Small-Scale Melter Testing with LAW Simulants to Assess the Impact of Higher Temperature Melter Operations

**Final Report, VSL-04R4980-1, Rev. 0, 2/13/03, Vitreous State
Laboratory, The Catholic University of America, Washington,
D.C.**

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

**P.O. Box 450
Richland, Washington 99352**

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Final Report

**Small-Scale Melter Testing with LAW Simulants to Assess the
Impact of Higher Temperature Melter Operations**

prepared by

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for

Duratek, Inc.

and

**Department of Energy
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Test Plan: Small Scale Melter Testing to Assess Impact of Higher Temperature Melter Operations, VSL-03T4980-1, 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.

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List of Abbreviations

AA	Atomic Absorption Spectroscopy
ADS	Air Displacement Slurry
DCP-AES	Direct Current Plasma Atomic Emission Spectroscopy
DF	Decontamination Factor
DM	DuraMelter®
DOE	Department of Energy
EPA	Environmental Protection Agency
FTIR	Fourier Transform Infrared Spectroscopy
GC	Gas Chromatography
HEPA	High-Efficiency Particulate Air Filter
HLW	High Level Waste
LAW	Low Activity Waste
M	Molarity
N	Normality
ORP	Office of River Protection
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
RPP	River Protection Project
VSL	Vitreous State Laboratory
WTP	Waste Treatment and Immobilization Plant
XRF	X-Ray Fluorescence

SECTION 1.0 INTRODUCTION

About 50 million gallons of high-level mixed waste is currently in storage in underground tanks at The United States Department of Energy's (DOE's) Hanford site in the State of Washington. The Hanford Tank Waste Treatment Plant (WTP) will provide DOE's Office of River Protection (ORP) with a means of treating this waste by vitrification for subsequent disposal. The tank waste will be separated into low- and high-activity fractions, which will then be vitrified respectively into Immobilized Low Activity Waste (ILAW) and Immobilized High Level Waste (IHLW) products. The ILAW product will be disposed of in an engineered facility on the Hanford site while the IHLW product will be directed to the national deep geological disposal facility for high-level nuclear waste. The ILAW and IHLW products must meet a variety of requirements with respect to protection of the environment before they can be accepted for disposal.

The Office of River Protection is currently examining options to optimize the Low Activity Waste (LAW) Facility and the LAW glass waste form. One option under evaluation is to enhance the waste processing rate of the vitrification plant currently under construction. It is likely that the capacity of the LAW vitrification plant can be increased incrementally by implementation of a variety of low-risk, high-probability changes, either separately or in combination. These changes include:

- Operating at the higher processing rates demonstrated at the LAW pilot melter
- Increasing the glass pool surface area within existing external melter envelope
- Increasing plant availability
- Increasing the glass waste loading
- Removing sulfate from the LAW stream
- Operating the melter at slightly higher temperature
- Installing the third LAW melter into the WTP plant
- Other smaller impact changes

The Vitreous State Laboratory at The Catholic University of America (VSL) and Duratek, Inc. are evaluating several of these potential incremental improvements for ORP in support of its evaluation of WTP LAW facility optimization [1]. The present report focuses on the effect of slightly higher melter operating temperature (1175 to 1225°C instead of the current 1150°C) on processing rate. Although melt rates generally increase with temperature, so do the challenges imposed on the melter materials of construction and, ultimately, the melter design. The present work was therefore limited to modest temperature increases in order to limit these impacts while reaping the potential low-risk benefits of increased glass production rates.

The Vitreous State Laboratory is also developing and testing glass formulations for WTP waste envelopes to provide data to meet the WTP contract requirements and to support system design activities [2]. That work is based upon small-scale batch melts ("crucible melts") using waste simulants. Selected formulations have also been tested in small-scale, continuously-fed,

joule-heated melters (DM10 and DM100 systems) [3-8] and, ultimately, in the LAW Pilot Melter [9-15]. Such melter tests provide information on key process factors such as feed processing behavior, dynamic effects during processing, sulfate incorporation, processing rates, off-gas amounts and compositions, foaming control, etc., that cannot be reliably obtained from crucible melts. This sequential scale-up approach in the vitrification testing program ensures that maximum benefit is obtained from the more costly pilot-scale tests and that the most effective use is made of that resource. Consistent with that proven testing approach, the principal objective of the work reported here was to collect the necessary small-scale melter test data while operating at higher temperatures to support subsequent larger-scale tests on the LAW Pilot Melter; the results of those tests will be reported separately. The present work was performed in accordance with a corresponding Test Plan that was prepared for ORP [16].

Consistent with the general increase of reaction rates with temperature, it is expected, and found [17-19], that melter processing rates increase with increasing operating temperature. WTP LAW feeds would also be expected to process faster at higher temperatures but the extent of this effect for relatively modest temperature increases (i.e., within the operational limits of the materials of construction) is not known. Furthermore, the solubility of sulfate, its rate of incorporation, and its partitioning between the glass and the off-gas stream are all temperature dependent; the direction of these effects generally favors increased sulfate tolerance with increasing temperature. Again, the magnitude of these effects for WTP LAW feeds for relatively modest temperature increases is not known. Any increase in the partitioning of sulfur to the off-gas stream at higher temperatures would lead to increases in waste loading provided the current WTP recycle loop can be broken (i.e., if the sulfur collected in the off-gas system is not recycled to the melter feed, as is currently the case). Clearly, increases in processing rate and/or waste loading could reduce the operating time required for the WTP to process the same quantity of waste. The present tests represent a first step in assessing the potential benefits of these effects.

The tests described in this report utilized blended feed (glass formers plus waste simulant) prepared by Optima Chemicals according to VSL specifications. Sufficient feed was prepared to produce nearly two metric tons of glass. Sugar was added (at VSL) to the feed at a ratio of 0.5 (1 mole sucrose per 16 mole NO_x). The DM100-WV melter was used in order to provide a direct comparison with the LAW tests previously conducted on the same melter [3-8]. Two 75-hour melter tests were conducted at two elevated temperatures, 1175 and 1225°C. These tests were preceded by the production of sufficient glass to turn over the melt pool to the target composition. Key operating parameters were held constant to investigate the effects of the operating temperature on processing characteristics, particularly melting rate. At each operating temperature, the feed rate was adjusted to provide a near-complete cold cap (90-100% of melt surface covered with feed). Quantitative measurements of glass production rates, melter operating conditions (temperatures, pressures, power, flows, etc.), and off-gas characteristics (NO_x, SO₂, CO, particulate load and composition, and acid gases) were made for each test.

1.1 Test Objectives

The principal objectives of the DM100 tests were to determine the processing characteristics of a LAW Envelope A melter feed at elevated temperatures, to demonstrate the robustness of the vitrification process with respect to operation at increased temperature, and to serve as screening tests prior to the corresponding larger-scale tests on the LAW Pilot Melter. These tests provided information on the effects of higher operating temperature on LAW feed processing rate, as well as sulfur incorporation and partitioning.

The DM100 melter tests were conducted at 1175 and 1225°C, which spans the range that was subsequently tested successfully on the LAW Pilot Melter (tests were conducted at 1175, 1200 and 1225°C). The processing rate information as a function of temperature that is most relevant for large-scale processing will be obtained from the LAW Pilot melter.

Two DM100 melter tests were conducted using a LAW Envelope A feed based on a glass composition that was formulated for higher temperature (1175 – 1225°C) operations. One of the objectives of this test was to confirm that only single-phase glass was being produced. Accordingly, the melt pool was examined at the end of each feeding period to verify that no separate sulfate phase was detectable. Crucible-scale tests were conducted prior to the melter tests to confirm that the glasses and feeds were processable in the melter and that the glasses met the waste form (ILAW) performance requirements.

Thus, the major objectives of these tests were to:

- Perform tests on the DM100-WV system using a LAW -Envelope A feed formulated for higher temperature (1175 – 1225°C) operations.
- Demonstrate sustained processability and product quality while operating at 1175 and 1225°C.
- Collect melter emissions data to determine the effect of temperature on melter emissions.
- Collect and analyze discharged glass to determine sulfur retention in the glass.
- Prepare and characterize feeds and glasses to confirm that the feeds and the glass-melts are suitable for processing in the DM100 and LAW Pilot Melters.
- Prepare and characterize glasses to confirm that the glasses meet the waste form (ILAW) performance requirements.
- Provide supporting data necessary to ensure the success of the larger-scale Pilot Melter tests.

1.2 Quality Assurance

This work was conducted under an NQA-1 (1989) and NQA-2a (1990) Part 2.7 based quality assurance program that is in place at the VSL. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work [20] that is conducted at VSL. Test and procedure requirements by which the testing activities were planned and controlled are defined in the Test Plan [16]. The program is supported by VSL standard operating procedures that were used for this work [21]. Requirements of DOE/RW-0333P were not applicable to this work.

1.3 Melter System Description

1.3.1 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. The way in which the feed is introduced into the melter is designed to mimic the operation of an ADS pump, which is the present WTP baseline. The recirculation loop extends to the top of the melter where feed is diverted from the recirculation loop into the melter through a Teflon-lined feed line and water-cooled feed tube. Two computer operated pinch valves, one on the feed line and one on the recirculation loop, are activated in a timed sequence to introduce feed into the melter at the desired rate. The feed rate is regulated by adjusting the length of each pulse, the time between each pulse, and the pressure applied to the recirculation loop. A compressed air line is attached to the feed line and can be used to automatically clear the feed line into the melter after each pulse. The mixed feed enters the melter through a water-cooled, vertical feed tube.

1.3.2 Melter System

Cross-sectional diagrams through the DM100-WV melter are shown in Figures 1.2a-c. The DM100-WV unit is a ceramic refractory-lined melter fitted with a pair of opposing Inconel 690 plate electrodes as well as a bottom electrode. The melter can be operated with either three-phase or single-phase power. However, the standard mode of operation, which was used for these tests, is single-phase with voltage applied to the side electrodes only. The bubbler used for stirring the melt pool enters from the top and is removable. The glass product is removed from the melter by means of an air-lift discharge system. The DM100-WV has a melt surface of 12×14 inches, giving a melt surface area of 0.108 m^2 . The nominal depth of the melt pool is about 19 inches, which gives a typical glass inventory of between 115 and 120 kg. The plenum height is 27.5 inches. Temperatures are monitored by means of a series of thermocouples located in the melt pool, the electrodes, the plenum space, and the discharge chamber.

1.3.3 Off-Gas System

For operational simplicity, the DM100-WV 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 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.

SECTION 2.0 WASTE SIMULANT AND GLASS FORMULATIONS

2.1 Waste Simulants

The LAW Envelope A waste simulant is based on composition data for tank AN-105 given in the TFCOUP Rev. 3 [22]. The sodium concentration in the simulant was increased by 2.56 % to account for sodium additions in pretreatment [2, 23]. The sulfate content in the feed was increased to represent recycle from the off-gas treatment system to the melter feed assuming that 20% of the sulfur in the feed reports to the off-gas stream [2-14]. Sulfur from the recycle stream was added as the respective sodium salt. The nominal concentration, expressed in terms of the sodium molarity, was determined on the basis of melter feed rheology tests on similar formulations [24]. The results of those tests led to the selection of 8.0 molar sodium as the nominal simulant concentration for the LAW AN-105 waste.

The nominal simulant formulation is given in Table 2.1. The resulting simulant is a solution of predominantly sodium, aluminum, hydroxide, nitrate, and nitrite. Samples of the simulant were prepared according to Table 2.1 and tested at VSL. For the melter tests, Optima Chemicals, which has supplied all of the LAW simulants for the previous DM100 and LAW Pilot Melter studies, prepared the simulant and added the glass forming chemicals before shipment to VSL in 55-gallon drums. Sugar was added at VSL.

2.2 Glass Formulation

The feed additives were selected on the basis of glass formulation studies, which in the present case focused on the viscosity of the glass melt. The current WTP LAW glass formulations are designed to have viscosities of about 30-70 Poise at an operating temperature of 1150°C. For higher temperature operation, a similar range of viscosities can be achieved by modifying the glass composition. If this were not done, the glass contact refractory (Monofrax K3) would experience both higher temperature and a lower viscosity melt, both of which increase its rate of corrosion [25]. Accordingly, the new, higher temperature glass composition was designed to have a viscosity of about 30-70 Poise at 1200°C, which is the middle of the test range (1175°C to 1225°C), instead of the value of about 30-70 Poise at 1150°C for current WTP glasses.

The composition of the glass selected for melter testing (LAWA140) is given in Table 2.2, where it is compared with the composition of the current WTP formulation for tank AN-105, which is LAWA44. With respect to LAWA44, the increase in viscosity was achieved by increasing the SiO₂ content by about 3.5 wt% at the expense of 2.5 wt% Fe₂O₃, 0.5 TiO₂, and 0.5 wt% MgO. The measured viscosity of this glass is 60 Poise at 1200°C. This and other properties of LAWA140 are compared with those for LAWA44 in Table 2.3. As can be seen, the

new formulation still meets the ILAW contact requirements by a wide margin. Interestingly, although the PCT performance of LAWA140 is about the same as that for LAWA44, the VHT performance is somewhat worse, although still well below the requirement, despite the increased silica content. This difference probably reflects the beneficial effects on VHT response of the components that were removed, particularly iron.

Once the glass composition for melter testing was selected, melter feeds were prepared and characterized to ensure that they were suitable for processing in the DM100 and LAW Pilot Melters (see Section 2.4). A list of the glass forming chemicals used to prepare the melter feed is given in Table 2.4; these are the same chemical sources as are presently planned for use in the WTP.

2.3 Sugar Additions

With high nitrate feeds, the addition of reductants is necessary in order to control melt foaming. Sugar, which was used for this purpose at West Valley, has also been selected as the baseline reductant for the WTP. The amount of sugar required increases with the amount of nitrates present in the feed and decreases with the amount of waste organics present in the feed, which themselves act as reductants. Excessive additions of reductants can be deleterious, leading to over-reduction of the melt and formation of sulfides and molten metals. Consequently, the oxidants and reductants in the feed must be suitably balanced. The basis for achieving this balance was developed by VSL and Duratek for the vitrification of high-sodium-nitrate feeds at Savannah River's M-Area and has been successfully applied to the processing of a wide variety of simulated WTP feeds over the past six years. In developing this approach, we elected to conservatively adopt the most reducing potential reaction as the basis for the *definition* of a "sugar ratio" of 1.0 as a result of concerns for over-reducing the melt. Such a reaction, using sodium salts as an example, is:

Fundamentally, the basis that is selected is simply a convention, since the precise stoichiometry of the reactions involved is neither known nor constant under the conditions prevailing in the melter. However, with this convention, a sugar ratio of 1.0 corresponds to one mole of sucrose per eight moles of nitrate or, more generally, 1.5 moles of organic carbon per mole of nitrate. It is then expected that significantly less sugar than this will be required in practice. The empirically determined amount required to successfully control melt foaming without significantly reducing the glass melt was found to correspond to a ratio of 0.5 when any nitrites present were counted as nitrates (i.e., 0.75 moles of organic carbon per mole of nitrate + nitrite). This approach has been employed for all WTP melter testing. It is, however, expected that slight variations around the nominal value of 0.5 may be necessary to account for differences in the reducing power of waste organics in comparison to sugar, particularly for LAW streams that are high in organics.

As an example, the calculation of the amount of sugar needed for the present Sub-Envelope A1 feed to achieve a sugar ratio of 0.5 proceeds as follows:

- One liter of simulant contains 1.888 moles of nitrite and 1.978 moles of nitrate, giving a total of 3.866 moles of NO_x (see Table 2.1)
- Required total amount of organic carbon for a sugar ratio of 0.5 is $3.866 \times 0.75 = 2.900$ moles
- One liter of simulant contains 0.462 moles of organic carbon (see Table 2.1)
- Therefore, $2.900 - 0.462 = 2.438$ moles of organic carbon must be added.

Since the molecular weight of sucrose is 342 g per mole, $2.438 \times 342/12 = 69.48$ g sugar must be added per liter of simulant, as shown in Table 2.4.

2.4 Analysis of Feed Samples

2.4.1 General Properties

Feed samples were analyzed from each received feed batch and from each test that was conducted to confirm physical properties and chemical composition. Samples taken during testing were from an inline sampling port. Sample names, sampling dates, and measured properties are given in Table 2.5. The narrow range in the measured water content, density, glass yield and pH values show the consistency of the feed processed throughout testing. The measured glass yield was about 10.5% below the target value of 522 g per kg feed due perhaps to water additions during feed transfers. The average measured feed properties for the previous glass formulation using the same LAW A simulant (LAWA44 [26]) are very similar, indicating that the changes made to the glass forming additives had little effect on the melter feed properties. Also notice that the measured glass yield for the LAWA44 is also below target yield although the deviation is smaller. This observation is important since comparisons of production rates from the DM100 are based on target glass conversion ratios.

2.4.2 Rheology

Samples of the melter feeds that were used for these tests were also subjected to rheological characterization. The results from rheological characterization of a variety of other melter feeds and waste simulants, as well as the effects of a range of test variables, are described in detail in a separate report [24]. Melter feeds were characterized using a Haake RS75 rheometer, which was equipped with either a Z40DIN or a FL22-SZ40 sensor. A typical set of measurements consists of identifying the flow characteristics of the slurry by measuring the shear stress on the slurry at controlled shear rates and temperatures. In these measurements, the shear rate values are preset and are increased stepwise from 0.01 s^{-1} to 200 s^{-1} (70 s^{-1} for FL22-SZ40) with a sufficient delay (typically 15 to 30 seconds) between steps to ensure that shear stress is allowed to fully relax and therefore is measured at equilibrium. This approach is somewhat different from the "flow curve" approach in which the shear rate is ramped up to some

maximum value and then ramped back down to produce a hysteresis curve that is dependent on the selected ramp rate. The viscosity of the sample as a function of the shear rate is then calculated as the ratio of the shear stress to the shear rate. The yield stress data for the melter feeds were measured using a controlled-stress mode in which the torque on the rotor was slowly increased while the resulting deformation of the fluid was monitored. The discontinuity in the measured deformation-torque curve was identified as the yield stress. It should be noted that this direct measurement of the yield stress can be quite different from the value that is often reported as the yield stress, which is obtained by extrapolation of the shear stress-shear rate curve to zero shear rate. All of the measurements in this work were made at 25°C; previous work [24], which examined a range of temperatures, showed a relatively weak effect of temperature.

Rheograms for the melter feeds, which show the feed viscosity versus shear rate, are presented in Figures 2.1. Also included in that figure are values measured for feed from the previous glass formulation using the same LAW A simulant (LAWA44 [26]). Figure 2.2 shows an alternative presentation of the data as plots of the shear stress versus shear rate; also included are proposed WTP bounds for feed rheology [27]. Rheological properties of both feeds were well within the proposed bounds. Notice that both feeds have nearly identical rheological properties indicating that the change in glass formulation and additives had little effect on feed rheology. This was also observed in measurements of yield stress, which were 1.1 and 0.8 Pa for the LAW140 and LAWA44 feeds, respectively.

2.4.3 Chemical Composition

The chemical compositions of the feed samples were determined by first making a glass from the feed sample via crucible melt. The glass was subsequently crushed and analyzed directly by X-Ray Fluorescence Spectroscopy (XRF). The boron oxide target value was used for normalizing the XRF data since its concentration was not determined by XRF. The results, which are compared to the target compositions in Table 2.6, generally corroborate the consistency of the feed composition and show good agreement with the target composition for the major elements. Of the oxides with a target composition greater than one percent, only oxides in the intermediate range (1-3 wt. %), had deviations greater than 10% from target. These deviations, for oxides of titanium, magnesium, and zirconium, were also observed in the product glasses but the magnitude is considerably smaller (see Section 4.1). For example, the deficit of magnesium oxide was about 27% in the feed samples but only about 5% in the product glass. A surplus in titanium has also been observed previously in LAW melter feeds [6-8, 26, 28-31] and is presumed to be due to its presence as a contaminant in the glass forming additives. Volatile minor elements such as sulfur and chlorine are, as expected, below target due to loss during crucible melting.

SECTION 3.0 MELTER OPERATIONS

Melter tests were conducted on the DM100-WV with the LAW Sub-Envelope A1 simulant between 9/15/03 and 9/24/03. These tests produced almost two metric tons of glass from approximately four metric tons of feed. The tests were divided as follows:

- Turnover: 33 hours feeding, variable glass temperature
- Test 1: 75 hours feeding, 1175°C target glass temperature
- Test 2: 75 hours feeding, 1225°C target glass temperature

Summaries are provided in Table 3.1 for all three test periods. Note that feeding had to be interrupted for about 42 hours during Test 1 as a result of hurricane Isabelle. Attempts were made to replicate the melter configuration and operating conditions used for the corresponding tests conducted earlier [3, 4] and the previous LAW Sub-Envelope [5-8, 28-31] tests. 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.

As expected, the glass production rate increased with increasing glass temperature, as shown in Figure 3.1. The feeding interruption during Test 1, starting at about 75 hours run-time, is evident in this figure. The measured rates from the present tests can also be compared with the rates obtained with LAW Envelope A simulants at the nominal melting temperature of 1150°C, as shown in Figure 3.2. Over this temperature range, the glass production rate increases approximately linearly with temperature, giving an increase of about 50% (~2000 to ~3000 kg/m²/day) with a 75°C increase in glass temperature. It should be noted that the rates compared in Figure 3.2 are all based on target glass yields; use of measured glass yields would result in production rates of about 5 to 11 percent lower but the same relationship between glass temperature and production rate would be observed. The feeds met the acceptance criteria for larger scale testing on the LAW Pilot Melter in that the required processing rates were achieved, no processing problems were observed, and a secondary sulfate phase was not observed.

The results of various operational measurements that were made during these tests are given in Table 3.2. Glass temperatures at various heights are plotted in Figure 3.3; temperatures near the top of the melt pool are not reliable indicators of bulk glass temperatures as a result of gradients near the cold cap. Readings from the deeper thermocouples show the intended increases for each test and approximate the targets of 1175°C and 1225°C in the bulk of the glass pool. Plenum temperatures typically ranged from 500 to 650°C, within the 450 to 650°C target, as shown in Figure 3.4. This is deliberately somewhat higher than for the larger melters (DM1200 and LAW Pilot Melter) in order to reduce cold cap bridging that occurs in the smaller melters. Note the rise in plenum temperature during the period of idling as a result of the burn-off of the cold cap. During feeding periods, plenum temperatures increased with increasing glass temperature. Electrode temperatures also increased with increasing glass temperature, as shown in Figure 3.5. The East and West electrode temperatures were very close to the bulk glass

temperature and averaged between 1140-1149°C while the bottom electrode was typically about 170°C cooler than the side electrodes. This lower temperature is due in part to the bottom electrode not being powered. Power supplied to the electrodes typically varied by only 2 kW from the average value. The average bubbling rate for Tests 1 and 2 approximated the target rate of 15 lpm, which is the value used for the corresponding tests performed at 1150°C. Consequently, the results of these tests can be directly compared and the changes in glass production rate attributed to the changes in operating temperature.

The gas temperature at the film cooler averaged between 286 and 318°C depending on the plenum temperature as well as the amount and temperature of added film cooler air. Little or no drop in gas temperature was observed across the (insulated) transition line, which serves to prevent condensation, as intended.

SECTION 4.0 GLASS PRODUCTS

Almost two metric tons of glass was produced in these tests. The glass was discharged from the melter periodically into 5-gallon carbon steel pails using an airlift system. The discharged product glass was sampled at the end of each test by removing sufficient glass from the top of the cans for total inorganic analysis. Product glass masses, discharge date, and analysis performed are listed in Table 4.1. Glass samples were also obtained by dipping a rod into the glass pool at the beginning and end of each test. These "dip samples" underwent visual examinations to detect the presence of a separate sulfate phase on the glass surface as well as total inorganic compositional analysis.

4.1 Compositional Analysis

Discharge and dip glass samples were crushed and analyzed directly by XRF. The target values for boron oxide, which is not determined by XRF, were used for normalizing the XRF data to 100 wt%. The XRF-analyzed compositions of discharged glass samples are provided in Table 4.2. Analysis results for dip samples by XRF are provided in Table 4.3. All discharged glass samples were subjected to XRF analysis. The majority of the XRF analysis results compared very favorably to their corresponding target values. The only significant oxides with relative deviations from target of more than 10% were TiO_2 and ZrO_2 , which were about 11% and 10% above their target values, respectively. Compositional trends during Tests 1 and 2 shown in Figures 4.1- 4.3 illustrate the closeness to target and the consistency of composition over the course of the tests. The oxides comprising the product glass change very little during testing, including the nearly two-day idling period.

The concentrations of chlorine and sulfur, which are relatively volatile, are plotted over the course of the tests in Figure 4.4. Notice that at each of the two processing temperatures, the concentration of SO_3 is stable over the tests. Also observe the small but discernable decrease in SO_3 in the glass product as the processing temperature was increased. Chlorine concentrations followed a similar trend with a wider disparity from target and a higher degree of variability in the data. A slight decrease in chlorine concentration may have occurred as a result of the idling period, whereas no decrease is evident in the sulfur data.

Glass dip samples were obtained at the beginning and end of each test, primarily to ascertain whether a secondary sulfate layer had formed on the surface of the glass melt. Table 4.3 provides a listing of all of the dip samples together with their analyzed compositions and whether or not a separate salt phase was evident. Dip samples taken immediately after both tests (WVT-D-46A, WVT-D-110B) as well as a dip sample taken after a period of idling at about 1050°C (WVT-D-18A) in the middle of the first test were all free of secondary phases. Note, however, the increased sulfur content in the dip sample after idling, which is often observed in such samples even when a separate sulfate phase is not evident.

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 during each test segment. 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 acid gases, particularly halogens. The collected materials were analyzed using direct current plasma atomic emission spectroscopy (DCP-AES) for the majority of the constituents and ion chromatography (IC) for anions. Melter emission fluxes are compared to feed fluxes in Table 5.1 where the distinction 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.

The results from previous tests have shown that particulate melter emissions tend to increase with increasing glass processing temperature [17-19, 32]; the results from the present tests are consistent with this finding. The 50°C increase in processing temperature resulted in about a doubling of particle and many elemental carry-over rates. In contrast, measurements of emission rates as a percentage of feed for previous tests with LAW Sub-Envelope A1 conducted at 1150°C [7, 26, 29] were both above and below the emission rates measured at 1175°C, suggesting that effect of the 25°C increase is within the variability of the measurements. As expected, the feed elements with the lowest melter decontamination factors (DF) were halogens and sulfur, followed by chromium, alkali metals, and boron. It should be noted, however, that the chromium values are likely biased high as a result of the prevalence of chromium-containing materials in the melter (K-3 and Inconel). Sulfur and chlorine emissions were predominately particulate, which is consistent with previous studies using high-alkali LAW A simulants [4, 7, 8, 26, 29]. Fluorine emissions were difficult to evaluate due to the low feed concentrations combined with its ubiquity as a contaminant in water and raw materials. Boron, sulfur, and the halides 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 HEPA filter to prevent analyte loss due to condensation prior to monitoring. A summary of average concentrations monitored during each test is provided in Table 5.2. Concentrations of various monitored species are plotted in Figures 5.1 - 5.3. The large variations in the measured concentrations evident in these figures are a result of the pulsed feeding system and the dynamic nature of the cold cap. Data collection was stopped at the onset of idling during Test 1 and restarted about 10 hours into the second test resulting in about two days of data for each of the two tests. The analytes listed in Table 5.2 are those that were expected to be observed during the test, based on previous work; no other species were detected in the off-gas stream by FTIR. The most abundant nitrogen species monitored was NO, which is consistent with previous tests [3-8, 28-31] in which nitrates and nitrites were abundant in the feed. Concentrations of NO₂ and N₂O were about an order of magnitude less than NO throughout testing. Also consistent with previous tests were measured concentrations of CO, NH₃, and CO₂ arising from the decomposition of sugar. As expected, emissions increased in proportion to the increased feed rate in Test 2. No HF or HCl were observed by FTIR, which is consistent with the low concentrations of gaseous chlorine and fluorine observed using the Method 5-type sampling discussed earlier (Method 5-type methods have lower detection limits). The variations in emissions over the course of each test segment are due in part to the pulsed feed system and changes in the melt pool cold cap.

A nitrogen mass balance is summarized in Table 5.3. In both tests, about 50% of the feed nitrogen oxides were reduced to diatomic nitrogen, which is consistent with expectations based on previous tests with feed at sugar ratio of 0.5. The increase in processing temperature gave no apparent change in nitrogen speciation from the decomposition of feed nitrates and nitrites.

5.3 Mass Balance of Sulfur and Chlorine

Table 5.4 provides the percentages of sulfur and chlorine that were retained in the glass product or identified in the various off-gas stream samples for each of the tests. Data for other melter tests processing LAW Sub-Envelope A1 simulants are included for comparison. Sulfur mass balance around the melter was excellent for all tests, with totals ranging from 100 - 109 percent. Total recovery for chlorine was reasonable for most of the tests. Sulfur retention in the glass ranged between 91 and 100% for tests at 1150 and 1175°C but dropped to 81% in the test conducted at 1225°C. A trend for chlorine glass retention over all the tests is not as easy to discern due to the excess chlorine measured in several tests, which may be due to its ubiquity as a contaminant. However, tests conducted from the same feed batch in this study clearly show a decrease in chlorine retention in the glass with increasing glass temperature (see Figure 4.4). Almost all of the sulfur and chlorine not retained in the glass was emitted as particles.

SECTION 6.0 CONCLUSIONS

Two tests were conducted on a DM100 vitrification system to assess melter performance and feed processing characteristics at elevated temperatures of 1175 and 1225°C. A glass formulation for the LAW Sub-Envelope A1 simulant was developed and tested to accommodate these higher processing temperatures. No difficulties were encountered during processing and at no time during or after testing did a separate sulfate phase form on the melt pool surface. Glass production rates increased approximately linearly with increasing processing temperatures from about 2000 kg/m²/day in previous tests at 1150°C to about 3000 kg/m²/day at 1225°C. Based on the DM100 results, the feed formulation and processing temperatures were accepted for larger-scale testing on the LAW Pilot Melter.

During the present tests, total particulate emissions from the melter ranged from 0.47-0.85 wt%. Melter DFs were determined for each element in the feed for the two tests that were performed. Both total particulate and elemental carryover approximately doubled as the processing temperature was increased from 1175 to 1225°C. Excellent mass balance closure around the melter was achieved for sulfur.

SECTION 7.0 RECOMMENDATIONS FOR FUTURE WORK

As noted previously, the present test program [1] includes melter runs at high temperature at much larger scale (by a factor of about 30, which is one-third of full-scale for the WTP) on the LAW Pilot Melter. The results from those tests will be reported separately but the results are generally consistent with those presented in this report with respect to the effect of increased temperature on glass production rates: Very significant increases in LAW processing rates are possible with rather modest increases in operating temperature. In view of the potential impacts for the WTP facility, further testing is recommended to underpin this conclusion. This work should include:

- *Materials Corrosion (Baseline Materials)* - Testing should be performed to evaluate the impacts of increased temperature on the existing baseline melter materials of construction over the range of LAW compositions and for extended periods of time under as realistic operating conditions as possible. Initial efforts in this area are included in the present test program [1].
- *Materials Corrosion (Alternate Materials)* - Similar testing should be performed on potential alternate materials of construction for deployment in replacement LAW melters. Initial efforts in this area are included in the present test program [1].
- *Bubbler Lifetime* - The WTP LAW Pilot Melter test program demonstrated that long-term melter tests are required to reliably predict the lifetime of bubblers because of the nature of the failure mechanisms involved. It is expected that bubbler lifetimes will decrease with increased operating temperature but the magnitude of the effect is presently unknown. Similar tests are therefore required at higher operating temperatures with both the present baseline and potential alternate bubbler materials of construction. The same tests could be used to assess impacts on other melter components, such as thermowells and level detectors.
- *Sulfate Solubility and Partitioning* - The present tests indicate that sulfur partitioning to the off-gas stream increases with increased operating temperature. It is expected that the solubility of sulfur in the glass melt also increases with temperature. Both of these effects should increase the level of sulfur in the feed that can be tolerated before a separate sulfate phase develops, which would lead to increased waste loadings, decreased glass volumes, and further reductions in the time required to process LAW. Tests are required at increased temperature with progressively increasing sulfate levels in the feed, up to the point that a separate sulfate phase forms, to determine the extent of this additional benefit to the LAW facility.

- *LAW Composition Envelope Testing* – The present tests have employed a single LAW Envelope A composition and glass formulation. Corresponding tests are required across the expected LAW composition range and, at a minimum, for representative LAW Envelope B and C compositions. Such tests would address the robustness of the observed production rate increases over the LAW composition range as well as the effects of composition on the factors discussed above (materials corrosion, sulfate solubility, sulfate partitioning).

SECTION 8.0 REFERENCES

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Table 2.1. LAW Envelope A (AN-105) Waste Simulant Recipe at 8 Molar Sodium.

Envelope Constituents	Simulant AN-105 (sup) including Pretreatment		Glass Oxides	LAW A Simulant as Oxides (wt%)	Waste Contribution to Glass	Source in Simulant	Order for Addition	Formula Weight	Assay	Target Weight (g)
-	mg/l	M	Loading		25.707 %	In 295 ml water add following compounds in the order listed below				
Al	28595	1.060	Al ₂ O ₃	16.957	4.359	Al(NO ₃) ₃ ·9H ₂ O, 60% sol	1	375.14	0.61	406.57
						Al(OH) ₃	7	78.00	0.77	31.49
Ca	58	0.001	CaO	0.025	0.007	Ca(NO ₃) ₂ ·4H ₂ O	2	236.16	0.99	0.34
Cr	166	0.003	Cr ₂ O ₃	0.076	0.020	Na ₂ CrO ₄ ·4H ₂ O	10	234.04	0.99	0.76
Fe	19	0.000	Fe ₂ O ₃	0.009	0.002	Fe(NO ₃) ₃ ·9H ₂ O	3	404.01	1.00	0.14
K	4570	0.117	K ₂ O	1.728	0.444	KOH	9	56.10	0.91	7.22
Na	183920	8.000	Na ₂ O	77.805	20.000	NaOH, 50% sol d=1.53	8	40.00	0.50	416.95
Ni	28	0.000	NiO	0.011	0.003	Ni(NO ₃) ₂ ·6H ₂ O	4	290.81	1.00	0.14
Si	150	0.005	SiO ₂	0.101	0.026	SiO ₂	11	60.09	0.99	0.33
Cl	6933	0.196	Cl	2.176	0.559	NaCl	12	58.45	0.99	11.55
F	305	0.016	F	0.096	0.025	NaF	13	42.00	0.99	0.68
PO ₄	1121	0.012	P ₂ O ₅	0.263	0.068	Na ₃ PO ₄ ·12H ₂ O	14	380.12	0.99	4.53
SO ₄	2883	0.030	SO ₃	0.754	0.194	Na ₂ SO ₄	15	142.06	0.99	4.31
NO ₂	86856	1.888	NO ₂	-	-	NaNO ₂	20	69.00	1.00	130.94
NO ₃	122642	1.978	NO ₃	-	-	NaNO ₃	-	84.99	0.99	-
CO ₃	11938	0.199	CO ₃	-	-	Na ₂ CO ₃	21	105.99	1.00	21.08
OH	93721	5.513	OH	-	-	From KOH + NaOH + Al(OH) ₃				
Org Carbon	5543	0.462	-	-	-	-	-	-	-	-
EDTA	3640	0.013	-	-	-	Na ₂ EDTA 2H ₂ O (C10)	5	372.24	0.99	4.72
HEDTA	4324	0.016	-	-	-	NaHEDTA 4H ₂ O (C10)	6	344.20	0.415	13.03
Acetate	2115	0.036	-	-	-	Sodium Acetate (C2)	16	136.08	0.99	4.92
Formate	2007	0.045	-	-	-	Sodium Formate (C1)	17	68.01	0.99	3.06
Oxalate	677	0.008	-	-	-	Sodium Oxalate (C2)	18	134.00	0.99	1.04
Glycolate	1820	0.024	-	-	-	Glycolic Acid (C2)	19	76.05	0.709	2.72
-	-	-	-	-	-	Target Glass				1239.60
-	-	-	SUM	100.00	25.707	Total simulant weight				1361.93

"-" empty data field

Table 2.2. Composition of High-Temperature Glass: LAWA140

Glass Oxides	AN-105 (sup) in glass @ 20.0 % Na ₂ O	Additives Mix	Recycled Sodium Sulfate	LAWA140	Nominal Glass LAWA44 [7, 26]
Loading	25.707 %	74.293 %	-	-	-
Al ₂ O ₃	4.359	1.843	-	6.20	6.18
B ₂ O ₃	0.000	8.999	-	8.99	8.98
CaO	0.007	1.986	-	1.99	1.99
Ca ₂ O ₃	0.020	-	-	0.02	0.02
Cs ₂ O	0.000	-	-	0.00	0.14
Fe ₂ O ₃	0.002	4.482	-	4.48	6.96
K ₂ O	0.444	-	-	0.44	0.44
MgO	0.000	1.492	-	1.49	1.99
Na ₂ O	20.000	-	0.038	20.04	20.02
NiO	0.003	-	-	<0.01	<0.01
SiO ₂	0.026	48.043	-	48.02	44.44
TiO ₂	0.000	1.492	-	1.49	1.99
ZnO	0.000	2.973	-	2.97	2.96
ZrO ₂	0.000	2.983	-	2.98	2.98
Cl	0.559	-	-	0.56	0.56
F	0.025	-	-	0.03	0.02
P ₂ O ₅	0.068	-	-	0.07	0.07
SO ₃	0.194	-	0.048	0.23	0.24
Total	25.707	74.293	0.086	100.00	100.00

"-" empty data field

Table 2.3. Characterization Data for High-Temperature Glass LAWA140 and LAW Sub-Envelope A1 Glass LAWA44.

Glass Name	LAWA140	LAWA44 [Melter Support]
Glass density (g/cc)	2.65	2.67
Liquidus Information		
Heat treated at 850°C for 20 hours after premelt at 1200°C: Optical microscopy examination	Clear homogeneous glass	Clear homogeneous glass
Viscosity (Poise)		
950°C	1088	759
1000°C	522	375
1050°C	275	200
1100°C	156	114
1150°C	94	69
1200°C	60	44
1250°C	40	29
Electrical Conductivity (S/cm)		
950°C	0.13	0.24
1000°C	0.16	0.30
1050°C	0.20	0.36
1100°C	0.24	0.44
1150°C	0.29	0.52
1200°C	0.34	0.60
1250°C	0.40	0.70
PCT (90°C – 304L stainless steel vessel) (specification: < 2 g/m ²)		
B (g/m ²)	0.42	0.52
Na (g/m ²)	0.50	0.52
Si (g/m ²)	0.18	0.20
VHT (g/m ² /day) (specification: < 50 g/m ² /day)	4.0	1.0
Glass Transition Temperature, T _g (onset)	511°C	509°C

Table 2.4. Glass Forming Additives for 1 Liter of Simulant (Nominal) and Corresponding Melter Feed Properties.

Additives Source	Feed LAWAI40
Additives in Glass (wt%)	74.29 %
Kyanite (Al_2SiO_5) 325 Mesh (Kyanite Mining) (g)	38.21
H_2BO_3 (US Borax – Technical Granular) (g)	200.61
Wollastonite NYAD 325 Mesh (NYCO Minerals) (g)	53.56
Fe_2O_3 (Prince Manufacturing, 98%) (g)	53.02
Olvine (Mg_2SiO_4) 325 Mesh (#180 Unimin) (g)	37.90
SiO_2 (Sil-co-Sil 75 - US Silica) (g)	517.80
TiO_2 (Ti-Pure Rutile DuPont) (g)	19.65
ZnO (KADOX – 920 Zinc Corp. of America) (g)	36.82
Zircon ZrSiO_4 (Flour) Mesh 325 (Am. Mineral) (g)	56.37
Addition of Sucrose as Reductant (nominal) (g)	69.48
+ Na_2SO_4 (from recycled off-gas) (g)	1.08
Simulant Weight for 1 liter (g)	1362
Sum of Additives (g)	1014
Sum of Complete Batch (g)	2377
Final Volume (l) (based on measured density)	1.39
Measured Density (g/ml)	1.69
Expected Glass Produced (g), i.e., Glass Yield (g/l of simulant)	1240
Measured Weight % Water in Slurry Feed	38.4%
Weight % Additives in Slurry	42.7%
Target Glass Yield (g/kg of Feed)	522
Target Glass Yield (g/l of Feed)	882
Measured Total Solids (g/l of Feed)	1041
Additives (g/l of Feed)	721

Table 2.5. Measured Properties of Melter Feed Samples.

Date	Name	% Water	Density (g/ml)	Glass Yield		pH
				(kg/kg)	(g/l)	
9/16/03	WVS-F-135A	38.5	1.70	0.474	805	11.88
9/17/03	WVS-F-150A	38.8	1.71	0.473	808	11.96
9/20/03	WVT-F-28A	38.9	1.68	0.462	777	11.93
9/21/03	WVT-F-38A	37.1	1.70	0.482	819	11.98
9/22/03	WVT-F-57A	38.8	1.69	0.472	798	11.96
9/23/03	WVT-F-71A	38.1	1.67	0.477	797	11.91
9/23/03	WVT-F-86A	38.2	1.68	0.448	753	12.12
9/24/03	WVT-F-102A	38.8	1.67	0.448	748	11.91
Average		38.4	1.69	0.467	788	11.96
Average for LAWA44 Formulation [26]		37.6	1.72	0.481	827	12.10

Table 2.6. XRF-Analyzed Compositions of Feed Samples (wt%).

Constitute	Target	WVS-F- 135A	WVS-F- 150A	WVT-F- 28A	WVT-F- 38A	WVT-F- 57A	WVT-F- 71A	WVT-F- 86A	WVT-F- 102A	Average	%Dev
Al ₂ O ₃	6.20	6.22	6.42	6.45	6.73	6.20	6.53	6.69	6.42	6.46	4.20
B ₂ O ₃ *	8.99	8.98	8.98	8.98	8.98	8.98	8.98	8.98	8.98	NC	NC
CaO	1.99	2.03	2.04	2.16	1.97	2.01	2.10	2.19	2.21	2.09	5.08
Cl	0.56	0.25	0.13	0.01	0.17	0.28	0.03	0.06	0.03	0.12	NC
Cr ₂ O ₃	0.02	0.04	0.04	0.03	0.05	0.05	0.05	0.03	0.03	0.04	NC
F	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NC	NC
Fe ₂ O ₃	4.48	4.49	4.37	4.76	4.39	4.71	4.73	4.29	4.56	4.54	1.41
K ₂ O	0.44	0.46	0.42	0.32	0.42	0.46	0.37	0.42	0.39	0.41	NC
MgO	1.49	1.08	1.05	1.08	1.38	1.49	1.27	0.51	0.72	1.07	-27.93
Na ₂ O	20.04	20.01	19.59	17.32	19.84	19.85	18.16	18.83	17.89	18.94	-5.44
P ₂ O ₅	0.07	0.10	0.11	0.11	0.09	0.09	0.11	0.10	0.12	0.10	NC
SiO ₂	48.02	48.14	48.67	50.13	48.30	47.67	49.34	49.19	49.69	48.89	1.90
SO ₃	0.23	0.14	0.11	0.05	0.12	0.15	0.07	0.09	0.08	0.10	NC
TiO ₂	1.49	1.67	1.69	1.81	1.67	1.67	1.74	1.86	1.88	1.75	17.39
ZnO	2.97	2.95	2.97	3.20	2.75	2.89	3.04	3.30	3.36	3.06	3.16
ZrO ₂	2.98	3.43	3.41	3.58	3.13	3.49	3.49	3.45	3.63	3.45	16.00
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC

* Target value

NA – Not analyzed

NC – Not calculated

**Table 3.1. Summary of Test Conditions and Results for
LAW Sub-Envelope A (AN-105) High-Temperature Tests.**

-		Turnover	Test 1	Test 2
Target Glass Temperature		Variable	1175°C	1225°C
Time	Feed Start	9/15/03, 11:46	9/16/03, 22:03	9/21/03, 19:14
	Feed End	9/16/03, 22:02	9/21/03, 19:11	9/24/03, 22:15
	Water Feeding (hr)	1.25	1.0	NA
	Feeding Interruptions	NA	9/18/03, 16:27 – 9/20/03, 10:10	NA
	Total Feeding Interruptions (hr)	0	41.7	0
	Net Slurry Feeding (hr)	33.0	75.2	75.0
	Cold Cap Burn-Off (hr)	NA	1.45	1.5
Reductant Ratio		0.5	0.5	0.5
Glass Yield (g/kg of feed)	Target	0.522	0.522	0.522
	Average Measured	0.474	0.472	0.461
Total Feed Processed (kg)		587	1511	1922
Average Production Rate (kg/m ³ /day)	From Target Yield	2044	2309	2945
	From Measured Yield	1856	2085	2602
Steady State Production Rate (kg/m ³ /day)	From Target Yield	NA	2400	3000
	From Measured Yield	NA	2167	2650
Particle Emissions Rate (mg/min)		ND	994	2500
% Solids Carryover from Melter		ND	0.47	0.85
Sulfur Mass Balance	% of Feed Sulfur in Glass Product	ND	91	81
	% of Feed Sulfur in Particle Emissions	ND	9.2	18.5
	% of Feed Sulfur in Gaseous Emissions	ND	0.6	0.4
	% Total Recovery of Feed Sulfur	ND	100.8	99.9
Sulfate Gall During Test or at Test End		No	No	No

"-" empty data field

NA – Not Applicable

ND – Not Determined

Table 3.2. Summary of Measured Melter Parameters.

Target Glass Temperature			1175°C, Test 1			1225°C, Test 2		
-			Avg	Min	Max	Avg	Min	Max
TEMPERATURE(°C)	Electrode	East	1167	1138	1189	1208	1158	1230
		West	1193	1145	1215	1227	1182	1253
		Bottom	973	938	983	1007	974	1019
	Glass	19" from floor	1061	841	1138	1070	891	1147
		16" from floor	1165	1096	1196	1200	1145	1239
		10" from floor	1180	1149	1204	1219	1164	1245
		4" from floor	1175	1129	1196	1220	1161	1243
	Plenum (thermowell)		554	501	828	597	528	646
	Plenum (exposed)		543	455	794	606	366	720
	Discharge	Chamber	1026	964	1052	1044	971	1072
		Air Lift	1116	957	1172	1168	1113	1220
	Film Cooler Outlet		286	256	343	306	229	346
	Transition Line Outlet		284	222	341	306	257	343
	Lance Bubbling (lpm)		14.9	1.6	15.8	15.2	0.0	31.3
	Electrode	Voltage (V)	42.5	37.9	45.4	43.9	2.8	51.3
		Total Power (kW)	23.8	18.4	28.0	28.0	0.3	36.5

"-" empty data field

Table 4.1. Listing of Glass Discharged, Masses, and Analysis Performed.

Test	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)
Turnover	09/15/03	WVS-G-114A	-	13.0	13.0
		WVS-G-114B	XRF		
		WVS-G-115A	XRF	20.3	33.3
		WVS-G-116A	XRF	22.0	55.3
	09/16/03	WVS-G-121A	XRF	19.5	74.8
		WVS-G-122A	-	26.0	100.8
		WVS-G-123A	XRF		
		WVS-G-123B	-	22.9	123.7
		WVS-G-125A	XRF		
		WVS-G-125B	-	26.1	149.8
		WVS-G-126A	XRF		
		WVS-G-126B	-	18.6	168.4
		WVS-G-126C	XRF		
		WVS-G-129A	-	19.2	187.6
		WVS-G-129B	XRF		
		WVS-G-129C	-	34.0	221.6
		WVS-G-133A	XRF		
		WVS-G-133B	-	25.0	246.6
		WVS-G-134A	XRF		
Test 1 (Glass Temperature Target: 1175°C)	9/17/03	WVS-G-135A	-	29.3	275.9
		WVS-G-135B	XRF		
		WVS-G-138A	-	28.7	304.6
		WVS-G-138B	XRF		
		WVS-G-138C	-	33.9	338.5
		WVS-G-140A	XRF		
		WVS-G-140B	-	19.9	358.4
		WVS-G-141A	XRF		
		WVS-G-141B	-	24.8	383.2
		WVS-G-141C	XRF		
		WVS-G-143A	-	23.8	407.0
		WVS-G-143B	XRF		
		WVS-G-143C	-	21.3	428.3
		WVS-G-144A	XRF		
		WVS-G-144B	-	26.9	455.2
		WVS-G-144C	XRF		
		WVS-G-148A	-	26.6	481.8
		WVS-G-148B	XRF		
	9/18/03	WVS-G-150A	-	32.0	513.8
		WVS-G-150B	XRF		
		WVS-G-151A	-	38.4	552.2
		WVS-G-154A	XRF		
		WVS-G-154B	-	32.3	584.5
		WVS-G-155A	XRF		

"-" empty data field

Table 4.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)
Test 1 (Glass Temperature Target: 1175°C)	9/18/03	WVT-G-6A	-	21.0	605.5
		WVT-G-6B	XRF		
		WVT-G-6C	-	26.1	631.6
		WVT-G-7A	XRF		
		WVT-G-7B	-	20.3	651.9
		WVT-G-7C	XRF		
		WVT-G-11A	-	23.4	675.3
		WVT-G-11B	XRF		
	9/20/03	WVT-G-29A	-	23.3	698.6
		WVT-G-30A	XRF		
		WVT-G-30B	-	25.2	723.8
		WVT-G-30C	XRF		
		WVT-G-31A	-	27.4	751.2
		WVT-G-31B	XRF		
		WVT-G-31C	-	28.6	779.8
		WVT-G-32A	XRF		
		WVT-G-32B	-	37.3	817.1
		WVT-G-32C	XRF		
	9/21/03	WVT-G-36A	-	29.6	846.7
		WVT-G-36B	XRF		
		WVT-G-38A	-	31.8	878.5
		WVT-G-38B	XRF		
		WVT-G-39A	-	18.6	897.1
		WVT-G-39B	XRF		
		WVT-G-39C	XRF	31.3	928.4
		WVT-G-40A	-	20.6	949.0
		WVT-G-40B	XRF		
		WVT-G-45A	-	24.9	973.9
		WVT-G-45B	XRF		
		WVT-G-46A	-	26.8	1000.7
		WVT-G-47A	XRF		
WVT-G-47B		-	29.4	1030.1	
WVT-G-47C		XRF			
9/22/03	WVT-G-49A	-	30.7	1060.8	
	WVT-G-52A	XRF			
	WVT-G-52B	-	35.2	1096.0	
	WVT-G-53A	XRF			
	WVT-G-54A	-	31.2	1127.2	
	WVT-G-54B	XRF			
	WVT-G-56A	-	31.2	1158.4	
	WVT-G-56B	XRF			
	WVT-G-57A	-	21.8	1180.2	
	WVT-G-57B	XRF			
WVT-G-57C	-	25.5	1205.7		
WVT-G-57D	XRF				

"-" empty data field

Table 4.1. Listing of Glass Discharged, Masses, and Analysis Performed (continued).

Test	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)
Test 2 (Glass Temperature Target: 1225°C)	9/22/03	WVT-G-59A	-	23.6	1229.3
		WVT-G-59B	XRF		
		WVT-G-63A	-	40.0	1269.3
		WVT-G-64A	XRF		
		WVT-G-64B	-	33.4	1302.7
		WVT-G-65A	XRF		
		WVT-G-66A	-	34.7	1337.4
		WVT-G-66B	XRF		
		WVT-G-68A	-	26.1	1363.5
	9/23/03	WVT-G-68B	XRF		
		WVT-G-68C	-	27.7	1391.2
		WVT-G-71A	XRF		
		WVT-G-71B	-	24.7	1415.9
		WVT-G-72A	XRF		
		WVT-G-72B	-	34.4	1450.3
		WVT-G-74A	XRF		
		WVT-G-76A	-	31.5	1481.8
		WVT-G-76B	XRF		
		WVT-G-77A	-	30.8	1512.6
		WVT-G-78A	XRF		
		WVT-G-78B	-	27.2	1539.8
		WVT-G-78C	XRF		
		WVT-G-81A	-	38.4	1578.2
		WVT-G-82A	XRF		
		WVT-G-84A	-	36.5	1614.7
		WVT-G-85A	XRF		
		WVT-G-85B	-	28.6	1643.3
		WVT-G-86A	XRF		
		WVT-G-86B	-	28.2	1671.5
	9/24/03	WVT-G-88A	XRF		
		WVT-G-92A	-	25.2	1696.7
		WVT-G-92B	XRF		
		WVT-G-93A	-	25.9	1722.6
		WVT-G-93B	XRF		
		WVT-G-94A	-	26.9	1749.5
		WVT-G-94B	XRF		
		WVT-G-95A	-	33.0	1782.5
		WVT-G-95B	XRF		
		WVT-G-95C	-	20.1	1802.6
		WVT-G-97A	XRF		
		WVT-G-97B	-	34.3	1836.9
		WVT-G-97C	XRF		
		WVT-G-100A	-	32.2	1869.1
		WVT-G-102A	XRF		

"-" empty data field

**Table 4.1. Listing of Glass Discharged, Masses, and Analysis Performed.
(continued).**

Test	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)
Test 2	9/24/03	WVT-G-102B	-	32.6	1901.7
		WVT-G-102C	XRF		
		WVT-G-104A	-	23.5	1925.2
		WVT-G-104B	XRF		
		WVT-G-110A	-	21.8	1947.0
		WVT-G-110B	XRF		

"-" empty data field

Table 4.2. XRF-Analyzed Compositions for Discharged Glass Samples (wt%).

Test	-	Turnover										
Glass (kg)	-	13.0	33.3	55.3	74.8	100.8	123.7	149.8	168.4	187.6	221.6	246.6
Constituent	Target	WVS-G-114B	WVS-G-115A	WVS-G-116A	WVS-G-121A	WVS-G-123A	WVS-G-125A	WVS-G-126A	WVS-G-126C	WVS-G-129B	WVS-G-133A	WVS-G-134A
Al ₂ O ₃	6.20	7.47	6.97	6.77	6.46	6.51	6.52	6.10	6.24	6.15	6.39	6.11
B ₂ O ₃ *	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99
CaO	1.99	1.97	1.95	2.00	1.96	1.98	1.92	2.08	1.98	1.98	1.90	1.92
Cl	0.56	0.03	0.10	0.24	0.33	0.38	0.38	0.39	0.39	0.39	0.39	0.38
Cr ₂ O ₃	0.02	0.37	0.34	0.28	0.22	0.19	0.17	0.18	0.16	0.16	0.13	0.14
F	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe ₂ O ₃	4.48	6.88	6.69	6.24	5.61	5.32	4.99	5.40	5.04	5.05	4.65	4.75
K ₂ O	0.44	0.53	0.51	0.53	0.51	0.52	0.49	0.52	0.50	0.50	0.50	0.49
MgO	1.49	1.83	1.86	1.79	1.76	1.60	1.64	1.57	1.59	1.56	1.55	1.56
Na ₂ O	20.04	18.92	19.64	19.24	20.25	19.67	19.58	19.13	20.06	19.77	20.78	21.08
P ₂ O ₅	0.07	0.09	0.08	0.08	0.10	0.09	0.11	0.09	0.09	0.09	0.09	0.08
SiO ₂	48.02	45.12	44.82	45.63	45.89	46.63	47.50	46.92	46.89	47.17	46.97	46.75
SO ₃	0.23	0.09	0.11	0.13	0.16	0.18	0.19	0.18	0.19	0.19	0.19	0.19
TiO ₂	1.49	2.03	2.00	1.93	1.78	1.75	1.68	1.79	1.70	1.72	1.61	1.65
ZnO	2.97	2.63	2.70	2.79	2.74	2.83	2.69	3.03	2.81	2.85	2.67	2.74
ZrO ₂	2.98	3.05	3.23	3.36	3.25	3.35	3.15	3.65	3.37	3.43	3.18	3.17
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Target value

NA – Not analyzed

"-" empty data field

Table 4.2. XRF-Analyzed Compositions for Discharged Glass Samples (wt%), continued.

Test	-	1 (Target Glass Temperature: 1175°C)														
Glass (kg)	-	275.9	304.6	338.5	358.4	383.2	407	428.3	455.2	481.8	513.8	552.2	584.5	605.5	631.6	651.9
Constituent	Target	WVS-G-135B	WVS-G-138B	WVS-G-140A	WVS-G-141A	WVS-G-141C	WVS-G-143B	WVS-G-144A	WVS-G-144C	WVS-G-148B	WVS-G-150B	WVS-G-154A	WVS-G-155A	WVT-G-6B	WVT-G-7A	WVT-G-7C
Al ₂ O ₃	6.20	6.36	6.37	6.00	6.40	6.42	6.38	6.06	5.76	6.19	6.21	6.17	6.27	6.23	6.34	6.23
B ₂ O ₃ *	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99
CaO	1.99	2.03	1.98	1.98	1.95	1.95	1.92	2.04	2.04	1.96	2.01	2.07	1.95	1.98	1.99	2.00
Cl	0.56	0.39	0.41	0.40	0.41	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.42	0.42	0.45
Cr ₂ O ₃	0.02	0.14	0.14	0.13	0.13	0.13	0.12	0.13	0.31	0.13	0.13	0.13	0.13	0.12	0.12	0.13
F	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe ₂ O ₃	4.48	4.85	4.60	4.69	4.52	4.41	4.39	4.73	5.34	4.38	4.54	4.64	4.26	4.41	4.35	4.37
K ₂ O	0.44	0.51	0.50	0.50	0.51	0.50	0.51	0.51	0.52	0.52	0.54	0.55	0.51	0.53	0.54	0.54
MgO	1.49	1.43	1.41	1.42	1.38	1.37	1.39	1.39	1.37	1.34	1.21	1.23	1.22	1.25	1.22	1.18
Na ₂ O	20.04	19.56	19.89	21.24	20.11	20.34	20.32	19.73	19.44	20.24	19.54	18.61	20.34	20.12	20.05	19.25
P ₂ O ₅	0.07	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.10	0.09	0.10	0.09	0.11
SiO ₂	48.02	47.39	47.71	46.66	47.68	47.80	47.82	47.54	47.03	48.09	48.21	48.75	48.14	47.91	48.00	48.83
SO ₃	0.23	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.21	0.21	0.21	0.20	0.21	0.21	0.20	0.22
TiO ₂	1.49	1.70	1.64	1.66	1.63	1.60	1.59	1.68	1.70	1.59	1.67	1.71	1.59	1.64	1.63	1.64
ZnO	2.97	2.90	2.80	2.85	2.77	2.69	2.70	2.98	3.09	2.72	2.88	2.97	2.73	2.82	2.80	2.84
ZrO ₂	2.98	3.45	3.27	3.18	3.22	3.07	3.13	3.49	3.67	3.10	3.33	3.41	3.13	3.26	3.24	3.25
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Target value

NA – Not analyzed

"-" empty data field

Table 4.2. XRF-Analyzed Compositions for Discharged Glass Samples (wt%), continued.

Test	-	Test 1 (Target Glass Temperature: 1775°C)												Test 2		
Glass (kg)	-	675.3	698.6	723.8	751.2	779.8	817.1	846.7	878.5	897.1	928.4	949.0	973.9	1000.7	1030.1	1060.8
Constituent	Target	WVT-G-11B	WVT-G-30A	WVT-G-30C	WVT-G-31B	WVT-G-32A	WVT-G-32C	WVT-G-36B	WVT-G-38B	WVT-G-39B	WVT-G-39C	WVT-G-40B	WVT-G-45B	WVT-G-47A	WVT-G-47C	WVT-G-52A
Al ₂ O ₃	6.20	6.32	6.46	6.47	6.13	5.84	5.91	6.19	6.20	6.33	6.40	5.98	5.86	6.35	6.22	6.20
B ₂ O ₃ *	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99
CaO	1.99	1.91	1.96	2.02	2.01	2.03	2.01	2.01	2.02	1.95	1.98	2.04	2.05	1.98	2.00	1.98
Cl	0.56	0.43	0.40	0.42	0.42	0.43	0.42	0.42	0.43	0.40	0.41	0.42	0.42	0.42	0.41	0.41
Cr ₂ O ₃	0.02	0.12	0.14	0.15	0.13	0.24	0.21	0.13	0.13	0.12	0.13	0.23	0.25	0.12	0.13	0.13
F	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe ₂ O ₃	4.48	4.14	4.27	4.48	4.37	4.79	4.68	4.42	4.54	4.36	4.47	4.94	5.06	4.53	4.57	4.51
K ₂ O	0.44	0.51	0.51	0.53	0.52	0.50	0.50	0.54	0.55	0.50	0.51	0.51	0.52	0.51	0.53	0.52
MgO	1.49	1.24	1.27	1.27	1.26	1.23	1.23	1.25	1.29	1.40	1.33	1.33	1.40	1.44	1.46	1.52
Na ₂ O	20.04	20.64	20.39	19.58	19.63	20.28	20.36	19.81	19.64	20.62	19.71	19.67	19.82	19.71	19.77	19.82
P ₂ O ₅	0.07	0.10	0.10	0.10	0.10	0.09	0.10	0.11	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.10
SiO ₂	48.02	48.21	47.81	47.95	48.51	47.28	47.50	48.06	47.97	47.51	48.00	47.41	47.05	47.79	47.79	47.94
SO ₃	0.23	0.21	0.21	0.20	0.21	0.20	0.20	0.23	0.20	0.20	0.20	0.20	0.21	0.21	0.20	0.19
TiO ₂	1.49	1.55	1.62	1.68	1.63	1.68	1.64	1.67	1.67	1.63	1.65	1.70	1.72	1.69	1.67	1.65
ZnO	2.97	2.65	2.75	2.90	2.85	2.98	2.89	2.89	2.93	2.77	2.84	3.00	3.04	2.87	2.84	2.80
ZrO ₂	2.98	3.00	3.13	3.25	3.25	3.45	3.36	3.29	3.33	3.13	3.28	3.48	3.51	3.30	3.33	3.24
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Target value

NA – Not analyzed

"-" empty data field

Table 4.2. XRF-Analyzed Compositions for Discharged Glass Samples (wt%), continued.

Test	-	Test 2 (Target Glass Temperature: 1225°C)														
Glass (kg)	-	1096.0	1127.2	1158.4	1180.2	1205.7	1229.3	1269.3	1302.7	1337.4	1363.5	1391.2	1415.9	1450.3	1481.8	1512.6
Constituent	Target	WVT- G-53A	WVT- G-54B	WVT- G-56B	WVT- G-57B	WVT- G-57D	WVT- G-59B	WVT- G-64A	WVT- G-65B	WVT- G-66B	WVT- G-68B	WVT- G-71A	WVT- G-72A	WVT- G-74A	WVT- G-76B	WVT- G-78A
Al ₂ O ₃	6.20	6.29	6.18	6.31	6.19	6.19	6.31	6.25	6.30	6.15	6.20	6.40	6.27	6.26	6.21	6.46
B ₂ O ₃ *	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99
CaO	1.99	1.95	1.96	1.99	2.02	1.99	2.00	1.95	2.01	2.07	2.01	1.96	1.99	1.93	1.98	1.98
Cl	0.56	0.39	0.40	0.36	0.37	0.38	0.38	0.36	0.36	0.37	0.38	0.36	0.37	0.37	0.39	0.38
Cr ₂ O ₃	0.02	0.13	0.14	0.14	0.13	0.13	0.14	0.13	0.13	0.14	0.13	0.13	0.13	0.12	0.13	0.13
F	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.00
Fe ₂ O ₃	4.48	4.41	4.54	4.55	4.69	4.64	4.66	4.51	4.80	4.93	4.70	4.57	4.66	4.45	4.64	4.70
K ₂ O	0.44	0.52	0.52	0.52	0.51	0.52	0.51	0.50	0.50	0.51	0.52	0.51	0.53	0.50	0.52	0.50
MgO	1.49	1.52	1.46	1.58	1.54	1.58	1.52	1.60	1.56	1.58	1.54	1.58	1.64	1.67	1.64	1.70
Na ₂ O	20.04	19.91	19.87	19.70	19.22	19.44	19.15	20.23	19.60	19.18	19.13	19.37	18.96	19.76	18.91	19.39
P ₂ O ₅	0.07	0.09	0.10	0.10	0.09	0.10	0.10	0.09	0.11	0.10	0.11	0.10	0.10	0.09	0.10	0.09
SiO ₂	48.02	48.09	47.90	47.87	48.07	47.99	48.29	47.67	47.32	47.36	48.20	48.23	48.46	48.27	48.69	47.60
SO ₃	0.23	0.19	0.18	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19	0.19	0.18
TiO ₂	1.49	1.62	1.66	1.65	1.68	1.67	1.68	1.63	1.70	1.74	1.68	1.66	1.65	1.62	1.66	1.68
ZnO	2.97	2.73	2.82	2.79	2.93	2.85	2.80	2.75	2.95	3.05	2.87	2.76	2.79	2.65	2.74	2.85
ZrO ₂	2.98	3.16	3.28	3.25	3.37	3.34	3.29	3.15	3.48	3.64	3.34	3.18	3.29	3.12	3.21	3.37
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Target value

NA – Not analyzed

"-" empty data field

Table 4.2. XRF-Analyzed Compositions for Discharged Glass Samples (wt%), continued.

Test	-	Test 2 (Target Glass Temperature: 1225°C)															Average	%Dev
Glass (kg)	-	1578.2	1614.7	1643.3	1671.5	1696.7	1722.6	1749.5	1782.5	1802.6	1836.9	1869.1	1901.7	1925.2	1947.0			
Constituent	Target	WVT- G-82A	WVT- G-85A	WVT- G-86A	WVT- G-88A	WVT- G-92E	WVT- G-93E	WVT- G-94E	WVT- G-95E	WVT- G-97A	WVT- G-97C	WVT- G-102A	WVT- G-102C	WVT- G-104E	WVT- G-110E			
Al ₂ O ₃	6.20	6.40	6.43	6.27	6.25	6.22	6.20	5.85	5.89	6.22	6.24	6.11	6.24	6.24	6.27	6.22	0.34	
B ₂ O ₃ *	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	NC	NC	
CaO	1.99	1.96	1.98	1.85	1.93	1.91	1.93	2.10	2.06	2.00	1.99	2.02	2.05	2.03	2.00	1.99	-0.03	
Cl	0.56	0.39	0.37	0.37	0.38	0.38	0.38	0.39	0.38	0.39	0.38	0.39	0.39	0.34	0.37	0.40	NC	
Cr ₂ O ₃	0.02	0.13	0.13	0.11	0.12	0.12	0.12	0.27	0.22	0.13	0.12	0.13	0.13	0.13	0.28	0.15	NC	
F	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NC	-NC	
Fe ₂ O ₃	4.48	4.77	4.72	4.21	4.37	4.30	4.33	5.27	5.09	4.59	4.52	4.60	4.49	4.56	4.42	4.58	2.26	
K ₂ O	0.44	0.49	0.50	0.48	0.50	0.50	0.50	0.50	0.49	0.51	0.50	0.52	0.52	0.50	0.51	0.51	NC	
MgO	1.49	1.66	1.58	1.59	1.49	1.52	1.50	1.42	1.39	1.37	1.37	1.32	1.20	1.14	1.18	1.41	-5.39	
Na ₂ O	20.04	19.74	19.36	20.34	19.93	19.98	19.73	19.02	19.66	19.48	19.64	19.69	19.49	19.28	19.81	19.75	-1.45	
P ₂ O ₅	0.07	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.10	0.11	0.10	0.10	0.10	0.10	0.10	0.10	NC	
SiCl ₂	48.02	47.41	47.68	48.58	48.44	48.61	48.73	47.32	47.14	48.31	48.32	48.00	48.44	48.51	48.15	47.93	-0.18	
SO ₃	0.23	0.19	0.18	0.18	0.18	0.17	0.19	0.20	0.19	0.19	0.18	0.18	0.19	0.17	0.18	0.19	NC	
TiO ₂	1.49	1.65	1.69	1.53	1.59	1.57	1.60	1.78	1.77	1.68	1.67	1.71	1.70	1.70	1.67	1.66	11.23	
ZnO	2.97	2.80	2.86	2.50	2.65	2.60	2.65	3.13	3.05	2.80	2.80	2.90	2.82	2.97	2.88	2.84	-4.48	
ZrO ₂	2.98	3.33	3.41	2.90	3.09	3.03	3.07	3.67	3.58	3.25	3.20	3.32	3.24	3.33	3.19	3.28	10.15	
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC	

* Target value

NA – Not analyzed

NC – Not calculated

"-" empty data field

Table 4.3. XRF-Analyzed Compositions for Dip Samples.

Test, Target Glass Temperature		Test 1, 1175°C				Test 2, 1225°C	
Glass Produced (kg)		0.0	453.7	453.7	747.8	1694.1	1694.1
Sampling Date		9/16/03	9/18/03	9/20/03	9/21/03	9/24/03	9/24/03
Constituent	Target	WVS-D-134A	WVT-D-11A	WVT-D-18A	WVT-D-46A	WVT-D-110A	WVT-D-110B
Al ₂ O ₃	6.20	6.05	6.16	5.70	6.23	6.22	6.27
B ₂ O ₃ *	8.99	8.98	8.98	8.98	8.98	8.98	8.98
CaO	1.99	1.96	2.01	1.99	1.91	1.94	2.00
Cl	0.56	0.41	0.47	0.45	0.44	0.48	0.37
Cr ₂ O ₃	0.02	0.13	0.16	0.44	0.12	0.54	0.28
F	0.03	NA	NA	NA	NA	NA	NA
Fe ₂ O ₃	4.48	4.66	4.44	4.86	4.25	4.39	4.43
K ₂ O	0.44	0.49	0.54	0.50	0.51	0.51	0.51
MgO	1.49	1.49	1.18	1.18	1.42	1.15	1.18
Na ₂ O	20.04	20.96	19.99	20.22	19.30	20.41	19.81
P ₂ O ₅	0.07	0.09	0.09	0.10	0.11	0.10	0.10
SiO ₂	48.02	46.79	47.85	46.61	49.26	47.23	48.16
SO ₃	0.23	0.19	0.23	1.04	0.22	0.24	0.18
TiO ₂	1.49	1.63	1.65	1.64	1.58	1.66	1.67
ZnO	2.97	2.97	2.97	2.97	2.67	3.01	2.88
ZrO ₂	2.98	3.19	3.27	3.33	3.00	3.14	3.19
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulfate Salt Present?	-	No	No	No	No	No	No

* Target value

NA – Not analyzed

"-" empty data field

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

Target Glass Temperature		1175°C, Test 1				1225°C, Test 2			
Sampling Interval		09/18/03, 12:41 – 13:41				09/23/03, 15:41 – 16:18			
		101.2% Isokinetic, 10.8% Moisture				104.8% Isokinetic, 16.7% Moisture			
		Feed Rate (mg/min)	Emissions Rate (mg/min)	% of Feed	DF	Feed Rate (mg/min)	Emissions Rate (mg/min)	% of Feed	DF
Particulate	Total*	210000	994	0.47	211	316000	2680	0.85	118
	Al	5904	4.93	< 0.1	1198	8836	31.29	0.35	283
	B	5022	26.17	0.52	192	7533	105	1.40	72
	Ca	2560	2.06	< 0.1	1244	3841	11.43	0.30	336
	Cl*	1008	423	42.0	2.4	1512	920	60.8	1.6
	Cr	25	1.29	5.25	19	37	2.98	8.07	12
	F*	54	46.4	85.9	1.2	81	178	220	0.5
	Fe	5639	2.08	0.04	2712	8438	13.51	0.16	626
	K	657	25.18	3.83	26	986	57.39	5.82	17
	Mg	1617	0.21	< 0.1	7749	2426	0.73	< 0.1	3309
	Na	26763	286	1.07	93	40145	720	1.79	56
	P	55	0.12	0.21	475	83	0.48	0.58	173
	S*	166	15.3	9.22	108	249	46.1	18.5	5.4
	Si	40406	13.39	< 0.1	3018	60609	101	0.17	601
	Ti	1608	2.32	0.14	694	2412	13.36	0.55	181
	Zn	4295	6.17	0.14	696	6442	30.30	0.47	213
	Zr	3971	0.61	0.02	6560	5936	3.59	0.06	1658
Gas	B	5022	12.68	0.25	396	7533	22.71	0.30	332
	Cl	1008	0.41	0.04	2432	1512	0.33	< 0.1	4587
	F	54	3.05	5.65	18	81	1.85	2.29	44
	S	166	0.98	0.59	169	249	1.00	0.40	249

\$ From gravimetric analysis of filters and particulate nitric acid rinses

* Based on analysis of water dissolution of filter particulate and calculated proportion in acid rinse

"-" empty data field

Table 5.2. Average Concentration (ppmv) of Selected Species in Off-Gas Measured by FTIR Spectroscopy.

Analyte	Test 1	Test 2
N ₂ O	116	137
NO	1098	1426
NO ₂	97	148
NH ₃	59	64
H ₂ O%	5.7	7.1
CO ₂	2700	3300
HNO ₂	< 1.0	< 1.0
HNO ₃	< 1.0	< 1.0
HCN	< 1.0	< 1.0
CO	46	59
HCl	< 1.0	< 1.0
HF	< 1.0	< 1.0

Table 5.3. Average NO_x Fluxes in Off-Gas Measured by FTIR Spectroscopy.

Target Glass Temperature	Feed [mol/hr]	Emissions [mol/h]			% Feed NO _x Emittted as Nitrogen Oxides
		N ₂ O [mol/hr]	NO [mol/hr]	NO ₂ [mol/hr]	
1175°C	32.7	1.4	13.2	1.2	48
1225°C	41.7	1.6	17.1	1.8	49

Table 5.4. Mass Balance for Sulfur and Chlorine during Vitrification of LAW Sub-Envelope A1 Simulants (% of Feed).

Glass Temperature		1150°C	1150°C	1150°C	1175°C	1225°C
Melter		DM100	DM1200	DM100	DM100	DM100
Glass		LAWA44	LAWA44	LAWA44	LAWA140	LAWA140
Feed		Average of +/-15 wt% simulant [7]	Nominal [26]	Added NaCl recycle [29]	Nominal	Nominal
Glass	Cl	58	68	56	75	66
	S	91	100	95	91	81
Particle Emissions	Cl	57	34	43	42	61
	S	14	40	14	92	19
Gaseous Emissions	Cl	0.6	1.5	0.1	< 0.1	< 0.1
	S	0.1	< 0.1	< 0.1	0.6	0.4
Totals	Cl	116	104	99	117	127
	S	105	104	109	101	100

Figure 1.1. Schematic diagram of DuraMelter 100-WV vitrification system.

SECTION B-B
(BACKGROUND OMITTED)

Figure 1.2(a). Cross-section through the DM100-WV melter—Plan View.

Figure 1.2(b). Cross-section through the DM100-WV melter—Section AA.

Figure 1.2(c). Cross-section through the DM100-WV melter—Section CC.

Figure 2.1. Measured viscosity of LAW A melter feed samples.

Figure 2.2. Comparison of measured feed rheology with proposed WTP bounds (bounds from WTP-RPT-075, Rev. 0, Feb. 2003).

Figure 3.1. Glass production rates and bulk glass temperature.

Figure 3.2. Comparison of production rates from DM100 LAW Sub-Envelope A1 tests.

Figure 3.3. Glass temperatures and electrode power.

Figure 3.4. Plenum temperatures and electrode power.

Figure 3.5. Electrode temperature and power.

Figure 4.1. XRF analysis of Na₂O and SiO₂ in melter glasses from Tests 1 and 2.

Figure 4.2. XRF analysis of select major oxides in product glasses from Tests 1 and 2.

Figure 4.3. XRF analysis of select oxides in product glasses from Tests 1 and 2.

Figure 4.4. XRF analysis of volatile constituents in melter glasses from Tests 1 and 2.

Figure 5.1. Nitrogen oxide concentrations in off-gas from FTIR.

Figure 5.2. CO concentration in off-gas from FTIR.

Figure 5.3. Ammonia concentration in off-gas from FTIR.