.1.d. The HLW oxide processing rate ranged from 348 to 551 kg/m^2/day at nominal bubbling. Since the HLW oxide waste loading is the same for each glass composition, the changes in HLW oxide processing rate are solely attributable to changes in glass production rate; thus, the lowest HLW oxide processing rates are associated with the unwashed waste. Processing rates for the LAW oxides range from zero for the fully washed waste to over 200 kg/m^2/day for the unwashed waste. Coincidently, the total waste oxide processing rate was relatively constant over the various washing cycles due to the decreases in glass production rate being compensated by the increasing contribution of LAW oxides.

The results of various operational measurements that were made during these tests are given in Tables 3.7 – 3.10. Glass temperatures are shown in Figures 3.2.a – 3.2.c, plenum temperatures in Figures 3.3.a – 3.3.c, electrode temperatures in Figure 3.4.a – 3.4.c, glass resistance in Figure 3.5.a – 3.5.c., melt pool bubbling in Figure 3.6.a – 3.6.c; electrode power is included in the figures with electrode temperatures and glass resistance. Bulk glass temperatures (measured at 5 and 10 inches from the bottom of the melt pool) were largely within 10°C of the target glass temperatures of 1150°C throughout the vast majority of the feeding portions of each test. Glass temperatures closer to the top of the melt pool (measured at 16 and 27 inches from the bottom) were 10-20°C lower than those deeper in the melt pool and are not reliable indicators of bulk glass temperatures as a result of their sensitivity to variations in the level of glass in the melter and gradients near the melt surface. During the idling period in the midst of Test 2, power supplied to the electrodes was adjusted to maintain a glass temperature of 1100°C. Temperatures in the discharge chamber were maintained above 1000°C while feeding the melter to facilitate glass discharge. The upper and lower electrode temperatures typically ranged between 1000 and 1125°C, 25 to 150ºC lower than the glass pool. The bottom electrode, which was not powered, was about 250 to 350ºC colder than the powered side electrodes. These electrode temperatures increased modestly with bubbling over the course of the tests processing the unwashed waste. Plenum temperatures ranged between 400 and 600°C over the majority of the tests, indicative of a complete cold-cap and steady processing. A relative 50°C increase in plenum temperature was measured during Test 1 in response to increases in bubbling disrupting the cold cap and creating more openings. Higher plenum temperatures were also measured at the beginning of each test during the development of the cold cap and in between Tests 3 and 2 as the melt pool was sampled and as the feed tank content was exchanged. The highest plenum temperatures of over 900°C were measured during the idling period in the midst of Test 2 due to the lack of a cold cap barrier between the glass and plenum air space. Plenum temperatures measured in the thermowell were on average about 20-50°C lower than those measured by the exposed thermocouple due to more direct exposure to the glass surface. The target bubbling rate of 9 lpm was maintained while processing each feed; the bubbling rate was reduced in between Tests 3 and 2 as well as during the idling period in the midst of Test 2. The bubbling rate was doubled to 18 lpm when being optimized during the latter portion of Test 1 while processing the unwashed waste.

Power supplied to the electrodes is used to maintain the temperature of the glass pool at 1150°C, incorporate feed components into the glass pool, and volatilize water, thus the amount

of power used is partially a function of feed rate and the water content of the feed. Since the water content of the feed was relatively constant, the least power was used at the lowest feed rate during Test 1 (test segment average of 18.4 kW) and the most during Test 4 (test segment average of 29.1 kW). As bubbling was optimized to increase production rate, power utilization also increased, as expected. About 13 kW of power was used to maintain a glass temperature of 1100°C during the idling period in the midst of Test 2, indicating that over half the power supplied to the electrodes during testing is used to maintain the glass pool temperature, depending on feed rate. The average power usage normalized to glass production for each test segment varied within a relatively narrow range from 3.0 to 3.6 kWhr/kg due to the narrow range of water contents in the feed. Given the constant glass pool temperature of 1150°C, the melt pool resistance changes can be attributed to changes in the composition of the glass pool. There was a slight decrease from 0.073 ohms at the beginning of testing during transition from the HLW-NG-Fe2 composition, followed by increases from about 0.070 ohms to about 0.11 ohms on transition from the A104D4-11 to the AY104D1-04 glass composition during the last test. One other point of note is that measured parameters, including glass production rate, were the same for each of the two segments during Test 2, indicating that the interruption had no effect on the test results.

The gas temperature at the film cooler averaged between 278 to 285ºC while feeding and depended on the plenum temperature, the amount of added film cooler air, the temperature of the added film cooler air, and the moisture content of the gas exiting the melter. Drops of less than fifteen degrees in gas temperature were observed across the (insulated) transition line; the high temperature is maintained in order to prevent condensation in the downstream filtration units.

SECTION 4.0
FEED SAMPLE AND GLASS PRODUCT ANALYSIS

4.1 Analysis of Feed Samples

4.1.1 General Properties

Feed samples from as-received drums were analyzed to confirm physical properties and chemical composition. Based on the analysis of the as-received material, boric acid, iron oxide, lithium carbonate, and water were added to the feeds prior to testing to achieve the target compositions and solid contents (see Table 2.17). Samples were also taken during each melter test directly from the feed tube. Sample names and measured properties are given in Table 4.1. Density, pH, water content, glass conversion ratio, and oxide composition by XRF and DCP were measured on all samples. The analysis shows the intended changes in water content, glass yield, and density as a result of modifications to the as-received feed. The analysis of the melter feed shows increases in water content with concomitant decreases in density and glass yield in response to the measured dilution with water. The measured glass conversion ratios for all feed samples from melter tests were up to a maximum of about nine percent higher than the target values on a weight per weight basis, validating the use of the target conversion ratio for calculating glass production rates. The water content, density, glass yield, and pH varied within a narrow range for the feed samples within each as-received feed batch and melter feed. As expected, feed containing a higher proportion of the A-104 supernate, and thus more sodium and potassium hydroxide, had higher measured pH values than feeds that contained mostly HLW solids.

4.1.2 Chemical Composition

The methods used for analysis of feed sample chemical compositions are described in Section 1.6. The boron and lithium oxide concentrations from the DCP-AES analysis were used for normalizing the XRF data since their concentrations were not determined by XRF. The analyzed compositions of the as-received and melter test feeds are compared to the target compositions in Tables 4.2 - 4.5 for each feed and glass composition. The results from the as-received and melter test feed samples generally show agreement with the target composition and corroborate the consistency of the feed for the major elements. Additions were made to the as-received feed to correct for elements targeted at three percent oxide or greater with relative deficits of eight percent or greater compared to the target concentration. Analysis of feed from melter tests shows the additions of boron, iron, and lithium to feed reduced or eliminated deficits in these elements for feeds processed during the melter tests. Major oxides which had measured surpluses in the as-received feed, such as alumina and silica, had smaller surpluses in the melter feed after the addition of boron, iron, and lithium. Similarly, oxides with deficits measured in the as-received feed, such as sodium and manganese oxides, had larger deficits in the adjusted melter feed. The only oxides with deviations from target concentrations greater than ten percent in the melter feed samples were manganese, with deficits from 10.37 to 14.14 percent, and sodium in

one test with a deficit of 10.48 percent. Deficits of these oxides were relatively minor and smaller in the discharged glass (see Section 4.2.1) and therefore are not expected to have an impact on glass or processing properties of the melter feed. Low concentrations (0.02 – 0.12 wt%) of chlorine and potassium, titanium, and zinc oxides were measured in feed samples, even though they were not included in some of the target compositions. Surpluses of magnesium of about 0.2 wt% oxide were measured in most of the feeds. Many of these surplus constituents were also present in the last feed processed [7, 3] and presumably originate from trace level contamination of feed additives and chemicals used to produce the waste simulant and are not expected to have an impact on glass or processing properties of the melter feed.

4.2 Analysis of Glass Samples

Nearly 1800 kg of glass was produced in these tests. The glass was discharged from the DM100 periodically into 5-gallon carbon steel pails using an air lift system. The discharged product glass was sampled by removing sufficient glass from the top of each pail for total inorganic analysis. Product glass masses and discharge date are given in Table 4.6. Glass samples were also taken by inserting a threaded metal rod directly into the glass pool. These "dip" samples serve to document the composition of the glass pool before and after each test. No macroscopic secondary phases were observed in any of the discharged glasses and dip glass samples.

4.2.1 Compositional Analysis of Discharge and Dip Glass Samples

All discharge glass samples were crushed, sieved, and analyzed directly by XRF. Since boron and lithium are not determined by XRF, boron and lithium concentrations were calculated from the measured concentration in the glass pool prior to testing, target concentrations, and the nominal glass volume of the melter. The XRF analyzed compositions of discharged and dip glass samples are provided in Tables 4.7 - 4.11. A comparison of analyzed discharge glass compositions with target compositions is provided in Table 4.12. The majority of the XRF analysis results compare favorably to their corresponding target values and feed sample analyses (see Section 4.1.2). The only oxide with a target concentration greater than one weight percent that showed greater than 10% deviation from the target value was manganese in two of the tests; manganese deviations were less than 13%. DCP-AES analysis of the dip samples shows the closeness of the measured boron and lithium concentrations to the target concentrations, validating the use of the target concentrations for renormalizing the XRF data. Bismuth, cerium, chlorine, potassium, lanthanum, sulfur, tin, titanium, and zinc were measured in the product glass at low concentrations, despite not being included in many of the target compositions, as a result of being present in the melt pool prior to these tests or being present in the feed as a contaminant.

Compositional trends for selected constituents shown in Figures 4.1.a - 4.1.g illustrate the approach of the majority of the glass constituents to the target compositions over the course of the tests. The composition of the glass in the melter prior to the testing reflects the HLW-NG-Fe2 glass composition [43] which is similar to the A104D4-11 glass composition for most of the major components. At the onset of the present tests, silicon, iron, nickel, and lithium increase in

concentration at the expense of boron, manganese, and several minor elements including cerium, chromium, lanthanum, phosphorus, lead, strontium, tin, zinc, and zirconium. Many of these minor constituents were present in the melt pool at the beginning of testing but not present in the target glass composition and decrease in concentration to the trace contamination levels measured in feed samples. Measured concentrations of elements originating from the HLW solids such as iron, aluminum, and manganese remain constant between the four tests as a result of the loading of HLW oxides being the same for feeds processed in each of the tests. Measured concentrations of chlorine, sulfur, and calcium increase over the course of the tests, reflecting the decreased washing of the wastes. The increasing contribution of sodium from the supernatant is not observed in the product glass over the course of the first three tests as a result of the compensating decrease in the use of sodium as an additive. The measured sodium concentrations increase at the end of testing due to the highest proportion of supernatant in the feed being compensated by the removal of lithium carbonate as an additive. Magnesium and potassium are present at concentrations above the low target values over the course of the tests, consistent with feed sample analysis. Sulfur was also measured above the low target concentrations over the first three tests due to trace level contamination of the feed; however, it was below target at the higher concentration during the final test due to volatilization.

4.2.2 Chemical Durability of Discharge Glasses

Discharge glass from the end of processing each of the four feed/glass compositions was evaluated for chemical durability using the PCT and TCLP methods. The PCT results are compared to those for the benchmark DWPF-EA glass in Table 4.13 and the TCLP results are compared to the WTP delisting limits [44, 45] and Universal Treatment Standard (UTS) limits in Table 4.14. The chemical durability determined for the melter glasses by both of these methods is excellent. All measured PCT concentrations and normalized leach rates for the discharge glass samples are over an order of magnitude lower than the corresponding values for the DWPF-EA glass. All regulated TCLP leachate concentrations are less than 0.4 mg/l and more than an order of magnitude less than WTP delisting limits; no lead or chromium were detected in any of the leachates. All measured concentrations are also well below the UTS limits. The chemical durability of these glasses is largely within the range measured on glasses produced from wastes limited by bismuth, chromium, aluminum, and aluminum plus sodium [6], chromium and iron [36, 39], and glasses formulated with a high proportion of HLW solids during the first phase of HLW direct feed testing [7]. Leach rates were largely similar for melter and crucible glasses although some of the measured PCT releases were a little lower for the melter glasses. PCT releases for A104D4-11 glass with slight variations in composition were also very similar although they increased slightly with reduction in waste washing. These results again confirm that glasses can be formulated from a direct-feed HLW stream, which has undergone various degrees of washing with no other pretreatment, while maintaining high waste loadings and high processing rates without compromising the quality of the vitrified product.

4.2.3 SEM Analysis of Melter Glass Samples

Melt pool samples from the end of each of the four tests and prior to the first test were subjected to SEM analysis to determine the extent of crystal formation. The results are summarized in Table 4.15. Significant amounts of crystalline phases (> 0.1 vol %) were detected only in the sample taken at the end of testing. Illustrations of typical crystal morphologies observed in a sample from the end of testing are given in Figure 4.2. The crystalline phases observed by SEM were composed of iron, manganese, and chromium spinels similar to those in the earlier Phase 1 HLW direct feed test samples [7]. A significant difference between the two sets of direct feed glasses is that significant secondary phases were observed only in the fully washed waste glass in the previous HLW direct feed tests, whereas in the present tests, significant secondary phases were observed only in the unwashed waste glasses.

SECTION 5.0
MONITORED OFF-GAS EMISSIONS

5.1 Particulate Sampling

The melter exhaust was sampled for metals/particles according to 40-CFR-60 Methods 3, 5, and 29 at steady-state operating conditions and nominal bubbling during each of the four tests. The concentrations of off-gas species that are present as particulates and gaseous species that are collected in impinger solutions were derived from laboratory data on solutions extracted from air samples (filters and various solutions) together with measurements of the volume of air sampled. Particulate collection required isokinetic sampling, which entails removing gas from the exhaust at the same velocity that the air is flowing in the duct (40-CFR-60, Methods 1-5). Typically, a sample size of 30 dscf was taken at a rate of between 0.5 and 0.75 dscfm. Total particulate loading was determined by combining gravimetric analysis of the standard particle filter and chemical analysis of probe rinse solutions. An additional impinger containing 2 N NaOH was added to the sampling train to ensure complete scrubbing of all acid gases and, particularly, iodine. The collected materials were analyzed using direct current plasma atomic emission spectroscopy for the majority of the constituents and ion chromatography (IC) for anions. Melter emission fluxes are compared to feed fluxes and emission samples taken while processing the four feed compositions in Table 5.1. Notice the distinction that is made between constituents sampled as particles and as "gas". The "gaseous" constituents are operationally defined as those species that are scrubbed in the impinger solutions after the air stream has passed through a 0.3 μm heated filter. All five samples were within the 90 – 110% limits for isokinetic sampling.

Particulate emissions constituted from 0.42 to 0.57 percent of feed solids for feeds containing fully and partially washed solids processed with bubbling fixed at 9 lpm. The level of solids carryover is well within the range measured while processing various feeds containing high iron HLW simulants processed on the same melter at a temperature of 1150^{o}C: C-106/AY-102 SIPP (0.61 to 0.81 percent) [18]; the former C-106/AY-102 baseline (0.3 - 0.74 percent) [37]; a C-106/AY-102 high waste loading formulation (0.66 and 0.71) [4], HLW AZ-101 (0.46 percent) [39], and for feeds containing unwashed to partially washed AY-102 HLW solids (0.46 to 0.53 percent) [7]. Solids carryover while processing unwashed waste solids with bubbling fixed at 9 lpm constituted only 0.19 percent of feed solids. This is surprising since the principal differences between the glasses is the replacement of lithium with more volatile sodium and increasing the concentration of the most volatile constituents, chlorine and sulfur. It is also noteworthy that the exhaust sample taken while processing the unwashed solids was the only sample without any measurable lead or barium. Since measured emissions decreased despite the increasing concentrations of volatile constituents in the unwashed waste, it is tempting to suggest that the sample was not indicative of the melter exhaust from this test; however, no data from the melter operation or sampling system supports this conclusion. The amount of carryover decreased with the number of wash cycles except for the unwashed waste, as shown in Figure 5.1.a. Given the consistency in melter operation, glass composition, and feed water content, this observation would be expected given the increasing volatile content in the feed, except for the

unwashed solids. The relationship between feed water content and particulate which defined emissions trends during the first HLW direct feed tests [7] was not a significant factor in the present tests, as shown in Figure 5.1.b, due to the minimal range of feed water contents tested. The feed with the lowest particulate emissions also had the lowest water content; however, it would be difficult to attribute a greater than two-fold reduction in particulate emissions to an absolute one percent reduction in feed water content.

As expected, the feed elements emitted at the lowest melter decontamination factor (DF) were chlorine and sulfur, which were present only in the three feed formulations containing the A-104 supernate. The chlorine and sulfur measured in the exhaust from the first test, even though no chlorine or sulfur were targeted in the waste, reinforces the notion that there is low level contamination of these constituents in the feed. Other elements exhibiting some volatile behavior were boron, chromium, potassium, and lead. The expected increasing volatility of alkali metals with increasing molecular weight was observed: potassium carryover being the highest followed by sodium, then lithium. Boron and sulfur were the only elements detected in the impinger solutions collected downstream of the heated particle filter in the sampling train, which constitutes the "gas" fraction of the melter emissions.

5.2 Gases Monitored by FTIR

Melter emissions were monitored in each test for a variety of gaseous components, most notably CO and nitrogen species, by Fourier Transform Infra Red Spectroscopy (FTIR). The off-gas system temperature is maintained well above 100°C beyond the sampling port downstream of the DM100 HEPA filter to prevent analyte loss due to condensation prior to monitoring. The data, therefore, represent the relative concentrations of volatile gaseous species in the melter exhaust. A summary of the range and average concentrations of gaseous species monitored during the four tests subdivided into contiguous feeding periods with either fixed bubbling or optimized bubbling is provided in Table 5.2. The analytes listed in these tables are those that were thought likely to be observed during the tests based on previous work; no other species were detected in the off-gas stream by FTIR. The concentrations of two of the most abundant monitored species, nitrogen oxides and water, are plotted in Figures 5.2.a - 5.3.d. The amount of moisture in the exhaust was in proportion to the feed rate since the water content was relatively constant between the four feeds; therefore the most moisture was measured while processing the fully washed solids and the least moisture while processing the unwashed solids. Generally, emissions of nitrogen oxides and products of incomplete combustion increase with greater proportions of A-104 supernate in the melter feed. The fully washed HLW solids used in the feed processed in Test 4 contained no nitrogen oxides or organic carbon (see Table 2.2) and therefore monitored concentrations of volatiles were either not detectable or were very low. Conversely, the unwashed waste used in the feed processed in Test 1 contained the highest concentrations of nitrates and nitrites (see Table 2.2) and sugar added in proportion to the feed nitrates and nitrites, which resulted in the highest relative concentrations of nitrogen oxides and measurable amounts of products of incomplete combustion such as ammonia (see Figure 5.4.a) and carbon monoxide. Monitored emissions during Tests 2 and 3 while processing feed containing variable amounts of the A-104 supernate were in between these two extremes. The most abundant nitrogen species monitored was NO, which is in keeping with previous melter

tests with both HLW and LAW feeds. The amount of carbon dioxide monitored in the exhaust reflected the use of carbonates as additive forms; thus, the highest amounts were measured while processing the washed waste during the first test and near ambient air concentrations were measured while processing the unwashed waste, which was not blended with carbonates as additives. The measured concentrations increased from the first segment with fixed bubbling to the second segment with optimized bubbling, in response to the increase in feed rate during Tests 3 and 1. The scatter in the emissions data over the course of the tests is due in part to changes in the cold cap. Consistent with the Method 5-type results, no HCl was detected during the tests.

SECTION 6.0
SUMMARY AND CONCLUSIONS

In the HLW direct feed option that is under consideration for early WTP operations, the pretreatment facility would be bypassed in order to support an earlier start-up of the vitrification facility. In the present work, this strategy was evaluated by developing new glass and feed formulations originating from the direct vitrification of HLW with minimal or no pretreatment, focusing on the impacts of increased supernate on wastes from one of the candidate source tanks for the direct feed option. A series of waste compositions were investigated that span the range of washing efficiencies between the baseline WTP full-wash case and the no-wash case. The present tests focused on high plutonium wastes from tank A-104 while the previous phase of testing focused on the AY-102 tank wastes [7]. The HLW direct feed option has been proposed as a potential route for treating HLW streams that contain the highest concentrations of fast-settling plutonium-containing particles, thereby avoiding some of the potential issues associated with such particles in the WTP Pretreatment facility [1].

Crucible scale testing was conducted to identify glass compositions and glass forming additive blends for a direct-feed HLW stream that has undergone various degrees of washing with no other pretreatment, while maintaining high waste loadings and acceptable glass properties. Based on those results, the unwashed, fully washed, and two intermediate-wash options were selected for testing on the DM100 melter system. These tests assessed impacts on processability and melt rates as well as the need for redox control resulting from the higher levels of nitrates from the increased supernate fraction. Off-gas data were collected to assess the potential for increased NOx generation, which could have impacts on the WTP HLW facility. The effects on glass production rate, melter operations, and off-gas carryover were determined.

Glass formulations were developed for four waste blends from Hanford tank A-104 with varying amounts of LAW and HLW. The compositions of the waste blends given in Table 2.2 were estimated assuming no pretreatment other than washing. Waste Blend 1 assumed no washing, Blend 2 one wash cycle, Blend 3 two wash cycles, and the fourth composition is the fully washed HLW solids. As the number of wash cycles increases, the contribution of LAW to the overall waste composition decreases. Blend 1 waste with the highest LAW contribution contains 35.89 wt% Na_2O, but also 35.73 wt% Fe_2O_3. The glass composition selected to treat Blend 1, A104D1-04 (see Table 2.13), has a waste loading of 46.32 wt% with an LAW contribution of 17.32 wt% and an HLW contribution of 29.00 wt%. Even for this Blend 1 waste with no washing, spinel crystallization due to the high transition metal content was the waste loading limiting constraint. Thus, the HLW components of the waste (Fe, Mn, Ni, Cr), rather than the LAW components (Na, S, Cl) were waste loading limiting. This is in contrast to previous tests with AY-102 waste [7], where LAW components limited waste loading of the unwashed waste. Blend 2 waste, with lower LAW contribution, has lower Na_2O and higher Fe_2O_3 concentrations but spinel crystallization was still the waste loading limiting factor. This was the case also for the Blend 3 waste and the fully washed HLW solids. Therefore, the same glass composition, A104D4-11 (Table 2.16) could be used to treat the fully washed HLW solids

and Blend 2 and Blend 3 wastes with one and two washings, respectively. The only significant difference between the melter feeds for these waste streams was the source of sodium, whether from LAW, as a glass former additive, or a combination of the two. The glass formulation for Blend 2 given in Table 2.14 has a waste loading of 34.78 wt% with 5.77 wt% from LAW and 29.01wt% from HLW. The glass formulation for Blend 3 waste given in Table 2.15 has a waste loading of 30.95 wt% with 1.93 wt% from LAW and 29.03 wt% from HLW. The glass formulation for the fully washed HLW solids given in Table 2.16 has a waste loading of 29.0 wt%, all from HLW. The above glasses meet all of the processing and product quality requirements for WTP [46, 47] and show acceptable feed processing rates based on VGF tests. A review of the above glass formulations show that the loading of HLW in the glass remains constant, whether it is fully washed, subjected to one or two washings, or unwashed. In terms of HLW loading in the glass, there is clearly no advantage in conducting any washing because the sodium that is removed from the waste is put back as an alkali glass former additive in order to limit spinel crystallization in the glass formulation.

A series of melter tests were conducted on the DM100-BL vitrification system with four blends of simulated HLW A-104 waste solids and supernates processed with glass forming additives optimized for each blend. The four tests are distinguished by four different total waste compositions based on blending differing amounts of LAW supernate with HLW solids and two different base glass compositions: three corresponding to washed waste and one corresponding to the unwashed waste. The feed solids content targeted a relatively narrow range from 0.316 to 0.346 kg glass per kg feed as result of the concentration of HLW solids in the waste being the same for each feed. The bubbling rate was fixed at 9 lpm and the feed rate was adjusted to maintain a complete cold cap. Additional production rate data were collected for two of the feeds while optimizing bubbling by using feed remaining after the completion of the 50-hour tests at a bubbling rate of 9 lpm per minute. The principal results of these tests can be summarized as follows:

- All feed formulations were readily processed with HLW oxide loadings of 29 wt% and total waste oxide loadings of up to 46 wt% while meeting all WTP processing and product quality requirements and maintaining acceptable glass and feed processing properties.

- Glass production rates ranged from 1900 kg/m^2/day for the fully washed HLW solids to 1200 kg/m^2/day for the unwashed waste at nominal bubbling (fixed at 9 lpm). The feed solids content is relatively constant for the four feeds and is thus not a factor in differences in production rate. Decreases in production rate appear to be related to increases in waste sodium hydroxide at the expense of lithium and sodium carbonate as additives. The slower melting for the unwashed waste was consistent with the results from VGF testing.

- HLW oxide processing rates ranged from 348 kg/m^2/day for unwashed waste to 551 kg/m^2/day for the fully washed waste at nominal bubbling (fixed at 9 lpm). HLW oxide processing rates were dependent on the overall glass production rate since the HLW oxide loading was the same for all glasses tested.

- LAW oxide processing rates ranged from zero for fully washed waste to 208 kg/m^2/day for unwashed waste at nominal bubbling (fixed at 9 lpm). LAW oxide processing rates were dependent on the LAW oxide loading in the glass as well as the overall glass production rate. The total waste oxide processing rate was relatively constant across the four feed compositions tested at around 550 kg/m^2/day.

Melter exhaust was sampled as each feed composition was processed at the nominal bubbling rate to determine the effect of changing feed composition on particulate and gaseous emissions. Particulate emissions constituted from 0.42 to 0.57 percent of feed solids for feeds containing fully and partially washed solids processed with bubbling fixed at 9 lpm, consistent with the level of solids carryover measured while processing various feeds containing high iron HLW simulants. Solids carryover while processing unwashed waste solids constituted only 0.19 percent of feed solids while processing with bubbling fixed at 9 lpm; however, it is not clear whether this sample is fully indicative of the typical melter exhaust during the test. Melter DFs were determined for most elements in the feed. The most volatile species were chlorine and sulfur, which is typical. Other elements exhibiting volatile behavior in some of the tests include boron, chromium, potassium, and lead. Gaseous emissions of nitrogen oxides and byproducts of incomplete combustion, such as carbon monoxide and ammonia, ranged from virtually none while processing the fully washed HLW solids, to significant concentrations of nitrogen oxides (particularly NO) and carbon monoxide and ammonia while processing the unwashed waste. This was expected given the lack of nitrates and organic carbon in the fully washed HLW stream and the high concentration of nitrates in the A-104 supernate. The extent of the nitrogen oxide emissions was partially mitigated by the addition of sugar to the feed (0.75 moles of carbon per mole of nitrogen oxide) using procedures developed for vitrifying LAW streams. The amount of carbon dioxide monitored in the exhaust reflected the use of carbonates as additives; thus, the highest amounts were measured while processing the washed waste and near ambient air concentrations were measured while processing the unwashed waste.

Glass samples from the crucible and melter tests were subjected to leach testing using the PCT and TCLP methods in order to evaluate product quality. Despite the high waste loading of HLW oxides in each composition tested, the glass products significantly out-performed the DWPF-EA benchmark glass on the PCT leaching procedure by at least one or two orders of magnitude and exhibited TCLP leachate concentrations that are well below the WTP delisting limits.

6.1 Implications for HLW Direct Feed at WTP

The results from the glass formulation and melter testing demonstrate the viability of the HLW direct feed approach and illustrate the relative merits for each waste pretreatment strategy. The of amount time required to vitrify the 76 MT of HLW oxides in Hanford tank A-104 [26, 27] using a single HLW melter with a surface area of 3.75 m^2 operated at 70% total operating efficiency (TOE) is depicted in Figure 6.1. Also shown is the number of HLW canisters, each assumed to contain 3020 kg of glass [48], required for HLW oxides in tank A-104. Only eighty seven HLW canisters are produced from the fully washed, partially washed, or unwashed waste since the waste loading of HLW oxides is the same for all waste pretreatment strategies tested.

This is in contrast to the initial phase of HLW direct feed testing with AY-102 [7] in which the HLW oxide loading decreased without washing due to the high concentration of alkali in the supernate, resulting in a more than two-fold increase in HLW canisters produced. Since the HLW loading for each of the formulations for the A-104 waste is the same, the number of days required to process the HLW oxides in each feed is dependent on the glass production rate. Based on the glass production rates obtained from the present tests, the time required to process the A-104 HLW oxides range from 53 days for the fully washed waste to 83 days for the unwashed waste. However, it should be noted that other factors that could constrain throughput, such as feed preparation, off-gas system constraints, or canister handling limitations, were not considered in this analysis.

The results from this and the initial phase of the HLW direct feed studies [7] provide the initial basis for assessments of the relative merits of progressively more intensive pretreatment in HLW direct feed options. Although a simple in-tank settle/decant washing process was assumed in the analysis, similar considerations arise in the evaluation of various possible alternative direct feed interim pretreatment facilities and operations. The principal conclusion from the present work is the lack of significant benefit of washing this waste as a form of pretreatment. Although the fully washed waste processed faster than the unwashed waste, the time and secondary waste generation associated with washing off-sets this modest benefit in processing duration. Furthermore, there is no benefit in the number of canisters produced since the same HLW oxide loading was achieved for all A-104 waste blending scenarios evaluated. Although the benefits associated with washing were more substantial for AY-102 wastes, they rapidly diminish with the number of wash cycles, and, consequently, also for more complex and intensive washing facilities.

The importance of maintaining sufficiently high solids content in the HLW feed to the vitrification facility was clearly demonstrated in the tests with AY-102 HLW feeds [7]. Thus, of the pretreatment strategies for direct HLW feed evaluated in that work, the first wash cycle provides the vast majority of the overall benefit of washing in terms of HLW loading and HLW processing time; two wash cycles appears to be optimal in those respects for AY-102 since the second wash cycle provides further, though smaller, gains but that must be weighed against the operational costs of each successive wash cycle. In particular, in the in-tank scenario, settling times to achieve reasonable solids contents can be very long. Collectively, these studies demonstrate that the optimum washing strategy, in terms of minimizing the number of HLW canisters, processing duration, and secondary waste generation varies depending on the tank waste being treated.

It should be noted that the AY-102 and A-104 supernates evaluated in these studies are relatively low in sulfate and halides and therefore the primary benefit of washing on waste loading is via removal of sodium. Consequently, excessive washing is counter-productive since sodium is a required additive for HLW vitrification. This is particularly true for the A-104 supernate which has relatively low dissolved solids content. For supernates with high levels of sulfur or halides, more extensive washing may be required, particularly in view of the fact that, unlike the WTP LAW melter systems, the WTP HLW melter systems are not designed to tolerate high levels of these species. Together, these results illustrate that the washing strategy will

depend on the specific tank waste composition and will need to be evaluated on a tank-by-tank basis.

6.2 Recommendations for Future Work

The results of the testing presented herein and the earlier phase of testing [7] demonstrate the viability of the WTP HLW direct feed strategy, which involves minimal or no pretreatment. It is recommended that testing and assessment of these strategies be continued in order to provide a solid basis for their evaluation and implementation in order to maximize the cost and schedule benefits while minimizing technical risk. Further work that is recommended for optimization of processing of WTP HLW direct feed is outlined below.

- *Other WTP Direct Feed HLW Pretreatment Strategies:* The present and previous testing [7] was based on a simple in-tank settle/decant washing strategy. Other pretreatment strategies should be evaluated to optimize the HLW direct feed approach at the WTP.

- *Other WTP Direct Feed HLW Tank Waste:* The present and previous testing [7] are based on two HLW tank compositions from the Hanford tanks. Subsequent work should extend these results to address the full range of HLW direct feeds expected to be processed at the WTP. In particular, HLW feeds for which the supernate is high in sulfate and/or halides need to be evaluated since the acceptable limits for these components in HLW glass are much lower than those for sodium. Also, identification of tanks requiring no or minimal pretreatment such as A-104, could expedite the processing of HLW at WTP.

- *Glass Formulation:* The results from the glass formulation work indicate that further improvements may be possible through continued glass formulation optimization using the results of the present work as a basis. In particular, the development of HLW formulations that have improved tolerance to species in the supernate can decrease the burden on the washing process.

- *Salt Formation and Metal Corrosion:* The potential for molten salt formation and increased metal corrosion (bubblers, thermowells, levels detectors, etc.) increases as the levels of halides and sulfates in the HLW feed increase. Consequently, for HLW feeds for which the supernate is high in sulfate and/or halides, these properties will determine the level of washing that is required to reduce these species to acceptable levels. Testing is needed to define these limits.

- *Scale-Up Testing:* As in the previous enhancement work for ORP, testing should be extended to larger-scale melter systems in order to address potential risks associated with scale-up, particularly with respect to processing rates. Testing should be conducted at the DM1200 WTP HLW Pilot Melter scale (1.2 m^2). Optimization of bubbling rate is a critical variable and therefore testing with bubblers in the prototypical orientation at larger scale is required to confirm these findings.

- *Integrated System Testing:* Testing on the DM1200 WTP HLW Pilot Melter system provides data from a one-third scale system with a prototypical feed delivery system and off-gas treatment train. Such testing is necessary to evaluate potential interactive effects on system operation arising from implementation of the direct feed HLW strategy and to provide data on the performance of each unit operation, input for flow-sheet models and regulatory requirements, and information about recycle streams.

- *Throughput:* A key risk area addressed in the present work relates to the strong dependence of glass production rates on waste composition and the extent to which shortfalls in processing rate can be mitigated through glass formulation design and optimization of bubbling. The strategy can be extended to evaluate other pretreatment options and corresponding HLW compositions.

- *Settling of Pu Particles:* At present, the concerns about Pu particle settling are largely limited to tanks that employ pulsed jet mixers, mostly in the pretreatment facility. A detailed analysis of the fate of Pu particles in a direct feed HLW flowsheet has not been attempted because the feed system for such a flowsheet has not been designed. However, consideration of this factor should be part of the system design requirements to ensure that Pu particles do not settle and accumulate from batch to batch. Once system designs and analyses are complete and detailed information about Pu particle size distributions and concentrations are available, the flowsheet should be reviewed and test data collected to address any remaining concerns regarding Pu particle settling.

SECTION 7.0
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Table 2.1. Compositions (oxide wt%) of A-104 HLW Simulant.

Oxide	A-104 Washed Solids	Normalized HLW Simulant Composition
Al_2O_3	20.02%	20.59%
BaO	0.19%	0.20%
CaO	2.05%	2.10%
Cr_2O_3	0.31%	0.32%
Fe_2O_3	55.50%	57.07%
La_2O_3	0.01%	0.01%
MgO	0.62%	0.64%
MnO	7.02%	7.21%
Na_2O	2.55%	2.63%
NiO	3.21%	3.30%
P_2O_5	0.56%	0.57%
PbO	0.07%	0.07%
SiO_2	5.02%	5.16%
SrO	0.09%	0.09%
ZrO_2	0.04%	0.04%
TOTAL	97.3%	100.0%

Table 2.2. Compositions of the Supernate and Washed Solids from Tank A-104 and Various Blends of the Two.

Blending Ratios						
Wt% Oxides from Wash Solution		100.00%	37.39%	16.60%	6.22%	0.00%
Wt% Oxides from Washed Solids		0.00%	62.61%	83.40%	93.78%	100.00%
Waste Blend		**Generated Supernate**	**Blend 1**	**Blend 2**	**Blend 3**	**Fully Washed Solids**
Composition Wt%	Al_2O_3	0.00%	12.89%	17.17%	19.31%	20.59%
	BaO	0.00%	0.12%	0.16%	0.19%	0.20%
	CaO	1.94%	2.04%	2.08%	2.09%	2.10%
	Cl	0.28%	0.11%	0.05%	0.02%	0.00%
	Cr_2O_3	0.05%	0.22%	0.28%	0.30%	0.32%
	Fe_2O_3	0.00%	35.73%	47.60%	53.52%	57.07%
	K_2O	0.15%	0.06%	0.03%	0.01%	0.00%
	La_2O_3	0.00%	0.01%	0.01%	0.01%	0.01%
	MgO	0.00%	0.40%	0.53%	0.60%	0.64%
	MnO	0.00%	4.52%	6.02%	6.77%	7.21%
	Na_2O	91.57%	35.89%	17.39%	8.16%	2.63%
	NiO	0.00%	2.07%	2.75%	3.10%	3.30%
	P_2O_5	0.00%	0.36%	0.48%	0.54%	0.57%
	PbO	0.02%	0.05%	0.06%	0.07%	0.07%
	SO_3	2.75%	1.03%	0.46%	0.17%	0.00%
	SiO_2	3.23%	4.44%	4.84%	5.04%	5.16%
	SrO	0.00%	0.06%	0.07%	0.08%	0.09%
	ZrO_2	0.00%	0.02%	0.03%	0.03%	0.04%
	TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Volatiles, g/100g oxides	Carbonate	0.044	2.483	3.292	3.697	3.939
	Nitrate	0.664	0.248	0.110	0.041	0.000
	Nitrite	14.831	5.546	2.462	0.923	0.000
	Organic Carbon	0.000	0.000	0.000	0.000	0.000
	Sugar to be added	6.81	2.56	1.14	0.43	0.00
Solids and Oxide Contents	wt% LAW solids	11.45%	9.73%	3.24%	1.08%	0.00%
	wt% HLW solids	0.00%	15.00%	15.00%	15.00%	15.00%
	wt% Total solids	11.45%	24.73%	18.24%	16.08%	15.00%
	wt% LAW oxides	9.34%	7.94%	2.65%	0.88%	0.00%
	wt% HLW oxides	0.00%	13.30%	13.30%	13.30%	13.30%
	wt% Total oxides	9.34%	21.24%	15.95%	14.18%	13.30%

Table 2.3. Compositions of HLW Simulants to Produce 100 kg of Waste Oxides for Each Waste Blend.

Starting Materials	Blend 1 Target Weight (kg)*	Blend 2 Target Weight (kg)*	Blend 3 Target Weight (kg)*	Washed Solids Target Weight (kg)*
AlOOH (Boehmite)	15.320	20.4080	22.9481	24.4710
$BaCO_3$	0.161	0.214	0.241	0.257
$CaCO_3$	3.681	3.744	3.775	3.794
NaCl	0.177	0.079	0.029	0.000
Cr_2O_3	0.223	0.280	0.308	0.325
$Fe(OH)_3$ (13% Slurry)	367.807	489.944	550.925	587.486
K_2CO_3	0.084	0.037	0.014	0.000
La_2O_3	0.008	0.015	0.017	0.018
MgO	0.402	0.535	0.602	0.642
MnO	4.562	6.077	6.834	7.287
NaOH	39.734	17.835	6.900	0.345
$Ni(OH)_2$	2.592	3.452	3.882	4.140
Na_3PO_4	0.837	1.115	1.254	1.337
PbO	0.053	0.064	0.070	0.074
Na_2SO_4	1.847	0.820	0.307	0.000
SiO_2	4.483	4.887	5.088	5.209
$SrCO_3$	0.080	0.106	0.119	0.127
$Zr(OH)_4.xH_2O$ (49.9% ZrO_2)	0.046	0.061	0.068	0.073
Water	19.650	71.900	98.000	113.600
Na_2CO_3	0.324	1.690	2.373	2.782
$NaNO_3$	0.344	0.153	0.057	0.000
$NaNO_2$	8.402	3.731	1.398	0.000
TOTAL	470.82	627.15	705.21	751.97
Wt% Total Solids	27.86%	20.57%	18.14%	16.92%
Wt% Total Oxide	21.24%	15.95%	14.18%	13.30%

*Target weights adjusted for assumed assay information of starting materials

Table 2.4. Waste Loadings, Glass-Forming Additives, and Target Compositions (wt%) of Glasses for Tank 241-A-104 Fully Washed Solids Direct Feed Vitrification.

Washed Solids	A104D4-01	A104D4-02	A104D4-03	A104D4-04
Waste	25.50%	25.50%	25.50%	25.50%
B_2O_3	7.50%	7.50%	7.50%	9.00%
Li_2O	3.50%	6.00%	2.00%	3.00%
Na_2O	16.50%	14.00%	16.50%	14.00%
SiO_2	47.00%	47.00%	48.50%	48.50%
Glass ID / Composition	A104D4-01	A104D4-02	A104D4-03	A104D4-04
Al_2O_3	5.250%	5.250%	5.250%	5.250%
B_2O_3	7.500%	7.500%	7.500%	9.000%
BaO	0.050%	0.050%	0.050%	0.050%
CaO	0.537%	0.537%	0.537%	0.537%
Cr_2O_3	0.082%	0.082%	0.082%	0.082%
Fe_2O_3	14.553%	14.553%	14.553%	14.553%
La_2O_3	0.003%	0.003%	0.003%	0.003%
Li_2O	3.500%	6.000%	2.000%	3.000%
MgO	0.162%	0.162%	0.162%	0.162%
MnO	1.840%	1.840%	1.840%	1.840%
Na_2O	17.170%	14.670%	17.170%	14.670%
NiO	0.842%	0.842%	0.842%	0.842%
P_2O_5	0.146%	0.146%	0.146%	0.146%
PbO	0.019%	0.019%	0.019%	0.019%
SiO_2	48.315%	48.315%	49.815%	49.815%
SrO	0.023%	0.023%	0.023%	0.023%
ZrO_2	0.009%	0.009%	0.009%	0.009%
TOTAL	100.00%	100.00%	100.00%	100.00%

Table 2.4. Waste Loadings, Glass-Forming Additives, and Target Compositions (wt%) of Glasses for Tank 241-A-104 Fully Washed Solids Direct Feed Vitrification (continued).

Washed Solids	A104D4-05	A104D4-06	A104D4-07	A104D4-08
Waste	27.00%	29.00%	28.00%	28.00%
B_2O_3	7.50%	5.00%	8.50%	10.00%
Li_2O	3.00%	2.25%	3.00%	2.50%
Na_2O	14.50%	19.75%	14.50%	14.00%
SiO_2	48.00%	44.00%	46.00%	45.50%
Glass ID / Composition	A104D4-05	A104D4-06	A104D4-07	A104D4-08
Al_2O_3	5.559%	5.970%	5.765%	5.765%
B_2O_3	7.500%	5.000%	8.500%	10.000%
BaO	0.053%	0.057%	0.055%	0.055%
CaO	0.568%	0.610%	0.589%	0.589%
Cr_2O_3	0.087%	0.093%	0.090%	0.090%
Fe_2O_3	15.409%	16.551%	15.980%	15.980%
La_2O_3	0.003%	0.004%	0.003%	0.003%
Li_2O	3.000%	2.250%	3.000%	2.500%
MgO	0.172%	0.184%	0.178%	0.178%
MnO	1.948%	2.092%	2.020%	2.020%
Na_2O	15.209%	20.511%	15.235%	14.735%
NiO	0.892%	0.958%	0.925%	0.925%
P_2O_5	0.155%	0.166%	0.161%	0.161%
PbO	0.020%	0.021%	0.020%	0.020%
SiO_2	49.392%	45.496%	47.444%	46.944%
SrO	0.024%	0.026%	0.025%	0.025%
ZrO_2	0.010%	0.010%	0.010%	0.010%
TOTAL	100.00%	100.00%	100.00%	100.00%

Table 2.4. Waste Loadings, Glass-Forming Additives, and Target Compositions (wt%) of Glasses for Tank 241-A-104 Fully Washed Solids Direct Feed Vitrification (continued).

Washed Solids	A104D4-09	A104D4-10	A104D4-11
Waste	29.00%	28.20%	29.00%
B_2O_3	8.00%	13.80%	12.00%
Li_2O	7.00%	2.00%	3.00%
Na_2O	10.50%	14.00%	14.00%
SiO_2	45.50%	42.00%	42.00%
Glass ID / Composition	A104D4-09	A104D4-10	A104D4-11
Al_2O_3	5.970%	5.806%	5.970%
B_2O_3	8.000%	13.800%	12.000%
BaO	0.057%	0.056%	0.057%
CaO	0.610%	0.593%	0.610%
Cr_2O_3	0.093%	0.091%	0.093%
Fe_2O_3	16.551%	16.094%	16.551%
La_2O_3	0.004%	0.003%	0.004%
Li_2O	7.000%	2.000%	3.000%
MgO	0.184%	0.179%	0.184%
MnO	2.092%	2.034%	2.092%
Na_2O	11.261%	14.740%	14.761%
NiO	0.958%	0.931%	0.958%
P_2O_5	0.166%	0.162%	0.166%
PbO	0.021%	0.021%	0.021%
SiO_2	46.996%	43.454%	43.496%
SrO	0.026%	0.025%	0.026%
ZrO_2	0.010%	0.010%	0.010%
TOTAL	100.00%	100.00%	100.00%

Table 2.5. Compositions of HLW Glasses (wt%) Analyzed by XRF.

Oxide	A104D4-01	A104D4-02	A104D4-03	A104D4-04	A104D4-05
Al_2O_3	5.28%	5.21%	5.20%	5.29%	5.47%
B_2O_3[(1)]	**7.50%**	**7.50%**	**7.50%**	**9.00%**	**7.50%**
BaO	0.07%	0.06%	0.06%	0.07%	0.08%
CaO	0.55%	0.57%	0.57%	0.58%	0.64%
Cl	0.01%	0.01%	0.00%	0.00%	0.01%
Cr_2O_3	0.09%	0.09%	0.09%	0.10%	0.10%
Fe_2O_3	14.27%	14.91%	15.21%	14.71%	15.95%
K_2O	0.04%	0.03%	0.03%	0.03%	0.04%
La_2O_3	0.02%	—[(2)]	—	—	—
Li_2O[(1)]	**3.50%**	**6.00%**	**2.00%**	**3.00%**	**3.00%**
MgO	0.16%	0.14%	0.16%	0.13%	0.14%
MnO	1.85%	1.90%	1.98%	1.85%	2.03%
Na_2O	17.55%	14.14%	16.53%	14.43%	14.70%
NiO	0.98%	1.00%	1.00%	0.98%	1.02%
P_2O_5	0.18%	0.18%	0.17%	0.17%	0.17%
PbO	0.02%	0.02%	0.02%	0.02%	0.02%
SO_3	0.13%	0.16%	0.15%	0.15%	0.15%
SiO_2	47.73%	48.00%	49.26%	49.42%	48.93%
SrO	0.04%	0.04%	0.04%	0.04%	0.04%
ZrO_2	0.02%	0.02%	0.02%	0.02%	0.02%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%

(1) B_2O_3 and Li_2O are not analyzed by XRF; target values (boldface) are used.
(2) — Empty data field (not detected or components not present in glass).

Table 2.5. Compositions of HLW Glasses (wt%) Analyzed by XRF (continued).

Oxide	A104D4-06	A104D4-07	A104D4-08	A104D4-09	A104D4-10
Al_2O_3	5.84%	5.69%	5.72%	5.82%	5.78%
B_2O_3[(1)]	5.00%	8.50%	10.00%	8.00%	13.80%
BaO	0.08%	0.09%	0.06%	0.08%	0.06%
CaO	0.65%	0.64%	0.66%	0.64%	0.65%
Cl	0.01%	0.01%	0.01%	0.00%	0.01%
Cr_2O_3	0.11%	0.10%	0.08%	0.09%	0.09%
Fe_2O_3	16.92%	15.91%	15.77%	16.77%	16.01%
K_2O	0.03%	0.04%	0.03%	0.03%	0.03%
La_2O_3	—[(2)]	—	—	—	—
Li_2O[(1)]	2.25%	3.00%	2.50%	7.00%	2.00%
MgO	0.16%	0.18%	0.18%	0.18%	0.15%
MnO	2.18%	2.04%	2.04%	2.16%	2.05%
Na_2O	20.06%	15.28%	14.90%	11.07%	14.98%
NiO	1.10%	1.03%	1.05%	1.09%	1.03%
P_2O_5	0.20%	0.20%	0.18%	0.20%	0.18%
PbO	0.02%	0.02%	0.02%	0.02%	0.02%
SO_3	0.17%	0.16%	0.15%	0.16%	0.13%
SiO_2	45.10%	47.04%	46.59%	46.62%	42.96%
SrO	0.04%	0.03%	0.03%	0.04%	0.04%
ZrO_2	0.02%	0.02%	0.02%	0.02%	0.02%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%

(1) B_2O_3 and Li_2O are not analyzed by XRF; target values (boldface) are used.
(2) — Empty data field (not detected or components not present in glass).

Table 2.5. Compositions of HLW Glasses (wt%) Analyzed by XRF (continued).

Oxide	A104D4-11	A104D1-01	A104D1-02	A104D1-03	A104D1-04
Al_2O_3	5.92%	5.66%	5.76%	5.94%	5.94%
B_2O_3[(1)]	12.00%	8.00%	7.00%	10.00%	12.00%
BaO	0.06%	0.06%	0.07%	0.08%	0.07%
CaO	0.67%	0.98%	1.00%	0.99%	1.00%
Cl	0.01%	0.04%	0.04%	0.04%	0.04%
Cr_2O_3	0.09%	0.10%	0.11%	0.12%	0.11%
Fe_2O_3	16.36%	15.77%	15.83%	16.55%	16.41%
K_2O	0.03%	0.06%	0.05%	0.05%	0.05%
La_2O_3	—[(2)]	—	—	—	—
Li_2O[(1)]	3.00%	2.00%	2.50%	0.00%	0.00%
MgO	0.15%	0.17%	0.16%	0.17%	0.16%
MnO	2.10%	2.05%	2.03%	2.09%	2.13%
Na_2O	14.77%	16.06%	16.36%	16.49%	16.71%
NiO	1.10%	1.02%	1.05%	1.10%	1.04%
P_2O_5	0.20%	0.18%	0.19%	0.19%	0.20%
PbO	0.02%	0.03%	0.02%	0.02%	0.02%
SO_3	0.13%	0.48%	0.61%	0.55%	0.49%
SiO_2	43.32%	47.27%	47.14%	45.54%	43.56%
SrO	0.04%	0.03%	0.03%	0.04%	0.03%
ZrO_2	0.02%	0.02%	0.01%	0.02%	0.02%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%

(1) B_2O_3 and Li_2O are not analyzed by XRF; target values (boldface) are used.
(2) — Empty data field (not detected or components not present in glass).

Table 2.6. Characterization Data for the A-104D4 (Washed Solids) Glasses.

Property			A104D4-01	A104D4-02	A104D4-03	A104D4-04
Crystal Content after Heat Treatment[1] (vol%)		800°C	—[2]	—	—	0.24 (Sp)
		850°C	—	0.30 (Sp)	trace (Sp)	0.22 (Sp)
		900°C	0.00	0.18 (Sp)	0.03 (Sp)	0.12 (Sp)
		950°C	0.00	0.02 (Sp)	0.00	0.10 (Sp)
Viscosity (P)	Predicted at 1150°C		25.69	13.69	56.21	44.09
	Experimental	Temperature 1	—	—	—	—
		Temperature 2	—	—	—	—
		Temperature 3	—	—	—	—
		Temperature 4	—	—	—	—
	Fitted	1050°C	—	—	—	—
		1150°C	—	—	—	—
		1250°C	—	—	—	—
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.595	0.729	0.464	0.412
	Experimental	Temperature 1	—	—	—	—
		Temperature 2	—	—	—	—
		Temperature 3	—	—	—	—
		Temperature 4	—	—	—	—
	Fitted	1050°C	—	—	—	—
		1150°C	—	—	—	—
		1250°C	—	—	—	—
Normalized PCT (7 Day) (g/l)		B	[2.484][3]	[2.845]	[1.184]	[1.109]
		Li	[2.545]	[4.135]	[1.110]	[1.261]
		Na	[2.010]	[2.527]	[1.298]	[1.142]

[1] Sp = Spinel.
[2] — Empty data field (not analyzed).
[3] Values in square brackets are model predicted.

Table 2.6. Characterization Data for the A-104D4 (Washed Solids) Glasses (continued).

Property			A104D4-05	A104D4-06	A104D4-07	A104D4-08
Crystal Content after Heat Treatment[1] (vol%)		800°C	0.29 (Sp)	—[2]	—	—
		850°C	0.25 (Sp)	0.36 (Sp)	0.57 (Sp)	0.52 (Sp)
		900°C	0.21 (Sp)	0.33 (Sp)	0.40 (Sp)	0.58 (Sp)
		950°C	0.15 (Sp)	0.22 (Sp)	0.24 (Sp)	0.46 (Sp)
Viscosity (P)	Predicted at 1150°C		45.38	29.10	35.14	39.22
	Experimental	Temperature 1	359.79 (950°C)	241.28 (953°C)	273.08 (953°C)	—
		Temperature 2	119.34 (1051°C)	81.88 (1055°C)	90.18 (1054°C)	—
		Temperature 3	49.29 (1153°C)	36.02 (1156°C)	38.70 (1155°C)	—
		Temperature 4	24.38 (1254°C)	17.93 (1258°C)	19.54 (1256°C)	—
	Fitted	1050°C	120.32	86.44	93.95	—
		1150°C	50.53	37.34	40.03	—
		1250°C	24.99	18.90	20.30	—
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.437	0.738	0.444	0.385
	Experimental	Temperature 1	0.223 (975°C)	0.394 (972°C)	0.226 (973°C)	—
		Temperature 2	0.362 (1071°C)	0.557 (1069°C)	0.354 (1070°C)	—
		Temperature 3	0.499 (1168°C)	0.756 (1165°C)	0.489 (1166°C)	—
		Temperature 4	0.599 (1266°C)	0.938 (1263°C)	0.652 (1261°C)	—
	Fitted	1050°C	0.335	0.528	0.324	—
		1150°C	0.471	0.717	0.470	—
		1250°C	0.586	0.916	0.630	—
Normalized PCT (7 Day) (g/l)		B	[0.951][3]	[1.494]	0.672	[0.963]
		Li	[1.135]	[1.289]	0.726	[1.063]
		Na	[1.113]	[2.080]	0.468	[0.960]

[1] Sp = Spinel.
[2] — Empty data field (not analyzed).
[3] Values in square brackets are model predicted.

Table 2.6. Characterization Data for the A-104D4 (Washed Solids) Glasses (continued).

Property			A104D4-09	A104D4-10	A104D4-11
Crystal Content after Heat Treatment[1] (vol%)		800°C	2.70 (Sp)	—[2]	1.07 (Sp)
		850°C	1.46 (Sp)	0.86 (Sp)	0.89 (Sp)
		900°C	1.04 (Sp)	0.88 (Sp)	0.84 (Sp)
		950°C	0.87 (Sp)	0.47 (Sp)	0.58 (Sp)
Viscosity (P)	Predicted at 1150°C		13.32	26.07	19.77
	Experimental	Temperature 1	—	—	141.74 (953°C)
		Temperature 2	—	—	50.41 (1054°C)
		Temperature 3	—	—	22.60 (1155°C)
		Temperature 4	—	—	11.80 (1256°C)
	Fitted	1050°C	—	—	52.36
		1150°C	—	—	23.38
		1250°C	—	—	12.23
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.704	0.362	0.435
	Experimental	Temperature 1	—	—	0.217 (974°C)
		Temperature 2	—	—	0.329 (1071°C)
		Temperature 3	—	—	0.455 (1165°C)
		Temperature 4	—	—	0.617 (1261°C)
	Fitted	1050°C	—	—	0.301
		1150°C	—	—	0.435
		1250°C	—	—	0.596
Normalized PCT (7 Day) (g/l)		B	1.144	[1.299][3]	0.810
		Li	1.267	[1.201]	0.804
		Na	1.024	[1.002]	0.800

[1] Sp = Spinel.
[2] — Empty data field (not analyzed).
[3] Values in square brackets are model predicted.

Table 2.7. Regression Results, Estimated One-Percent Crystal Fraction Temperature ($T_{1\%}$) and Major Crystalline Phase Near $T_{1\%}$ for the Direct Feed A-104 (Blend 1 and Washed Solids) Glasses.

Glass	Intercept	Slope	$T_{1\%}$ (°C)	Primary Crystalline Phase
A104D1-01	1033.89	-293.19	740.70	Spinel
A104D1-02	990.63	-156.25	834.38	Spinel
A104D1-04	1026.28	-288.15	738.13	Spinel
A104D4-07	1017.12	-288.57	728.55	Spinel
A104D4-09	984.43	-72.11	912.32	Spinel
A104D4-10	1034.42	-182.47	851.95	Spinel
A104D4-11	1136.27	-309.19	827.07	Spinel

Table 2.8. TCLP Results (mg/L) for Selected A-104 Direct Feed Glasses.

Glass	Ba	Cr	Ni	Pb
A104D1-03	0.21	0.03	0.12	<0.1
A104D1-04	0.20	0.03	0.13	<0.1
A104D4-07	0.27	0.02	0.13	<0.1
A104D4-09	0.27	0.02	0.14	<0.1
A104D4-11	0.28	0.02	0.15	<0.1
UTS Limit[(1)]	21.00	0.60	11.00	0.75
Delisting Limit	100	4.95	22.6	5

[(1)] For comparison only; does not apply to WTP glasses.

Table 2.9. Ranking Definition for Feed Conversion After 30-Minute VGF Test and Test Results for A-104 Glass/Feed Formulations.

Ranking	Definition
1	Very Fast, all feed converted
2	Fast with minor residue on side wall
3	Moderate with foamy residue on side wall
4	Slow with thick foam layer
5	Slow with partially collapsed dome
6	Very slow with fully developed dome

Sample	Test Ranking
A104D1-F (A104D1-04 Glass with sugar)	5
A104D2-F (Blend 2 Glass Based on A104D4-11 with sugar)	1
A104D3-F (Blend 3 Glass Based on A104D4-11 with sugar)	1-2
A104D4-A (A104D4-11 Glass with H_3BO_3/no sugar)	1-2
A104D4-B (A104D4-11 Glass with $Na_2B_4O_7.10H_2O$/no sugar)	1-2

Table 2.10. Waste Loadings, Glass-Forming Additives, and Target Compositions (wt%) of Blend 2 and Blend 3 Glasses for Tank 241-A-104 Direct Feed Vitrification (Based on A104D4-11).

	Blend 2	Blend 3
Waste	34.78%	30.95%
B_2O_3	12.00%	12.00%
Li_2O	3.00%	3.00%
Na_2O	8.70%	12.25%
SiO_2	41.52%	41.80%
Glass ID / Composition	Blend 2 Glass	Blend 3 Glass
Al_2O_3	5.972%	5.975%
B_2O_3	12.000%	12.000%
BaO	0.057%	0.057%
CaO	0.722%	0.648%
Cl	0.016%	0.005%
Cr_2O_3	0.096%	0.094%
Fe_2O_3	16.554%	16.564%
K_2O	0.009%	0.003%
La_2O_3	0.004%	0.004%
Li_2O	3.000%	3.000%
MgO	0.184%	0.184%
MnO	2.093%	2.094%
Na_2O	14.750%	14.776%
NiO	0.958%	0.958%
P_2O_5	0.166%	0.166%
PbO	0.022%	0.022%
SO_3	0.159%	0.053%
SiO_2	43.203%	43.359%
SrO	0.026%	0.026%
ZrO_2	0.010%	0.010%
TOTAL	100.00%	100.00%

Table 2.11. Waste Loadings, Glass-Forming Additives, and Target Compositions (wt%) of Glasses for Tank 241-A-104 (Blend 1) Direct Feed Vitrification.

Blended 1 Glasses	A104D1-01	A104D1-02	A104D1-03	A104D1-04
Waste	44.50%	45.50%	46.32%	46.32%
B_2O_3	8.00%	7.00%	10.00%	12.00%
Li_2O	2.00%	2.50%	0.00%	0.00%
Na_2O	0.00%	0.00%	0.00%	0.00%
SiO_2	45.50%	45.00%	43.68%	41.68%
Glass ID / Composition	A104D1-01	A104D1-02	A104D1-03	A104D1-04
Al_2O_3	5.736%	5.865%	5.970%	5.970%
B_2O_3	8.000%	7.000%	10.000%	12.000%
BaO	0.055%	0.056%	0.057%	0.057%
CaO	0.909%	0.929%	0.946%	0.946%
Cl	0.047%	0.048%	0.049%	0.049%
Cr_2O_3	0.098%	0.100%	0.102%	0.102%
Fe_2O_3	15.900%	16.257%	16.550%	16.550%
K_2O	0.025%	0.026%	0.026%	0.026%
La_2O_3	0.003%	0.003%	0.004%	0.004%
Li_2O	2.000%	2.500%	0.000%	0.000%
MgO	0.177%	0.181%	0.184%	0.184%
MnO	2.010%	2.055%	2.092%	2.092%
Na_2O	15.969%	16.328%	16.622%	16.622%
NiO	0.920%	0.941%	0.958%	0.958%
P_2O_5	0.160%	0.163%	0.166%	0.166%
PbO	0.023%	0.024%	0.024%	0.024%
SO_3	0.458%	0.469%	0.477%	0.477%
SiO_2	47.475%	47.019%	45.736%	43.736%
SrO	0.025%	0.025%	0.026%	0.026%
ZrO_2	0.010%	0.010%	0.010%	0.010%
TOTAL	100.00%	100.00%	100.00%	100.00%

(1) Component not present in glass.

Table 2.12. Characterization Data for the A-104D1 (Blend 1) Glasses.

Property			A104D1-01	A104D1-02	A104D1-03	A104D1-04
Crystal Content after Heat Treatment[1] (vol%)		800°C	—[2]	—	—	0.79 (Sp)
		850°C	0.64 (Sp)	0.90 (Sp)	0.54 (Sp)	0.44 (Sp)
		900°C	0.40 (Sp)	0.42 (Sp)	0.55 (Sp)	0.44 (Sp)
		950°C	0.33 (Sp)	0.42 (Sp)	0.40 (Sp)	0.43 (Sp)
Viscosity (P)	Predicted at 1150°C		50.85	40.95	87.60	60.54
	Experimental	Temperature 1	—	—	952.71 (952°C)	585.68 (952°C)
		Temperature 2	—	—	255.44 (1053°C)	163.24 (1054°C)
		Temperature 3	—	—	91.76 (1154°C)	61.16 (1156°C)
		Temperature 4	—	—	39.88 (1255°C)	27.88 (1258°C)
	Fitted	1050°C	—	—	265.00	170.84
		1150°C	—	—	94.86	64.31
		1250°C	—	—	41.45	29.49
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.392	0.446	0.309	0.315
	Experimental	Temperature 1	—	—	0.167 (975°C)	0.159 (975°C)
		Temperature 2	—	—	0.246 (1069°C)	0.246 (1069°C)
		Temperature 3	—	—	0.332 (1163°C)	0.339 (1163°C)
		Temperature 4	—	—	0.430 (1259°C)	0.419 (1256°C)
	Fitted	1050°C	—	—	0.229	0.230
		1150°C	—	—	0.321	0.324
		1250°C	—	—	0.420	0.415
Normalized PCT (7 Day) (g/l)		B	[0.925][3]	[0.971]	0.597	0.720
		Li	[0.920]	[1.029]	not in glass	not in glass
		Na	[0.988]	[1.148]	0.669	0.695

[1] Sp = Spinel.
[2] — Empty data field (not analyzed).
[3] Values in square brackets are model predicted.

Table 2.13. Summary of Oxide Contributions (as wt% oxide in glass) from LAW, HLW and Glass Forming Additives to Blend 1 Target Glass Formulation (A104D1-04, Waste Loading = 46.32 wt%)[1].

Oxide	Blended Waste	LAW	HLW	Glass Forming Additives	Target Glass
Al_2O_3	5.97%	—	5.97%	—	5.97%
B_2O_3	—[2]	—	—	12.00%	12.00%
BaO	0.06%	—	0.06%	—	0.06%
CaO	0.95%	0.34%	0.61%	—	0.95%
Cl	0.05%	0.05%	—	—	0.05%
Cr_2O_3	0.10%	0.01%	0.09%	—	0.10%
Fe_2O_3	16.55%	—	16.55%	—	16.55%
K_2O	0.03%	0.03%	—	—	0.03%
La_2O_3	0.00%	—	0.00%	—	0.00%
Li_2O	—	—	—	—	—
MgO	0.18%	—	0.18%	—	0.18%
MnO	2.09%	—	2.09%	—	2.09%
Na_2O	16.62%	15.86%	0.76%	—	16.62%
NiO	0.96%	0.00%	0.96%	—	0.96%
P_2O_5	0.17%	0.00%	0.17%	—	0.17%
PbO	0.02%	0.00%	0.02%	—	0.02%
SO_3	0.48%	0.48%	—	—	0.48%
SiO_2	2.06%	0.56%	1.50%	41.68%	43.74%
SrO	0.03%	—	0.03%	—	0.03%
ZrO_2	0.01%	—	0.01%	—	0.01%
TOTAL	46.32%	17.32%	29.00%	53.68%	100.0%

[1] Decimal rounding may cause slight differences in addition results and/or target glass composition when compared to Table 2.10.
[2] — Empty data field (oxides not present in waste or additives not used).

Table 2.14. Summary of Oxide Contributions (as wt% oxide in glass) from LAW, HLW and Glass Forming Additives to Blend 2 Target Glass Formulation (Based on A104D4-11, Waste Loading = 34.78 wt%)[(1)].

Oxide	Blended Waste	LAW	HLW	Glass Forming Additives	Target Glass
Al_2O_3	5.97%	—	5.97%	—	5.97%
B_2O_3	—[(2)]	—	—	12.00%	12.00%
BaO	0.06%	—	0.06%	—	0.06%
CaO	0.72%	0.11%	0.61%	—	0.72%
Cl	0.02%	0.02%	—	—	0.02%
Cr_2O_3	0.10%	0.00%	0.09%	—	0.10%
Fe_2O_3	16.55%	—	16.55%	—	16.55%
K_2O	0.01%	0.01%	—	—	0.01%
La_2O_3	0.00%	—	0.00%	—	0.00%
Li_2O	—	—	—	3.00%	3.00%
MgO	0.18%	—	0.18%	—	0.18%
MnO	2.09%	—	2.09%	—	2.09%
Na_2O	6.05%	5.29%	0.76%	8.70%	14.75%
NiO	0.96%	0.00%	0.96%	—	0.96%
P_2O_5	0.17%	—	0.17%	—	0.17%
PbO	0.02%	0.00%	0.02%	—	0.02%
SO_3	0.16%	0.16%	—	—	0.16%
SiO_2	1.68%	0.19%	1.50%	41.52%	43.20%
SrO	0.03%	—	0.03%	—	0.03%
ZrO_2	0.01%	—	0.01%	—	0.01%
TOTAL	34.78%	5.77%	29.01%	65.22%	100.0%

(1) Decimal rounding may cause slight differences in addition results and/or target glass composition when compared to Table 2.9.
(2) — Empty data field (oxides not present in waste or additives not used).

Table 2.15. Summary of Oxide Contributions (as wt% oxide in glass) from LAW, HLW and Glass Forming Additives to Blend 3 Target Glass Formulation (Based on A104D4-11, Waste Loading = 30.95 wt%)[1].

Oxide	Blended Waste	LAW	HLW	Glass Forming Additives	Target Glass
Al_2O_3	5.98%	—	5.98%	—	5.98%
B_2O_3	—[2]	—	—	12.00%	12.00%
BaO	0.06%	—	0.06%	—	0.06%
CaO	0.65%	0.04%	0.61%	—	0.65%
Cl	0.01%	0.01%	—	—	0.01%
Cr_2O_3	0.09%	0.00%	0.09%	—	0.09%
Fe_2O_3	16.56%	—	16.56%	—	16.56%
K_2O	0.00%	0.00%	—	—	0.00%
La_2O_3	0.00%	—	0.00%	—	0.00%
Li_2O	—	—	—	3.00%	3.00%
MgO	0.18%	—	0.18%	—	0.18%
MnO	2.09%	—	2.09%	—	2.09%
Na_2O	2.53%	1.76%	0.76%	12.25%	14.78%
NiO	0.96%	—	0.96%	—	0.96%
P_2O_5	0.17%	—	0.17%	—	0.17%
PbO	0.02%	—	0.02%	—	0.02%
SO_3	0.05%	0.05%	—	—	0.05%
SiO_2	1.56%	0.06%	1.50%	41.80%	43.36%
SrO	0.03%	—	0.03%	—	0.03%
ZrO_2	0.01%	—	0.01%	—	0.01%
TOTAL	30.95%	1.93%	29.02%	69.05%	100.0%

[1] Decimal rounding may cause slight differences in addition results and/or target glass composition when compared to Table 2.9.
[2] — Empty data field (oxides not present in waste or additives not used).

Table 2.16. Summary of Oxide Contributions (as wt% oxide in glass) from HLW and Glass Forming Additives to Washed Solids Target Glass Formulation (A104D4-11, Waste Loading = 29.00 wt%)[(1)].

Oxide	Blended Waste	Glass Forming Additives	Target Glass
Al_2O_3	5.97%	—	5.97%
B_2O_3	—[(2)]	12.00%	12.00%
BaO	0.06%	—	0.06%
CaO	0.61%	—	0.61%
Cl	—	—	—
Cr_2O_3	0.09%	—	0.09%
Fe_2O_3	16.55%	—	16.55%
K_2O	—	—	—
La_2O_3	0.00%	—	0.00%
Li_2O	—	3.00%	3.00%
MgO	0.18%	—	0.18%
MnO	2.09%	—	2.09%
Na_2O	0.76%	14.00%	14.76%
NiO	0.96%	—	0.96%
P_2O_5	0.17%	—	0.17%
PbO	0.02%	—	0.02%
SO_3	—	—	—
SiO_2	1.50%	42.00%	43.50%
SrO	0.03%	—	0.03%
ZrO_2	0.01%	—	0.01%
TOTAL	29.00%	71.00%	100.0%

(1) Decimal rounding may cause slight differences in addition results and/or target glass composition when compared to Table 2.4.
(2) — Empty data field (oxides not present in waste or additives not used).

Table 2.17. Summary of Glass Forming Additives (kg) Required to Produce 100 kg of Target Glasses for A-104 Direct Feed Vitrification[(1)].

Waste		Blend 1	Blend 2	Blend 3	Washed Solids
Target Glass		A104D1-04	A104D4-11	A104D4-11	A104D4-11
Waste Loading		46.32 wt%	34.78 wt%	30.95 wt%	29.00 wt%
Melter Test		1	2	3	4
Glass Forming Additives (kg) Required to Produce 100 kg of Target Glasses	H_3BO_3	21.315	21.315	21.315	21.315
	Li_2CO_3	—[(2)]	7.420	7.420	7.420
	Na_2CO_3	—	14.878	20.948	23.941
	SiO_2	41.680	41.520	41.800	42.000
	TOTAL	62.995	85.133	91.483	94.676
Modifications to Feed received from NOAH at VSL	Water	Added	Added	Added	Added
	Chemicals Added to Achieve Target Glass	Boric Acid, Fe_2O_3	Lithium Carbonate, Boric Acid, Fe_2O_3	Lithium Carbonate, Boric Acid, Fe_2O_3	Lithium Carbonate, Boric Acid, Fe_2O_3
	Sugar	Added	Added	Added	None
Target Feed Solids (g glass/kg feed)		320	316	322	346

[(1)] Assay values of all additives assumed to be 100%.
[(2)] — Empty data field (additives not used).

Table 3.1. Summary of Results from DM100 Test 4 with Fully Washed HLW Solids and A104D4-11 Glass Composition.

Test		Fixed Bubbling (9 lpm)
Time	Feed Start	1/5/15 13:05
	Feed End	1/7/15 15:05
	Interval	50.0 hr
Water Feeding for Cold Cap		75 min
Slurry Feeding		48.75 hr
Feeding Interruptions		18 min
Average Bubbling Rate		8.8 lpm
Waste	wt% LAW solids	0
	wt% HLW solids	15
	wt% total solids	15
Feed	Used	1275 kg
	Target Glass Yield	0.320 kg/kg
	Measured Glass Yield	459 g/l
		0.337 kg/kg
	Average Feed Rate	26.6 kg/hr
Glass Produced	Poured	410.6 kg
	Average Rate based on glass poured	1901 kg/m^2/day
	Average Rate based on feed consumed	1856 kg/m^2/day
	Steady State Rate*	1900 kg/m^2/day
	Average Power Use	3.4 kW hr/kg glass

*: Rates estimated from feed data.
Note: Rates do not take into account the time for water feeding and cold cap burn-off.

Table 3.2. Summary of Results from DM100 Test 3 with Blend 3 Waste and A104D4-11 Glass Composition.

Test		Fixed Bubbling (9 lpm)	Optimized Bubbling
Time	Feed Start	1/12/15 10:00	1/14/15 12:01
	Feed End	1/14/15 12:00	1/14/15 20:00
	Interval	50.0 hr	8.0 hr
Water Feeding for Cold Cap		120 min	0 min
Slurry Feeding		48.0 hr	34.4 hr
Feeding Interruptions		18 min	0 min
Average Bubbling Rate		8.9 lpm	13.7 lpm
Waste	wt% LAW solids	1.08	1.08
	wt% HLW solids	15	15
	wt% total solids	16.08	16.08
Feed	Used	1036 kg	224 kg
	Target Glass yield	0.316 kg/kg	0.316 kg/kg
	Measured Glass yield	469 g/l	469 g/l
		0.340 kg/kg	0.340 kg/kg
	Average Feed Rate	21.6 kg/hr	28.0 kg/hr
Glass Produced	Poured	346 kg	68.8 kg
	Average Rate based on glass poured	1602 kg/m^2/day	1911 kg/m^2/day
	Average Rate based on feed consumed	1515 kg/m^2/day	1975 kg/m^2/day
	Steady State Rate*	1500 kg/m^2/day	Not Achieved
	Average Power Use	3.4 kW hr/kg glass	3.4 kW hr/kg glass

*: Rates estimated from feed data.
Note: Rates do not take into account the time for water feeding and cold cap burn-off.

Table 3.3. Summary of Results from DM100 Test 2 with Blend 2 Waste and A104D4-11 Glass Composition.

Test		Fixed Bubbling (9 lpm)	Fixed Bubbling (9 lpm)
Time	Feed Start	1/14/15 21:35	1/20/15 9:13
	Feed End	1/15/15 22:38	1/21/15 19:13
	Interval	25.1 hr	34.0 hr
Water Feeding for Cold Cap		0 min	120 min
Slurry Feeding		25.1 hr	32.0 hr
Feeding Interruptions		7 min	5 min
Average Bubbling Rate		9.0 lpm	9.1 lpm
Waste	wt% LAW solids	3.24	3.24
	wt% HLW solids	15	15
	wt% total solids	18.24	18.24
Feed	Used	572 kg	685 kg
	Target Glass yield	0.322 kg/kg	0.322 kg/kg
	Measured Glass yield	477 g/l	477 g/l
		0.346 kg/kg	0.346 kg/kg
	Average Feed Rate	22.8 kg/hr	21.4 kg/hr
Glass Produced	Poured	193.6 kg	228.5 kg
	Average Rate based on glass poured	1707 kg/m^2/day	1587 kg/m^2/day
	Average Rate based on feed consumed	1631 kg/m^2/day	1532 kg/m^2/day
	Steady State Rate*	1600 kg/m^2/day	1600 kg/m^2/day
	Average Power Use	3.0 kW hr/kg glass	3.1 kW hr/kg glass

*: Rates estimated from feed data.
Note: Rates do not take into account the time for water feeding and cold cap burn-off.

Table 3.4. Summary of Results from DM100 Test 1 with Blend 1 Waste and A104D1-04 Glass Composition.

Test		Fixed Bubbling (9 lpm)	Optimized Bubbling
Time	Feed Start	1/26/15 9:05	1/28/15 13:21
	Feed End	1/28/15 13:15	1/30/15 7:21
	Interval	52.2 hr	42.0 hr
Water Feeding for Cold Cap		70 min	0 min
Slurry Feeding		51.1 hr	42.0 hr
Feeding Interruptions		24 min	9 min
Average Bubbling Rate		9.1 lpm	18.1 lpm
Waste	wt% LAW solids	9.73	9.73
	wt% HLW solids	15	15
	wt% total solids	24.73	24.73
Feed	Used	782 kg	734 kg
	Target Glass yield	0.346 kg/kg	0.346 kg/kg
	Measured Glass yield	517 g/l	517 g/l
		0.372 kg/kg	0.372 kg/kg
	Average Feed Rate	15.2 kg/hr	17.5 kg/hr
Glass Produced	Poured	297.0 kg	252.7 kg
	Average Rate based on glass poured	1291 kg/m^2/day	1337 kg/m^2/day
	Average Rate based on feed consumed	1180 kg/m^2/day	1336 kg/m^2/day
	Steady State Rate*	1200 kg/m^2/day	1300 kg/m^2/day
	Average Power Use	3.2 kW hr/kg glass	3.6 kW hr/kg glass

*: Rates estimated from feed data.
Note: Rates do not take into account the time for water feeding and cold cap burn-off.

Table 3.5. Steady-State Production Rates Achieved on the DM100 with High Iron HLW Compositions at a Glass Temperature of 1150°C, 9 lpm Bubbling Rate, and Solids Content Near (+/-50) 500 g glass/liter.

HLW Glass	Wt% Fe_2O_3	HLW Waste Loading %	Production Rate ($kg/m^2/day$)
A104D4-11 with fully washed solids	16.55	29.00	1900
A104D4-11 with Blend 3 Waste			1500
A104D4-11 with Blend 2 Waste			1600
A104D1-04			1200
HLW-E-SP-06 (2.2% Spinel Vol% @ 950°C) [36]	20.01	38.73	700
HLW-E-SP-05 (4.2% Spinel Vol% @ 950°C) [36]	21.30	41.23	500
HLW-NG-Fe2, $Fe(OH)_3$ [4]	16.01	42.00	1650
HLW-NG-Fe2, Goethite [43]			1725
HLW-NG-Fe2, Hematite [43]			1910
HLW-NG-Fe2, Magnetite [43]			1830
HLW-NG-Fe2, Mixture of iron sources [43]			1950
AZ-102, Nominal Rheology [21]	12.56	24.25	1200
AZ-102, Adjusted Rheology [21]			1400
C-106/AY-102 [37]	12.58	27.75	1000
C-106/AY-102- 15% GFCs [37]	14.31	31.57	1050
AZ-101 [17]	10.39	30.39	1300
HLW04-09, Feed made from HLW SIPP [18]	14.03	37.10	1200

Table 3.6. Steady-State Production Rates for Waste Components.

	Test	1	2	3	4
Waste	Washing	None	1 wash cycle*	2 wash cycles	Complete
	Wt% HLW Solids	15%	15%	15%	15%
	Wt% HLW Oxides	39	65.7	85.2	100
	Wt% LAW Oxides	61	34.3	14.2	0
Waste Loading	Wt% Total Oxides	46.32	34.78	30.95	29.00
	Wt% HLW Oxides	29.00	29.00	29.00	29.00
	Wt% LAW Oxides	17.32	5.78	1.95	0.00
Measured %Water		58.6	59.6	59.9	59.9
Glass Production Rate (kg/m2/day)	9 lpm bubbling	1200	1600	1500	1900
	Optimized bubbling	1300	ND	ND	ND
Total Waste Oxide Processing Rate (kg/m2/day)	9 lpm bubbling	556	556	464	551
	Optimized bubbling	602	ND	ND	ND
HLW Oxide Processing Rate (kg/m2/day)	9 lpm bubbling	348	464	435	551
	Optimized bubbling	377	NA	NA	NA
LAW Oxide Processing Rate (kg/m2/day)	9 lpm bubbling	208	92	29	0
	Optimized bubbling	225	ND	ND	ND

* A wash cycle is assumed to correspond to a three-fold dilution with water followed by settling to 15 wt% undissolved solids.
ND – Not Determined

Table 3.7. Summary of Measured DM100 Parameters from Test 4 with Fully Washed HLW Solids and A104D4-11 Glass Composition.

Test			Fixed Bubbling 9 lpm		
			AVG	MIN	MAX
TEMPERATURE (°C)	Electrode	East Upper	1124	1059	1137
		West Upper	1084	1072	1095
		West Lower	1126	1102	1136
		Bottom	756	748	763
	Glass	27” from bottom	1129	1018	1163
		16” from bottom	1133	1049	1160
		10” from bottom	1150	1107	1168
		5” from bottom	1148	1080	1171
	Plenum	Exposed	599	518	771
		Thermowell	582	519	778
	Discharge Chamber		1091	1065	1128
	Film Cooler Outlet		285	276	299
	Transition Line Outlet		274	223	285
Lance Bubbling (lpm)			8.8	1.2	9.5
Melter Pressure (inches water)			-0.91	-3.01	0.73
Total Electrode Voltage (V)			43.7	41.9	46.8
Total Electrode Power (kW)			29.1	26.2	30.5
Glass Resistance (ohms)			0.066	0.061	0.073

Table 3.8. Summary of Measured DM100 Parameters from Test 3 with Blend 3 Waste and A104D4-11 Glass Composition.

Test			Fixed Bubbling 9 lpm			Optimized Bubbling		
			AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (°C)	Electrode	East Upper	1076	1051	1100	1086	1073	1097
		West Upper	1017	989	1061	1026	1014	1040
		West Lower	1085	1070	1098	1084	1079	1093
		Bottom	715	702	725	724	722	726
	Glass	27” from bottom	1123	1040	1168	1127	1103	1146
		16” from bottom	1138	1115	1170	1136	1121	1150
		10” from bottom	1153	1135	1177	1151	1139	1166
		5” from bottom	1150	1132	1175	1148	1138	1162
	Plenum	Exposed	516	137	729	538	509	639
		Thermowell	477	337	684	473	429	517
	Discharge Chamber		1044	1006	1066	1061	1049	1071
	Film Cooler Outlet		283	273	296	284	278	293
	Transition Line Outlet		268	242	280	273	267	284
Lance Bubbling (lpm)			8.9	1.2	15.0	13.7	7.5	19.5
Melter Pressure (inches water)			-0.92	-2.97	0.84	-0.85	-2.29	-0.04
Total Electrode Voltage (V)			41.6	38.2	43.9	45.4	42.5	47.9
Total Electrode Power (kW)			24.3	21.2	25.7	29.1	25.5	31.9
Glass Resistance (ohms)			0.071	0.066	0.078	0.071	0.067	0.075

Table 3.9. Summary of Measured DM100 Parameters from Test 2 with Blend 2 Waste and A104D4-11 Glass Composition.

Test			Fixed Bubbling 9 lpm			Idling			Fixed Bubbling 9 lpm		
			AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (^oC)	Electrode	East Upper	1069	1044	1084	1046	1002	1066	1073	1040	1090
		West Upper	1003	988	1034	1002	957	1033	1011	985	1055
		West Lower	1084	1076	1097	1024	991	1064	1083	1061	1097
		Bottom	721	720	724	684	674	720	716	694	726
	Glass	27” from bottom	1122	1007	1155	1091	1055	1155	1124	1039	1153
		16” from bottom	1138	1116	1158	1088	1053	1155	1139	1095	1165
		10” from bottom	1153	1141	1172	1099	1062	1166	1154	1137	1177
		5” from bottom	1150	1138	1169	1099	1056	1159	1153	1133	1176
	Plenum	Exposed	483	360	750	885	671	921	515	281	703
		Thermowell	438	367	711	874	626	911	466	363	683
	Discharge Chamber		1055	1036	1069	956	863	1046	1075	1008	1116
	Film Cooler Outlet		284	236	292	47	41	367	279	272	291
	Transition Line Outlet		271	232	279	42	37	259	263	258	277
Lance Bubbling (lpm)			9.0	8.6	9.3	1.0	0.7	4.2	9.1	1.1	9.8
Melter Pressure (inches water)			-0.88	-3.51	1.86	-0.53	-3.13	-0.09	-0.87	-2.98	0.62
Total Electrode Voltage (V)			40.6	35.4	42.6	30.7	26.9	34.0	39.9	37.2	42.6
Total Electrode Power (kW)			23.2	19.2	24.0	12.8	11.6	16.9	22.4	19.8	23.9
Glass Resistance (ohms)			0.071	0.065	0.077	0.074	0.061	0.083	0.071	0.065	0.080

Table 3.10. Summary of Measured DM100 Parameters from DM100 Test 1 with Blend 1 Waste and A104D1-04 Glass Composition.

Test			Fixed Bubbling 9 lpm			Optimized Bubbling		
			AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (°C)	Electrode	East Upper	1051	992	1091	1082	1033	1109
		West Upper	999	953	1039	1012	985	1045
		West Lower	1075	1056	1087	1084	1058	1104
		Bottom	718	692	727	737	719	751
	Glass	27” from bottom	1116	1024	1155	1123	1032	1172
		16” from bottom	1131	1098	1164	1134	1088	1176
		10” from bottom	1157	1135	1177	1155	1125	1190
		5” from bottom	1157	1126	1176	1152	1126	1177
	Plenum	Exposed	499	224	819	539	365	660
		Thermowell	456	303	802	479	382	598
	Discharge Chamber		1067	1021	1113	1115	1037	1140
	Film Cooler Outlet		278	266	290	278	269	287
	Transition Line Outlet		264	239	277	265	260	276
Lance Bubbling (lpm)			9.1	1.8	9.7	18.1	8.6	22.5
Melter Pressure (inches water)			-0.91	-2.14	0.48	-0.94	-2.49	0.54
Total Electrode Voltage (V)			40.0	36.1	42.9	47.1	38.8	51.8
Total Electrode Power (kW)			18.4	16.5	20.7	21.6	16.6	24.2
Glass Resistance (ohms)			0.087	0.067	0.107	0.103	0.090	0.119

Table 4.1. Measured Characteristics of Melter Feed Samples.

Base Glass	Source	Date	Name	% Water	pH	Density (g/ml)	Glass Yield			
							(g/l)	Measured (kg/kg)	Target (kg/kg)	% Dev.
A104D4-11	As Received	12/15/14	SBL-F-59A	58.22	9.49	1.43	514	0.360	0.320	12.41
		12/17/14	SBL-F-59B	58.06	9.61	1.42	511	0.360	0.320	12.49
	Feed Tube	1/5/15	SBL-F-70A	58.97	9.47	1.34	441	0.329	0.320	2.78
		1/7/15	SBL-F-93A	59.86	9.47	1.38	477	0.345	0.320	7.94
A104D4-11 with Blend 3 Waste	As Received	1/7/15	SBL-F-95E	57.61	9.70	1.43	518	0.362	0.316	14.53
		1/7/15	SBL-F-95F	57.65	9.74	1.43	515	0.360	0.316	13.99
	Feed Tube	1/12/15	SBL-F-116A	60.24	9.48	1.38	462	0.335	0.316	5.89
		1/14/15	SBL-F-139A	59.61	9.59	1.38	476	0.345	0.316	9.08
A104D4-11 with Blend 2 Waste	As Received	1/7/15	SBL-F-95A	57.41	10.34	1.44	528	0.366	0.322	13.79
		1/7/15	SBL-F-95B	57.36	10.35	1.43	520	0.364	0.322	13.01
	Feed Tube	1/14/15	SBL-F-141A	60.18	9.98	1.37	466	0.340	0.322	5.59
		1/21/15	TBL-F-35A	58.97	9.94	1.39	488	0.351	0.322	9.01
A104D1-04	As Received	1/7/15	SBL-F-95C	57.74	12.80	1.39	533	0.383	0.346	10.75
		1/7/15	SBL-F-95D	57.96	12.74	1.39	531	0.382	0.346	10.46
	Feed Tube	1/26/15	TBL-F-42A	58.26	12.04	1.39	520	0.374	0.346	8.06
		1/29/15	TBL-F-87A	58.94	12.02	1.39	515	0.371	0.346	7.11

Table 4.2. XRF and DCP Analyzed Compositions of Vitrified Melter Feed Samples from DM100 Test 4 with Fully Washed HLW Solids and A104D4-11 Glass Composition. (wt%).

Target		As-Received Feed				Melter Feed			
		SBL-F-59A	SBL-F-59B	Avg.	% Dev.	SBL-F-70A	SBL-F-93A	Avg.	% Dev.
Al_2O_3	**5.97**	6.57	6.57	6.57	10.03	6.38	6.22	6.30	5.57
B_2O_3#	**12.00**	10.43	10.95	10.69	-10.92	11.91	11.58	11.75	-2.12
BaO	**0.06**	0.04	0.06	0.05	NC	0.05	0.04	0.05	NC
CaO	**0.61**	0.67	0.68	0.67	NC	0.63	0.79	0.71	NC
Cl	**&**	0.02	0.02	0.02	NC	0.01	0.02	0.02	NC
Cr_2O_3	**0.09**	0.08	0.09	0.09	NC	0.09	0.09	0.09	NC
Fe_2O_3	**16.55**	15.13	15.10	15.12	-8.67	16.13	16.72	16.43	-0.76
K_2O	**&**	0.04	0.04	0.04	NC	0.04	0.03	0.04	NC
Li_2O#	**3.00**	2.62	2.75	2.69	-10.33	3.03	3.41	3.22	7.33
MgO	**0.18**	0.34	0.31	0.33	NC	0.33	0.33	0.33	NC
MnO	**2.09**	1.88	1.96	1.92	-8.25	1.88	1.87	1.88	-10.34
Na_2O	**14.76**	14.14	14.68	14.41	-2.39	13.35	13.31	13.33	-9.71
NiO	**0.96**	0.98	0.96	0.97	NC	0.99	1.01	1.00	NC
P_2O_5	**0.17**	0.18	0.17	0.17	NC	0.17	0.18	0.17	NC
PbO	**0.02**	0.01	0.02	0.01	NC	0.02	0.02	0.02	NC
SO_3	**&**	0.12	0.12	0.12	NC	0.08	0.10	0.09	NC
SiO_2	**43.50**	46.61	45.38	45.99	5.74	44.74	44.12	44.43	2.14
SrO	**0.03**	0.02	0.02	0.02	NC	0.02	0.03	0.03	NC
TiO_2	**&**	0.10	0.09	0.10	NC	0.11	0.11	0.11	NC
ZnO	**&**	0.01	0.01	0.01	NC	0.01	0.01	0.01	NC
ZrO_2	**0.01**	0.01	0.01	0.01	NC	0.02	0.02	0.02	NC
Total	**100.00**	100.00	100.00	100.00		100.00	100.00	100.00	

Determined by DCP-AES
& Not a target constituent
NC Not calculated

Table 4.3. XRF and DCP Analyzed Compositions of Vitrified Melter Feed Samples from DM100 Test 3 with Blend 3 Waste and A104D4-11 Glass Composition. (wt%).

Target		As-Received Feed				Melter Feed			
		SBL-F-95E	SBL-F-95F	Avg.	% Dev.	SBL-F-116A	SBL-F-139A	Avg.	% Dev.
Al_2O_3	**5.98**	6.50	6.62	6.56	9.84	6.23	6.25	6.24	4.37
B_2O_3[#]	**12.00**	10.78	10.64	10.71	-10.75	12.24	12.30	12.27	2.25
BaO	**0.06**	0.05	0.05	0.05	NC	0.05	0.05	0.05	NC
CaO	**0.65**	0.67	0.67	0.67	NC	0.67	0.62	0.64	NC
Cl	**0.01**	0.02	0.02	0.02	NC	0.02	0.02	0.02	NC
Cr_2O_3	**0.09**	0.09	0.10	0.09	NC	0.10	0.10	0.10	NC
Fe_2O_3	**16.56**	14.84	15.08	14.96	-9.68	16.83	16.99	16.91	2.09
K_2O	**&**	0.05	0.05	0.05	NC	0.04	0.03	0.04	NC
Li_2O[#]	**3.00**	2.76	2.76	2.76	-8.00	2.96	3.32	3.14	4.67
MgO	**0.18**	0.41	0.36	0.38	NC	0.37	0.37	0.37	NC
MnO	**2.09**	1.88	1.87	1.87	-10.50	1.82	1.83	1.82	-12.91
Na_2O	**14.78**	14.59	14.30	14.45	-2.22	13.73	13.26	13.50	-8.67
NiO	**0.96**	0.95	0.95	0.95	NC	0.93	0.94	0.94	NC
P_2O_5	**0.17**	0.16	0.19	0.17	NC	0.16	0.15	0.15	NC
PbO	**0.02**	0.02	0.02	0.02	NC	0.01	0.02	0.02	NC
SO_3	**0.05**	0.18	0.15	0.17	NC	0.13	0.15	0.14	NC
SiO_2	**43.36**	45.90	46.02	45.96	6.00	43.56	43.44	43.50	0.33
SrO	**0.03**	0.02	0.02	0.02	NC	0.02	0.02	0.02	NC
TiO_2	**&**	0.11	0.10	0.10	NC	0.10	0.10	0.10	NC
ZnO	**&**	0.01	0.01	0.01	NC	0.01	0.01	0.01	NC
ZrO_2	**0.01**	0.02	0.01	0.02	NC	0.01	0.02	0.02	NC
Total	**100.00**	100.00	100.00	100.00		100.00	100.00	100.00	

Determined by DCP-AES
& Not a target constituent
NC Not calculated

Table 4.4. XRF and DCP Analyzed Compositions of Vitrified Melter Feed Samples from DM100 Test 2 with Blend 2 Waste and A104D4-11 Glass Composition. (wt%).

Target		As-Received Feed				Melter Feed			
		SBL-F-95A	SBL-F-95B	Avg.	% Dev.	SBL-F-141A	TBL-F-35A	Avg.	% Dev.
Al_2O_3	**5.97**	6.65	6.59	6.62	10.87	6.30	6.16	6.23	4.25
B_2O_3#	**12.00**	10.70	10.73	10.72	-10.71	12.38	12.08	12.23	1.92
BaO	**0.06**	0.06	0.04	0.05	NC	0.05	0.06	0.05	NC
CaO	**0.72**	0.71	0.74	0.73	NC	0.73	0.71	0.72	NC
Cl	**0.02**	0.01	0.02	0.01	NC	0.03	0.02	0.03	NC
Cr_2O_3	**0.10**	0.10	0.10	0.10	NC	0.09	0.09	0.09	NC
Fe_2O_3	**16.55**	14.63	15.25	14.94	-9.75	17.27	16.69	16.98	2.58
K_2O	**0.01**	0.04	0.05	0.05	NC	0.05	0.04	0.04	NC
Li_2O#	**3.00**	2.70	2.76	2.73	-9.00	2.97	3.31	3.14	4.67
MgO	**0.18**	0.41	0.40	0.41	NC	0.39	0.37	0.38	NC
MnO	**2.09**	1.87	1.93	1.90	-9.39	1.90	1.83	1.87	-10.71
Na_2O	**14.75**	14.71	14.42	14.57	-1.25	12.95	13.46	13.20	-10.48
NiO	**0.96**	0.92	0.98	0.95	NC	1.00	0.98	0.99	NC
P_2O_5	**0.17**	0.17	0.16	0.17	NC	0.15	0.16	0.16	NC
PbO	**0.02**	0.02	0.02	0.02	NC	0.01	0.02	0.02	NC
SO_3	**0.16**	0.13	0.21	0.17	NC	0.24	0.20	0.22	NC
SiO_2	**43.20**	46.01	45.48	45.74	5.88	43.34	43.69	43.52	0.73
SrO	**0.03**	0.03	0.02	0.03	NC	0.02	0.02	0.02	NC
TiO_2	**&**	0.09	0.09	0.09	NC	0.10	0.09	0.09	NC
ZnO	**&**	0.01	0.01	0.01	NC	0.01	0.01	0.01	NC
ZrO_2	**0.01**	0.02	0.01	0.01	NC	0.02	0.02	0.02	NC
Total	**100.00**	100.00	100.00	100.00		100.00	100.00	100.00	

Determined by DCP-AES
& Not a target constituent
NC Not calculated

Table 4.5. XRF and DCP Analyzed Compositions of Vitrified Melter Feed Samples from DM100 Test 1 with Blend 1 Waste and AY104D1-04 Glass Composition. (wt%).

Target		As-Received Feed				Melter Feed			
		SBL-F-95C	SBL-F-95D	Avg.	% Dev.	TBL-F-42A	TBL-F-87A	Avg.	% Dev.
Al_2O_3	**5.97**	6.61	6.54	6.57	10.08	6.39	6.32	6.35	6.43
B_2O_3#	**12.00**	10.74	10.80	10.77	-10.25	12.05	11.92	11.99	-0.13
BaO	**0.06**	0.05	0.06	0.06	NC	0.08	0.06	0.07	NC
CaO	**0.95**	0.97	0.89	0.93	NC	0.90	0.87	0.88	NC
Cl	**0.05**	0.03	0.03	0.03	NC	0.04	0.03	0.04	NC
Cr_2O_3	**0.10**	0.11	0.10	0.11	NC	0.08	0.08	0.08	NC
Fe_2O_3	**16.55**	14.74	14.75	14.75	-10.90	16.60	16.43	16.51	-0.24
K_2O	**0.03**	0.06	0.06	0.06	NC	0.05	0.06	0.05	NC
Li_2O#	**&**	0.10	0.03	0.07	NC	0.03	0.01	0.02	NC
MgO	**0.18**	0.37	0.39	0.38	NC	0.38	0.40	0.39	NC
MnO	**2.09**	1.86	1.89	1.88	-10.35	1.81	1.78	1.80	-14.14
Na_2O	**16.62**	16.21	15.97	16.09	-3.19	15.46	15.65	15.55	-6.42
NiO	**0.96**	0.94	0.93	0.93	NC	0.93	0.91	0.92	NC
P_2O_5	**0.17**	0.17	0.17	0.17	NC	0.16	0.17	0.16	NC
PbO	**0.02**	0.02	0.02	0.02	NC	0.02	0.02	0.02	NC
SO_3	**0.48**	0.37	0.35	0.36	NC	0.40	0.36	0.38	NC
SiO_2	**43.74**	46.50	46.87	46.69	6.74	44.47	44.79	44.63	2.04
SrO	**0.03**	0.02	0.02	0.02	NC	0.02	0.02	0.02	NC
TiO_2	**&**	0.11	0.10	0.10	NC	0.10	0.10	0.10	NC
ZnO	**&**	0.01	0.01	0.01	NC	0.01	0.01	0.01	NC
ZrO_2	**0.01**	0.01	0.01	0.01	NC	0.01	0.01	0.01	NC
Total	**100.00**	100.00	100.00	100.00		100.00	100.00	100.00	

Determined by DCP-AES
& Not a target constituent
NC Not calculated

Table 4.6. Listing of Discharged Glass Masses.

Glass Formulation	Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
Test 4 A104D4-11	1/5/2015	SBL-G-75A	31.93	31.93
		SBL-G-75B		
		SBL-G-76A	26.26	58.19
		SBL-G-76B		
		SBL-G-78A	26.04	84.23
	1/6/2015	SBL-G-78B		
		SBL-G-78C	27.72	111.95
		SBL-G-81A		
		SBL-G-81B	28.97	140.92
		SBL-G-81C		
		SBL-G-81D	32.84	173.76
		SBL-G-81E		
		SBL-G-83A	23.60	197.36
		SBL-G-83B		
		SBL-G-83C	29.47	226.83
		SBL-G-83D		
		SBL-G-87A	36.77	263.60
		SBL-G-87B		
		SBL-G-87C		
		SBL-G-89A	26.78	290.38
	1/7/2015	SBL-G-89B		
		SBL-G-89C	35.00	325.38
		SBL-G-89D		
		SBL-G-93A	27.48	352.86
		SBL-G-93B		
		SBL-G-93C	27.33	380.19
		SBL-G-93D		
		SBL-G-93E	30.36	410.55
		SBL-G-95A		

Table 4.6. Listing of Discharged Glass Masses (continued).

Glass Formulation	Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
Test 3 A104D4-11 with Blend 3 Waste	1/12/2015	SBL-G-116A	22.91	22.91
		SBL-G-117A		
		SBL-G-117B	28.75	51.66
		SBL-G-117C		
		SBL-G-119A	29.73	81.39
		SBL-G-119B		
	1/13/2015	SBL-G-119C	25.46	106.85
		SBL-G-119D		
		SBL-G-122A	27.01	133.86
		SBL-G-122B		
		SBL-G-124A	29.18	163.04
		SBL-G-124B		
		SBL-G-124C	32.96	196.00
		SBL-G-127A		
		SBL-G-127B	25.34	221.34
		SBL-G-129A		
		SBL-G-129B	29.80	251.14
		SBL-G-129C		
	1/14/2015	SBL-G-129D	27.96	279.10
		SBL-G-129E		
		SBL-G-134A	31.35	310.45
		SBL-G-134B		
		SBL-G-134C	35.55	346.00
		SBL-G-138A		
		SBL-G-138B	16.85	362.85
		SBL-G-138C		
		SBL-G-139A	28.70	391.55
		SBL-G-139B		
		SBL-G-139C	23.25	414.80
		SBL-G-141A		

Table 4.6. Listing of Discharged Glass Masses (continued).

Glass Formulation	Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
Test 2 A104D4-11 with Blend 2 Waste	1/14/2015	SBL-G-141B	21.88	21.88
	1/15/2015	SBL-G-141C		
		SBL-G-144A	18.60	40.48
		SBL-G-144B		
		SBL-G-144C	32.92	73.40
		SBL-G-144D		
		SBL-G-147A	28.65	102.05
		SBL-G-147B		
		SBL-G-147C	24.75	126.80
		SBL-G-147D		
		SBL-G-151A	23.20	150.00
		SBL-G-151B		
		SBL-G-151C	21.92	171.92
		SBL-G-151D		
		TBL-G-10A	21.68	193.60
	1/20/2015	TBL-G-22A	24.27	217.87
		TBL-G-23A		
		TBL-G-23B	21.82	239.69
		TBL-G-23C		
		TBL-G-25A	22.52	262.21
		TBL-G-25B		
		TBL-G-25C	26.96	289.17
		TBL-G-28A		
	1/21/2015	TBL-G-28B	23.85	313.02
		TBL-G-28C		
		TBL-G-29A		
		TBL-G-29B	20.26	333.28
		TBL-G-29C		
		TBL-G-29D	26.768	360.05
		TBL-G-31A		
		TBL-G-31B	26.11	386.16
		TBL-G-31C		
		TBL-G-31D	23.65	409.81
		TBL-G-31E		
		TBL-G-35A	12.25	422.06

Table 4.6. Listing of Discharged Glass Masses (continued).

Glass Formulation	Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
Test 1 A104D1-04 Glass Composition	1/26/2015	TBL-G-55A	30.02	30.02
		TBL-G-55B		
		TBL-G-55C	22.02	52.04
		TBL-G-55D		
		TBL-G-59A	26.48	78.52
		TBL-G-59B		
	1/27/2015	TBL-G-59C	20.92	99.44
		TBL-G-59D		
		TBL-G-60A	22.26	121.70
		TBL-G-60B		
		TBL-G-60C	28.38	150.08
		TBL-G-60D		
		TBL-G-64A	22.90	172.98
		TBL-G-64B		
		TBL-G-64C	20.54	193.52
		TBL-G-65A		
		TBL-G-65B	24.22	217.74
		TBL-G-70A		
	1/28/2015	TBL-G-70B	17.18	234.92
		TBL-G-72A		
		TBL-G-72B	23.46	258.38
		TBL-G-72C		
		TBL-G-72D	26.18	284.56
		TBL-G-76A		
		TBL-G-77A	23.00	307.56
		TBL-G-77B		
		TBL-G-77C	25.30	332.86
		TBL-G-79A		
		TBL-G-79B	20.92	353.78
	1/29/2015	TBL-G-79C		
		TBL-G-82A	19.40	373.18
		TBL-G-82B		
		TBL-G-82C	20.94	394.12
		TBL-G-84A		
		TBL-G-84B	30.34	424.46
		TBL-G-87A		
		TBL-G-87B	23.18	447.64
		TBL-G-87C		
		TBL-G-89A	18.64	466.28
		TBL-G-91A		
		TBL-G-91B	22.48	488.76
		TBL-G-95A		

Table 4.6. Listing of Discharged Glass Masses (continued).

Glass Formulation	Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
Test 1 A104D1-04	1/30/2015	TBL-G-95B	22.22	510.98
		TBL-G-95C		
		TBL-G-95D	22.94	533.92
		TBL-G-96A		
		TBL-G-96B	15.78	549.70
		TBL-G-97A		

Table 4.7. XRF Analyzed Composition for Glass Discharged from DM100 Test 4 with Fully Washed HLW Solids and A104D4-11 Glass Composition (wt%).

	Glass (kg)	226.83	263.60	290.38	325.38	352.86	380.19	410.55
	Target	SBL-G-83D	SBL-G-87C	SBL-G-89B	SBL-G-89D	SBL-G-93B	SBL-G-93D	SBL-G-95A
Al_2O_3	5.97	6.20	6.18	6.29	6.21	6.26	6.21	6.39
B_2O_3#	12.00	12.82	12.67	12.58	12.47	12.41	12.35	12.30
BaO	0.06	0.05	0.04	0.07	0.08	0.07	0.05	0.04
Bi_2O_3	&	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
CaO	0.61	0.66	0.64	0.65	0.61	0.64	0.65	0.62
Ce_2O_3	&	0.04	0.03	0.06	< 0.01	0.03	< 0.01	< 0.01
Cl	&	0.02	0.02	0.01	0.02	0.01	0.01	0.02
Cr_2O_3	0.09	0.14	0.14	0.13	0.12	0.10	0.12	0.10
Fe_2O_3	16.55	15.62	15.60	15.97	16.08	15.86	15.76	15.61
K_2O	&	0.04	0.03	0.04	0.04	0.04	0.04	0.03
La_2O_3	&	0.03	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Li_2O#	3.00	2.61	2.68	2.72	2.77	2.80	2.83	2.86
MgO	0.18	0.32	0.34	0.31	0.32	0.33	0.33	0.35
MnO	2.09	2.19	2.09	2.11	2.08	2.00	1.99	1.99
Na_2O	14.76	14.22	14.14	13.54	13.51	13.82	13.95	13.84
NiO	0.96	0.80	0.83	0.86	0.85	0.88	0.88	0.84
P_2O_5	0.17	0.31	0.30	0.28	0.25	0.24	0.22	0.20
PbO	0.02	0.17	0.14	0.13	0.11	0.09	0.08	0.07
SO_3	&	0.07	0.09	0.08	0.08	0.08	0.08	0.09
SiO_2	43.50	43.04	43.49	43.65	43.94	43.91	44.09	44.30
SnO_2	&	0.02	0.02	< 0.01	< 0.01	0.01	< 0.01	< 0.01
SrO	0.03	0.08	0.07	0.06	0.06	0.05	0.05	0.04
TiO_2	&	0.12	0.10	0.12	0.11	0.12	0.10	0.11
ZnO	&	0.04	0.04	0.04	0.04	0.03	0.03	0.02
ZrO_2	0.01	0.39	0.32	0.29	0.24	0.20	0.18	0.15
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SBL-D-70A) and target composition using a simple well-stirred tank model.

Table 4.7. XRF Analyzed Composition for Glass Discharged from DM100 Test 4 with Fully Washed HLW Solids and A104D4-11 Glass Composition (wt%) (continued).

	Glass (kg)	433.46	462.21	491.94	517.40	544.41	573.59	606.55	631.89
	Target	SBL-G-117A	SBL-G-117C	SBL-G-119B	SBL-G-119D	SBL-G-122B	SBL-G-124B	SBL-G-127A	SBL-G-129A
Al_2O_3	5.98	6.29	6.35	6.33	6.21	6.28	6.40	6.23	6.27
B_2O_3#	12.00	12.26	12.22	12.19	12.16	12.14	12.12	12.10	12.09
BaO	0.06	0.06	0.06	0.06	0.05	0.07	0.05	0.04	0.04
Bi_2O_3	&	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01
CaO	0.65	0.66	0.65	0.64	0.66	0.67	0.65	0.62	0.65
Ce_2O_3	&	0.03	0.03	< 0.01	0.02	0.02	0.02	< 0.01	< 0.01
Cl	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02
Cr_2O_3	0.09	0.12	0.11	0.11	0.09	0.10	0.09	0.10	0.10
Fe_2O_3	16.56	16.08	15.91	16.03	15.94	16.15	16.32	16.46	16.18
K_2O	&	0.04	0.04	0.06	0.04	0.04	0.04	0.04	0.05
Li_2O#	3.00	2.87	2.89	2.91	2.92	2.93	2.94	2.95	2.96
MgO	0.18	0.32	0.34	0.34	0.33	0.34	0.34	0.36	0.35
MnO	2.09	1.95	1.99	1.90	1.91	1.88	1.88	1.91	1.84
Na_2O	14.78	13.54	13.51	13.74	13.63	13.86	13.56	13.67	13.83
NiO	0.96	0.83	0.81	0.82	0.74	0.77	0.78	0.84	0.80
P_2O_5	0.17	0.21	0.22	0.20	0.19	0.19	0.18	0.19	0.18
PbO	0.02	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.03
SO_3	0.05	0.10	0.09	0.10	0.12	0.12	0.14	0.12	0.13
SiO_2	43.36	44.19	44.39	44.20	44.64	44.11	44.18	44.07	44.27
SrO	0.03	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03
TiO_2	&	0.11	0.10	0.10	0.10	0.11	0.11	0.11	0.11
ZnO	&	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
ZrO_2	0.01	0.16	0.14	0.12	0.11	0.09	0.08	0.07	0.06
Total	99.99	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SBL-D-70A) and target composition using a simple well-stirred tank model.

Table 4.8. XRF Analyzed Composition for Glass Discharged from DM100 Test 3 with Blend 3 Waste and A104D4-11 Glass Composition (wt%).

	Glass (kg)	433.46	462.21	491.94	517.40	544.41	573.59	606.55	631.89
	Target	SBL-G-117A	SBL-G-117C	SBL-G-119B	SBL-G-119D	SBL-G-122B	SBL-G-124B	SBL-G-127A	SBL-G-129A
Al_2O_3	5.98	6.29	6.35	6.33	6.21	6.28	6.40	6.23	6.27
B_2O_3#	12.00	12.26	12.22	12.19	12.16	12.14	12.12	12.10	12.09
BaO	0.06	0.06	0.06	0.06	0.05	0.07	0.05	0.04	0.04
Bi_2O_3	&	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01
CaO	0.65	0.66	0.65	0.64	0.66	0.67	0.65	0.62	0.65
Ce_2O_3	&	0.03	0.03	< 0.01	0.02	0.02	0.02	< 0.01	< 0.01
Cl	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02
Cr_2O_3	0.09	0.12	0.11	0.11	0.09	0.10	0.09	0.10	0.10
Fe_2O_3	16.56	16.08	15.91	16.03	15.94	16.15	16.32	16.46	16.18
K_2O	&	0.04	0.04	0.06	0.04	0.04	0.04	0.04	0.05
Li_2O#	3.00	2.87	2.89	2.91	2.92	2.93	2.94	2.95	2.96
MgO	0.18	0.32	0.34	0.34	0.33	0.34	0.34	0.36	0.35
MnO	2.09	1.95	1.99	1.90	1.91	1.88	1.88	1.91	1.84
Na_2O	14.78	13.54	13.51	13.74	13.63	13.86	13.56	13.67	13.83
NiO	0.96	0.83	0.81	0.82	0.74	0.77	0.78	0.84	0.80
P_2O_5	0.17	0.21	0.22	0.20	0.19	0.19	0.18	0.19	0.18
PbO	0.02	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.03
SO_3	0.05	0.10	0.09	0.10	0.12	0.12	0.14	0.12	0.13
SiO_2	43.36	44.19	44.39	44.20	44.64	44.11	44.18	44.07	44.27
SrO	0.03	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03
TiO_2	&	0.11	0.10	0.10	0.10	0.11	0.11	0.11	0.11
ZnO	&	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
ZrO_2	0.01	0.16	0.14	0.12	0.11	0.09	0.08	0.07	0.06
Total	99.99	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SBL-D-70A) and target composition using a simple well-stirred tank model.

Table 4.8. XRF Analyzed Composition for Glass Discharged from DM100 Test 3 with Blend 3 Waste and A104D4-11 Glass Composition (wt%) (continued).

	Glass (kg)	661.69	689.65	721.00	756.55	773.40	802.10	825.35
	Target	SBL-G-129C	SBL-G-129E	SBL-G-134B	SBL-G-138A	SBL-G-138C	SBL-G-139B	SBL-G-141A
Al_2O_3	5.98	6.34	6.33	6.35	6.35	6.34	6.38	6.16
B_2O_3#	12.00	12.07	12.06	12.05	12.04	12.04	12.03	12.03
BaO	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.06
CaO	0.65	0.67	0.66	0.64	0.65	0.65	0.63	0.62
Ce_2O_3	&	0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02
Cl	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.02
Cr_2O_3	0.09	0.09	0.11	0.08	0.09	0.09	0.09	0.11
Fe_2O_3	16.56	16.08	15.93	16.27	16.34	16.54	16.22	16.80
K_2O	&	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Li_2O#	3.00	2.96	2.97	2.97	2.98	2.98	2.98	2.99
MgO	0.18	0.36	0.35	0.33	0.35	0.36	0.38	0.39
MnO	2.09	1.85	1.90	1.89	1.82	1.88	1.84	1.89
Na_2O	14.78	13.82	13.97	13.59	13.67	13.73	14.01	13.68
NiO	0.96	0.73	0.71	0.67	0.73	0.82	0.77	0.89
P_2O_5	0.17	0.17	0.18	0.16	0.16	0.18	0.16	0.17
PbO	0.02	0.03	0.03	0.03	0.02	0.03	0.03	0.02
SO_3	0.05	0.13	0.14	0.14	0.14	0.14	0.13	0.14
SiO_2	43.36	44.36	44.35	44.52	44.37	43.93	44.06	43.81
SrO	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03
TiO_2	&	0.10	0.10	0.11	0.10	0.10	0.09	0.10
ZnO	&	0.02	0.02	0.02	0.01	0.01	0.02	0.02
ZrO_2	0.01	0.05	0.06	0.04	0.04	0.04	0.03	0.04
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SBL-D-70A) and target composition using a simple well-stirred tank model.

Table 4.9. XRF Analyzed Composition for Glass Discharged from DM100 Test 2 with Blend 2 Waste and A104D4-11 Glass Composition (wt%).

	Glass (kg)	847.23	865.83	898.75	927.40	952.15	975.35	997.27	1018.95	1043.22
	Target	SBL-G-141C	SBL-G-144B	SBL-G-144D	SBL-G-147B	SBL-G-147D	SBL-G-151B	SBL-G-151D	TBL-G-10A	TBL-G-23A
Al_2O_3	5.97	6.38	6.31	6.17	6.31	6.32	6.36	6.26	6.25	6.31
B_2O_3#	12.00	12.03	12.02	12.02	12.02	12.01	12.01	12.01	12.01	12.01
BaO	0.06	0.05	0.05	0.05	0.07	0.05	0.04	0.06	0.05	0.05
CaO	0.72	0.67	0.67	0.69	0.70	0.69	0.74	0.63	0.73	0.68
Ce_2O_3	&	0.02	0.02	< 0.01	< 0.01	0.02	0.02	0.02	0.02	< 0.01
Cl	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Cr_2O_3	0.10	0.11	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Fe_2O_3	16.55	16.27	16.38	17.07	17.09	16.37	16.44	16.64	16.43	16.10
K_2O	0.01	0.05	0.05	0.04	0.05	0.04	0.04	0.05	0.05	0.04
Li_2O#	3.00	2.99	2.99	2.99	2.99	2.99	2.99	2.99	3.00	3.00
MgO	0.18	0.35	0.37	0.34	0.36	0.37	0.32	0.37	0.39	0.38
MnO	2.09	1.86	1.83	1.89	1.87	1.87	1.85	1.84	1.91	1.80
Na_2O	14.75	13.52	13.75	13.47	13.54	13.55	13.90	13.61	13.92	13.77
NiO	0.96	0.81	0.80	0.89	0.87	0.75	0.75	0.79	0.79	0.77
P_2O_5	0.17	0.16	0.18	0.16	0.18	0.16	0.16	0.17	0.16	0.18
PbO	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
SO_3	0.16	0.14	0.15	0.18	0.17	0.19	0.20	0.19	0.21	0.20
SiO_2	43.20	44.36	44.10	43.74	43.49	44.34	43.89	44.08	43.79	44.39
SrO	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.03
TiO_2	&	0.10	0.10	0.09	0.10	0.10	0.10	0.11	0.11	0.10
ZnO	&	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.02
ZrO_2	0.01	0.05	0.05	0.03	0.03	0.03	0.02	0.02	0.03	0.04
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SBL-D-70A) and target composition using a simple well-stirred tank model.

Table 4.9. XRF Analyzed Composition for Glass Discharged Corresponding from DM100 Test 2 with Blend 2 Waste and A104D4-11 Glass Composition (wt%) (continued).

	Glass (kg)	1065.04	1087.56	1114.52	1138.37	1158.63	1185.40	1211.51	1235.16	1247.41
	Target	TBL-G-23C	TBL-G-25B	TBL-G-28A	TBL-G-29A	TBL-G-29C	TBL-G-31A	TBL-G-31C	TBL-G-31E	TBL-G-35A
Al_2O_3	5.97	6.34	6.34	6.44	6.30	6.35	6.23	6.38	6.49	6.38
B_2O_3#	12.00	12.01	12.01	12.01	12.01	12.00	12.00	12.00	12.00	12.00
BaO	0.06	0.06	0.07	0.06	0.05	0.07	0.08	0.07	0.06	0.06
Bi_2O_3	&	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	0.01
CaO	0.72	0.72	0.66	0.66	0.70	0.65	0.70	0.69	0.70	0.67
Ce_2O_3	&	< 0.01	< 0.01	0.02	0.01	< 0.01	< 0.01	0.02	< 0.01	< 0.01
Cl	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Cr_2O_3	0.10	0.08	0.09	0.11	0.09	0.12	0.09	0.10	0.10	0.10
Fe_2O_3	16.55	16.84	16.55	16.12	16.70	16.54	16.94	16.37	16.25	16.45
K_2O	0.01	0.05	0.04	0.05	0.04	0.05	0.04	0.04	0.04	0.05
Li_2O#	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
MgO	0.18	0.35	0.36	0.39	0.37	0.37	0.36	0.39	0.35	0.37
MnO	2.09	1.87	1.79	1.80	1.86	1.81	1.88	1.85	1.81	1.80
Na_2O	14.75	13.25	13.80	13.85	13.67	13.55	13.49	14.19	13.67	13.85
NiO	0.96	0.80	0.79	0.71	0.81	0.83	0.90	0.69	0.65	0.75
P_2O_5	0.17	0.17	0.16	0.15	0.16	0.16	0.16	0.15	0.15	0.16
PbO	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
SO_3	0.16	0.20	0.19	0.19	0.20	0.20	0.21	0.22	0.20	0.20
SiO_2	43.20	44.03	43.97	44.22	43.80	44.09	43.72	43.65	44.35	43.96
SrO	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
TiO_2	&	0.10	0.10	0.11	0.11	0.11	0.10	0.09	0.10	0.11
ZnO	&	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01
ZrO_2	0.01	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SBL-D-70A) and target composition using a simple well-stirred tank model.

Table 4.10. XRF Analyzed Composition for Glass Discharged from DM100 Test 1 with Blend 1 Waste and A104D1-04 Glass Composition (wt%).

	Glass (kg)	1277.43	1299.45	1325.93	1346.85	1369.11	1397.49	1420.39	1440.93
	Target	TBL-G-55B	TBL-G-55D	TBL-G-59B	TBL-G-59D	TBL-G-60B	TBL-G-60D	TBL-G-64B	TBL-G-65A
Al_2O_3	5.97	6.40	6.50	6.33	6.37	6.38	6.34	6.41	6.48
B_2O_3#	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
BaO	0.06	0.04	0.05	0.08	0.07	0.06	0.07	0.07	0.08
CaO	0.95	0.72	0.73	0.75	0.79	0.79	0.80	0.81	0.84
Cl	0.05	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.03
Cr_2O_3	0.10	0.09	0.11	0.07	0.08	0.08	0.09	0.08	0.09
Fe_2O_3	16.55	16.67	16.20	16.21	16.35	16.42	16.38	16.29	16.17
K_2O	0.03	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.06
Li_2O#	&	2.54	2.25	1.94	1.73	1.53	1.30	1.15	1.02
MgO	0.18	0.39	0.36	0.38	0.40	0.34	0.35	0.40	0.41
MnO	2.09	1.84	1.79	1.81	1.80	1.83	1.82	1.82	1.80
Na_2O	16.62	13.68	14.36	14.46	14.36	14.80	14.86	14.89	15.00
NiO	0.96	0.85	0.74	0.75	0.74	0.76	0.74	0.72	0.73
P_2O_5	0.17	0.18	0.16	0.18	0.17	0.16	0.17	0.16	0.16
PbO	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
SO_3	0.48	0.24	0.26	0.29	0.29	0.30	0.33	0.33	0.37
SiO_2	43.74	44.08	44.19	44.50	44.57	44.30	44.47	44.60	44.58
SrO	0.03	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02
TiO_2	&	0.10	0.11	0.10	0.10	0.09	0.11	0.10	0.10
ZnO	&	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.01
ZrO_2	0.01	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SBL-D-70A) and target composition using a simple well-stirred tank model.

Table 4.10. XRF Analyzed Composition for Glass Discharged from DM100 Test 1 with Blend 1 Waste and A104D1-04 Glass Composition (wt%) (continued).

	Glass (kg)	1465.15	1482.33	1505.79	1531.97	1554.97	1580.27	1601.19	1620.59
	Target	TBL-G-70A	TBL-G-72A	TBL-G-72C	TBL-G-76A	TBL-G-77B	TBL-G-79A	TBL-G-79C	TBL-G-82B
Al_2O_3	5.97	6.38	6.36	6.42	6.35	6.35	6.31	6.36	6.37
B_2O_3#	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
BaO	0.06	0.08	0.08	0.06	0.04	0.07	0.07	0.06	0.06
CaO	0.95	0.84	0.85	0.89	0.85	0.86	0.86	0.85	0.88
Cl	0.05	0.04	0.03	0.04	0.05	0.03	0.03	0.04	0.04
Cr_2O_3	0.10	0.08	0.09	0.09	0.07	0.09	0.09	0.09	0.11
Fe_2O_3	16.55	16.61	16.57	16.53	16.56	16.30	16.24	16.35	16.59
K_2O	0.03	0.04	0.07	0.06	0.06	0.06	0.06	0.05	0.06
Li_2O#	&	0.89	0.81	0.71	0.62	0.54	0.47	0.42	0.38
MgO	0.18	0.39	0.38	0.36	0.37	0.38	0.37	0.37	0.35
MnO	2.09	1.81	1.87	1.84	1.83	1.83	1.81	1.84	1.87
Na_2O	16.62	14.62	14.72	14.93	15.20	15.05	15.38	15.04	15.06
NiO	0.96	0.78	0.80	0.79	0.81	0.73	0.70	0.71	0.80
P_2O_5	0.17	0.16	0.15	0.15	0.16	0.15	0.16	0.16	0.16
PbO	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
SO_3	0.48	0.35	0.37	0.40	0.38	0.39	0.41	0.40	0.39
SiO_2	43.74	44.77	44.69	44.57	44.47	44.98	44.87	45.07	44.69
SrO	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
TiO_2	&	0.09	0.09	0.09	0.11	0.11	0.10	0.11	0.10
ZnO	&	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
ZrO_2	0.01	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.04
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SBL-D-70A) and target composition using a simple well-stirred tank model.

Table 4.10. XRF Analyzed Composition for Glass Discharged from DM100 Test 1 with Blend 1 Waste and A104D1-04 Glass Composition (wt%) (continued).

	Glass (kg)	1641.53	1671.87	1695.05	1713.69	1736.17	1758.39	1781.33	1797.11
	Target	TBL-G-84A	TBL-G-87A	TBL-G-87C	TBL-G-91A	TBL-G-95A	TBL-G-95C	TBL-G-96A	TBL-G-97A
Al_2O_3	5.97	6.33	6.47	6.39	6.28	6.37	6.28	6.34	6.22
B_2O_3#	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
BaO	0.06	0.06	0.04	0.06	0.06	0.07	0.05	0.05	0.06
CaO	0.95	0.86	0.88	0.91	0.87	0.89	0.89	0.88	0.87
Ce_2O_3	&	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02
Cl	0.05	0.04	0.03	0.03	0.03	0.04	0.04	0.04	0.03
Cr_2O_3	0.10	0.09	0.07	0.09	0.09	0.08	0.09	0.08	0.09
Fe_2O_3	16.55	16.43	16.45	16.67	16.35	16.14	16.14	16.38	16.95
K_2O	0.03	0.05	0.06	0.06	0.05	0.07	0.05	0.05	0.05
Li_2O#	&	0.34	0.28	0.25	0.22	0.20	0.18	0.15	0.14
MgO	0.18	0.37	0.38	0.37	0.36	0.38	0.37	0.37	0.37
MnO	2.09	1.79	1.80	1.82	1.83	1.77	1.81	1.81	1.88
Na_2O	16.62	15.23	15.53	15.12	15.41	15.22	15.34	15.51	15.59
NiO	0.96	0.78	0.75	0.77	0.74	0.77	0.80	0.72	0.83
P_2O_5	0.17	0.16	0.15	0.15	0.16	0.15	0.17	0.17	0.16
PbO	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
SO_3	0.48	0.39	0.39	0.40	0.38	0.40	0.39	0.41	0.36
SiO_2	43.74	44.90	44.54	44.72	44.94	45.30	45.23	44.86	44.18
SrO	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
TiO_2	&	0.09	0.10	0.11	0.10	0.09	0.09	0.10	0.10
ZnO	&	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02
ZrO_2	0.01	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.03
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SBL-D-70A) and target composition using a simple well-stirred tank model.

Table 4.11. XRF Analyzed Composition for Dip Samples Taken During DM100 Melter Tests (wt%).

	A104D4-11			A104D4-11 with Blend 3 Waste			A104D4-11 with Blend 2 Waste		A104D1-04		
	Before		After	Before		After		After	Before		After
	SBL-D-70A	Target	SBL-D-95A	SBL-D-101A	Target	SBL-D-141A	Target	TBL-D-35A	TBL-D-42A	Target	TBL-D-96A
Al_2O_3	5.73	**5.97**	6.21	6.33	**5.98**	6.23	**5.97**	6.33	6.36	**5.97**	6.26
B_2O_3#	14.89	**12.00**	11.76	12.01	**12.00**	12.02	**12.00**	11.91	11.87	**12.00**	12.10
BaO	0.08	**0.06**	0.04	0.05	**0.06**	0.06	**0.06**	0.07	0.05	**0.06**	0.06
Bi_2O_3	0.01	**&**	< 0.01	< 0.01	**&**	< 0.01	**&**	< 0.01	0.01	**&**	< 0.01
CaO	0.56	**0.61**	0.68	0.66	**0.65**	0.65	**0.72**	0.68	0.69	**0.95**	0.83
Ce_2O_3	0.17	**&**	< 0.01	0.02	**&**	< 0.01	**&**	< 0.01	< 0.01	**&**	0.02
Cl	0.01	**&**	0.02	0.01	**0.01**	0.02	**0.02**	0.02	0.02	**0.05**	0.04
Cr_2O_3	0.22	**0.09**	0.12	0.10	**0.09**	0.10	**0.10**	0.10	0.16	**0.10**	0.09
Fe_2O_3	14.19	**16.55**	16.33	15.91	**16.56**	16.71	**16.55**	16.70	17.01	**16.55**	17.11
K_2O	0.05	**&**	0.04	0.04	**&**	0.03	**0.01**	0.05	0.05	**0.03**	0.06
La_2O_3	0.08	**&**	< 0.01	< 0.01	**&**	< 0.01	**&**	< 0.01	< 0.01	**&**	< 0.01
Li_2O#	1.61	**3.00**	2.98	3.03	**3.00**	3.01	**3.00**	3.05	3.09	**0.00**	0.22
MgO	0.28	**0.18**	0.32	0.34	**0.18**	0.35	**0.18**	0.38	0.37	**0.18**	0.37
MnO	2.73	**2.09**	2.08	2.01	**2.09**	1.80	**2.09**	1.84	1.88	**2.09**	1.81
Na_2O	15.48	**14.76**	13.68	13.85	**14.78**	13.70	**14.75**	13.50	13.45	**16.62**	15.73
NiO	0.37	**0.96**	0.97	0.79	**0.96**	0.91	**0.96**	0.92	0.90	**0.96**	0.89
P_2O_5	0.68	**0.17**	0.21	0.22	**0.17**	0.17	**0.17**	0.15	0.16	**0.17**	0.15
PbO	0.52	**0.02**	0.08	0.08	**0.02**	0.03	**0.02**	0.02	0.02	**0.02**	0.02
SO_3	0.04	**&**	0.09	0.08	**0.05**	0.14	**0.16**	0.22	0.22	**0.48**	0.39
SiO_2	40.55	**43.50**	44.00	44.12	**43.36**	43.91	**43.20**	43.93	43.48	**43.74**	43.71
SnO_2	0.07	**&**	0.02	< 0.01	**&**	< 0.01	**&**	< 0.01	< 0.01	**&**	< 0.01
SrO	0.19	**0.03**	0.04	0.05	**0.03**	0.03	**0.03**	0.03	0.03	**0.03**	0.02
TiO_2	0.14	**&**	0.11	0.11	**&**	0.09	**&**	0.08	0.10	**&**	0.10
ZnO	0.12	**&**	0.04	0.03	**&**	0.02	**&**	0.02	0.03	**&**	0.01
ZrO_2	1.19	**0.01**	0.19	0.17	**0.01**	0.03	**0.01**	0.03	0.05	**0.01**	0.02
Total	100.00	**100.00**	100.00	100.00	**100.00**	100.00	**100.00**	100.00	100.00	**100.00**	100.00

& Not a target constituent.
# Measured by DCP-AES

Table 4.12. Comparison of Test Average XRF Analysis of Discharged Glass to the Target Compositions.

	A104D4-11			A104D4-11 with Blend 3 Waste			A104D4-11 with Blend 2 Waste			A104D1-04		
	Target	Avg.	% Dev.	Target	Avg.	% Dev.	Target	Avg.	% Dev.	Target	Avg.	% Dev.
Al_2O_3	**5.97**	6.14	2.82	**5.98**	6.31	5.55	**5.97**	6.33	5.96	**5.97**	6.37	6.63
B_2O_3[#]	**12.00**	13.06	NC	**12.00**	12.11	NC	**12.00**	12.01	NC	**12.00**	12.00	NC
BaO	**0.06**	0.06	NC	**0.06**	0.05	NC	**0.06**	0.06	NC	**0.06**	0.06	NC
Bi_2O_3	**&**	0.01	NC	**&**	< 0.01	NC	**&**	< 0.01	NC	**&**	< 0.01	NC
CaO	**0.61**	0.62	NC	**0.65**	0.65	NC	**0.72**	0.69	NC	**0.95**	0.84	NC
Ce_2O_3	**&**	0.05	NC	**&**	0.01	NC	**&**	0.01	NC	**&**	< 0.01	NC
Cl	**&**	0.01	NC	**0.01**	0.02	NC	**0.02**	0.02	NC	**0.05**	0.03	NC
Cr_2O_3	**0.09**	0.16	NC	**0.09**	0.10	NC	**0.10**	0.09	NC	**0.10**	0.09	NC
Fe_2O_3	**16.55**	15.36	-7.18	**16.56**	16.22	-2.10	**16.55**	16.53	-0.14	**16.55**	16.41	-0.82
K_2O	**&**	0.05	NC	**&**	0.04	NC	**0.01**	0.05	NC	**0.03**	0.06	NC
La_2O_3	**&**	0.02	NC	**&**	< 0.01	NC	**0.00**	< 0.01	NC	**0.00**	< 0.01	NC
Li_2O[#]	**3.00**	2.49	NC	**3.00**	2.95	NC	**3.00**	2.99	NC	**&**	0.84	NC
MgO	**0.18**	0.32	NC	**0.18**	0.35	NC	**0.18**	0.36	NC	**0.18**	0.37	NC
MnO	**2.09**	2.26	8.22	**2.09**	1.89	-9.77	**2.09**	1.84	-11.90	**2.09**	1.82	-12.93
Na_2O	**14.76**	14.02	-5.03	**14.78**	13.72	-7.15	**14.75**	13.69	-7.21	**16.62**	14.97	-9.92
NiO	**0.96**	0.75	NC	**0.96**	0.78	NC	**0.96**	0.79	NC	**0.96**	0.76	NC
P_2O_5	**0.17**	0.36	NC	**0.17**	0.18	NC	**0.17**	0.16	NC	**0.17**	0.16	NC
PbO	**0.02**	0.22	NC	**0.02**	0.04	NC	**0.02**	0.02	NC	**0.02**	0.02	NC
SO_3	**&**	0.07	NC	**0.05**	0.13	NC	**0.16**	0.19	NC	**0.48**	0.36	NC
SiO_2	**43.50**	43.18	-0.72	**43.36**	44.23	2.01	**43.20**	44.00	1.84	**43.74**	44.67	2.14
SnO_2	**&**	0.02	NC	**&**	< 0.01	NC	**&**	< 0.01	NC	**&**	< 0.01	NC
SrO	**0.03**	0.10	NC	**0.03**	0.03	NC	**0.03**	0.03	NC	**0.03**	0.02	NC
TiO_2	**&**	0.12	NC	**&**	0.10	NC	**&**	0.10	NC	**&**	0.10	NC
ZnO	**&**	0.06	NC	**&**	0.02	NC	**&**	0.01	NC	**&**	0.01	NC
ZrO_2	**0.01**	0.50	NC	**0.01**	0.08	NC	**0.01**	0.03	NC	**0.01**	0.03	NC
Total	**100.00**	100.00		**100.00**	100.00		**100.00**	100.00		**100.00**	100.00	

NC Not calculated

Table 4.13. Results from PCT (ASTM C1285, 7-days at 90ºC, Stainless Steel Vessel; S/V=2000 m^{-1}).

		A104D4-11		A104D4-11 with Blend 3 Waste	DWPF-EA
Glass Samples		Melter Glass SBL-G-95A	Crucible Glass	Melter Glass SBL-G-141A	
PCT Concentration, mg/L	B	27.39		29.76	
	Li	9.85		11.44	
	Na	62.78		70.97	
	Si	70.36		76.66	
PCT Normalized Concentrations, g/L	B	0.74	0.81	0.80	17.68
	Li	0.71	0.80	0.82	9.98
	Na	0.57	0.80	0.70	13.69
	Si	0.35	0.38	0.37	3.72
	pH	10.16	10.34	10.21	11.85
PCT Normalized Mass Loss, g/m^2	B	0.37		0.40	
	Li	0.35		0.41	
	Na	0.29		0.35	
	Si	0.17		0.19	

Table 4.13. Results from PCT (ASTM C1285, 7-days at 90ºC, Stainless Steel Vessel; S/V=2000 m^{-1}) (continued).

		A104D4-11 with Blend 2 Waste	A104D1-04		DWPF-EA
Glass Samples		Melter Glass TBL-G-35A	Melter Glass TBL-G-97A	Crucible Glass	
PCT Concentration, mg/L	B	30.52	20.36		
	Li	12.02	BDL		
	Na	74.43	64.39		
	Si	75.82	56.41		
PCT Normalized Concentrations, g/L	B	0.82	0.55	0.72	17.68
	Li	0.86	NC	NC	9.98
	Na	0.72	0.56	0.70	13.69
	Si	0.37	0.27	0.31	3.72
	pH	10.31	9.81	9.92	11.85
PCT Normalized Mass Loss, g/m^2	B	0.41	0.27		
	Li	0.43	NC		
	Na	0.36	0.28		
	Si	0.18	0.14		

BDL – Below Detection Limits
NC – Not calculated

Table 4.14. TCLP Results for Discharged Glass Samples (mg/L).

Glass Formulation	Element	Ba	Cr	Ni	Pb
	UTS Limits[#]	21	0.60	11.00	0.75
	Delisting Limits [43, 44]	100	4.95	22.6	5.00
A104D4-11	SBL-G-95A	0.35	< 0.1	0.10	< 0.1
	Crucible Glass	0.28	< 0.1	0.15	< 0.1
A104D4-11 with Blend 3 Waste	SBL-G-141A	0.29	< 0.1	0.08	< 0.1
A104D4-11 with Blend 2 Waste	TBL-G-35A	0.33	< 0.1	< 0.04	< 0.1
A104D1-04	TBL-G-97A	0.27	< 0.1	0.04	< 0.1
	Crucible Glass	0.20	< 0.1	0.13	< 0.1

For comparison only; does not apply to WTP glasses
NM – Not Measured

Table 4.15. Results of XRD and SEM Analysis of Melter Glasses.

Target Glass Composition	Sample	SEM	
		Crystal Content	Crystal Morphology
	Dip Sample (SBL-D-70A) prior to testing	<0.1% volume percent Fe spinels	Fe-spinel is euhedral, granular, mostly 0.2-1 micron size, slightly clustered, and is heterogeneously distributed in the sample
A104D4-11	Dip Sample (SBL-D-95A) from end of Test 4 (411 kg glass discharged)	<0.1% volume percent Fe spinels with Ni Cr-Mn	Fe-spinel, probably chemically trevorite, is euhedral, granular, mostly 0.1-1 micron size, slightly clustered, and is heterogeneously distributed in the sample
A104D4-11 with Blend 3 Waste	Dip Sample (SBL-D-141A) from end of Test 3 (415 kg glass discharged)	<0.1% volume percent Fe spinels with Ni Cr and Mn	Fe-spinel, chemically trevorite, is euhedral, granular, mostly 0.1-1 up to 10 micron size, slightly clustered, and is heterogeneously distributed in the sample.
A104D4-11 with Blend 2 Waste	Dip Sample (TBL-D-35A) from end of Test 2 (422 kg glass discharged)	0.1% volume percent Fe spinels with Ni Cr-Mn	Fe-spinel, probably chemically trevorite, is sub-euhedral, granular to acicular; mostly 0.5-1.5 micron size up to 15 micron long, slightly clustered, and is heterogeneously distributed in the sample.
A104D1-04	Dip Sample (TBL-D-96A) from end of Test 1 (550 kg glass discharged)	0.4% volume percent Fe spinels with Cr and Mn	Fe-spinel is chemically trevorite, sub-euhedral, granular, mainly 5-10 micron size with a minor 20-60 micron phenocryst and trace amount of 1-2 micron crystals, slightly clustered, and is heterogeneously distributed in the sample.

Table 5.1. Results from DM100 Off-Gas Emission Samples.

		Test 4, A104D4-11 01/06/2015 19:15 – 20:15 19.4% Moisture, 110% Isokinetic				Test 3, A104D4-11 with Blend 3 Waste 01/13/2015 16:25 – 17:25 16.9% Moisture, 107% Isokinetic			
		Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF	Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total[$]	159977	674	0.42	237	144270	599	0.42	241
	A	4480	18.7	0.42	239	3599	20.1	0.56	179
	B	5283	61.9	1.17	85.4	4237	52.2	1.23	81.2
	Ba	76.2	0.20	0.27	375	61.1	0.21	0.34	292
	Cl*	0.00	4.54	NC	NC	11.4	6.54	57.5	1.74
	Ca	619	2.02	0.33	306	529	2.44	0.46	216
	Cr	87.4	1.42	1.63	61.3	70.1	0.71	1.02	98.2
	Fe	16418	66.6	0.41	246	13173	74.9	0.57	176
	Li	1977	7.68	0.39	257	1585	6.53	0.41	243
	Mg	154	1.29	0.84	119	123	1.41	1.14	87.8
	Mn	2296	7.83	0.34	293	1841	8.42	0.46	219
	Na	15536	95.7	0.62	162	12475	81.1	0.65	154
	Ni	1070	3.15	0.29	340	858	3.36	0.39	255
	P	105	0.34	0.33	307	84.4	0.43	0.50	199
	Pb	26.3	1.01	3.85	26.0	21.1	0.29	1.37	73.0
	S*	0.00	1.77	NC	NC	22.8	2.67	11.7	8.53
	Si	28848	55.9	0.19	516	23058	51.5	0.22	447
	Sr	36.0	< 0.10	< 0.28	> 360	28.9	0.11	0.38	263
	Zr	10.5	< 0.10	< 0.95	> 105	8.42	< 0.10	< 1.19	> 84
Gas	B	5283	40.9	0.77	129	4237	31.7	0.75	134
	Cl	0.00	<0.10	NC	NC	11.4	<0.10	<0.88	>114
	S	0.00	18.9	NC	NC	22.8	18.7	81.9	1.22

[$] - From gravimetric analysis of filters and particulate nitric acid rinses
[#] - Feed rate calculated from target composition and total glass production rate
* - Calculated from analysis of filter particulate by water dissolution and direct analysis of particulate rinse
NC – Not Calculated

Table 5.1. Results from DM100 Off-Gas Emission Samples (continued).

		Test 2, A104D4-11 with Blend 2 Waste 01/15/2015 17:16 – 18:16 16.2% Moisture, 104% Isokinetic				Test 1, A104D1-04 01/27/2015 16:55 – 17:55 12.3% Moisture, 105% Isokinetic			
		Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF	Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total[$]	153615	869	0.57	177	104880	204	0.19	514
	Al	3864	32.0	0.83	121	2768	5.78	0.21	479
	B	4557	58.4	1.28	78.1	3264	10.8	0.33	302
	Ba	65.8	0.36	0.54	184	47.1	< 0.10	< 0.21	> 471
	Cl*	24.5	15.5	63.5	1.57	43.8	19.5	44.6	2.24
	Ca	630	4.36	0.69	144	595	1.38	0.23	431
	Cr	83.7	0.52	0.62	161	60.0	0.20	0.34	297
	Fe	14160	114	0.81	124	10144	22.9	0.23	442
	K	10.2	0.48	4.76	21.0	21.8	0.24	1.11	90.0
	Li	1705	7.62	0.45	224	0.0	0.37	NC	NC
	Mg	133	2.35	1.77	56.5	95.1	0.35	0.37	273
	Mn	1981	13.5	0.68	146	1419	2.04	0.14	696
	Na	13391	102	0.76	132	10809	31.1	0.29	347
	Ni	923	6.15	0.67	150	661	0.57	0.09	1158
	P	90.8	0.48	0.53	190	65.1	0.31	0.48	210
	Pb	22.7	0.25	1.12	89.4	16.3	< 0.10	< 0.61	> 163
	S*	78.5	5.73	7.31	13.7	169	4.73	2.80	35.7
	Si	24710	82.1	0.33	301	17922	17.1	0.10	1045
	Sr	31.0	0.20	0.64	157	22.2	< 0.10	< 0.45	> 222
	Zr	9.06	< 0.10	< 1.10	> 91	6.49	< 0.10	< 1.54	> 65
Gas	B	4557	26.8	0.59	170	3264	15.1	0.46	216
	Cl	24.5	<0.10	<0.41	>245	43.8	<0.10	<0.23	>438
	S	78.5	26.9	34.3	2.91	169	24.4	14.5	6.92

[$] - From gravimetric analysis of filters and particulate nitric acid rinses
[#] - Feed rate calculated from target composition and total glass production rate
* - Calculated from analysis of filter particulate by water dissolution and direct analysis of particulate rinse
NC-Not Calculated

Table 5.2. Concentrations (ppmv) of Selected Species in DM100 Exhaust Measured by FTIR Spectroscopy.

Test	4 (A104D4-11)		3 (A104D4-11 with Blend 3 Waste)			
	Fixed Bubbling (9 lpm)		Fixed Bubbling (9 lpm)		Optimized Bubbling	
	Avg.	Range	Avg.	Range	Avg.	Range
H_2O (%)	10.1	1.7 - 15.9	8.8	4.3 - 15.8	10.7	7.9 - 14.9
CO	6.5	< 1.0 - 15.5	5.8	< 1.0 - 14.2	7.6	1.1 - 14.4
CO_2	3596	375 - 7053	3001	730 - 11834	3760	1810 - 9363
HCN	< 1.0	NA	< 1.0	NA	< 1.0	NA
HF	1.5	< 1.0 - 2.2	1.4	< 1.0 - 2.6	1.8	1.2 - 2.8
HCl	< 1.0	NA	< 1.0	NA	< 1.0	NA
NH_3	1.8	< 1.0 - 3.6	1.4	< 1.0 - 2.7	1.4	< 1.0 - 2.2
HNO_3	< 1.0	< 1.0 - 1.0	< 1.0	NA	< 1.0	NA
NO	3.7	< 1.0 - 16.0	14.8	2.0 - 61.1	20.4	3.9 - 45.8
NO_2	< 1.0	< 1.0 - 3.5	1.1	< 1.0 - 6.0	< 1.0	< 1.0 - 1.2
HNO_2	< 1.0	< 1.0 - 2.1	< 1.0	NA	< 1.0	NA
N_2O	< 1.0	NA	1.5	< 1.0 - 7.4	1.7	< 1.0 - 3.9

Table 5.2. Concentrations (ppmv) of Selected Species in DM100 Exhaust Measured by FTIR Spectroscopy (continued).

Test	2 (A104D4-11 with Blend 2 Waste)				1 (A104D1-04)			
	Fixed Bubbling (9 lpm)		Fixed Bubbling (9 lpm)		Fixed Bubbling (9 lpm)		Optimized Bubbling	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
H_2O (%)	9.0	< 1.0 - 15.1	8.8	5.3 - 15.8	6.2	1.3 - 17.3	6.9	< 1.0 - 16.2
CO	5.8	< 1.0 - 14.4	5.7	< 1.0 - 14.5	5.6	< 1.0 - 28.7	6.7	1.0 - 24.2
CO_2	2805	494 - 8953	2786	1381 – 8950	842	583 - 3047	903	437 - 2949
HCN	< 1.0	NA	< 1.0	NA	< 1.0	< 1.0 - 1.4	< 1.0	NA
HF	1.4	< 1.0 - 2.6	1.3	< 1.0 - 2.8	< 1.0	< 1.0 - 1.7	1.1	< 1.0 - 3.0
HCl	< 1.0	NA	< 1.0	NA	< 1.0	NA	< 1.0	NA
NH_3	1.5	< 1.0 - 2.8	2.5	< 1.0 - 28.0	28.3	< 1.0 - 197	21.6	3.6 - 104
HNO_3	< 1.0	NA	< 1.0	NA	< 1.0	NA	< 1.0	NA
NO	37.8	< 1.0 - 121	34.4	6.0 - 113	95.7	13.7 - 551	110	24.3 - 393
NO_2	< 1.0	< 1.0 - 3.2	< 1.0	< 1.0 - 3.9	< 1.0	< 1.0 - 8.1	< 1.0	< 1.0 - 5.5
HNO_2	< 1.0	NA	< 1.0	NA	< 1.0	NA	< 1.0	NA
N_2O	6.1	< 1.0 - 23.7	6.1	1.6 - 22.0	14.4	1.9 - 95.7	16.4	2.3 - 69.3

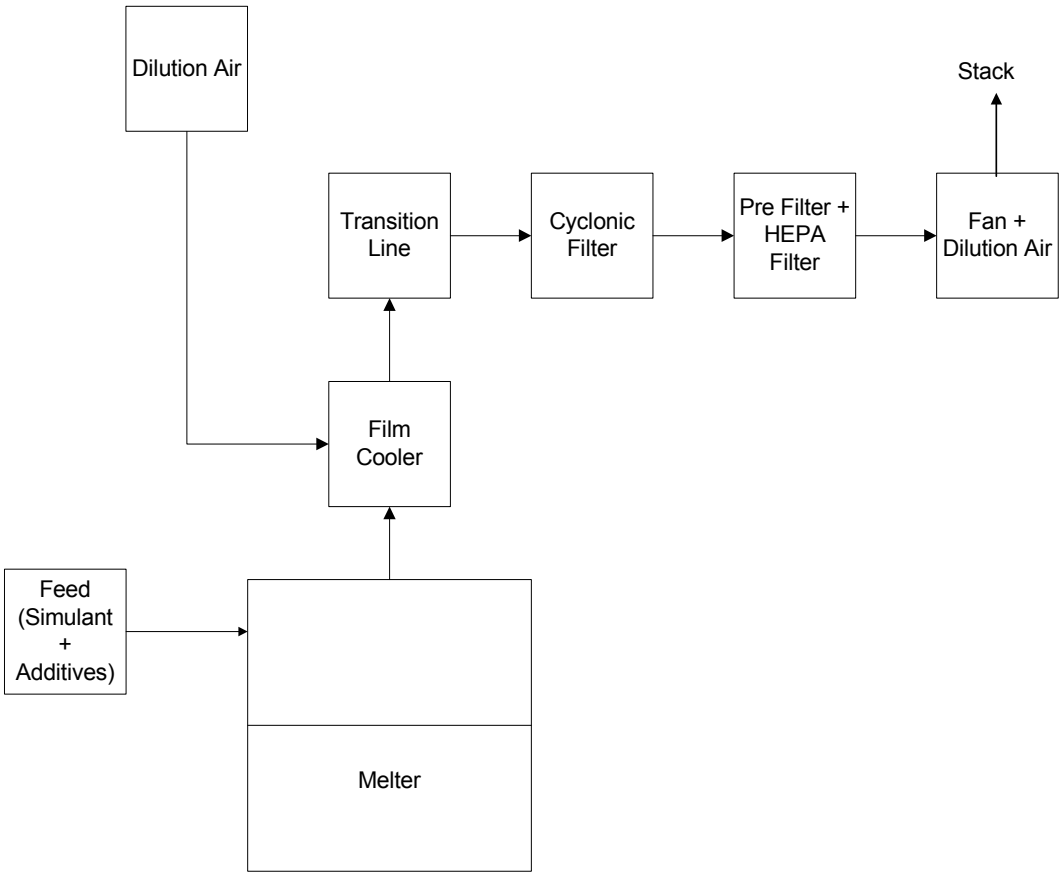


Figure 1.1. Schematic diagram of DuraMelter 100 vitrification system.

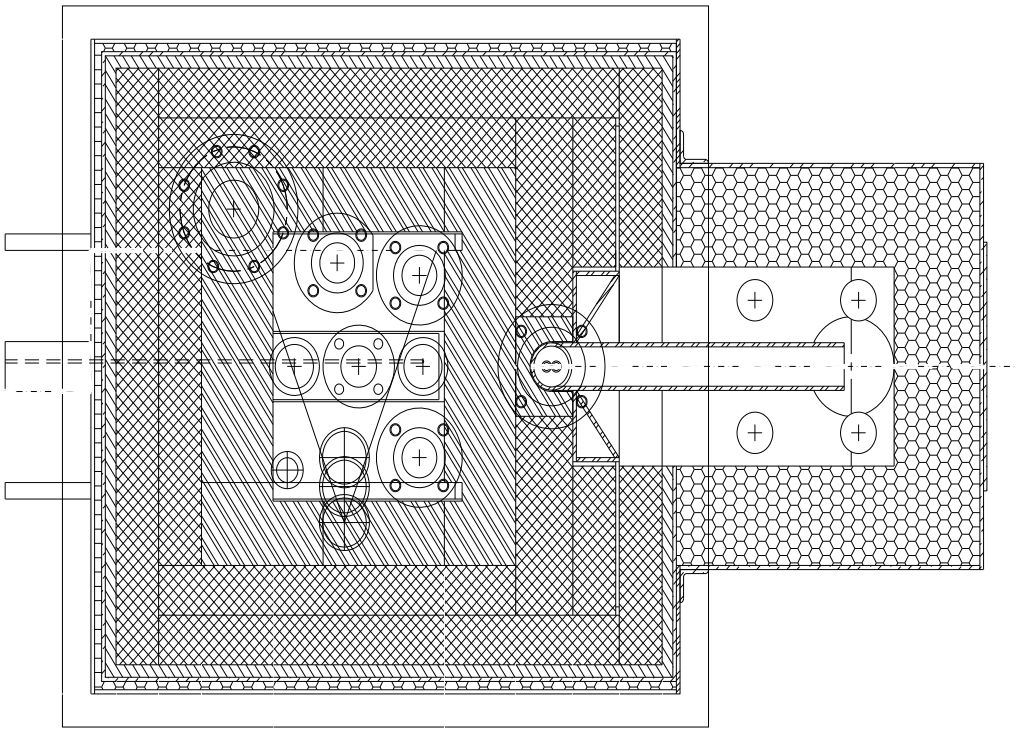


Figure 1.2.a. Schematic diagram showing cross-section through the DM100-BL-melter. Plan view showing locations of lid ports.

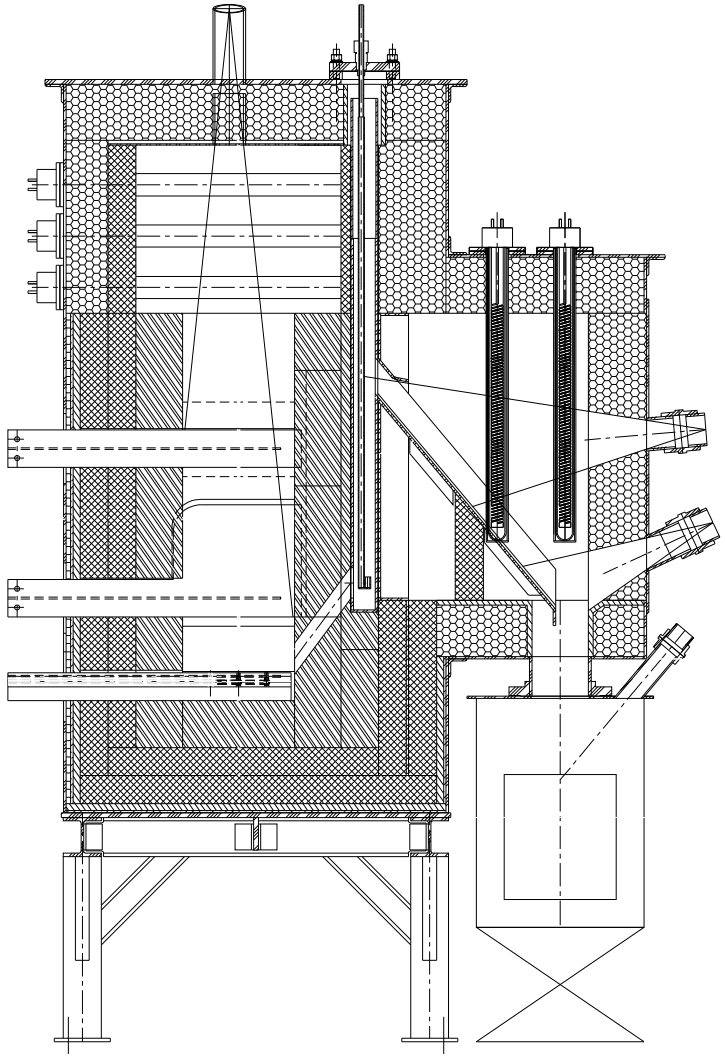


Figure 1.2.b. Schematic diagram showing cross-section through the DM100-BL melter.

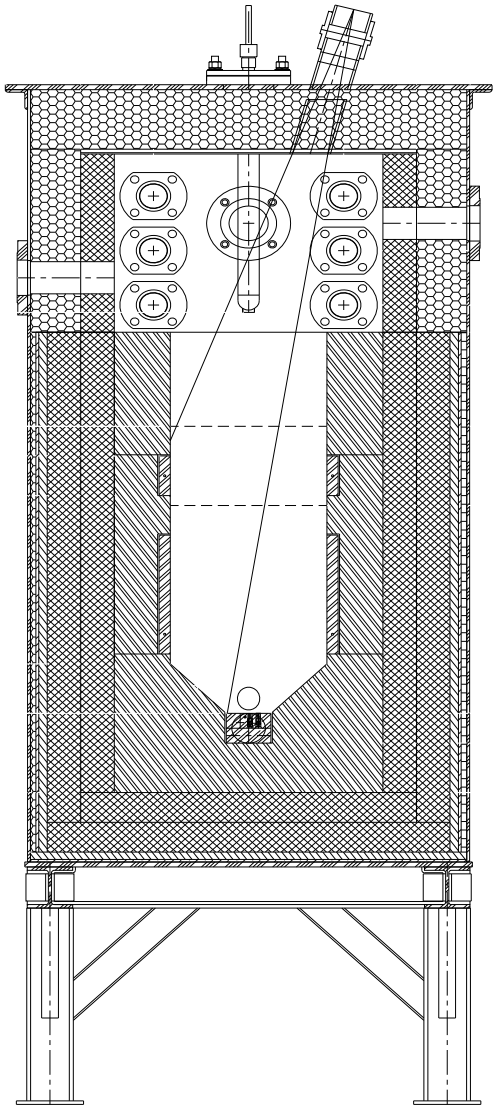


Figure 1.2.c. Schematic diagram showing cross-section through the DM100-BL melter.

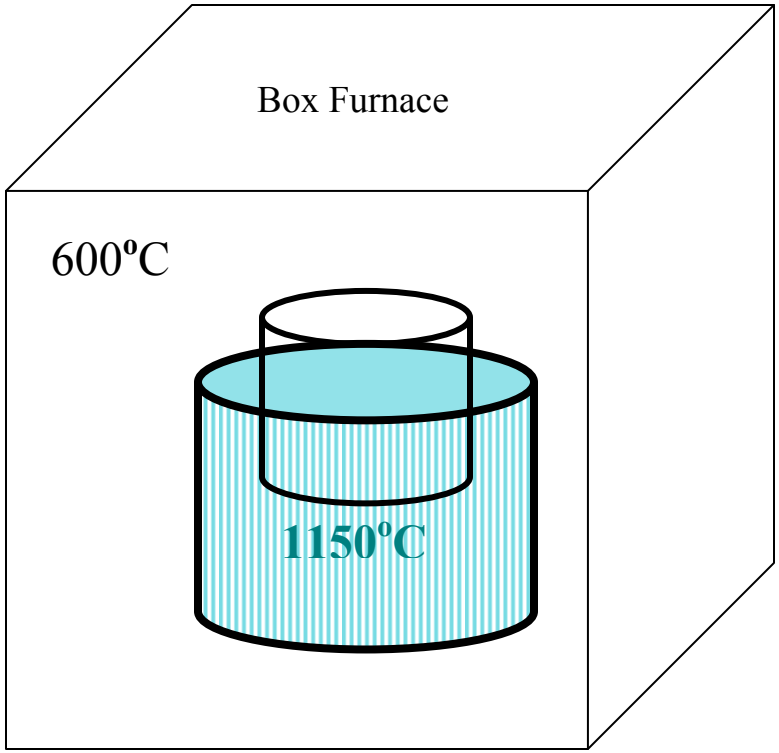


Figure 1.3. Schematic drawing of vertical gradient furnace (VGF) for feed conversion test.

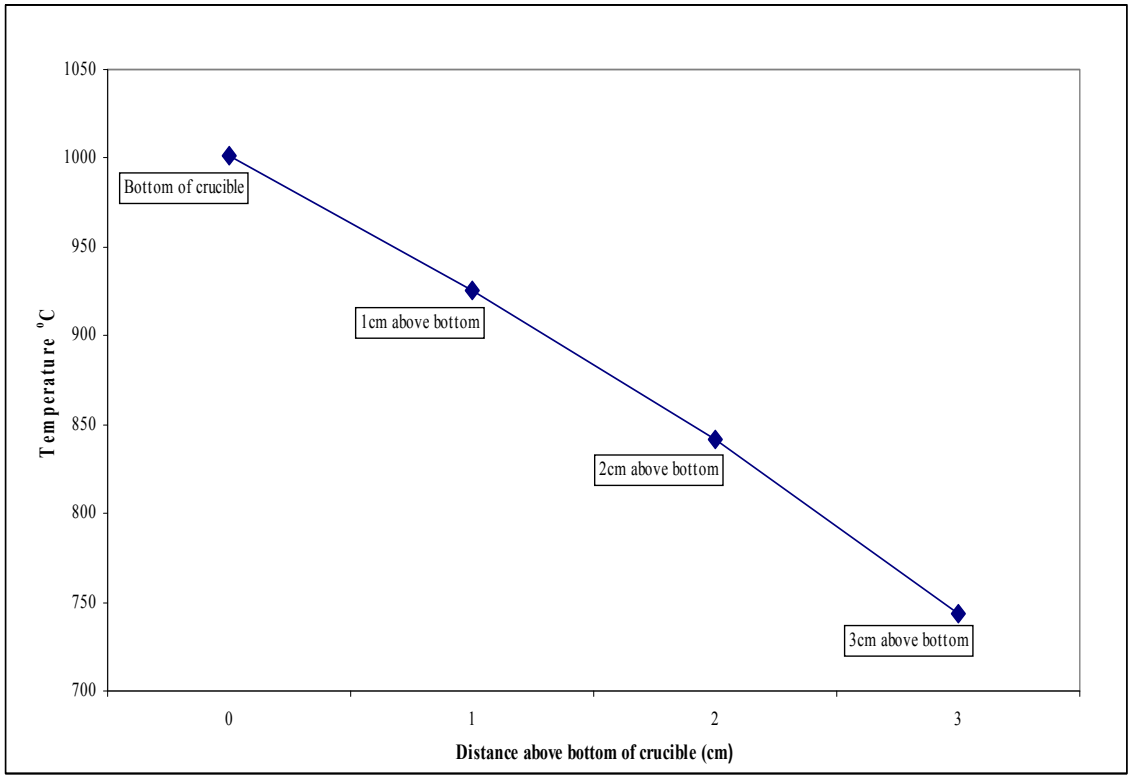


Figure 1.4. Temperature gradient (inside the loaded ceramic crucible) of the Vertical Gradient Furnace (VGF).

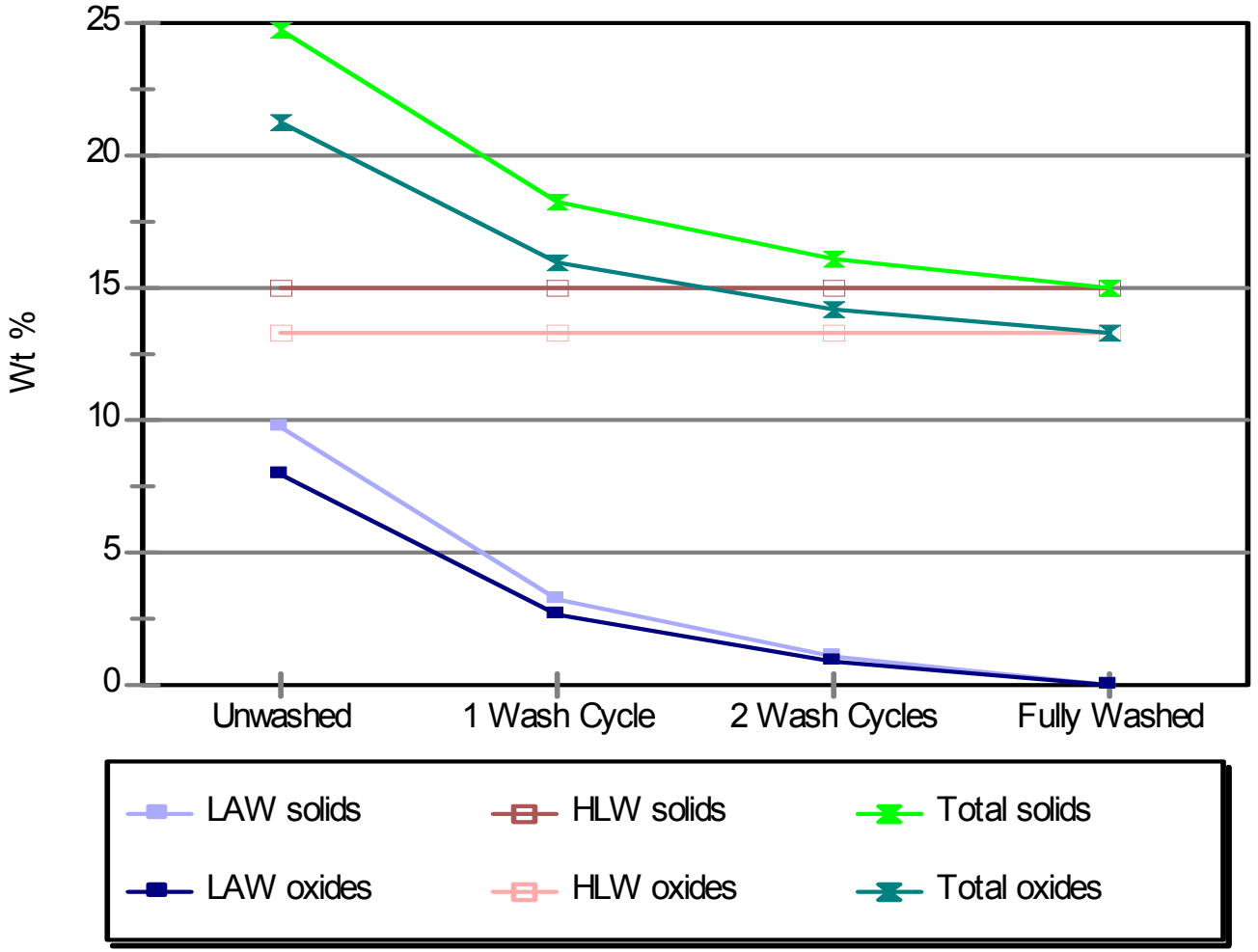


Figure 2.1. Changes in the waste solids and oxide contents (wt%) in response to waste washing.

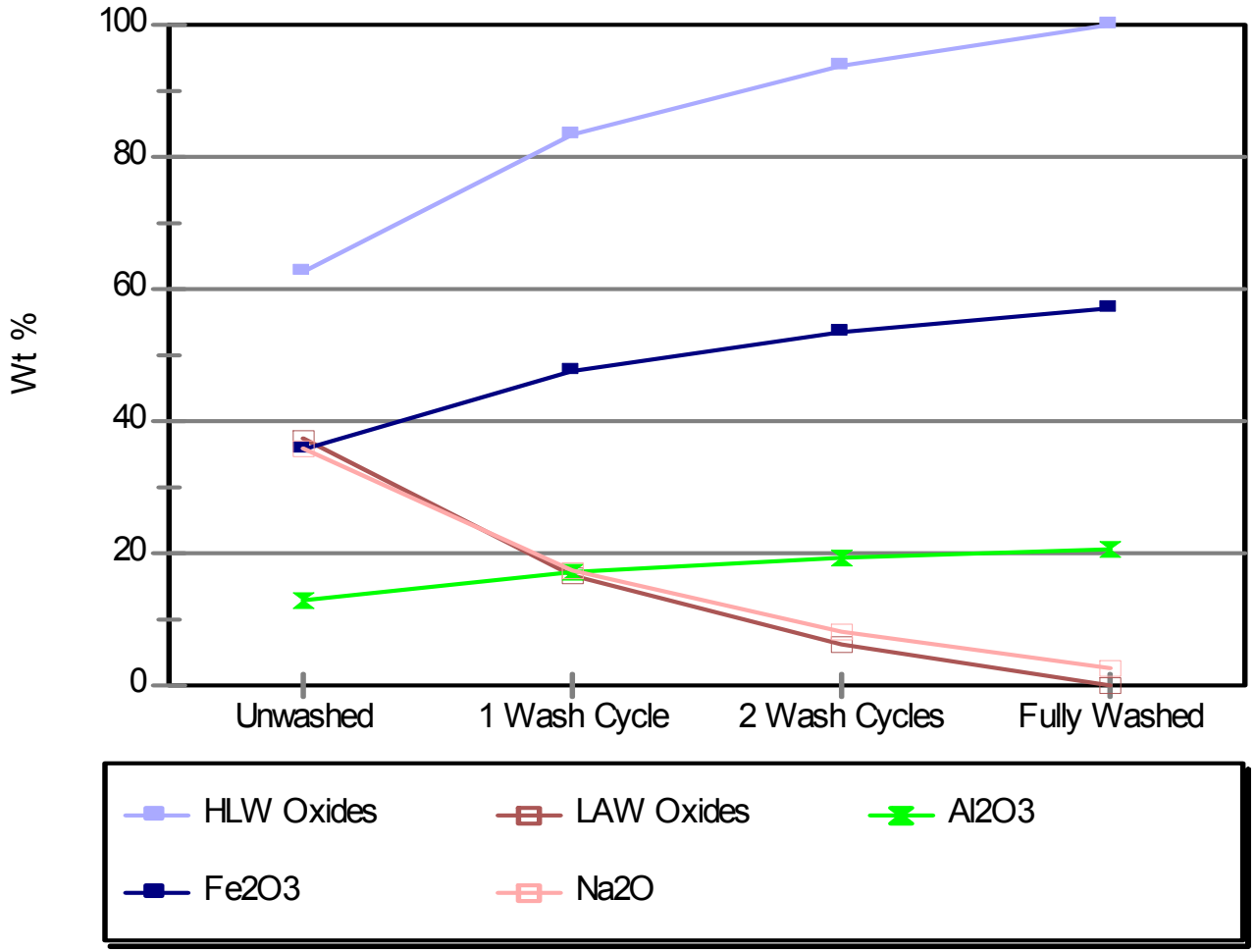


Figure 2.2. Changes in oxide composition (wt%) in response to waste washing.

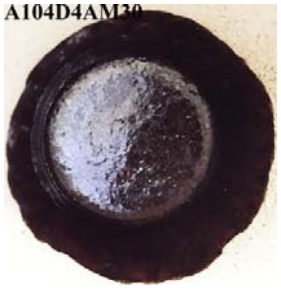
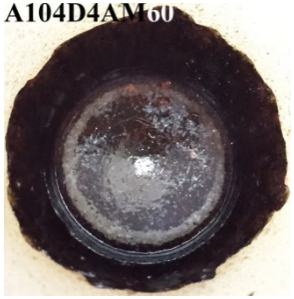
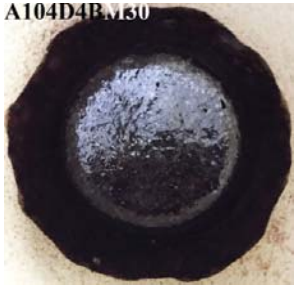
30 minutes	60 minutes	30 minutes	60 minutes
A104D4AM30 (17g glass yield) (Boric Acid/Sodium Carbonate)	**A104D4AM60** (17g glass yield) (Boric Acid/Sodium Carbonate)	**A104D4BM30** (17g glass yield) (Borax/Sodium Carbonate)	**A104D4BM60** (17g glass yield) (Borax/Sodium Carbonate)
 **Top View**	 **Top View**	 **Top View**	 **Top View**
 **Cross Section**	 **Cross Section**	 **Cross Section**	 **Cross Section**

Figure 2.3. Images of feed samples of A104D4-11 after vertical gradient furnace tests.

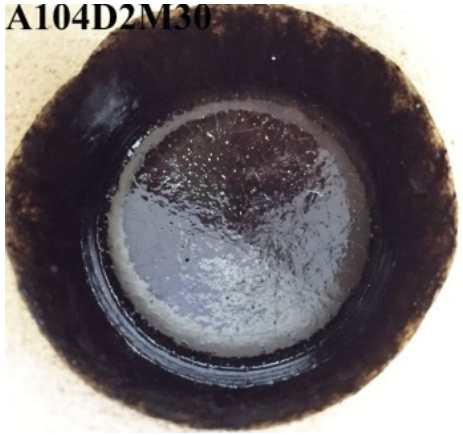
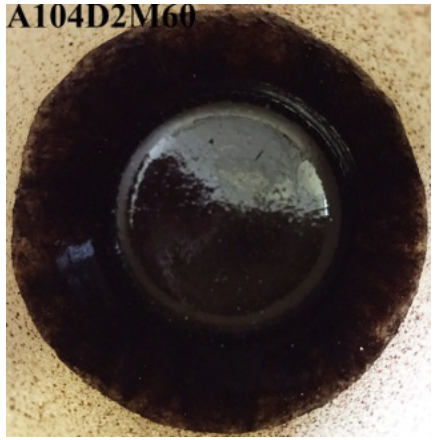
30 minutes	60 minutes
A104D2M30 (17g glass yield) (with sugar)	**A104D2M60** (17g glass yield) (with sugar)
 **Top View**	 **Top View**
 **Cross Section**	 **Cross Section**

Figure 2.4. Images of feed samples of A-104 Blend 2 waste (based on A104D4-11) after vertical gradient furnace tests.

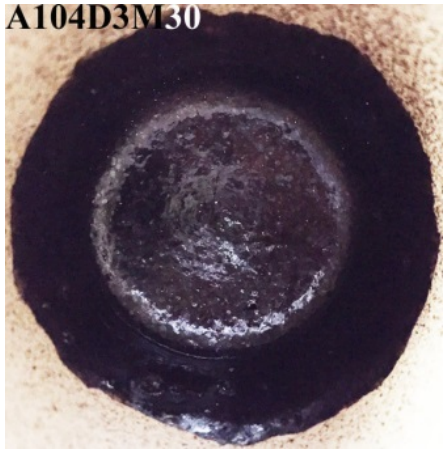
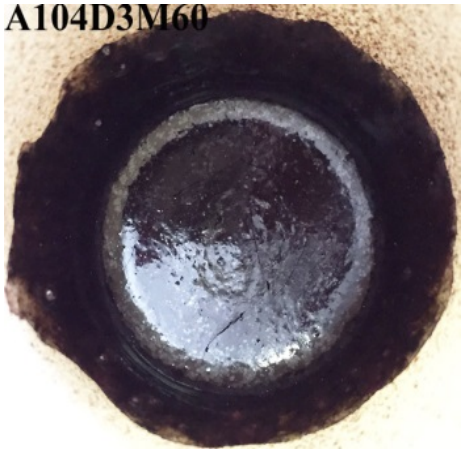
30 minutes	60 minutes
A104D3M30 (17g glass yield) (with sugar)	**A104D3M60** (17g glass yield) (with sugar)
 **Top View**	 **Top View**
 **Cross Section**	 **Cross Section**

Figure 2.5. Images of feed samples of A-104 Blend 3 waste (based on A104D4-11) after vertical gradient furnace tests.

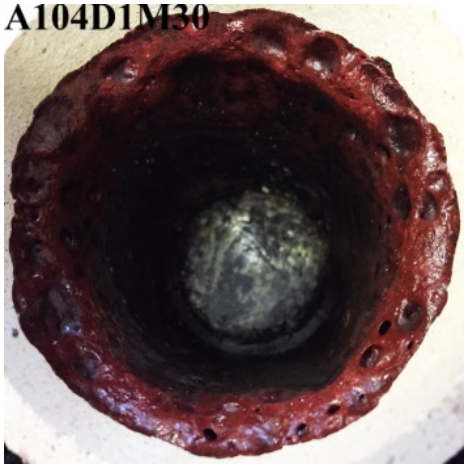
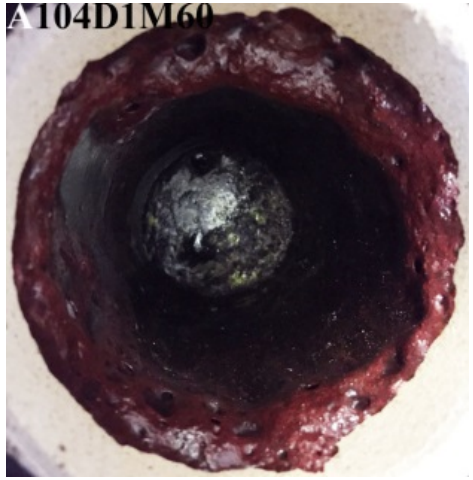
30 minutes	60 minutes
A104D1M30 (17g glass yield) (with sugar)	**A104D1M60** (17g glass yield) (with sugar)
 **Top View**	 **Top View**
 **Cross Section**	 **Cross Section**

Figure 2.6. Images of feed samples of A104D1-04 after vertical gradient furnace tests.

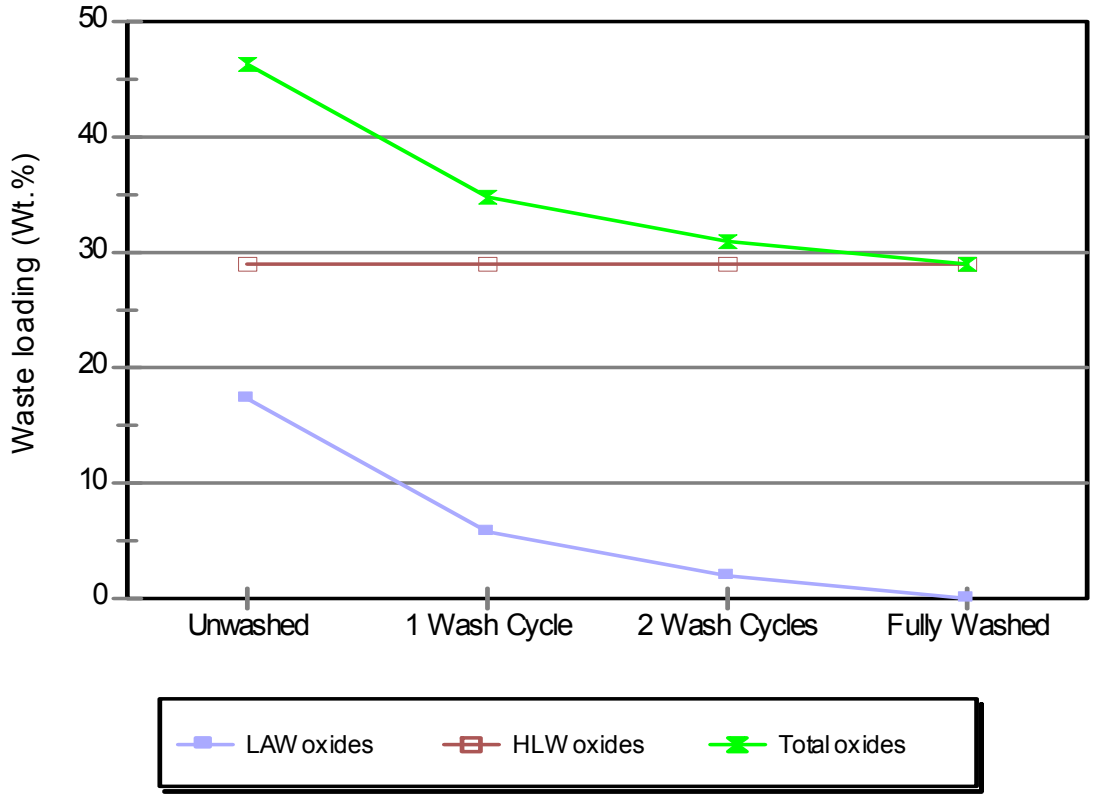


Figure 2.7. Waste loading for glasses formulated with AY-102 undissolved and dissolved solids.

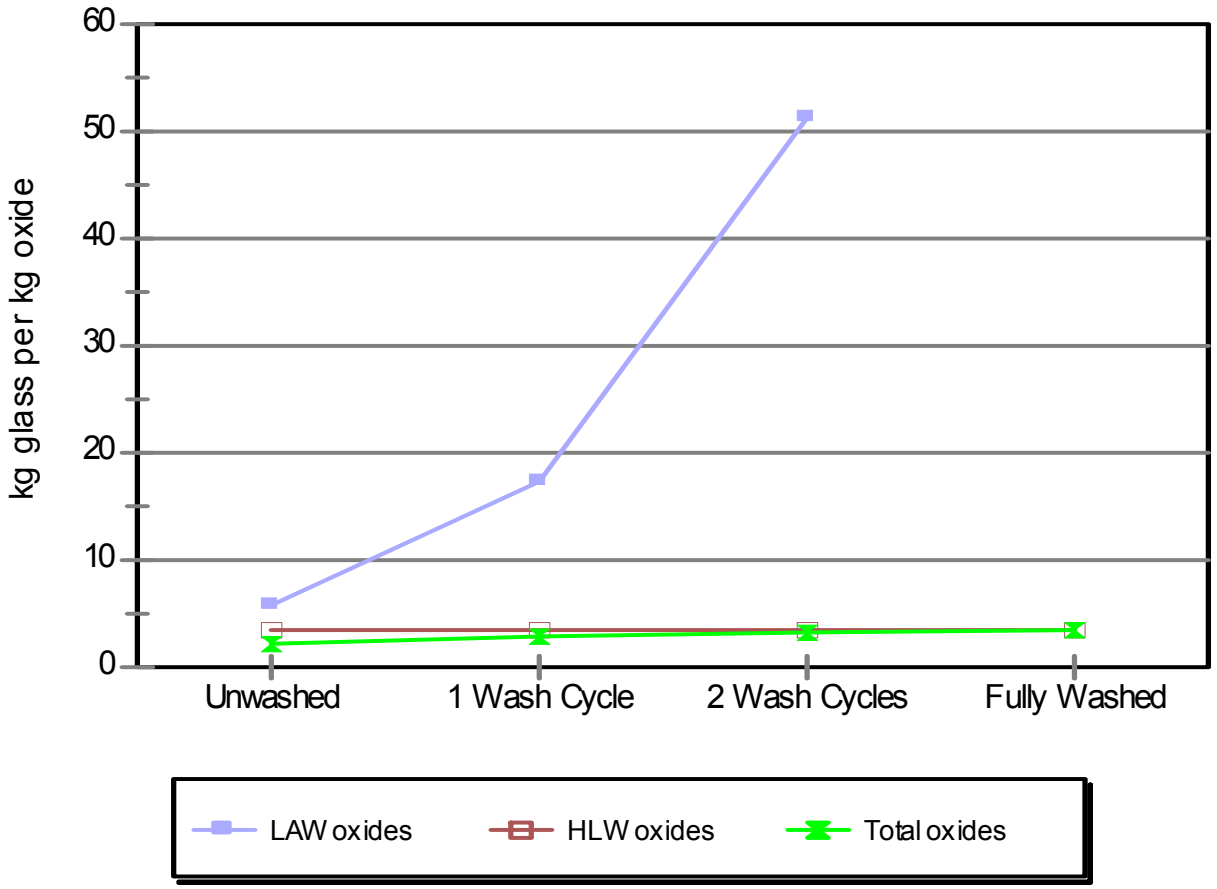


Figure 2.8. Amounts of glass produced for glasses formulated with A-104 undissolved and dissolved solids.

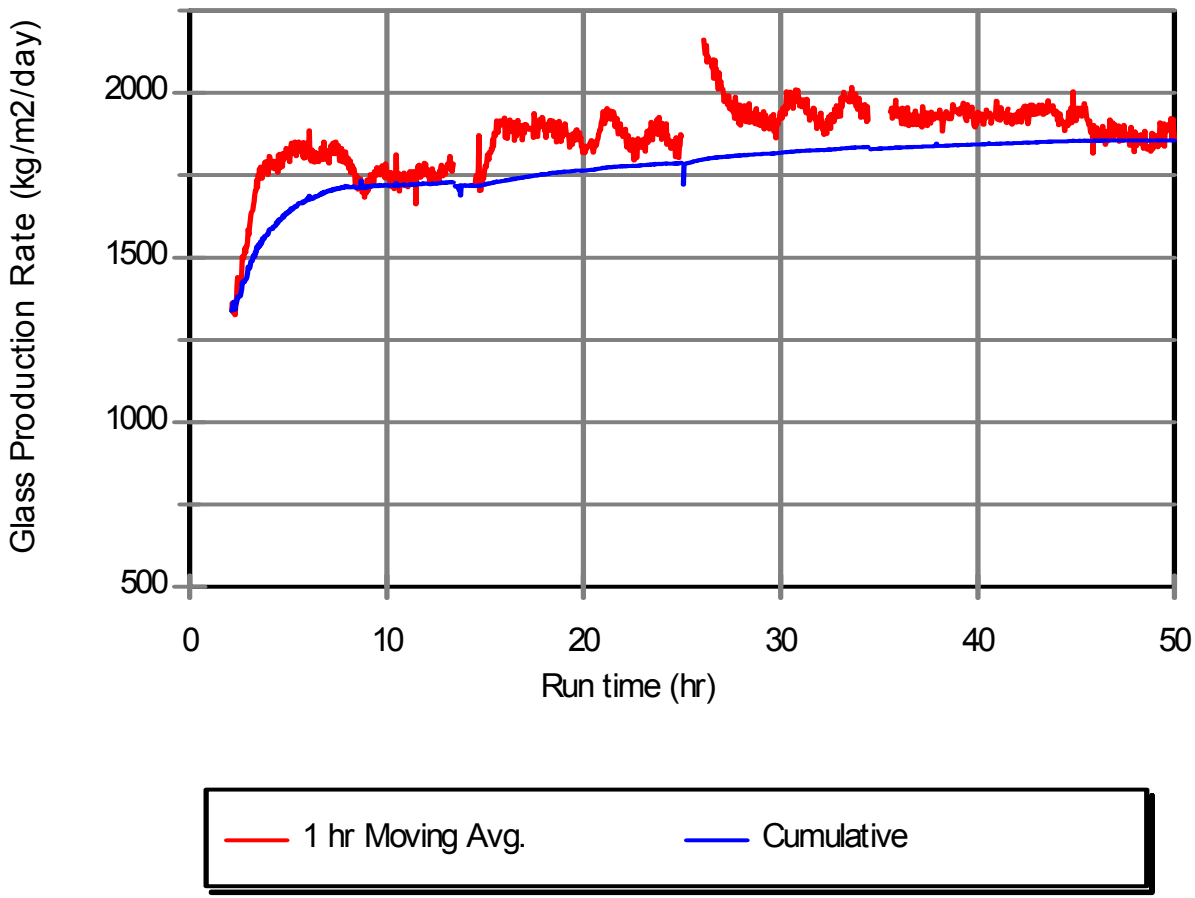


Figure 3.1.a. Glass production rates (hourly moving averages and cumulative) for DM100 Test 4 with A104D4-11 glass composition.

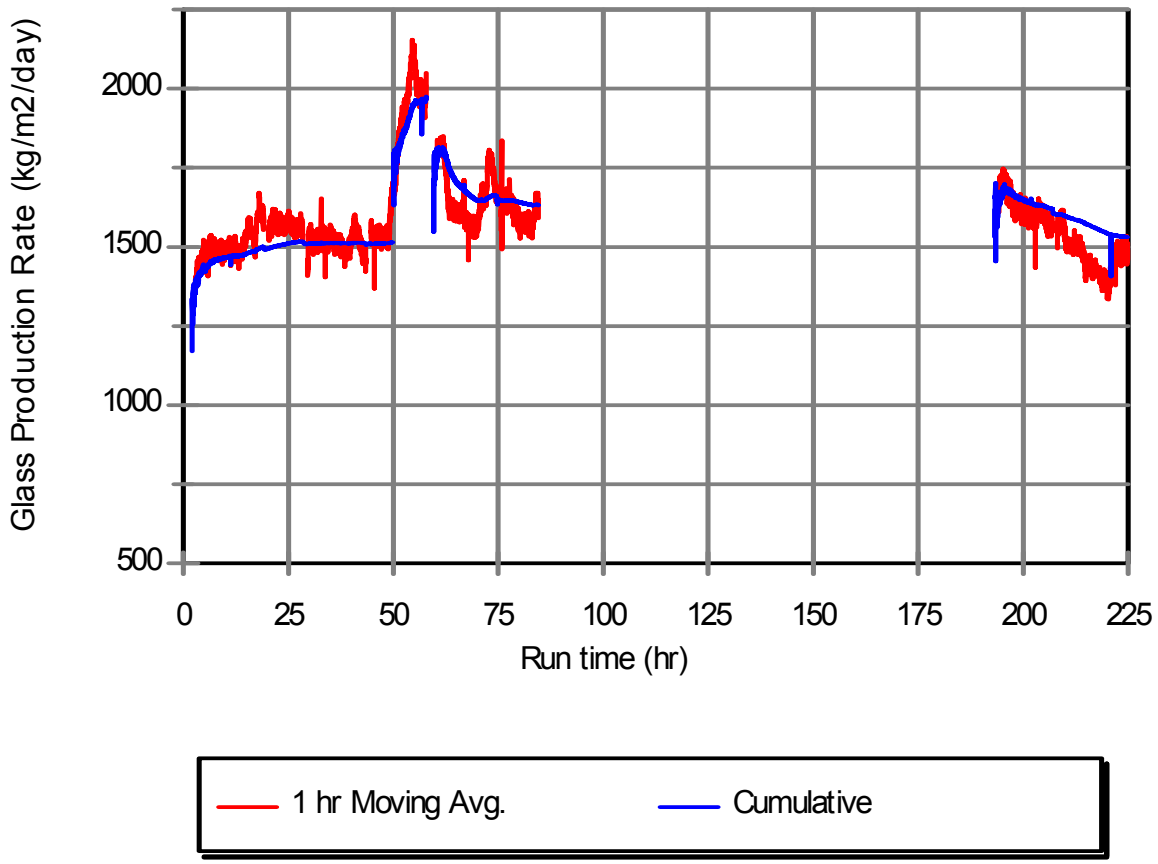


Figure 3.1.b. Glass production rates (hourly moving averages and cumulative) for DM100 Tests 3 and 2 with A104D4-11 glass composition with Blends 3 and 2 wastes.
Note: Melter idled between 85 and 193 hours run time.

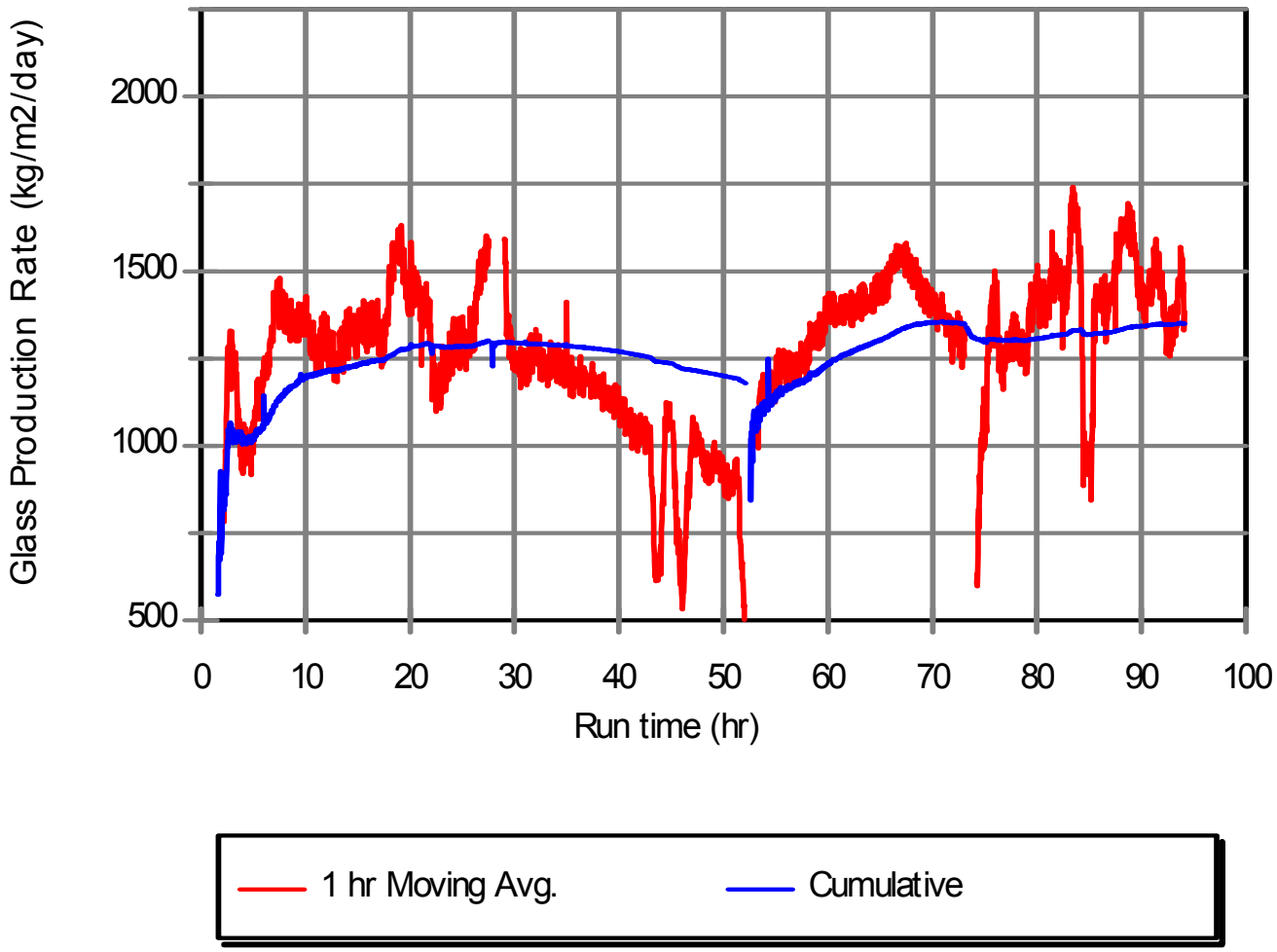


Figure 3.1.c. Glass production rates (hourly moving averages and cumulative) for DM100 Test 1 A104D1-04 glass composition at 9 lpm and optimized bubbling.

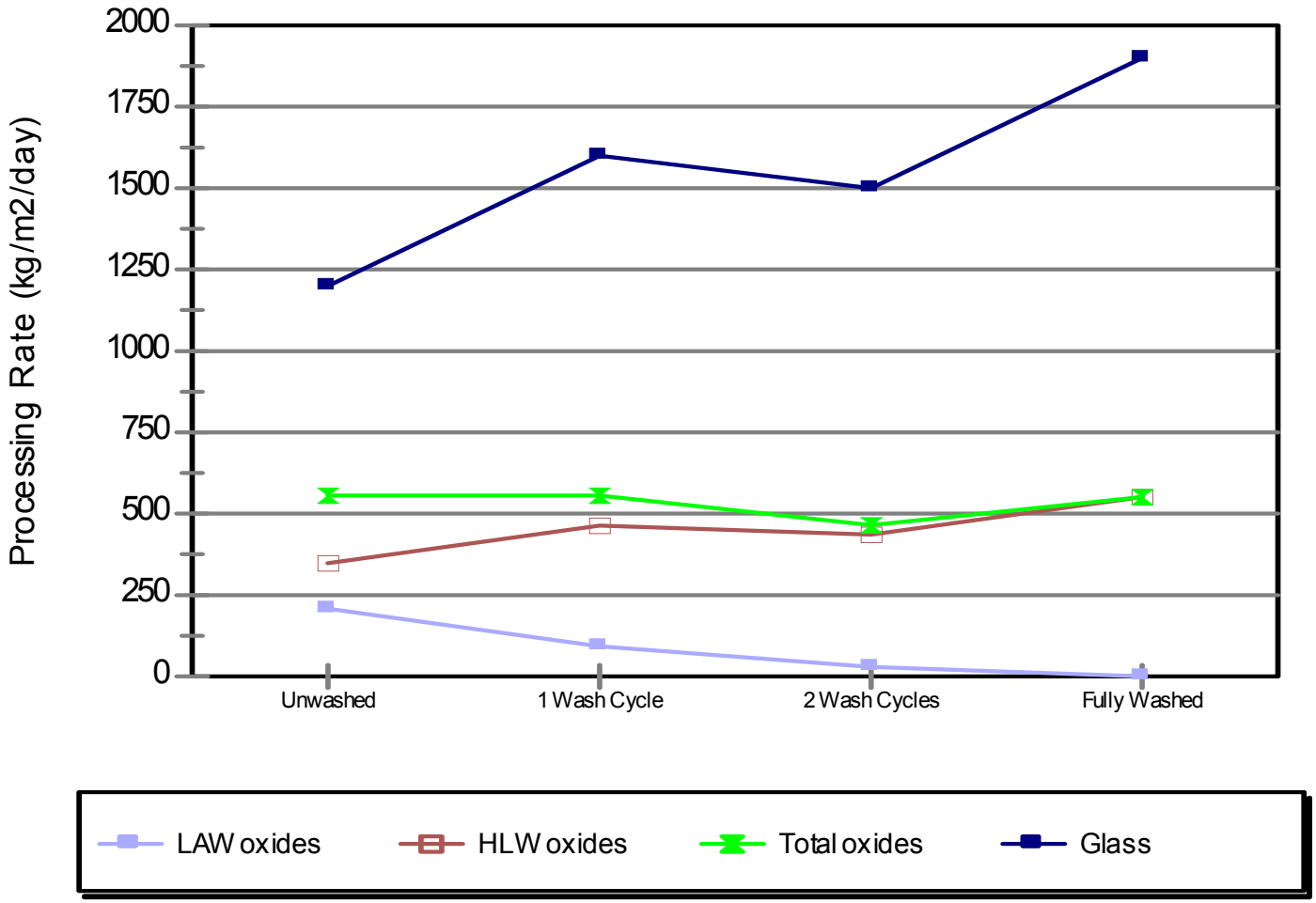


Figure 3.1.d. Glass and A-104 waste oxide processing rates for DM100 tests conducted with 9 lpm bubbling.

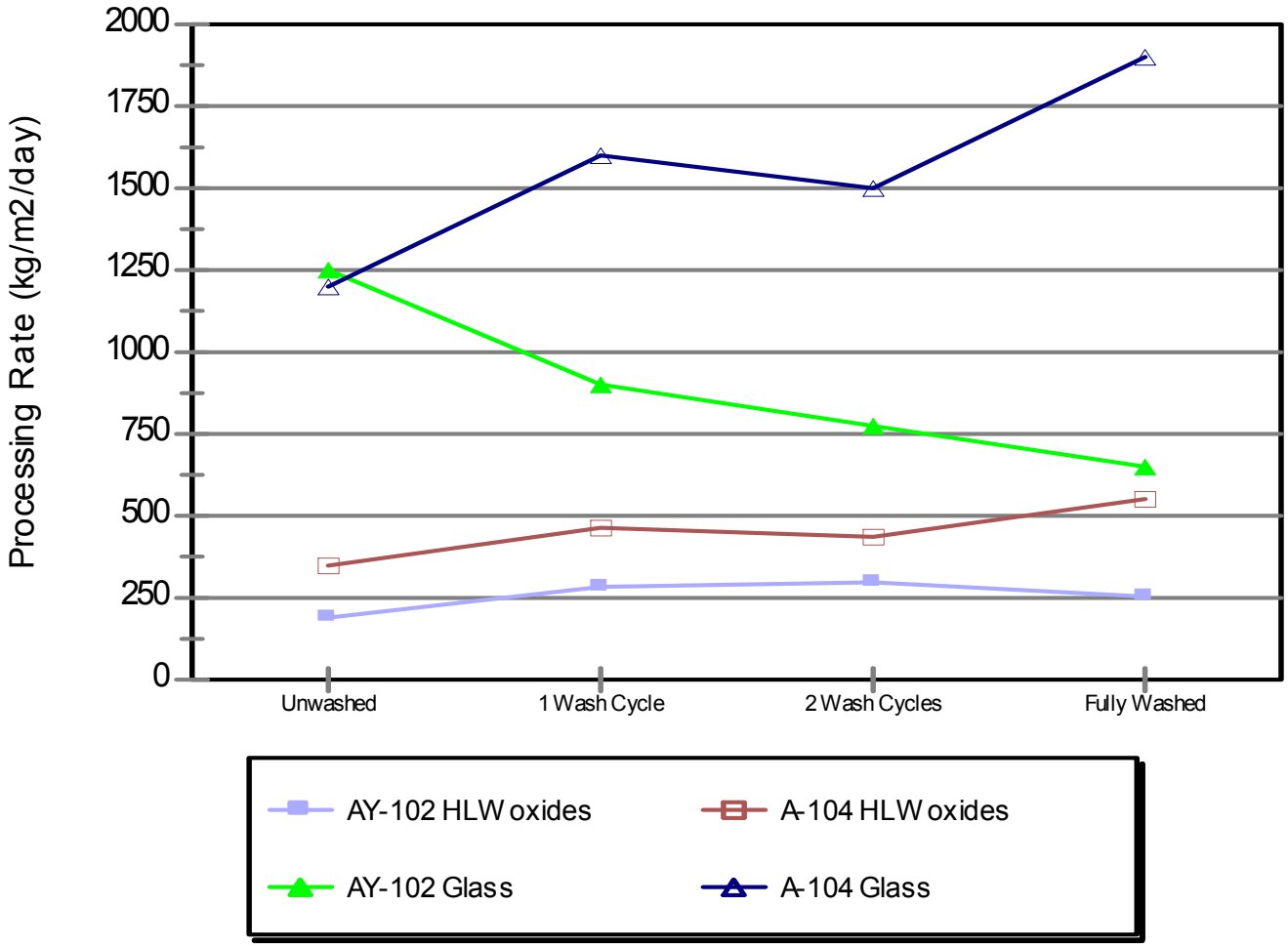


Figure 3.1.e. Glass and waste oxide processing rates for AY-102 and A-104 wastes during DM100 tests conducted with 9 lpm bubbling.

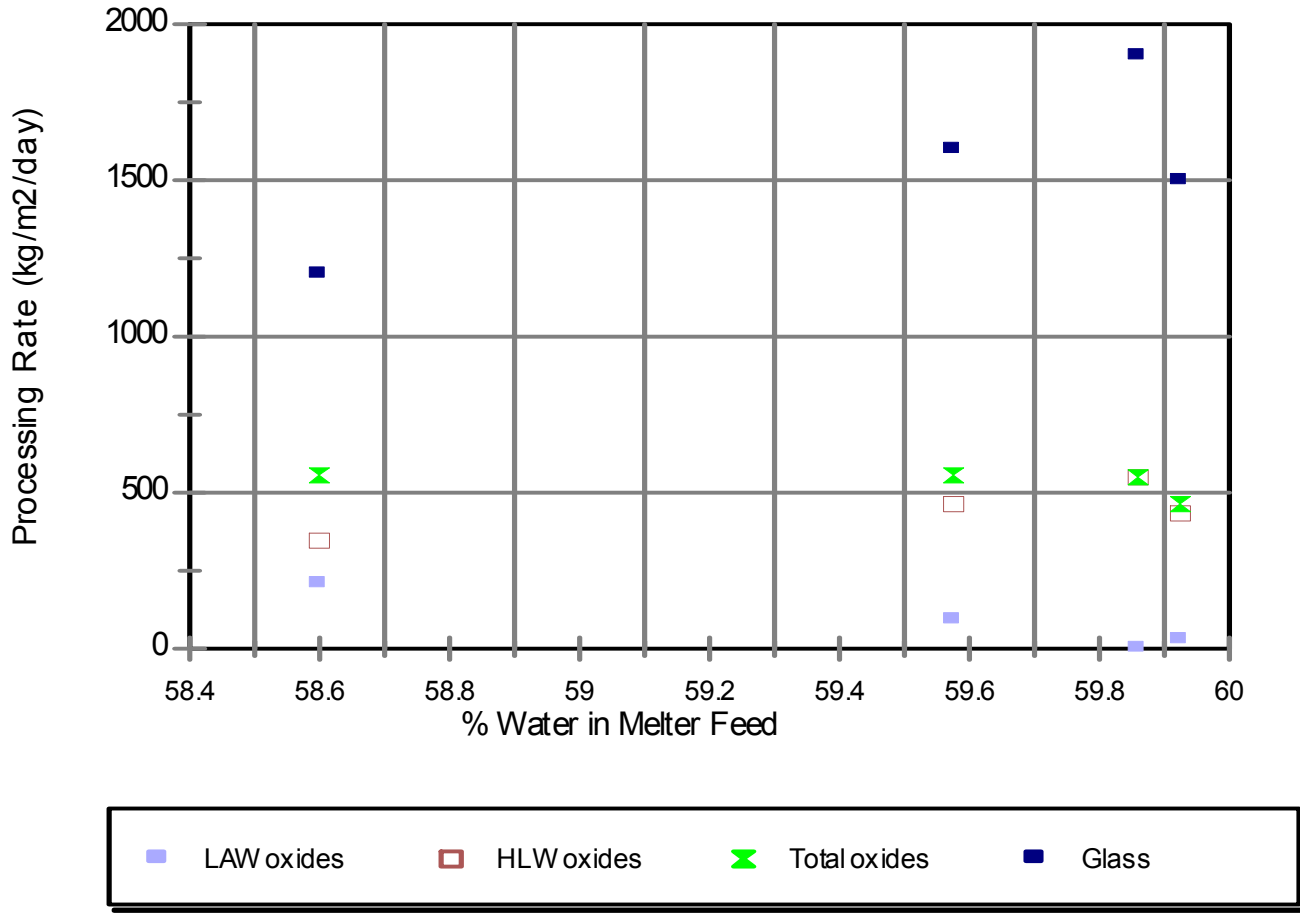


Figure 3.1.f. Glass and A-104 waste oxide processing rates versus measured feed water content for DM100 tests conducted with 9 lpm bubbling.

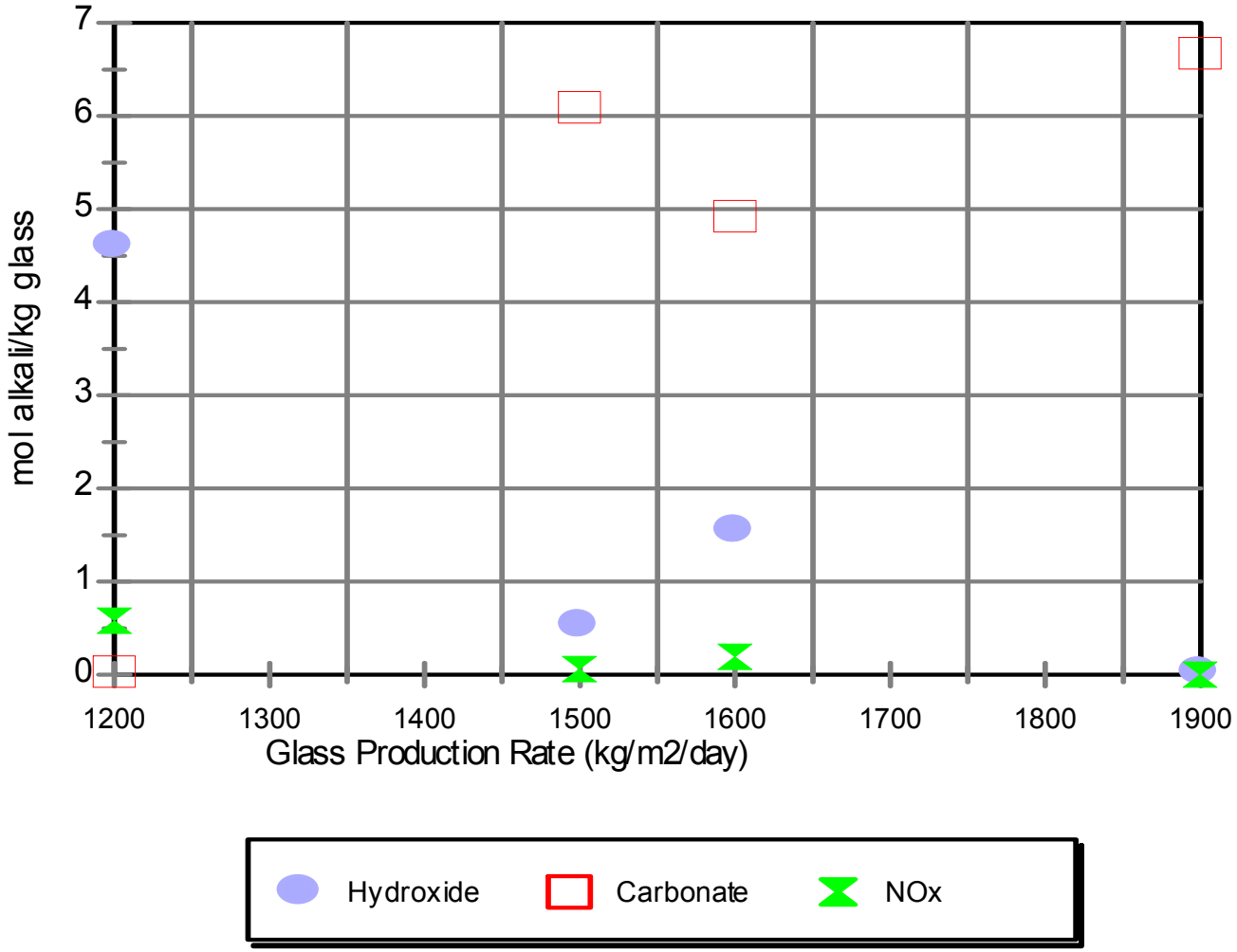


Figure 3.1.g. Glass production rates versus feed alkali form during DM100 tests conducted with 9 lpm bubbling.

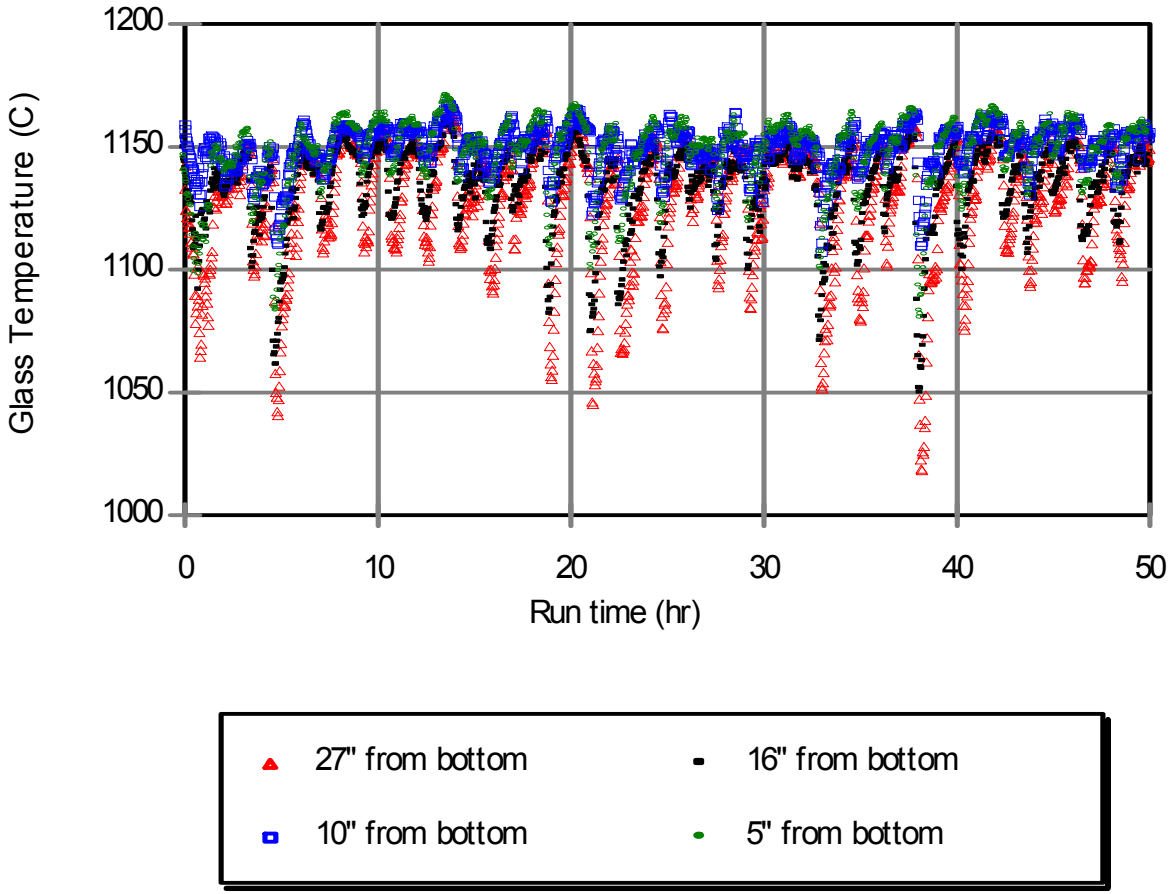


Figure 3.2.a. Glass temperatures during DM100 Test 4 with A104D4-11 glass composition.

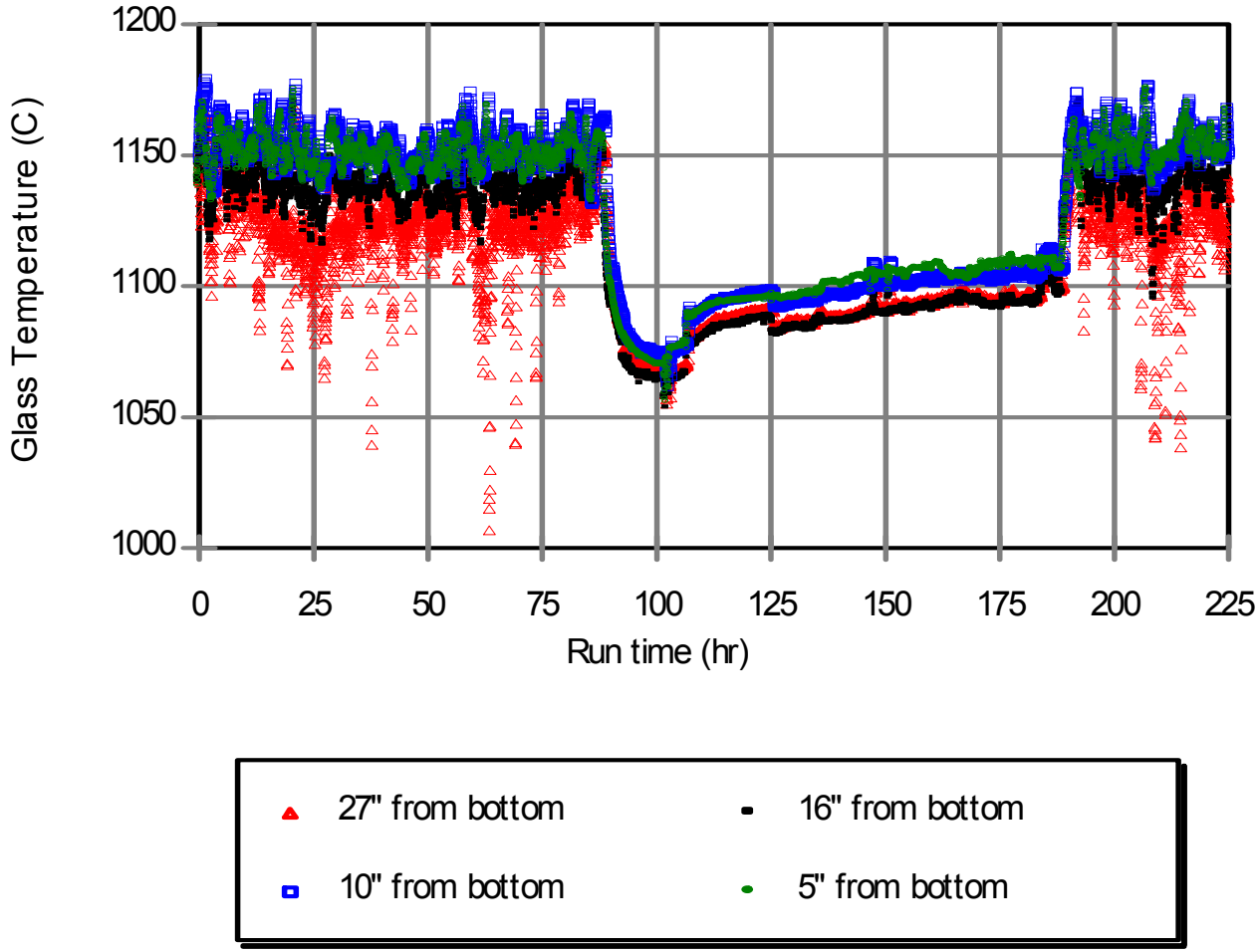


Figure 3.2.b. Glass temperatures during DM100 Tests 3 and 2 with A104D4-11 glass composition and Blends 3 and 2 wastes.
Note: Melter idled between 85 and 193 hours run time.

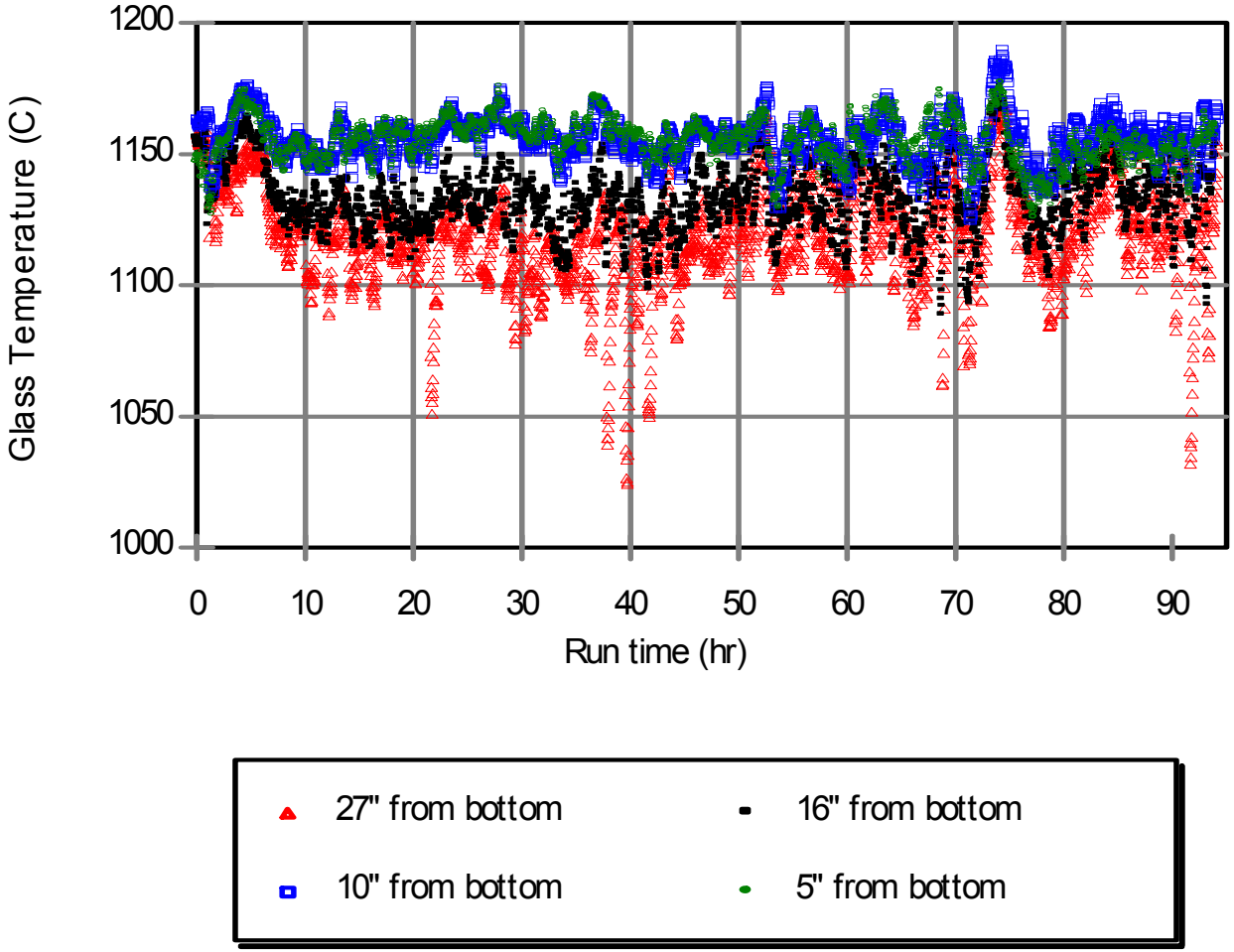


Figure 3.2.c. Glass temperatures during DM100 Test 1 with A104D1-04 glass composition at 9 lpm and optimized bubbling.

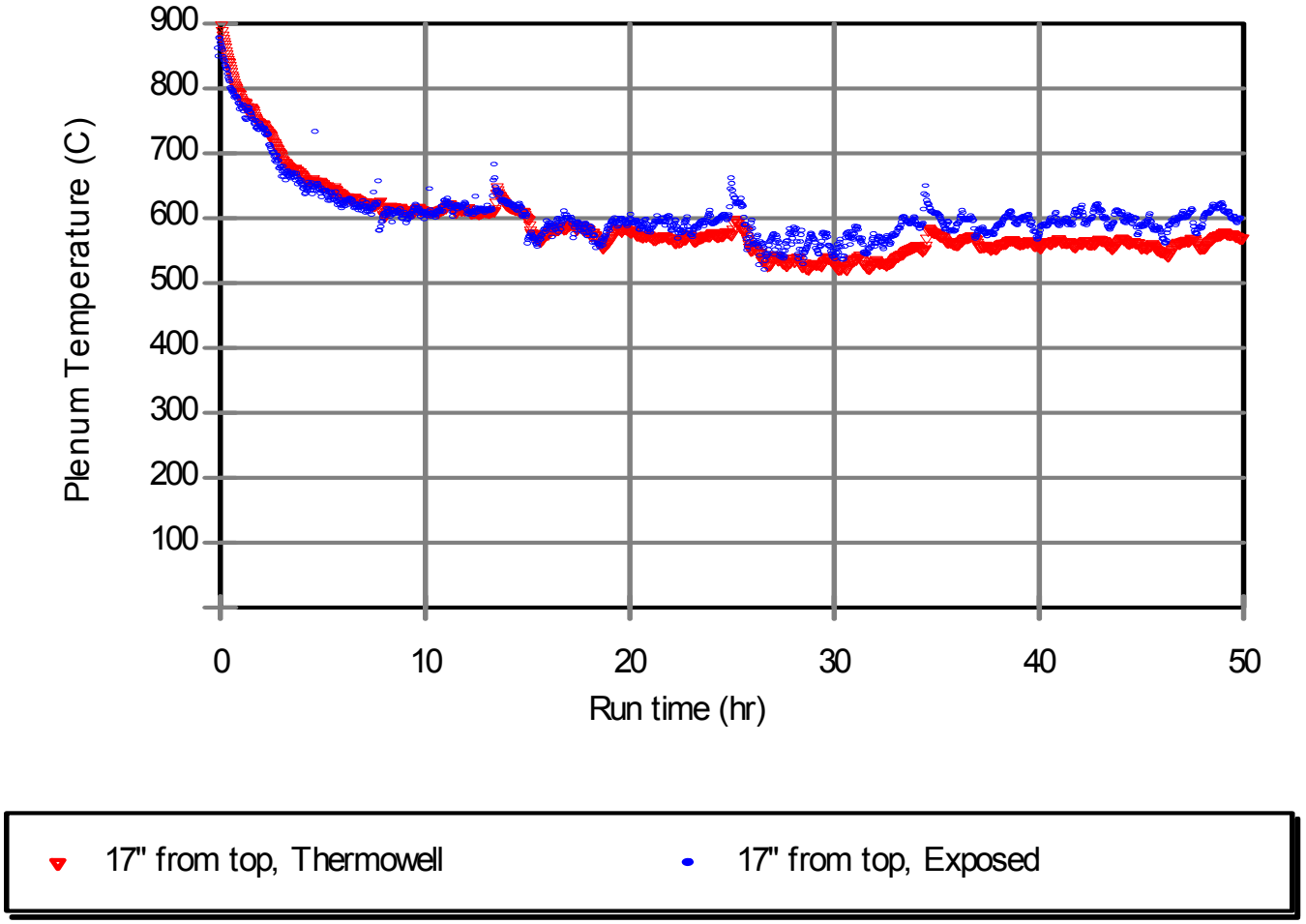


Figure 3.3.a. Plenum temperatures during DM100 Test 4 with A104D4-11 glass composition.

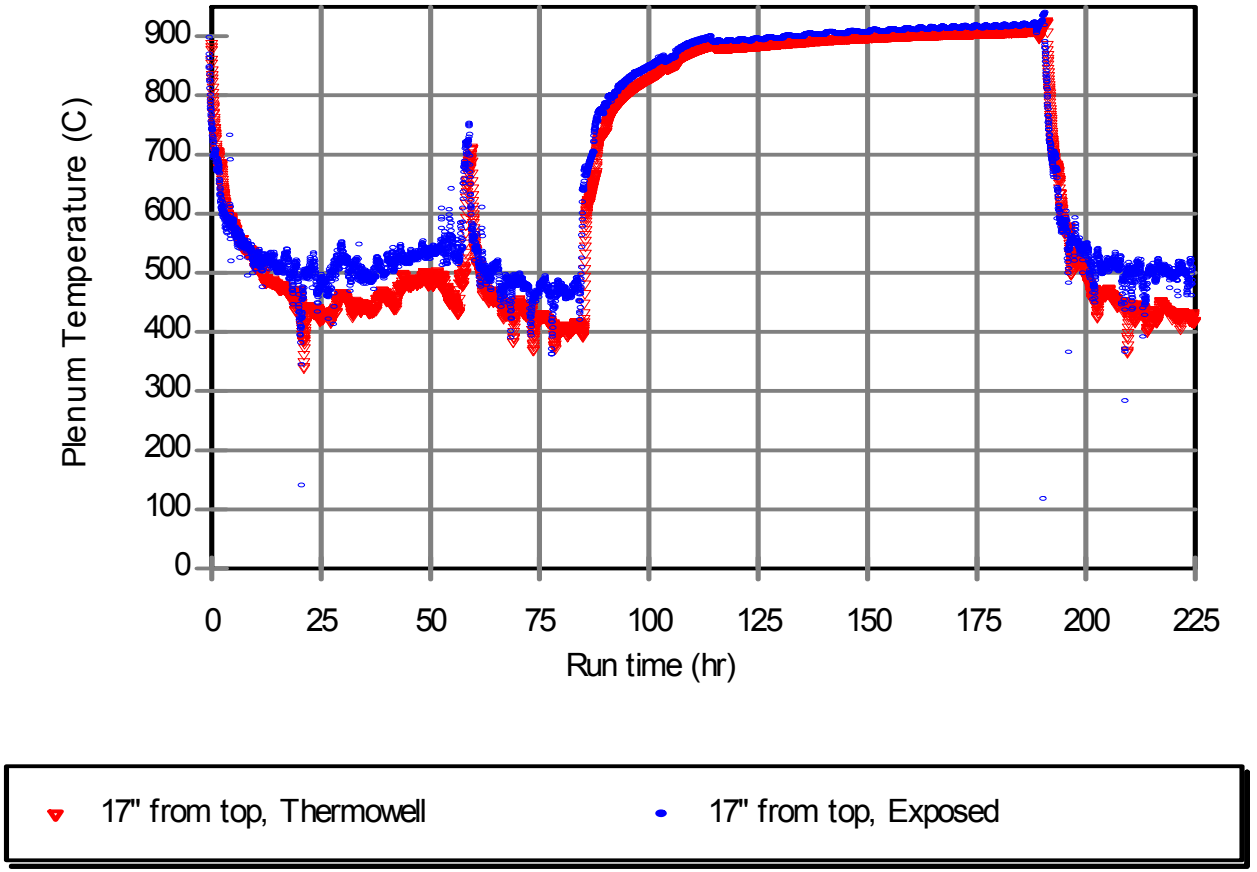


Figure 3.3.b. Plenum temperatures during DM100 Tests 3 and 2 with A104D4-11 glass composition and Blends 3 and 2 wastes.
Note: Melter idled between 85 and 193 hours run time.

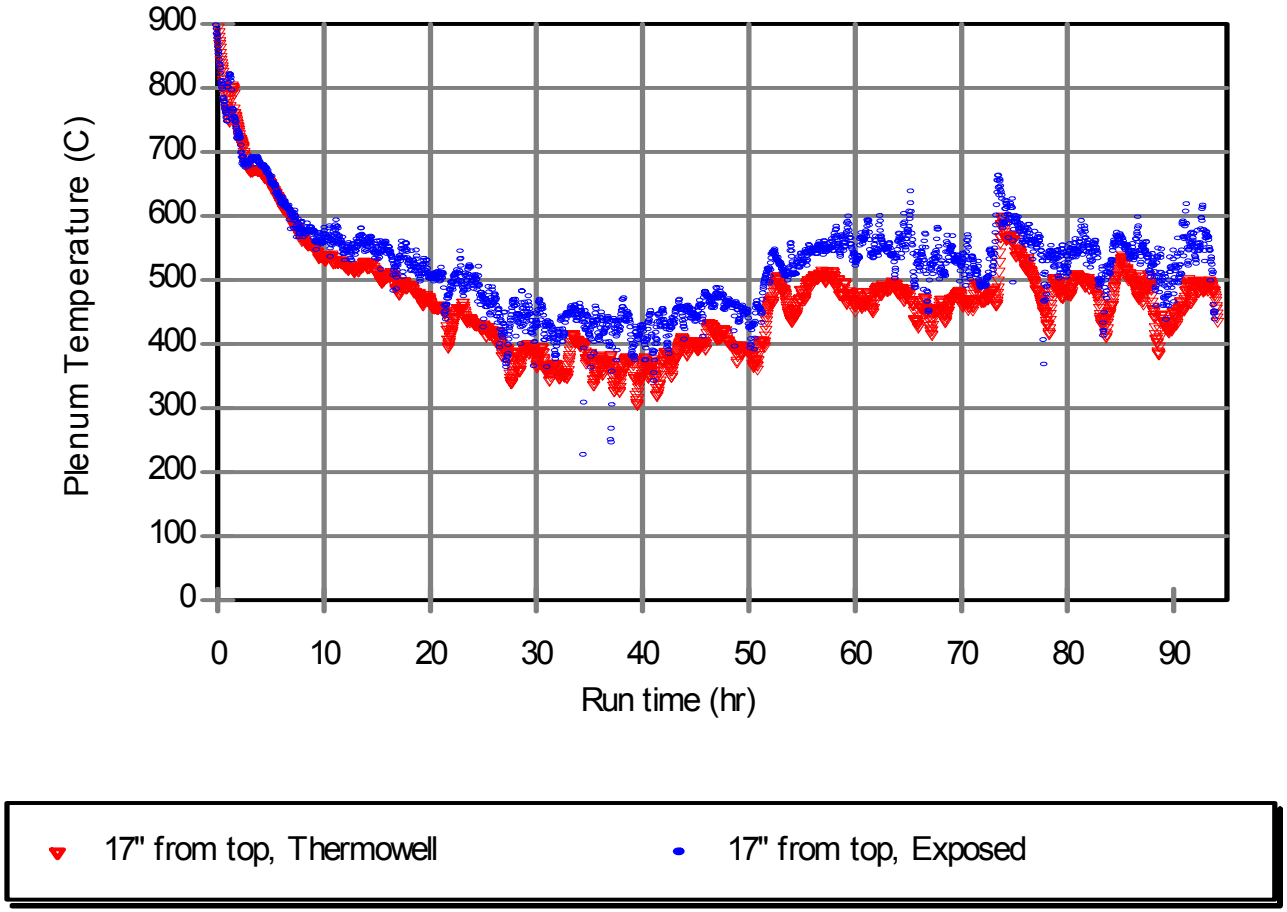


Figure 3.3.c. Plenum temperatures during DM100 Test 1 with A104D1-04 glass composition at 9 lpm and optimized bubbling.

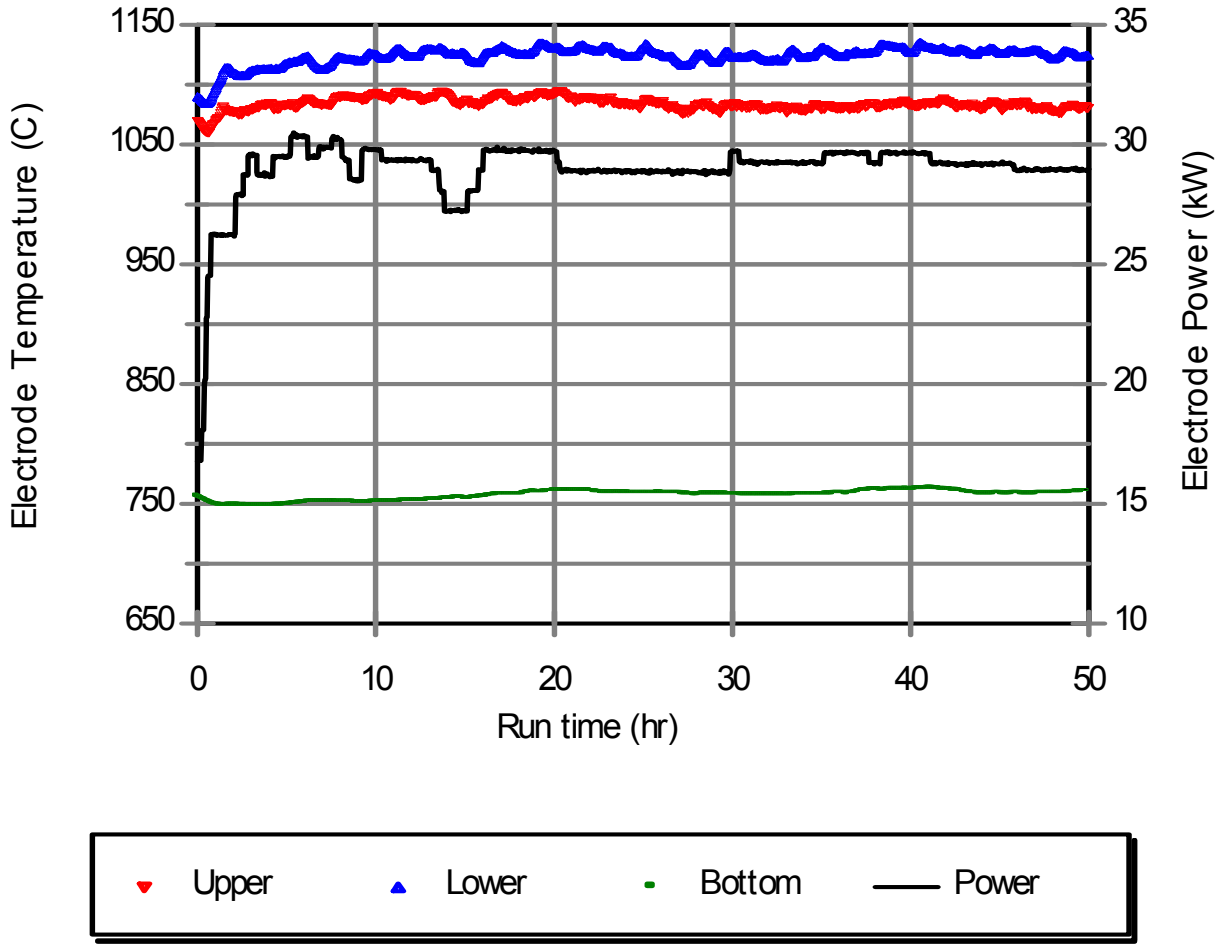


Figure 3.4.a. Electrode temperatures and power during DM100 Test 4 with A104D4-11 glass composition.

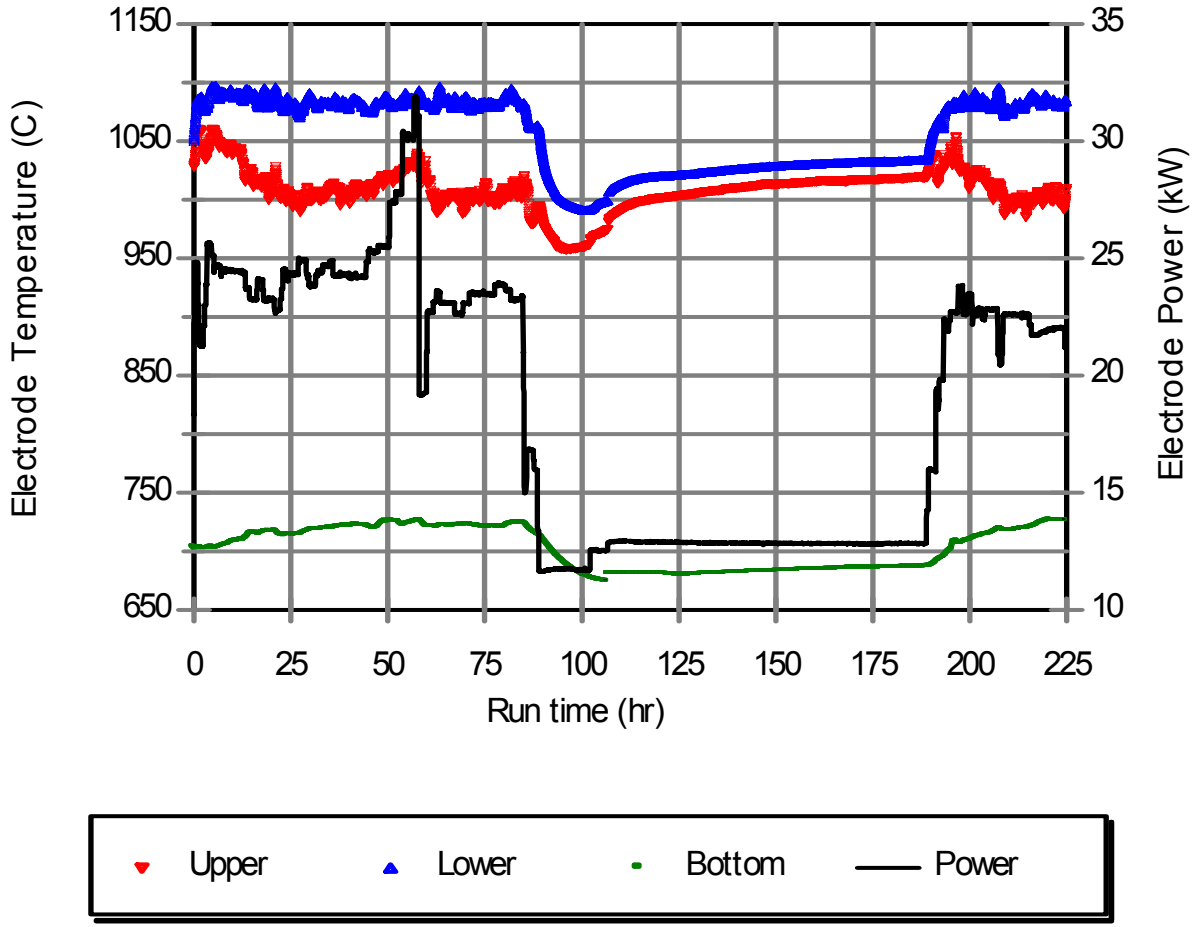


Figure 3.4.b. Electrode temperatures and power during DM100 Tests 3 and 2 with A104D4-11 glass composition and Blends 3 and 2 wastes.
Note: Melter idled between 85 and 193 hours run time.

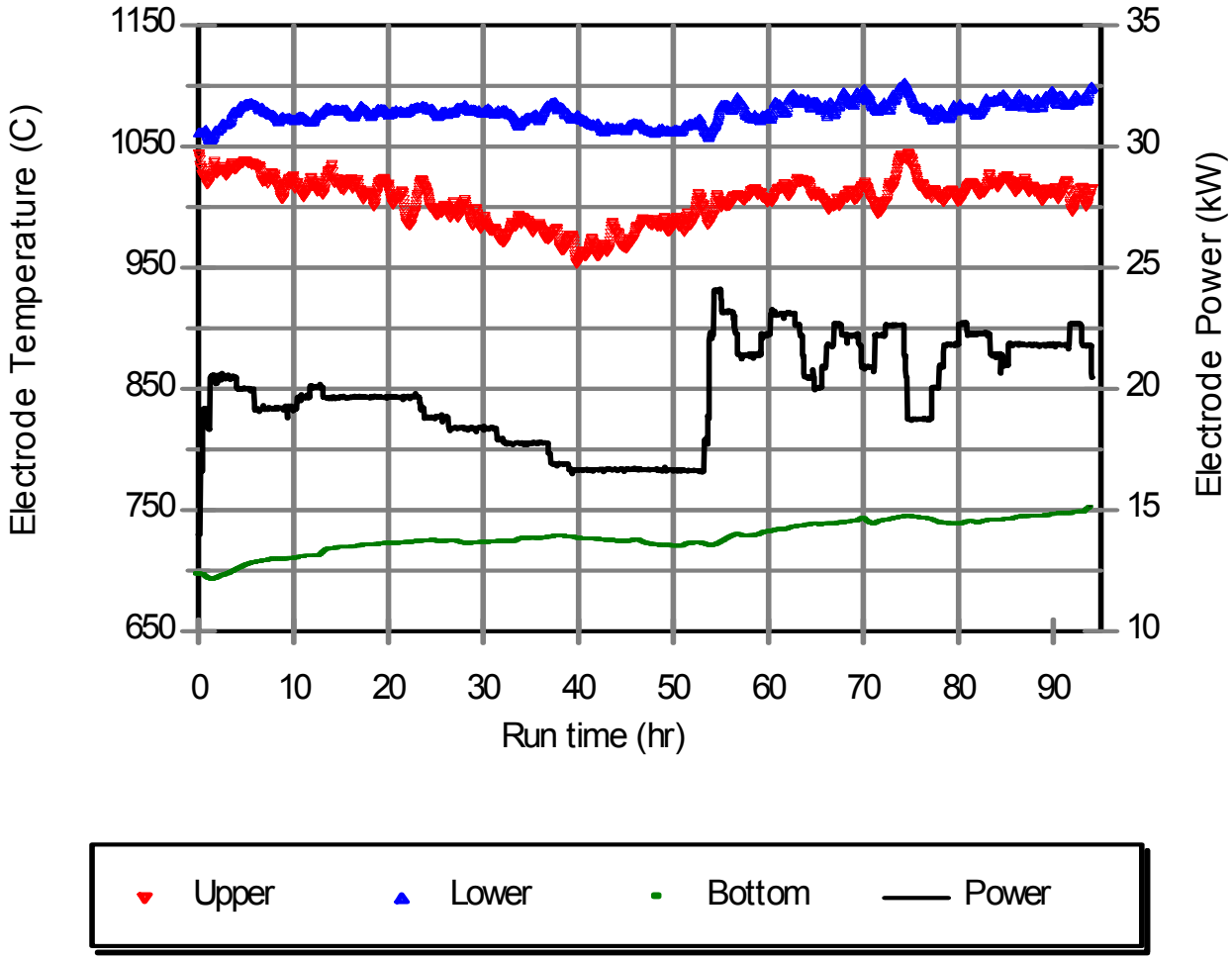


Figure 3.4.c. Electrode temperatures and power during DM100 Test 1 with A104D1-04 glass composition at 9 lpm and optimized bubbling.

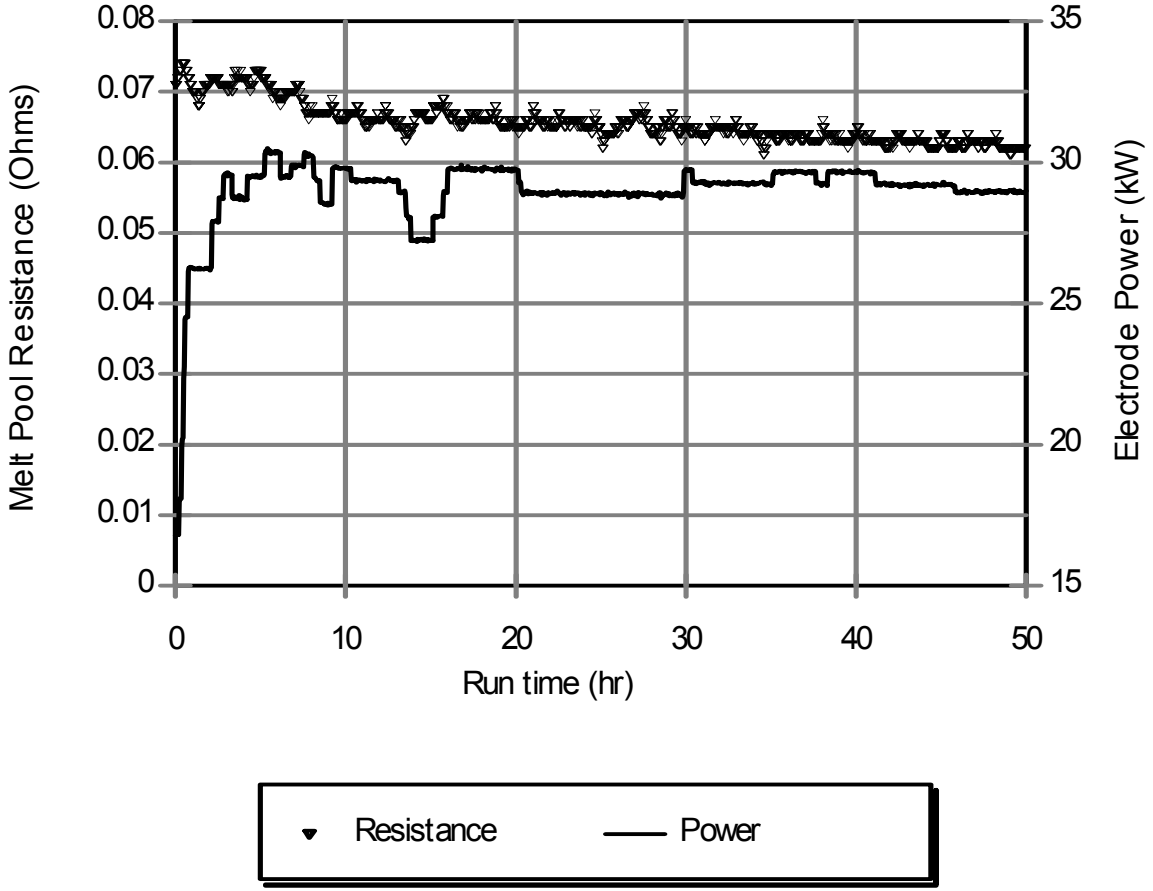


Figure 3.5.a. Melt pool resistance and total electrode power during DM100 Test 4 with A104D4-11 glass composition.

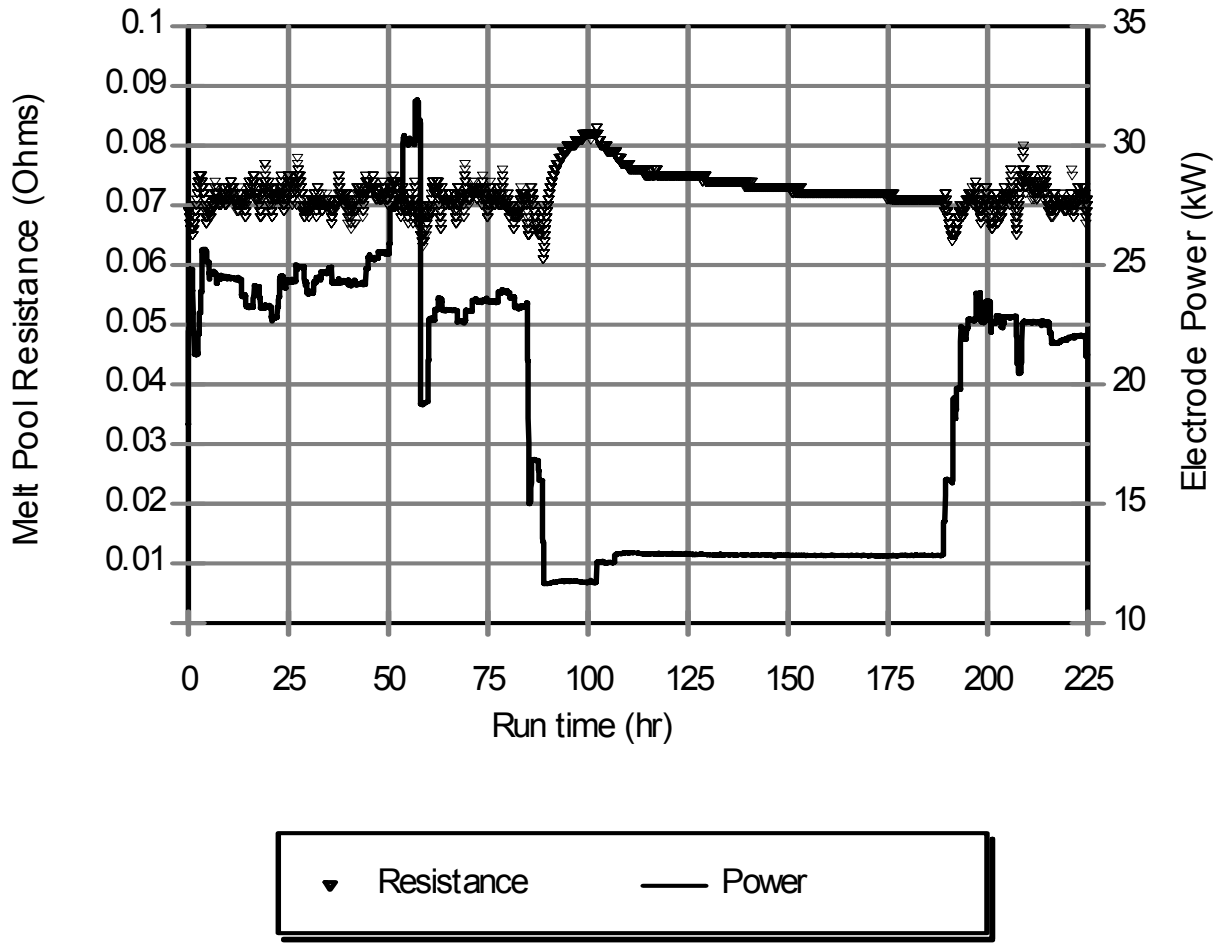


Figure 3.5.b. Melt pool resistance and total electrode power during DM100 Tests 3 and 2 with A104D4-11 glass composition and Blends 3 and 2 wastes.
Note: Melter idled between 85 and 193 hours run time.

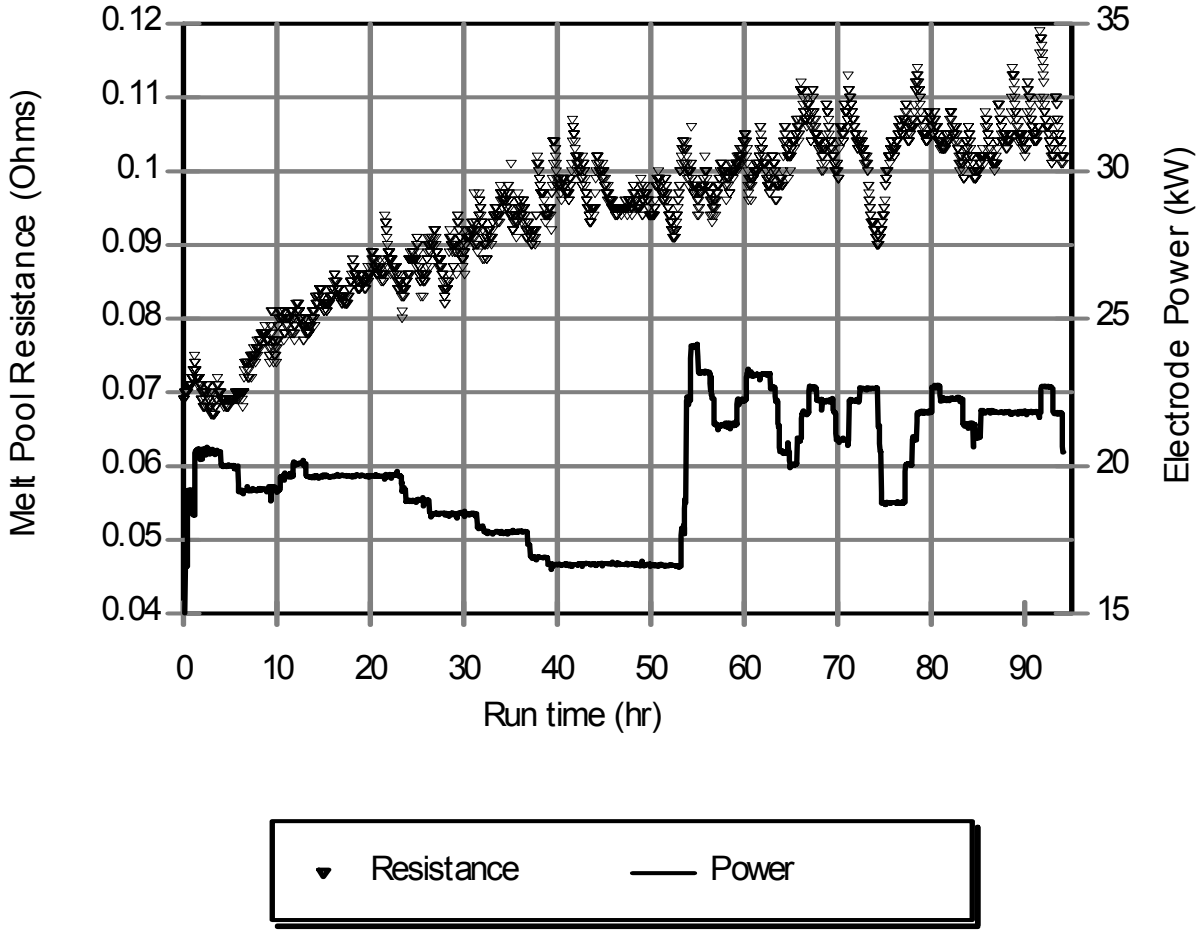


Figure 3.5.c. Melt pool resistance and total electrode power during DM100 Test 1 with A104D1-04 glass composition at 9 lpm and optimized bubbling.

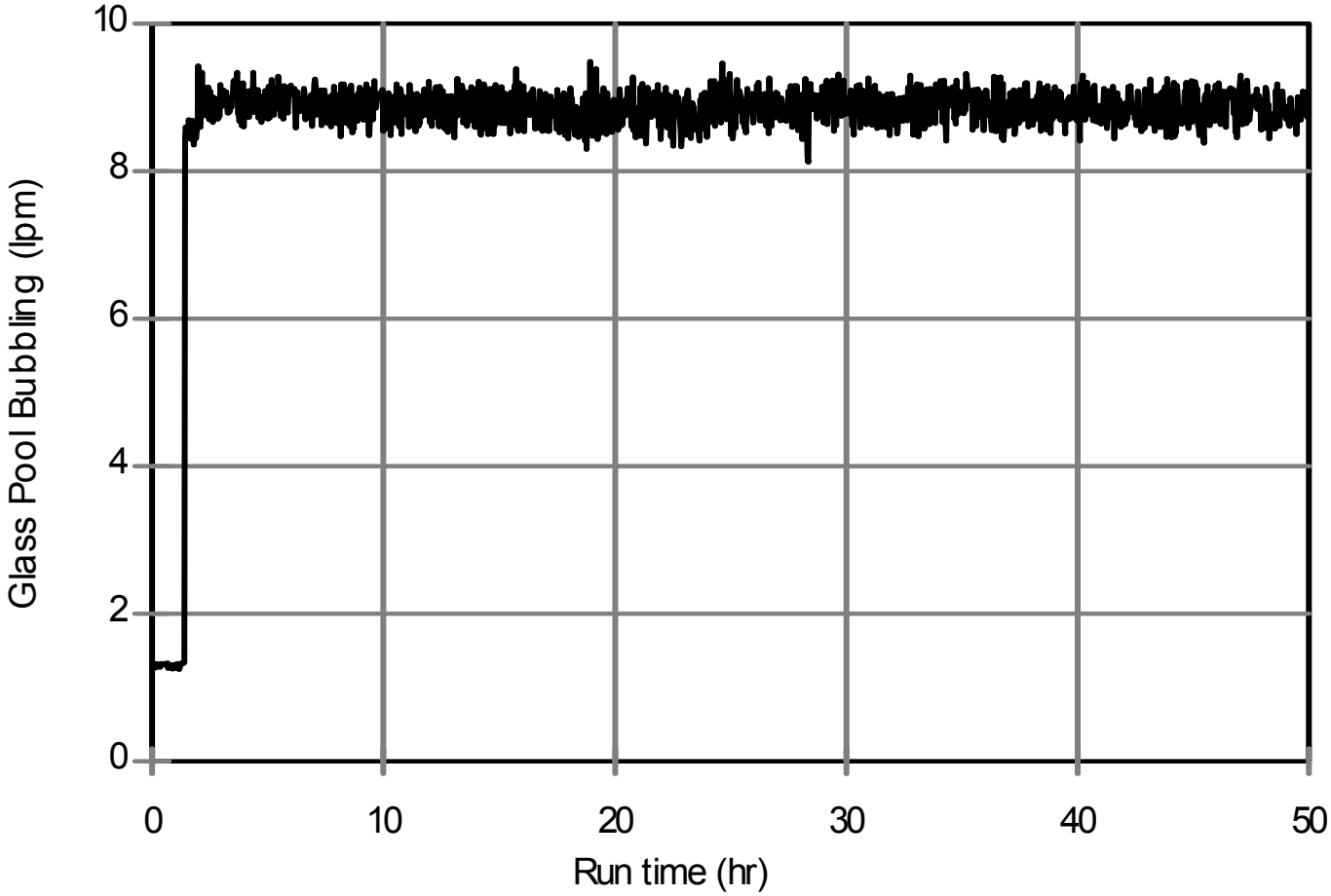


Figure 3.6.a. Melt pool bubbling during DM100 Test 4 with A104D4-11 glass composition.

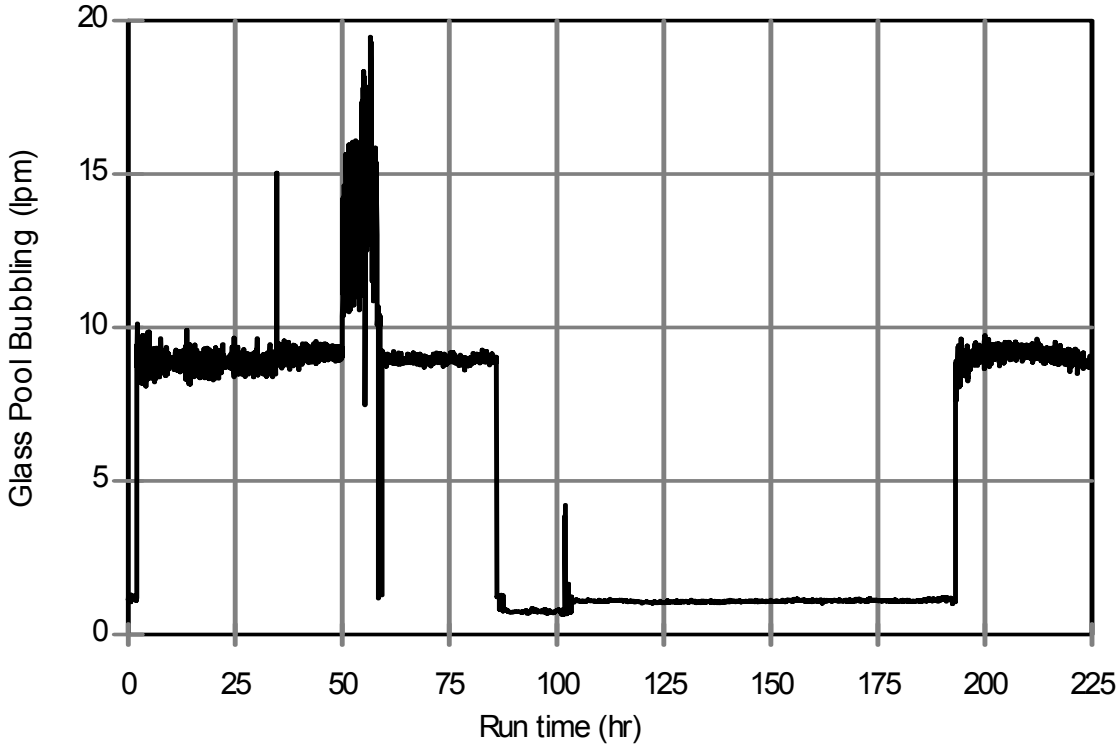


Figure 3.6.b. Melt pool bubbling during DM100 Tests 3 and 2 with A104D4-11 glass composition and Blends 3 and 2 wastes.
Note: Melter idled between 85 and 193 hours run time.

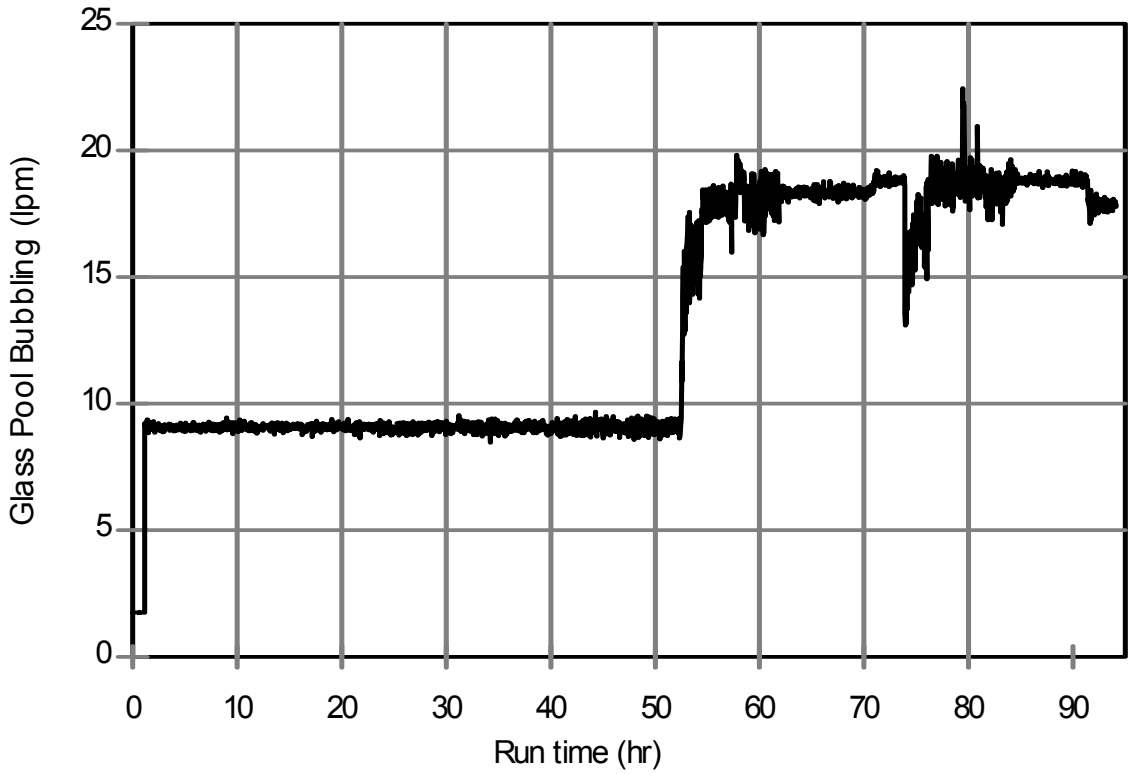


Figure 3.6.c. Melt pool bubbling during DM100 Test 1 with A104D1-04 glass composition at 9 lpm and optimized bubbling.

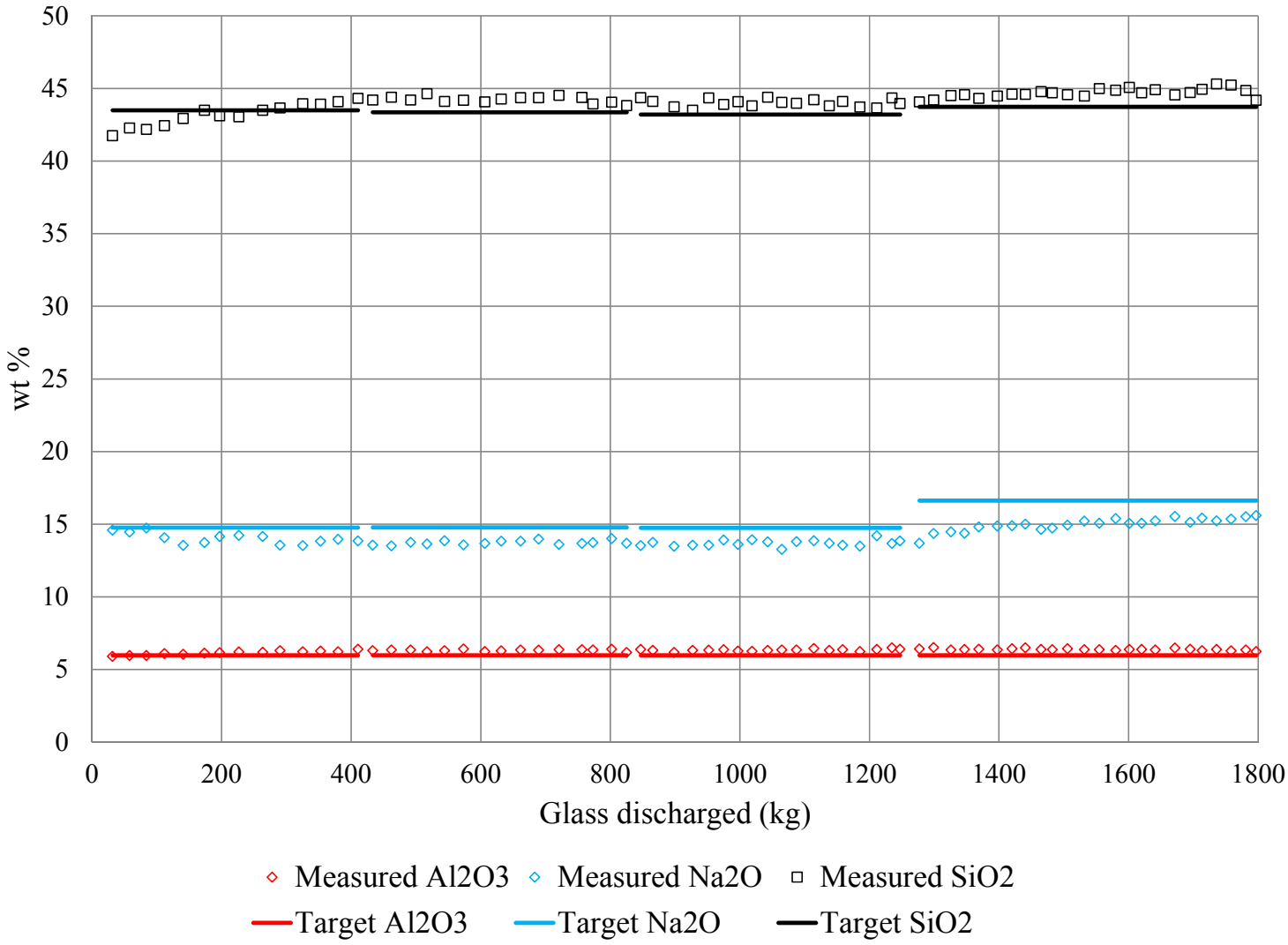


Figure 4.1.a. DM100 product and target glass compositions determined by XRF.

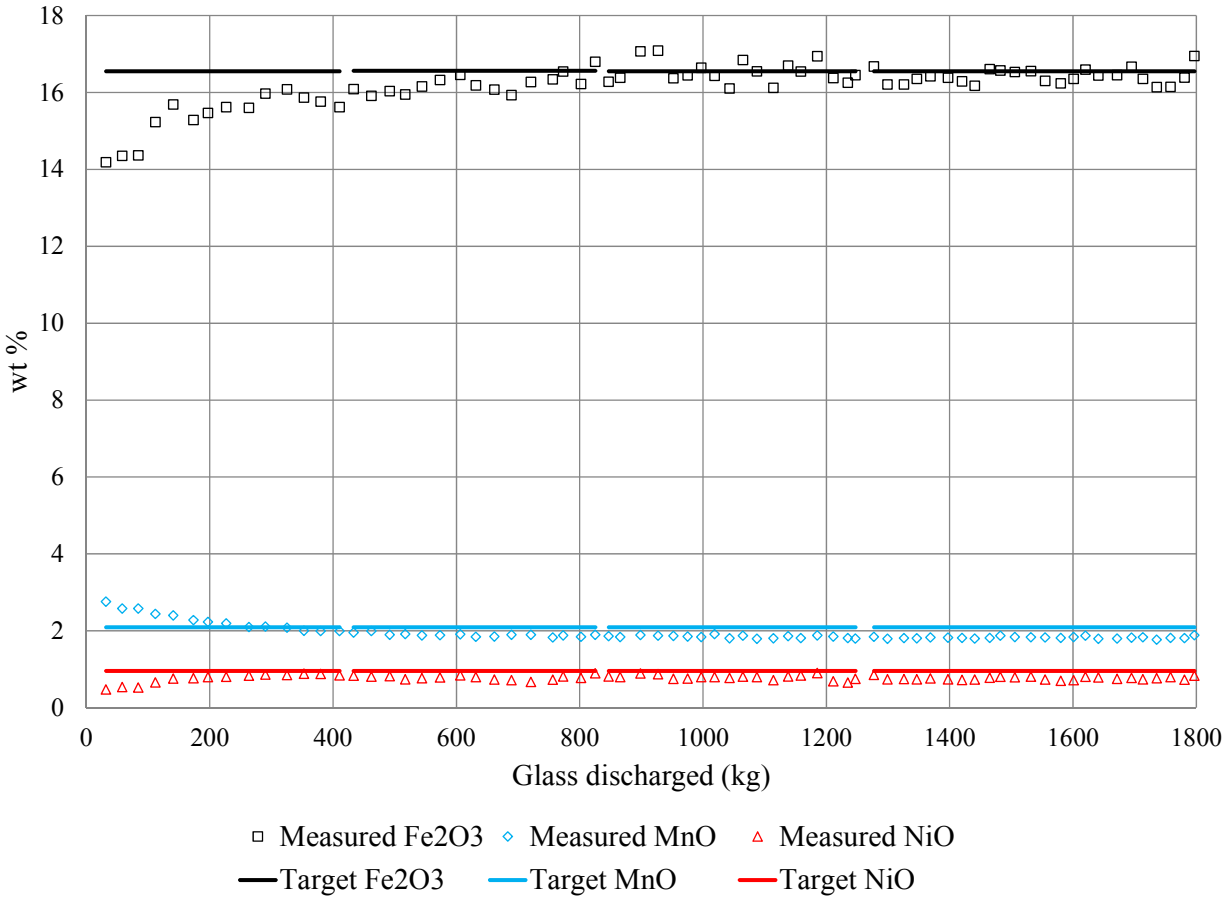


Figure 4.1.b. DM100 product and target glass compositions determined by XRF.

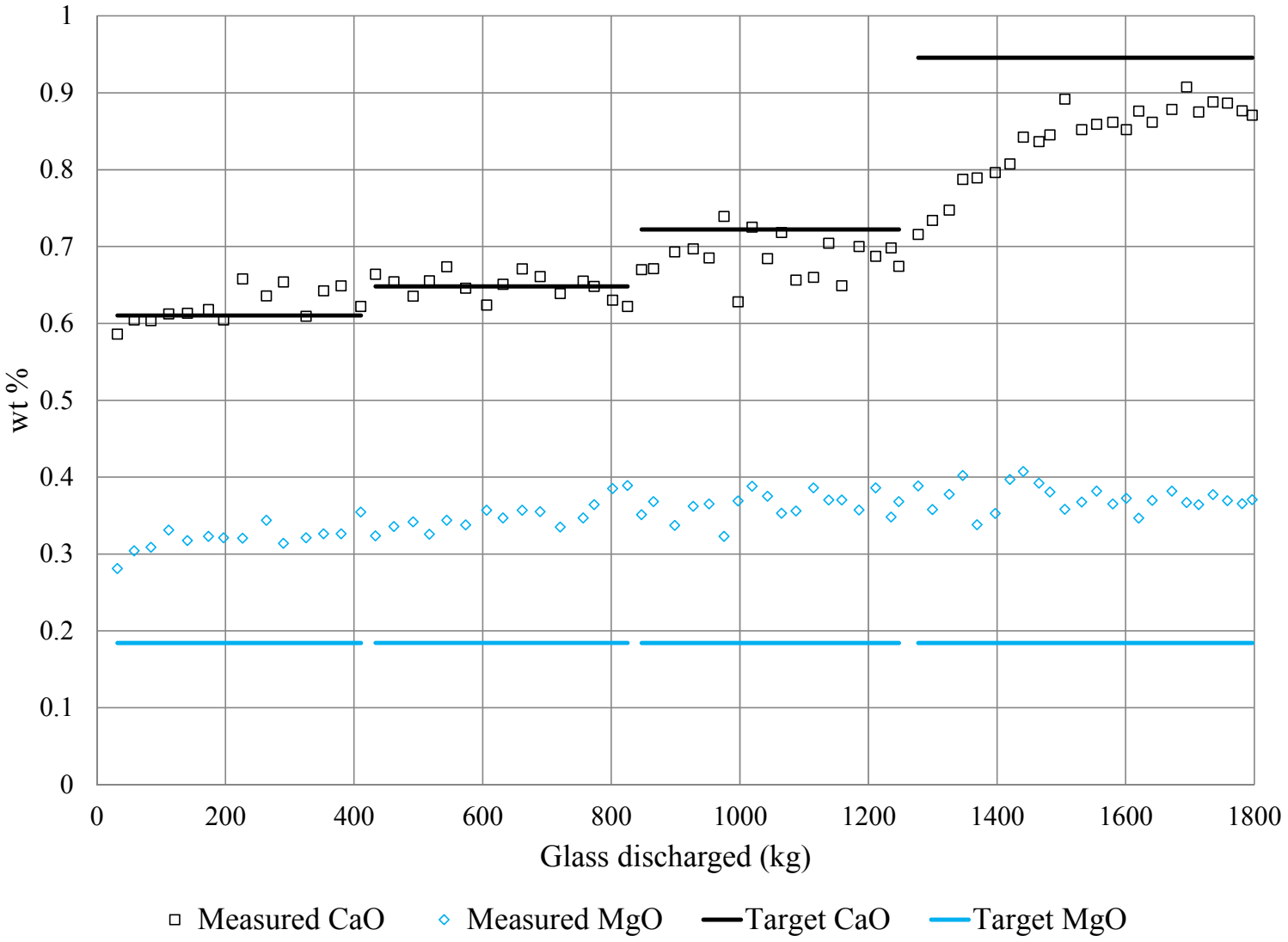


Figure 4.1.c. DM100 product and target glass compositions determined by XRF.

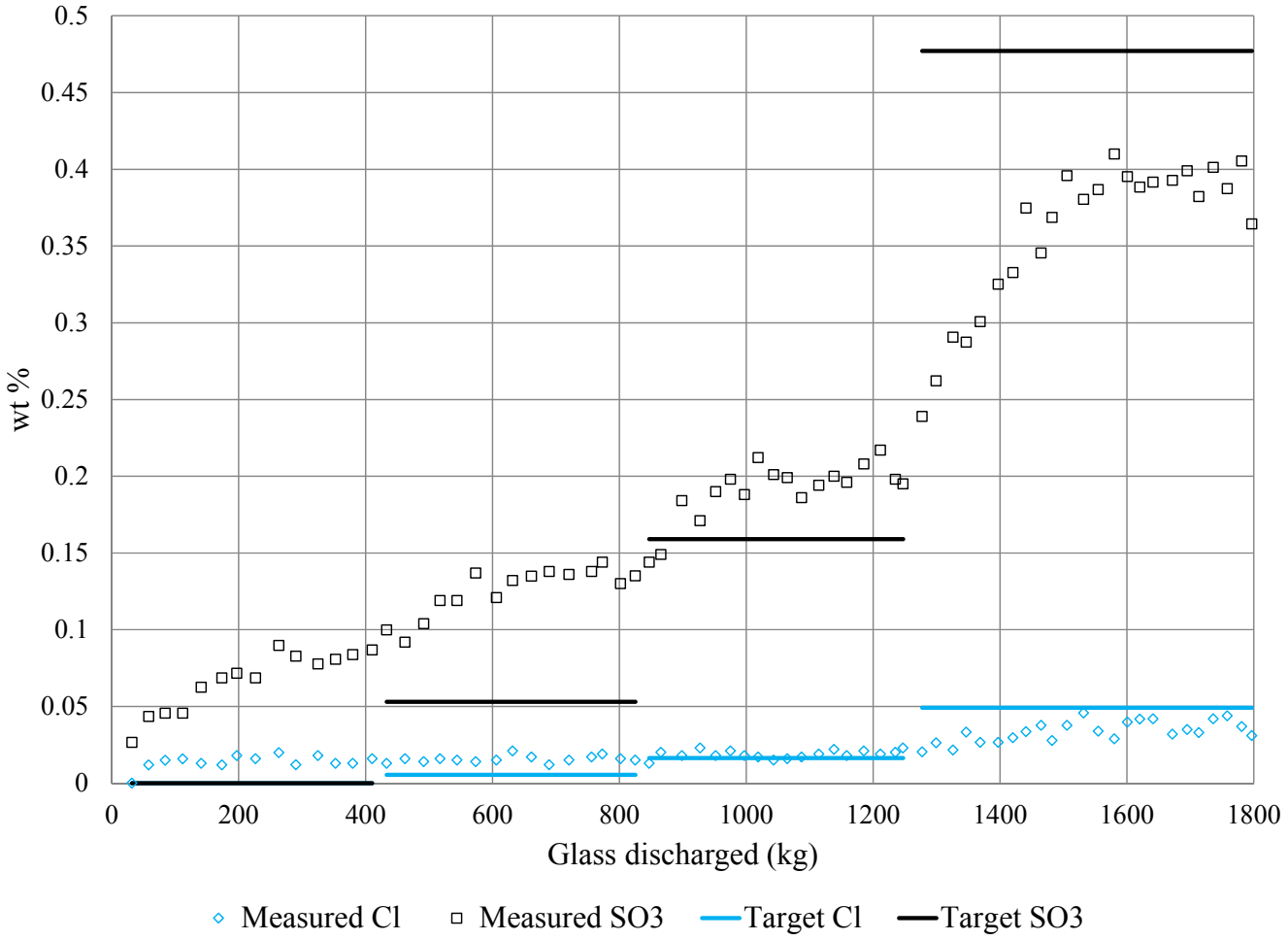


Figure 4.1.d. DM100 product and target glass compositions determined by XRF.

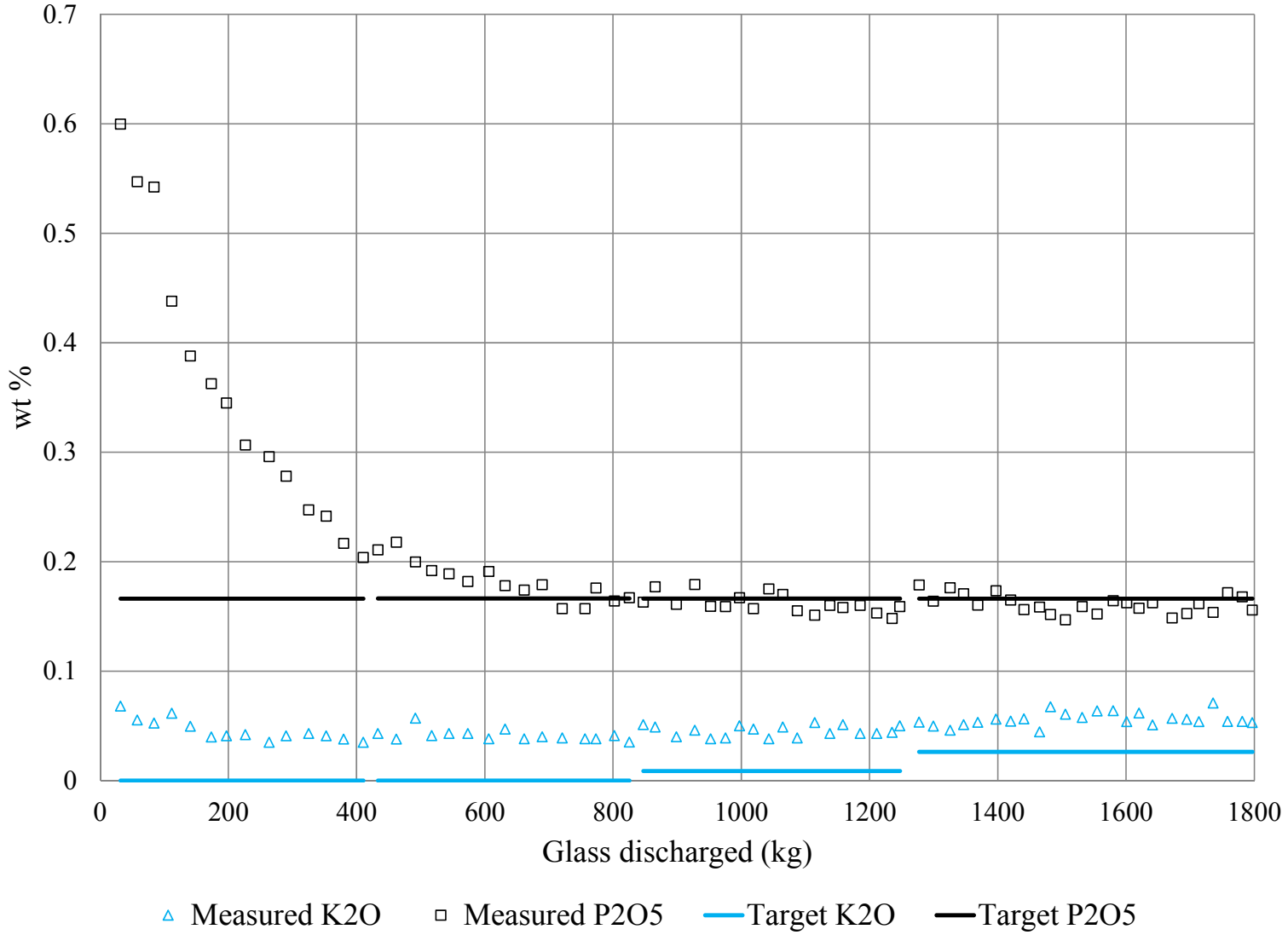


Figure 4.1.e. DM100 product and target glass compositions determined by XRF.

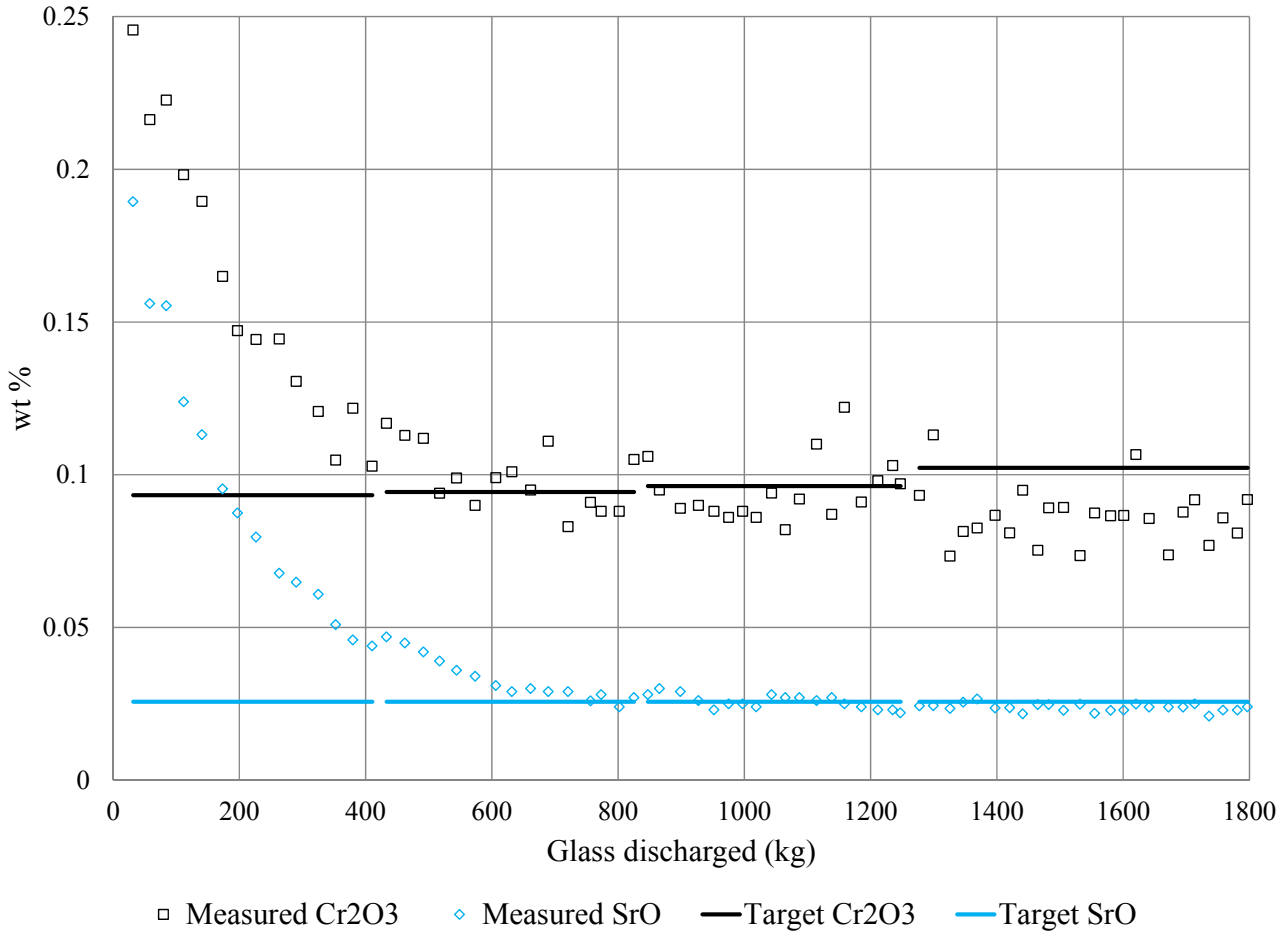


Figure 4.1.f. DM100 product and target glass compositions determined by XRF.

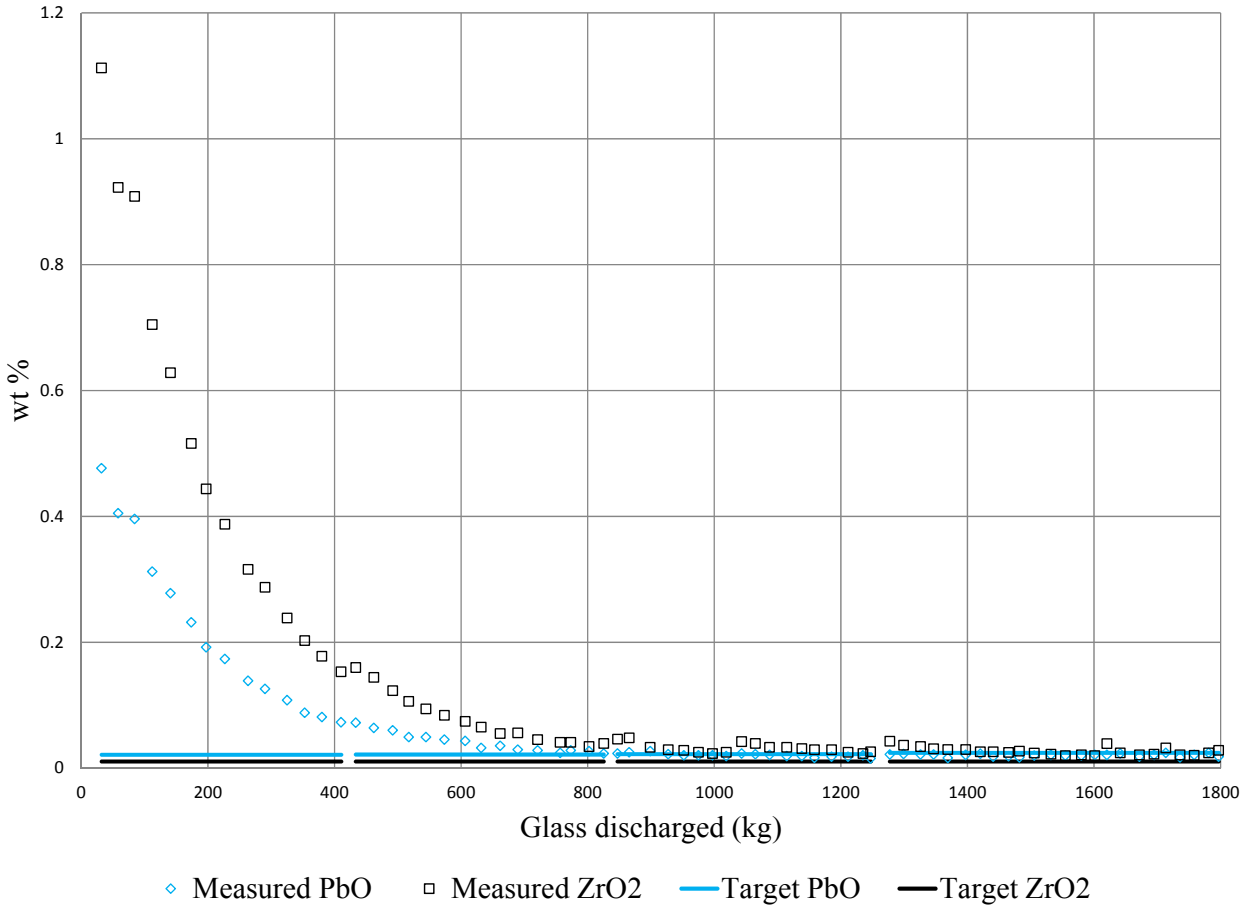


Figure 4.1.g. DM100 product and target glass compositions determined by XRF.

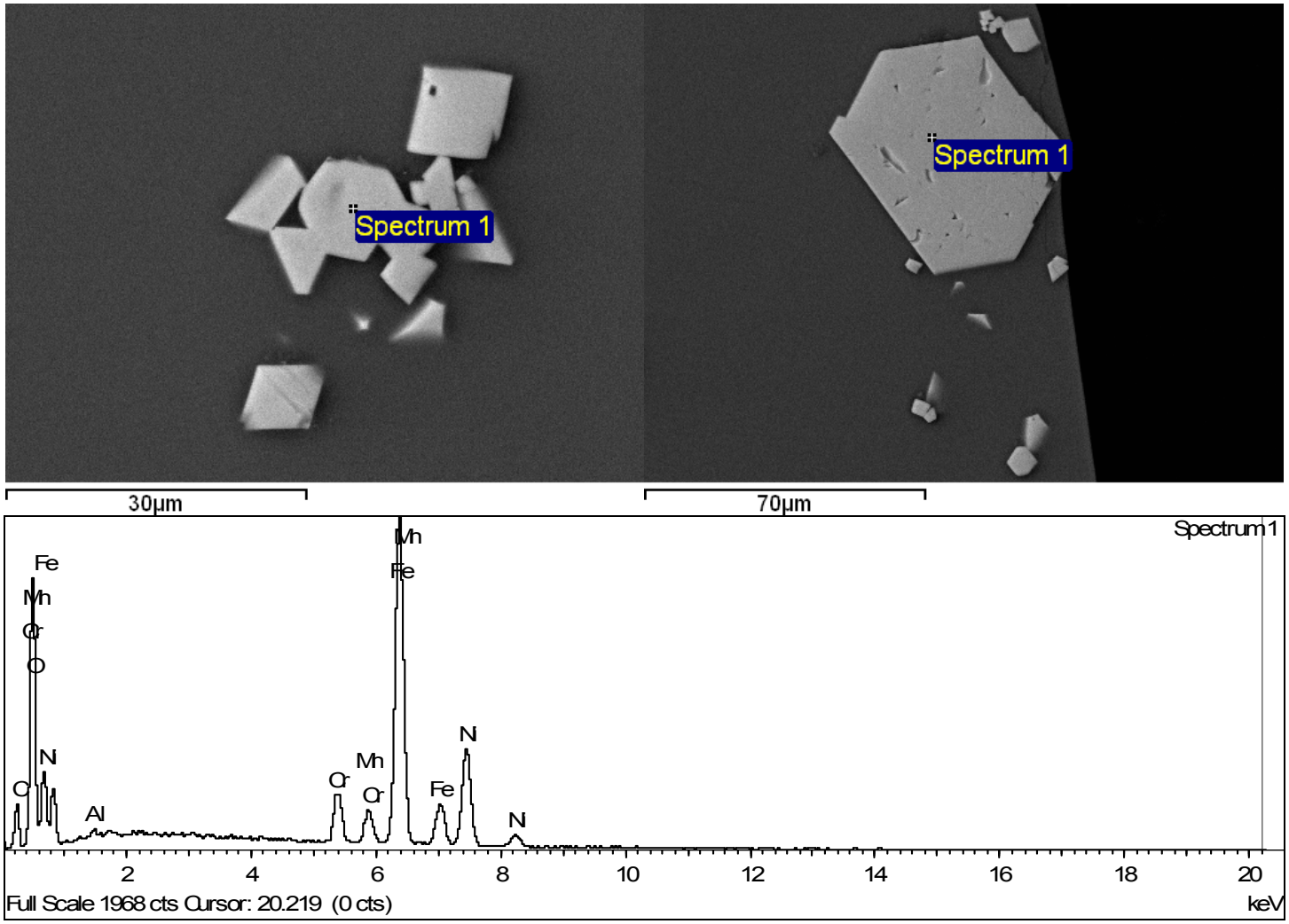


Figure 4.2. SEM micrograph of glass pool sample TBL-D-96A from the end of testing. Fe-spinel is chemically trevorite, sub-euhedral, granular, mainly 5-10 micron size with a minor 20-60 micron phenocryst and trace amount of 1-2 micron crystals, slightly clustered, and is heterogeneously distributed in the sample. The chemical composition of the crystal is relatively constant, and the spinel contains considerable levels of Cr and Mn.

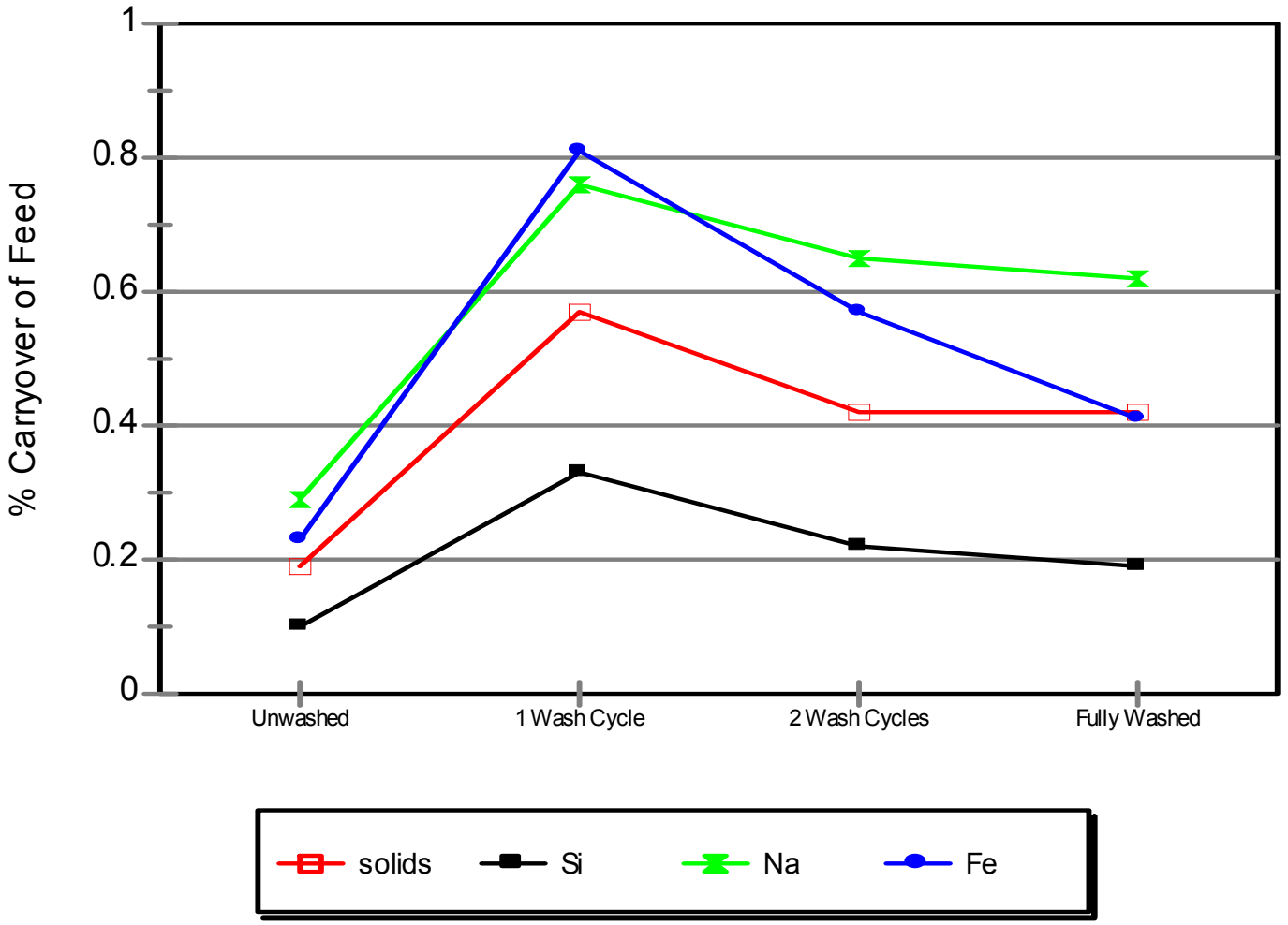


Figure 5.1.a. Percent carryover of feed constituents into the melter exhaust during DM100 tests with bubbling fixed at 9 lpm.

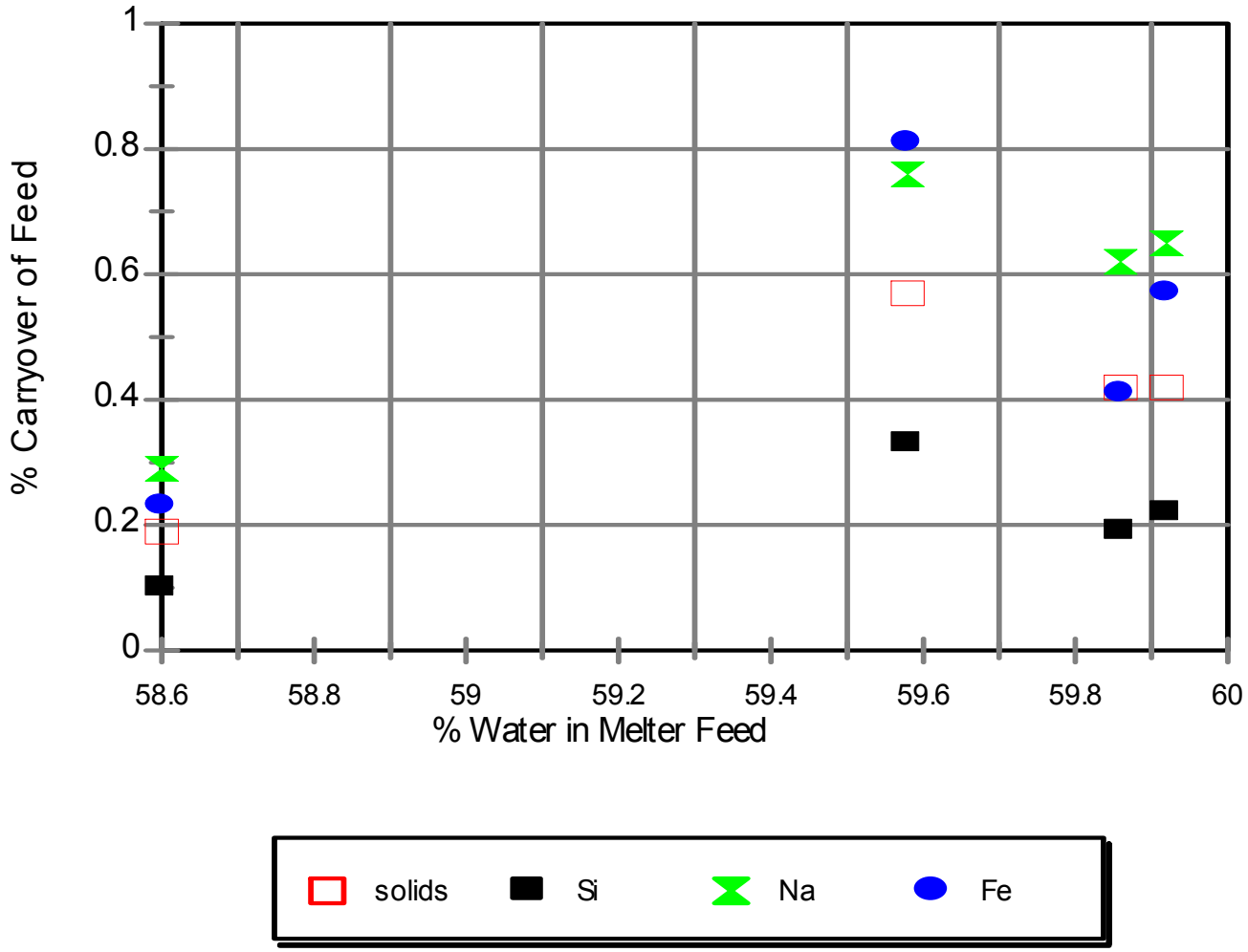


Figure 5.1.b. Percent carryover of feed constituents into the melter exhaust versus measured feed water content during DM100 tests with bubbling fixed at 9 lpm.

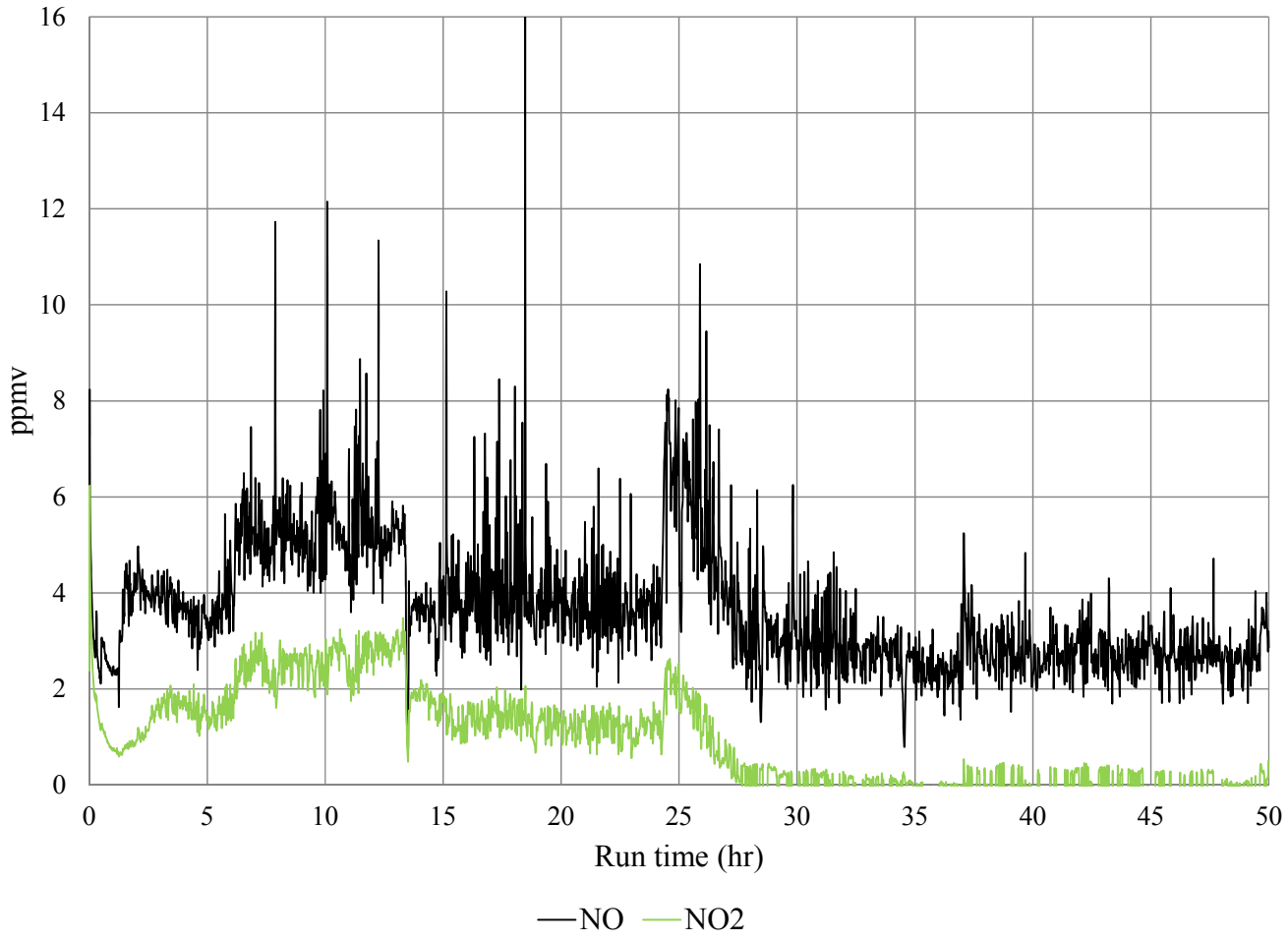


Figure 5.2.a. FTIR monitored nitrogen oxide emissions during Test 4.

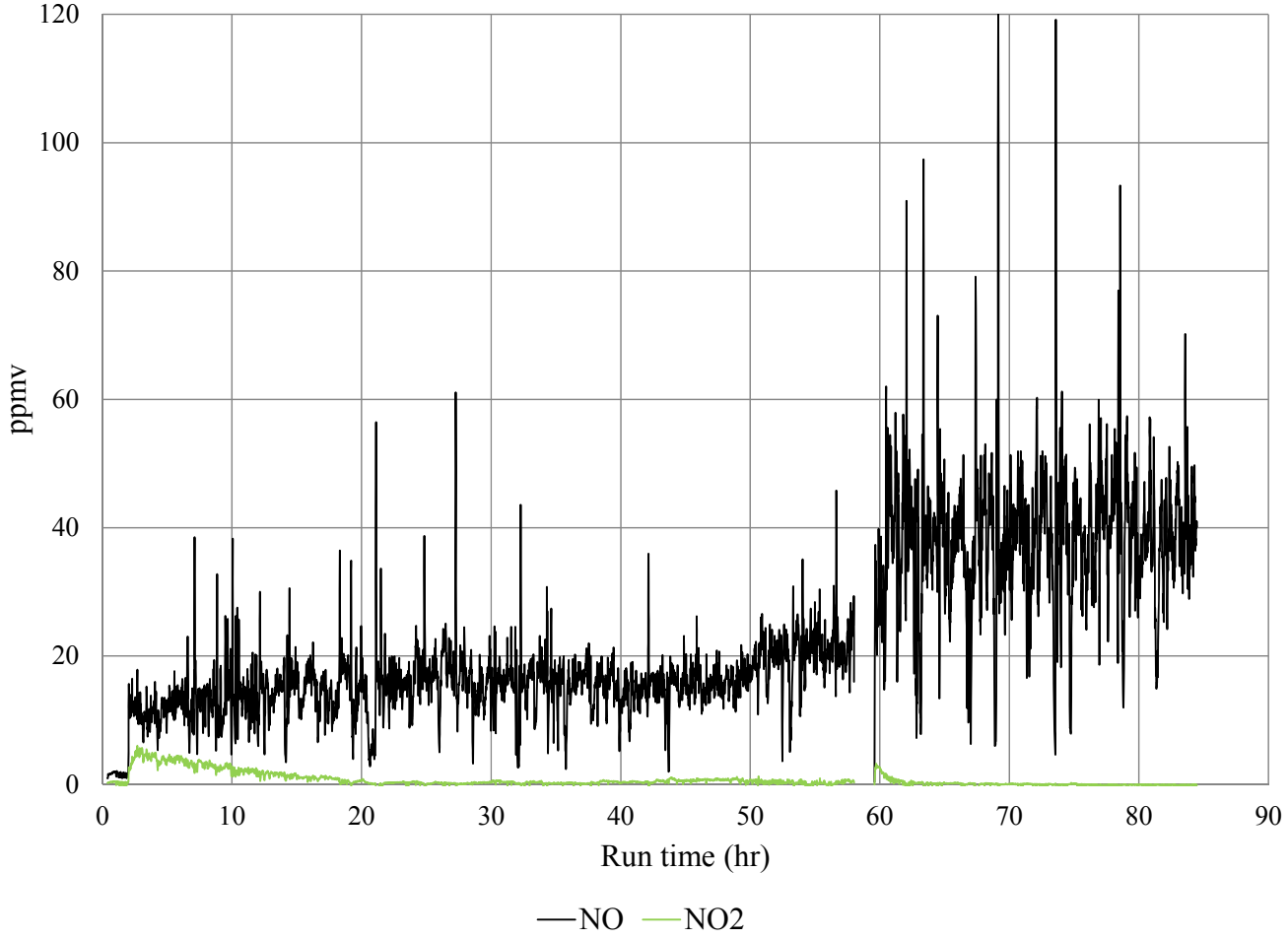


Figure 5.2.b. FTIR monitored nitrogen oxide emissions during Test 3 and the initial portion of Test 2.

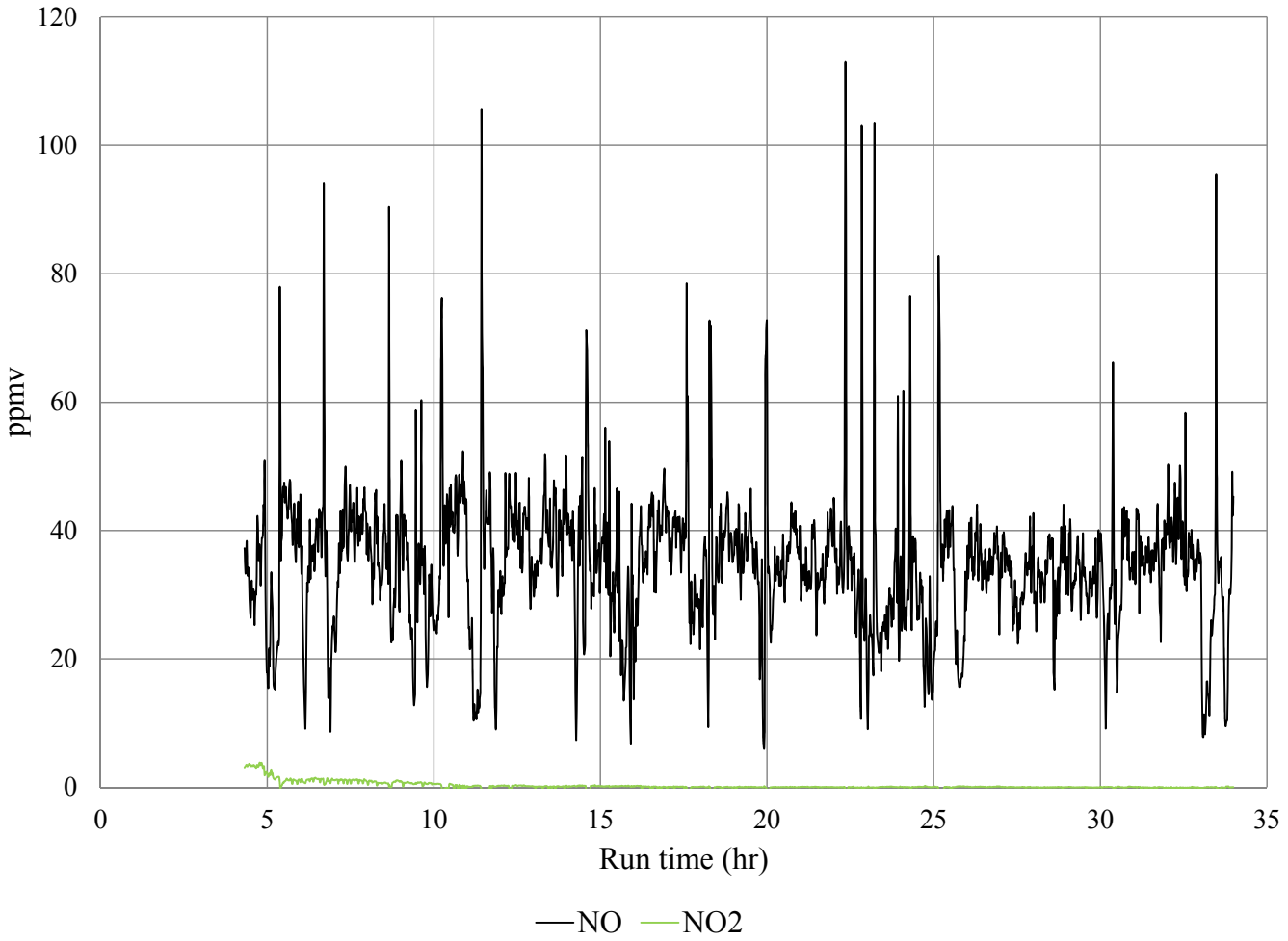


Figure 5.2.c. FTIR monitored nitrogen oxide emissions during the latter portion of Test 2.

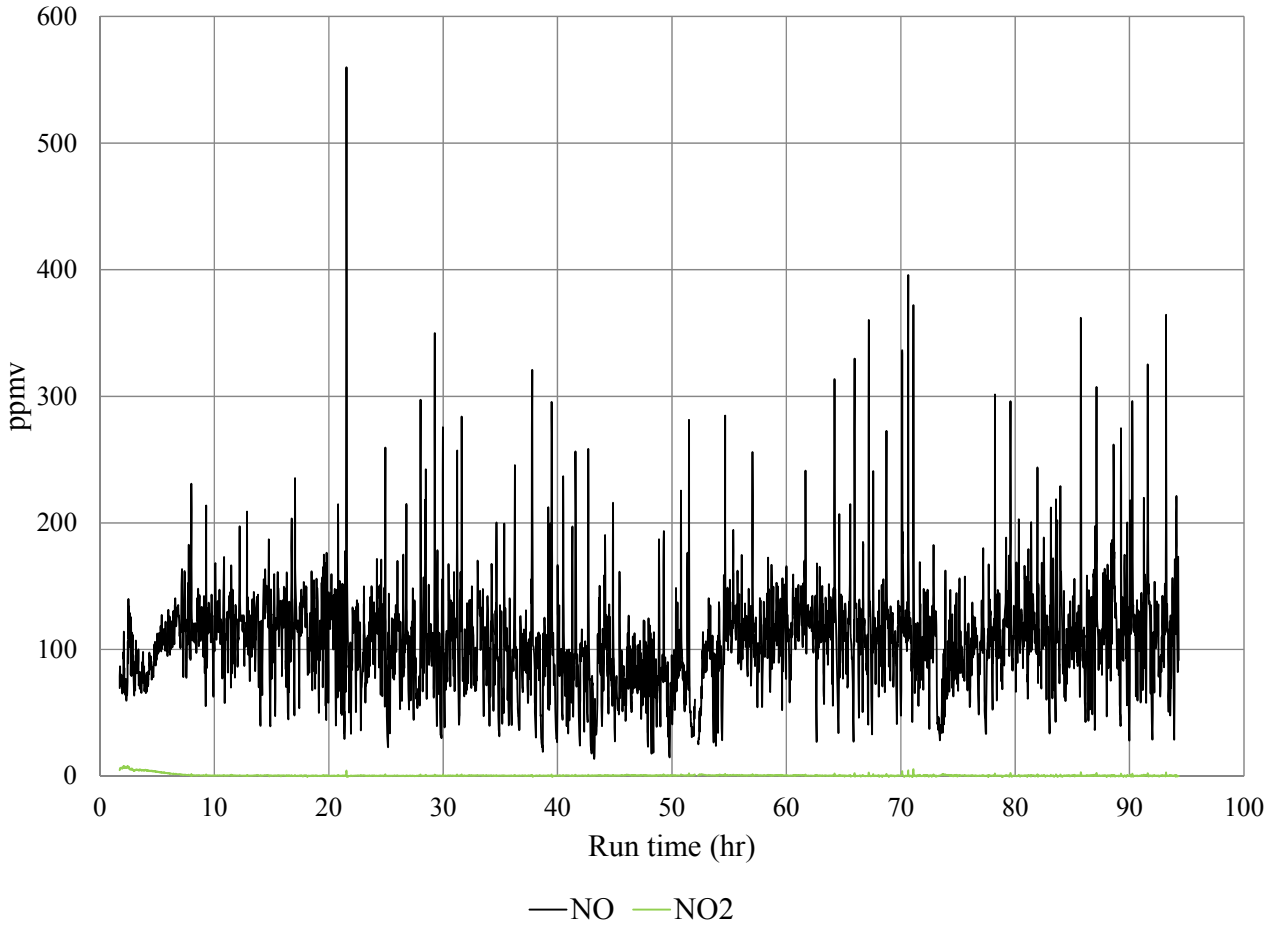


Figure 5.2.d. FTIR monitored nitrogen oxide emissions during Test 1.

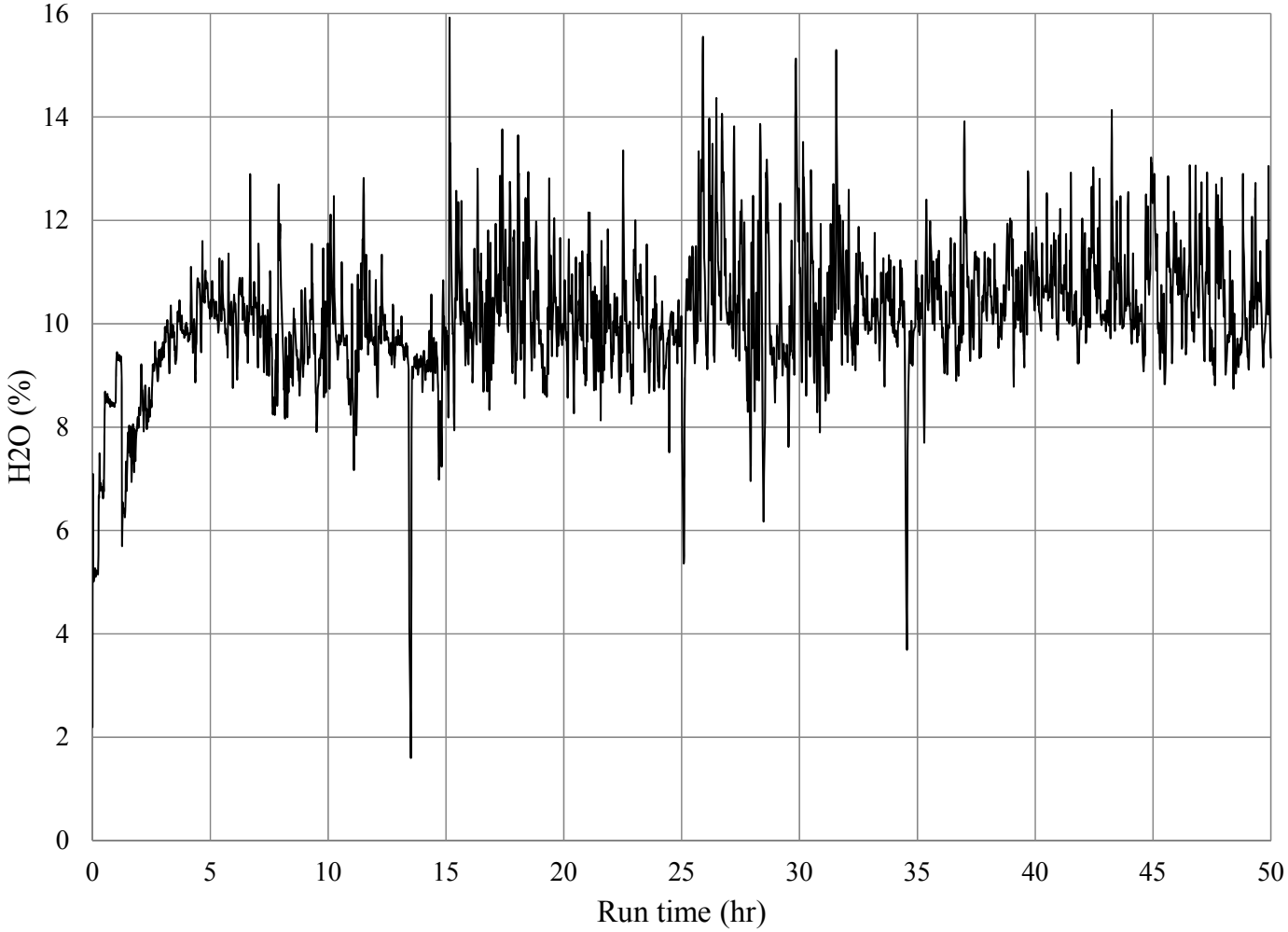


Figure 5.3.a. FTIR monitored water content in exhaust during Test 4.

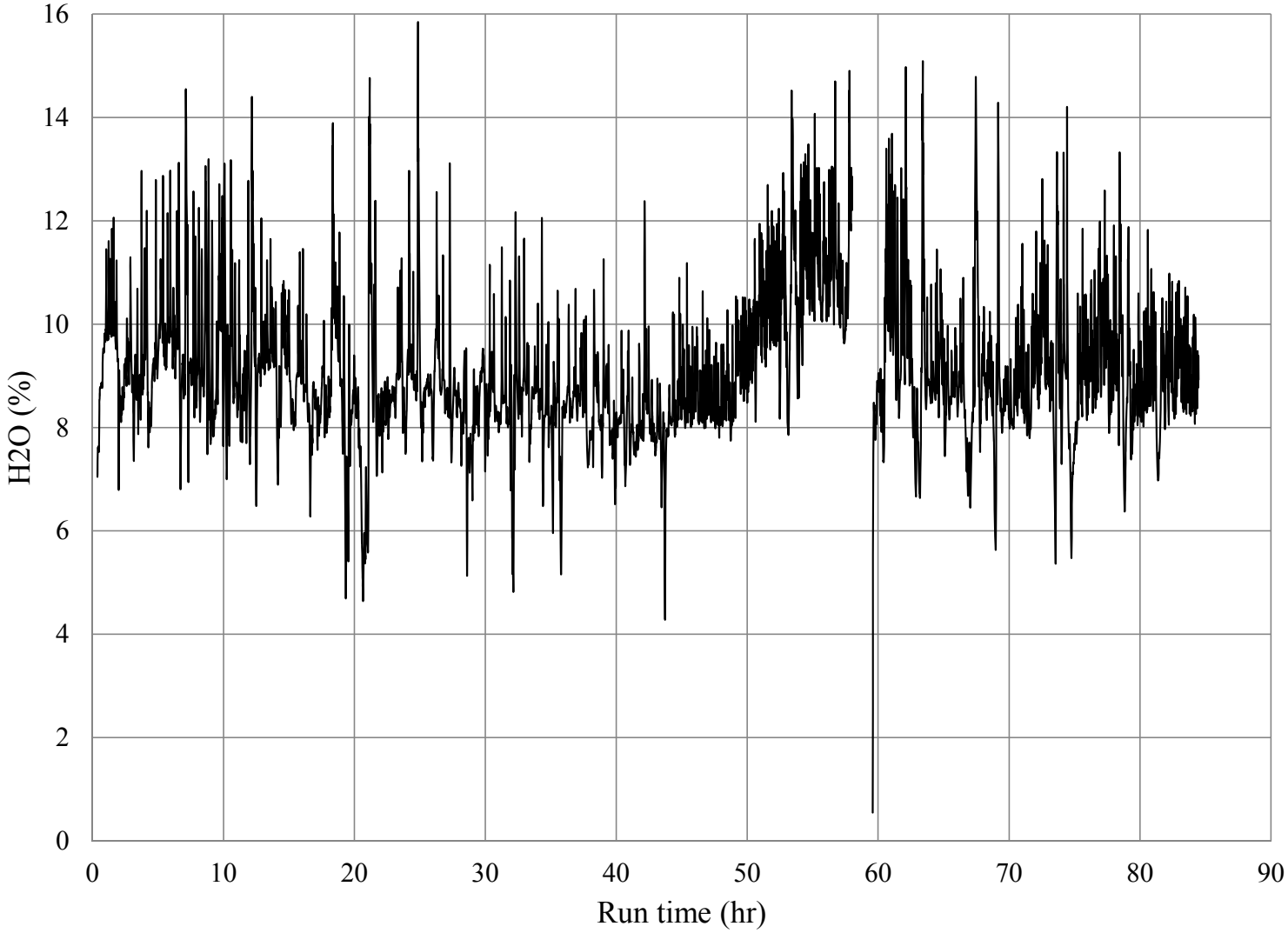


Figure 5.3.b. FTIR monitored water content in exhaust during Test 3 and the initial portion of Test 2.

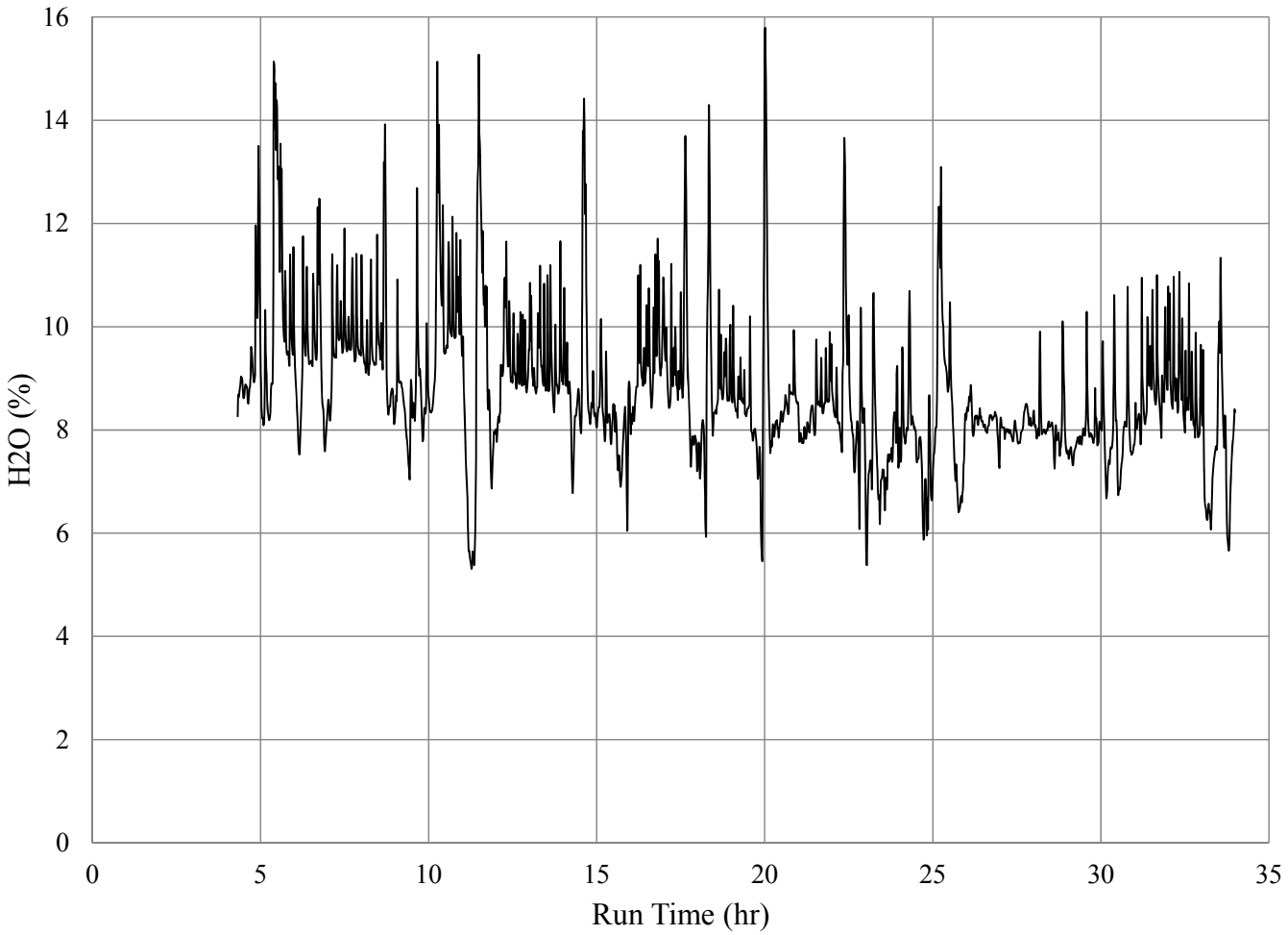


Figure 5.3.c. FTIR monitored water content in exhaust during the latter portion of Test 2.

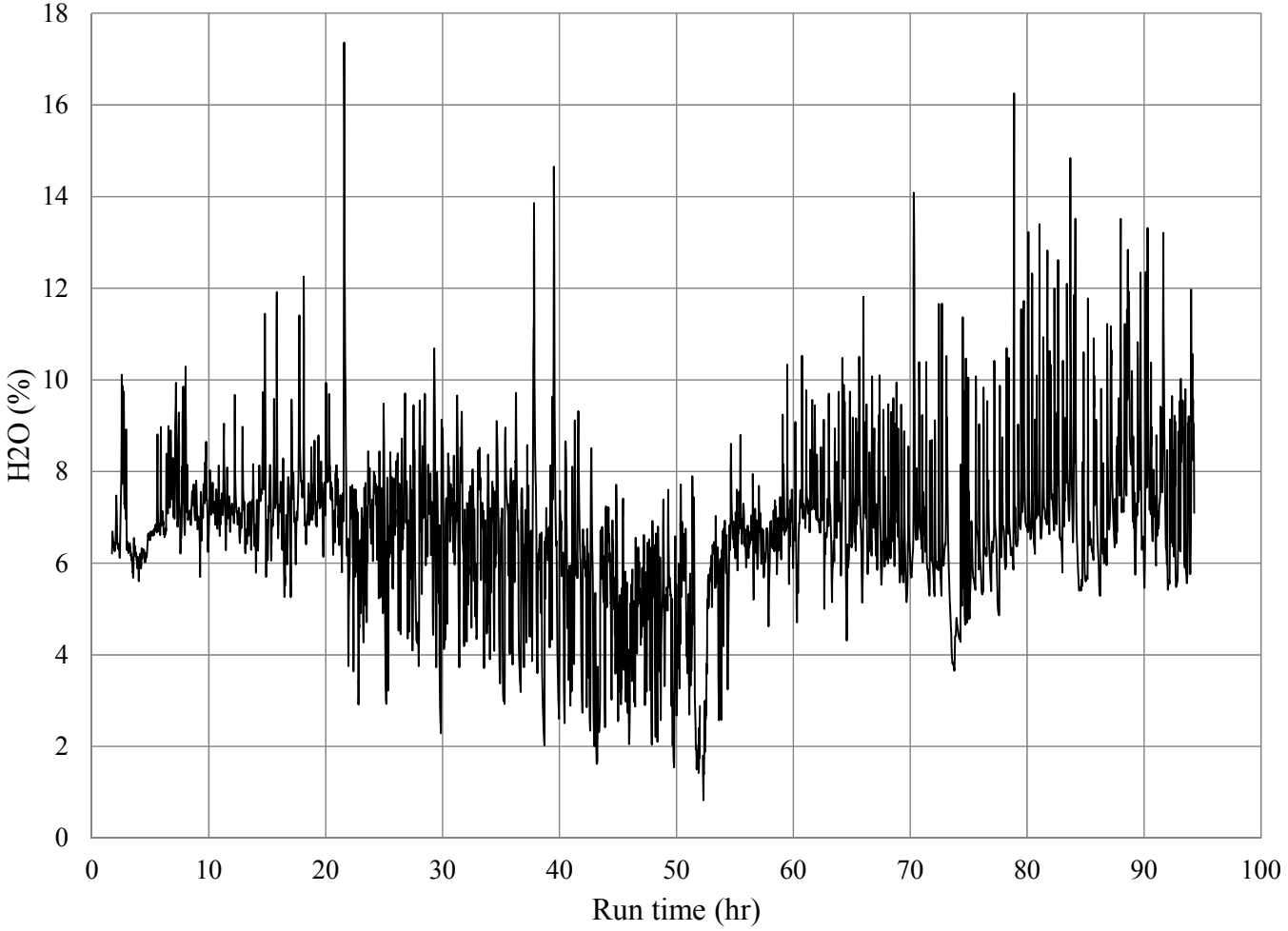


Figure 5.3.d. FTIR monitored water content in exhaust during Test 1.

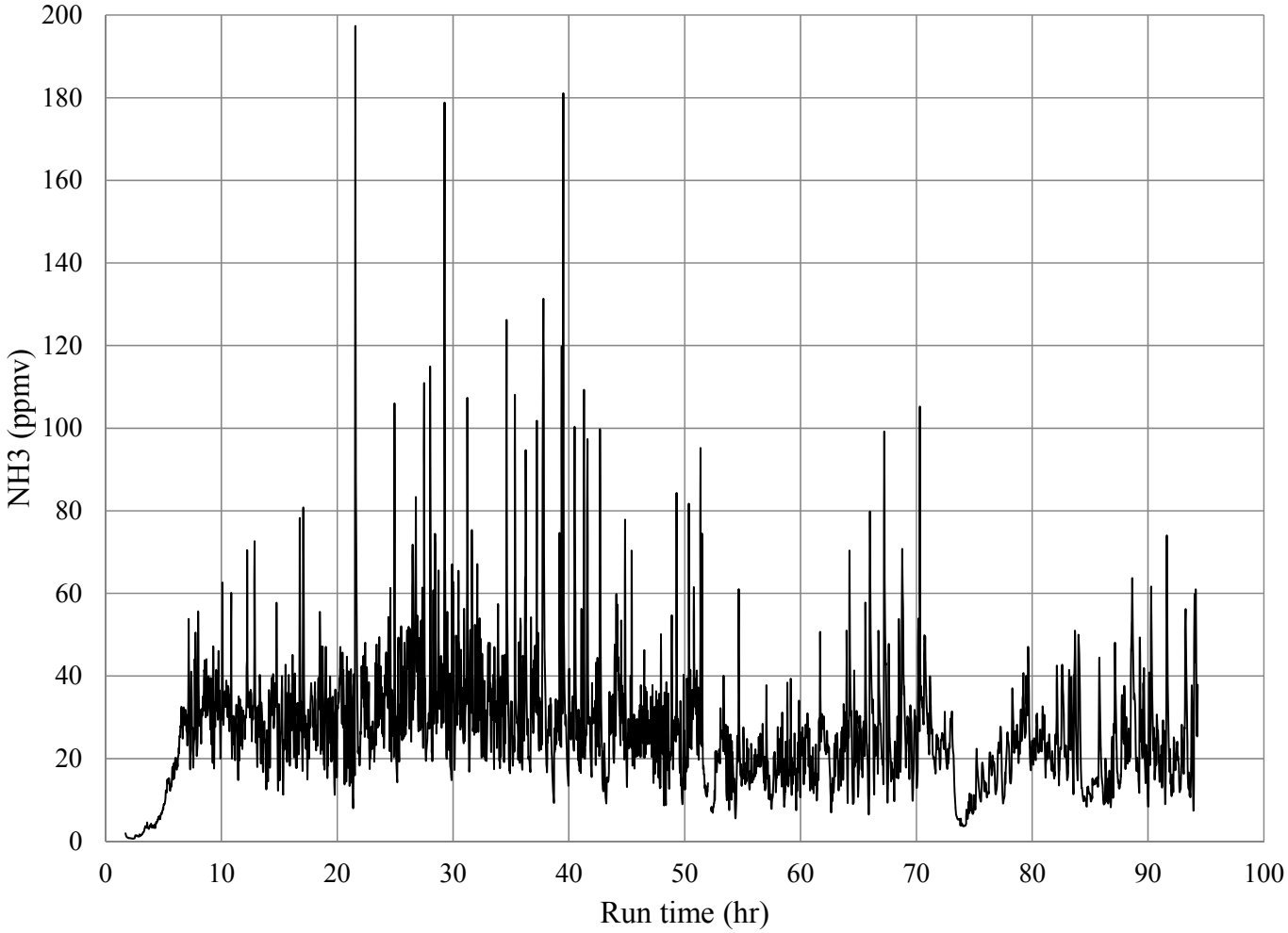


Figure 5.4. FTIR monitored ammonia content in exhaust during Test 1.

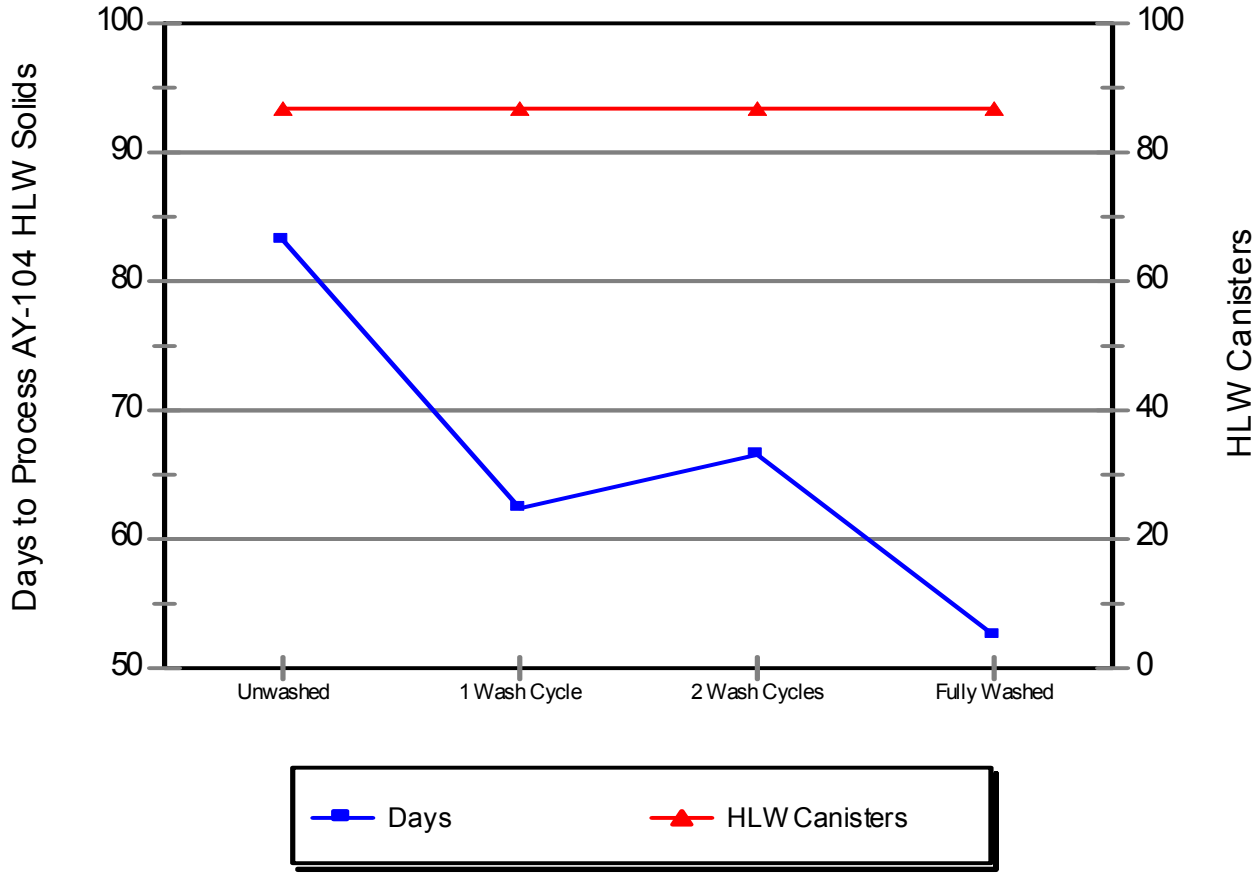


Figure 6.1. Time (at 70% TOE) and number of HLW canisters required to process the 78,000 kg of HLW oxides in tank A-104.