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Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A2 Feed (LAWA88 Glass) in Support of the LAW Pilot Melter, VSL-02R62N0-3, Rev. 1

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

Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A2 Feed (LAWA88 Glass) in Support of the LAW Pilot Melter

prepared by

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for

Duratek, Inc.

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SECTION 1.0
INTRODUCTION

The Vitreous State Laboratory at The Catholic University of America (VSL) is developing and testing glass formulations for RPP-WTP waste envelopes to provide data to meet the RPP-WTP contract requirements and to support system design activities [1]. That work is based upon small-scale batch melts ("crucible melts") using waste envelope simulants. Selected formulations have also been tested in small-scale continuously-fed joule-heated melters (DM10 and DM100 systems) [2-6] and, ultimately, in the LAW Pilot Melter [7-9]. 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. The principal objective of the work described in this report was to collect the necessary small-scale melter test data with a LAW Sub-Envelope A2 waste simulant in order to support the next series of tests with the same melter feed on the LAW Pilot Melter. This work was conducted under a corresponding Test Specification [10] and Test Plan [11]. A Test Exception was issued [12] for an additional test using nominal feed with formic acid at various concentrations in place of sugar, which is the WTP baseline reductant. The objective of that test was to compare the relative tendencies for hydrogen formation for feeds with sugar or formic acid as the reductant, the results of which have been reported separately [13].

A previous series of tests on the LAW Pilot Melter was directed towards demonstration of the ability to process flow-sheet levels of sulfate following the decision to delete the sulfate removal process from pretreatment [7-9]. Those tests were based on supporting crucible and small-scale melter tests [1-4, 14] as well as previous experience with high-sulfate feeds [15, 16]. High-sulfate feeds based on a representative tank composition from each waste envelope (A, B, and C) were used for those tests. In particular, the Envelope A tests were based on the composition of tank AN-104, which is designated as "Sub-Envelope A3"; the present work is based on the composition of tank AP-101, which is designated Sub-Envelope A2 [1]. While the earlier tests were based on nominal feed compositions, the objective of the present work, and the parallel LAW Pilot Melter tests, was to determine the effects of process variations around the nominal composition and, in particular, to evaluate variations in the ratio of waste to glass formers. The motivation for these tests is that the process should be robust enough to accommodate reasonable variations in the feed make-up without deleterious consequences such as the formation of a salt layer on the molten glass pool, unfavorable processing behavior, or adverse feed rheology or melt and glass product properties.

The three tests described in this report utilized blended feed (glass formers plus waste simulant) prepared by Optima Chemicals according to VSL specifications or from the LAW Pilot Melter at Duratek, which generated over 2 metric tons of glass. Sugar was added (at VSL)

to the nominal feed at a "reductant ratio" of 0.5 for each of the two variation tests[1]; however, since the sugar addition is assumed to be "blind" to the variations, the actual reductant ratios were 0.52 and 0.44. A third test was conducted with formic acid in place of sugar at three different reductant ratios (0.5, 0.75, and 1.0).

The DM100-WV melter was used in order to provide a direct comparison with the LAW tests previously conducted on the same melter [2-6]. Three melter tests varying in duration from 56 to 100 hours were conducted: one with a 15% deficiency in simulant one with 15% excess in simulant and one with the nominal feed. Key operating parameters including cold cap coverage, feed rate, and glass pool temperature were held constant to investigate the effects of the glass compositional changes on processing characteristics (including salt formation) and the product glass. The bubbling rate was adjusted to provide the desired glass production rate with 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, SO_2, CO, particulate load and composition, and acid gases) were made for each test.

1.1 Test Objectives

The principal objective of the DM100 tests was to demonstrate the robustness of the vitrification process with respect to feed and glass compositional changes resulting from variations in the simulant-to-additive ratio. The DM100-WV unit was selected for these tests; this melter was used for all of the Part B1 tests on LAW Envelopes A, B, and C sulfate incorporation [2, 3] that were used to support the subsequent tests on the Pilot Melter [7-9] as well as for the more recent LAW Sub-Envelope A3, C1, and A1 tests [4-6]. The same melter was selected for the present tests in order to maintain comparisons between the data sets. In addition, the somewhat smaller glass volume for the same melt surface area as compared to the DM100-BL melter means that more glass turnovers are achieved for a given test duration.

The DM100 tests used feeds with ±15% waste simulant over the nominal. Previous Pilot Melter tests on Envelope A simulant with 10% variations (but with sulfate removal) showed significant impacts on glass production rates that were ultimately corrected by adjustments in the sugar additions. Consequently, robustness with respect to throughput as well as sulfate tolerance are important motivations for these tests. Subsequent to the successful outcome of these tests, the same melter feeds were tested at a larger scale in subsequent Pilot Melter tests. The RPP-WTP Project has developed the underlying technical basis for the selected 15% variations. The amount of glass produced from an individual batch of pretreated waste is expected to be a function of either the sodium or sulfur content of that waste. The Project's estimates for the uncertainty of

[1] A "reductant ratio" of one is *defined* as 1.5 moles of total organic carbon per mole of NOx in the feed. If sugar was the only source of organic carbon, this would correspond to 1 mole of sugar per 8 moles of NOx; however, the contribution of organic carbon in the waste is taken into account in this calculation. In work performed by VSL and Duratek for the vitrification of high-sodium-nitrate feeds at Savannah River's M-Area, a reductant ratio of 0.5 was empirically determined to successfully control melt foaming without significantly reducing the glass. The same baseline reductant ratio of 0.5 has been successfully applied to the processing of a wide variety of simulated RPP-WTP feeds in small-scale and pilot-scale tests.

these analyses that have been used in the error assessments conducted by Process Engineering are 10%. These models have also assumed an error for volume transfer measurements of 5%. The 15% variation represents the sum of these errors assuming that both occur simultaneously in the same direction, i.e. combined low sulfate or sodium analysis and high volume transfer error for the high waste concentration case. Supporting crucible melt studies have indicated that no sulfate phase separation is expected for such variations. However, one of the objectives of this test was to confirm that only single-phase glass is being produced prior to exposing the LAW Pilot Melter to the high-sulfate feed. The melter was examined at the end of each feeding period to verify that no sulfate phase was detectable or otherwise determine an appropriate mitigating response.

Thus, the major objectives of these tests were to:

- Perform tests on the DM100-WV system using Sub-Envelope A2 feed compositions with ±15 weight % variations in the amount of simulant to ascertain the sensitivity of the vitrification process to variations in simulant-additive ratio.
- Demonstrate sustained processability and product quality with respect to composition and absence of secondary sulfate phases over compositional ranges resulting from variations of the simulant-additive ratio for a glass formulated for the Sub-Envelope A2 waste stream.
- Collect melter emissions data to determine the effect of composition on melter emissions.
- Provide supporting data necessary to ensure the success of the larger-scale Pilot Melter tests.
- Characterize the properties of the melter feed (rheological properties, composition, etc.)

The major objective for the added third test was to compare hydrogen generation with formic acid as the reductant in place of sugar; these results are addressed elsewhere [13]. Data on feed properties, feed and glass processability, product quality, and melter emissions for all three tests are provided in the present report.

1.2 Quality Assurance

This work was conducted under an NQA-1 based quality assurance program that is in place at VSL. This program is supplemented by a VSL Quality Assurance Project Plan (QAPP) for RPP-WTP work. Per RPP-WTP Project direction, the program was revised during the preparatory stages of this work. Accordingly, work performed before 8/1/01 was performed under an NQA-1 (1994) program and corresponding QAPP [17], while work performed after that

date was performed under an NQA-1 (1989) and NQA-2a (1990) Part 2.7 based quality assurance program and corresponding QAPP [18].

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 RPP-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 Figure 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 X 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 Sub-envelope A2 waste simulant is based on composition data for tank AP-101 derived from the TF COUP [19]. Specifically, the Sub-Envelope A2 simulant composition was formulated using the supernate compositions obtained from "Case 3S6E" of the feed delivery sequence [19]. The composition differs somewhat from recent sample analytical data for AP-101 [20] primarily in that the latter contains more potassium; however, the TF COUP data [19] were used for this work per WTP direction [11][2, 3]. In view of the rather limited information on organic speciation in the TF COUP, the total organic carbon (TOC) data in the TF COUP were supplemented by other Hanford tank waste information [21, 22]. The same mix of organics that was used for the AN-107 simulant [5] was used for AP-101 such that the ratios of the various organics were maintained at the same ratios as that for the AN-107 simulant but their overall concentrations were decreased to agree with the TOC concentration reported for AP-101 [19]. The organics data from the analysis report for AP-101 [20] were not used because of the limited number of analytes reported and the fact that the TOC concentration does not agree with the data provided in the TF COUP [19]. The sodium concentration in the simulant was increased by 2.56 % to account for sodium additions in pretreatment [1, 23, 24]. This increase changed the sodium concentration in the nominal LAWA88 glass from 19.5 wt% to 20.0 wt%. The sulfate content in the simulant was then 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[4] [2-6]. 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 molar sodium as the nominal simulant concentrations for Sub-Envelope A2. The nominal simulant formulation is shown in Table 2.1. The resulting waste simulant is a solution of predominantly sodium nitrite, nitrate, and carbonate, aluminum nitrate, and hydroxides of sodium and potassium.

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[2] Since this work was completed, additional DM100 melter tests have been performed using a simulant and glass formulation based on the higher-potassium composition for AP-101 (Test Plan VSL-02T62N0-4, Rev. 0, 10/23/02), which will be followed by tests on the LAW Pilot Melter. The revised glass composition has a slightly lower sodium content in order to accommodate the higher potassium. Thus, no difficulties have been identified in accommodating the revised composition.

[3] It should be noted that the TF COUP [19] has since been revised (see for example, TF COUP, Rev 3A) such that the composition of AP-101 LAW now agrees well with the sample analytical data [20].

[4] The integrated WTP flow sheet models were not available at the time this work was performed. However, since the same data [2-9] should be the input to the melter off-gas process models, the sulfur recycle data should be consistent. It is expected that the make-up of the feed batches for the LAW melter will be driven by the sodium or the sulfur in the waste stream from pre-treatment, whether these salts originated from the waste tank or from a LAW / HLW recycle stream.

2.2 Glass Formulation

The feed additives were selected on the basis of glass formulation studies, which included optimization with respect to sulfate incorporation and salt formation [1–3, 14], and rheological testing [24]. Based on these results, LAWA88 was selected for the Sub-Envelope A2, AP-101 waste. The compositions of these glasses and the waste and additive fractions are shown in Table 2.2; the additive sources are shown in Table 2.3. Glass formulations used in this work include the nominal formulation and those containing ±15 weight percent simulant with respect to the nominal formulation, as shown in Table 2.2.

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 RPP-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 "reductant ratio" of 1.0 as a result of concerns for over-reducing the melt. Such a reaction, using sodium salts as an example, is:

$$C_{12}H_{22}O_{11} + 8NaNO_3 = 8CO_2 + 4CO + 4N_2 + 11H_2O + 4Na_2O$$

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 reductant 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 A2 feed to achieve a reductant ratio of 0.5 proceeds as follows:

- One liter of simulant contains 1.075 moles of nitrite and 2.603 moles of nitrate, giving a total of 3.678 moles of NOx (see Table 2.1)
- Required total amount of organic carbon for a reductant ratio of 0.5 is 3.678x0.75=2.759 moles
- One liter of simulant contains 0.322 moles of organic carbon (see Table 2.1)
- Therefore, 3.678-0.322=2.437 moles of organic carbon must be added

Since the molecular weight of sucrose is 342 g per mole, 2.437x342/12=69.4 g sugar per liter of simulant, as shown in Table 2.3.

2.4 Preparation of Melter Feed

Feed for these melter tests was obtained from two sources, Optima for Test 1 and 3 and Duratek for Test 2. Optima Chemicals, which has supplied all of the LAW simulants for the previous DM100 and LAW Pilot Melter studies, prepared the simulant and added most of the glass forming chemicals for the feed compositions before shipment to VSL in 55-gallon drums. The remaining glass forming chemicals (principally boric acid) and sugar were added at VSL. Duratek receives simulant from Optima and additives from different suppliers. Nominal feed with an 8.5 molar sodium simulant and additional 9.5 molar simulant was shipped from Duratek to VSL for Test 2. The Duratek materials were combined at VSL with water and sugar to achieve a feed with 15% excess of 8 molar simulant. Potassium iodide (KI) at sufficient concentration to provide 0.1 wt% in the product glass (if all of it were retained in the glass) was added to the feed at VSL to determine the partitioning of iodine between the glass phase and the gas phase. It should be noted that this iodine concentration is much greater than that in actual AP-101 LAW (the sum of I-127 and I-129 is ~3 mg/l based on reference [20]) but the higher level was necessary for the analyses required to support a mass balance.

2.5 Analysis of Feed Samples

2.5.1 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. Sample names, sampling dates, and measured properties are provided in Table 2.4. As expected, both the feed density and glass conversion ratio were highest for the -15% simulant feed (Test 1) and lowest for the +15% simulant feed (Test 2). Feed pH also followed the anticipated trend; feed with the highest simulant content had the highest pH. It should be noted that the nominal feed samples (Test 3) did not have feed properties intermediate between the simulant variation samples as a result of the use of formic acid in the nominal feed in place of sugar. Notice that in the samples from Test 3 the pH, glass yield, and density all decrease as the formic acid content increases.

2.5.2 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 measured at equilibrium. It should be noted that this approach is somewhat different than the "flow curve" approach that is often used 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 arbitrarily selected ramp rate. In contrast, the present measurements are equilibrium values of the shear stress at each measured shear 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 "true" yield stress can be quite different from the value that is often reported as the yield stress, which is instead obtained simply 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 Figure 2.1; measured values for viscosity at selected shear rates and the yield stress values are shown in Table 2.4. As expected, the highest measured viscosities were for samples from the -15% simulant tests and the lowest for the samples from the +15% simulant test. Yield stress values remained low for all of the samples. The rheological properties of the measured nominal feed samples with formic acid were very similar to the surplus simulant samples, which used sugar. Sufficient formic acid was added to this sample to achieve a reductant ratio of 0.5 (0.75 moles carbon per 1 mole NOx). Although samples with other formic acid concentrations were not measured, it is likely that they would exhibit lower viscosities in view of their lower glass conversion ratio, density, and pH.

2.5.3 Chemical Composition

The chemical compositions of the feed samples were determined by first making a glass from the feed via crucible melt. The glass was subsequently crushed and analyzed directly by X-Ray Fluorescence Spectroscopy (XRF). Boron and lithium oxide target values were used for normalizing the XRF data since those elements were not determined by XRF. Data are compared to the target compositions in Table 2.5. A clear difference between feed obtained directly from

Optima (Test 1 and 3) and the Duratek Pilot Melter (Test 2) was observed. Test 1 and 3 results generally corroborate the consistency of the feed composition and show good agreement with the target composition for the major elements. Only two major oxides, MgO and TiO_2, have deviations from the target of greater than 10%. The deficiency in magnesium is significantly less in melter glasses, whereas the approximately 14% excess in TiO_2 is also observed in glasses produced during the melter tests (see Section 4.1). This same trend also occurred in the DM100 LAWA1 tests [6]. Results from the Test 2 feed samples indicate deficiencies between 27% and 31% for magnesium and iron, in addition to a 44% excess of calcium and a 14% excess of titanium. All of these deviations are also observed in the glass product except for magnesium, which again is much closer to the target value in the discharged glasses. The iron and calcium deviations have been identified in several feed batches used at the LAW Pilot Plant since the present tests were completed. At the LAW Pilot Melter, simulant prepared by Optima is blended in-house with feed additives purchased from a different supplier. In contrast, Optima supplies all of the chemicals and prepares the simulant and the melter feed for the VSL tests. Apparently, the deficiencies in the Pilot Melter feed relate to the additives (see Table 2.3) and, therefore, were not observed in completed feed obtained by VSL from Optima. Compositional deviations of the magnitudes observed would not be expected to materially affect the glass or feed properties and, consequently, their impact on the conclusions drawn from the test results should be minimal.

Volatile minor elements such as sulfur, cesium, and halogens shown in Table 2.5 are below target due to loss during crucible melting of the feed samples.

SECTION 3.0
MELTER OPERATIONS

Melter tests were conducted on the DM100-WV with the LAW Sub-Envelope A2 simulant between 11/12/01 and 1/25/02, producing over 2000 kg of glass from approximately 4,000 kg of feed. The tests were divided as follows:

- Test 1: - 15% Simulant, Reductant Ratio = 0.5 (nominal), 0.57 (actual)
- Test 2: +15% Simulant, Reductant Ratio = 0.5 (nominal), 0.44 (actual)
- Test 3: Nominal, Reductant Ratio = 0.5, 0.75, 1.0 using formic acid in place of sugar

Note that since the sugar additions are assumed to be "blind" to the +/- 15% variations, the actual reductant ratios for Tests 1 and 2 differ from the nominal. The nominal sugar addition results in a higher than nominal reductant ratio when there is less than the nominal amount of nitrates in the feed as a result of the -15% variation; the converse is true for the +15% variation. Formic acid was added to nominal feed to achieve the desired carbon to feed nitrate/nitrite ratios in Test 3.

Summaries are provided in Table 3.1 for the first two tests and Table 3.2 for Test 3. Attempts were made to replicate the melter configuration and operating conditions used for the corresponding tests conducted earlier [2, 3] plus the previous LAW Sub-Envelope A3 [4] and C1 [5] tests. These conditions include a 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. Visual observations indicated that the cold cap was relatively soft and fluid and spread evenly across the melt surface except for a small opening directly above the bubbler outlet. The target production rates were approximated for both tests, as depicted in Figures 3.1 - 3.3, although the instantaneous rates varied by 20-30% as a result of variable feed pulse sizes: drift in the feed pulse shot size has to be compensated in order to maintain the desired average feed rate, which produces the observed variability. The drop in feed at about 36 hours run time of Test 3 was due to an hour and half of down-time needed to remove occlusions from the film cooler region. The 15% variation feeds met the acceptance criteria in that the required processing rates were achieved, no processing problems were observed, and a secondary sulfate phase was not observed. These feeds were, therefore, accepted for further tests on the LAW Pilot Melter. The formated feed used in Test 3 showed a greater tendency to bridge across the plenum but was manageable.

The results of various operational measurements that were made during these tests are given in Table 3.3. The target glass temperature of 1150°C was successfully maintained during each of the tests, as illustrated in Figures 3.4 - 3.6. Glass temperatures for the center of the glass pool (10" from bottom) approximated the target, whereas temperature readings made near the melt surface and in the cold cap fluctuated with the level of glass in the melter. The average plenum temperatures for the tests were 582-611°C, well within the 450 - 650°C range targeted for the steady-state portions of the tests. Since plenum temperature is a function of the extent to

which the surface of the melt pool is covered by feed, plenum temperatures decrease over the course of each test as the cold cap develops, as shown in Figures 3.7 - 3.9. Of the two plenum thermocouples, one was exposed and the other was inside a thermowell. The exposed and thermowell-encased thermocouples provided comparable temperatures, with the exposed thermocouple being more sensitive to temperature changes, as expected. Temperatures for the three electrodes and the bubbler are compared in Figures 3.10 – 3.12. The electrode and bubbler temperatures were all lower than the bulk glass, with the exception of the West electrode. The bottom electrode (which was not energized) was 65°C to 135°C cooler than the East electrode. The thermocouple in the West electrode read about 60-115°C higher than the one in the East electrode; however, this apparent disparity is not believed to be accurate since, in subsequent tests after the thermocouples were replaced, the difference disappeared. Power supplied to the electrodes typically varied within only 3 kW from the average value. Bubbling rates and total electrode power were similar for all three tests.

Gas temperatures at the film cooler typically averaged around 300°C, depending on the plenum temperature, the amount of added film cooler air, and the temperature of the added film cooler air. Little or no drop in gas temperature was observed across the (insulated) transition line.

SECTION 4.0
GLASS PRODUCTS

Over 2000 kg of glass product was discharged from the melter using an airlift system; glass pours were made periodically into 5-gallon pails. 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. Selected samples were also analyzed with wet chemical techniques for iron redox. Product glass masses, discharge date, and analyses performed are given 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 sulfate salts on 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, which is not determined by XRF, was used for normalizing the XRF data to 100 wt%. The analyzed compositions of discharged glass samples are provided in Table 4.2 for XRF analysis. Analysis results for dip samples by XRF are provided in Table 4.3. All discharged glass samples were subjected to XRF analysis. Compositional trends for selected oxides are shown in Figures 4.1-4.4. The majority of the XRF analysis results for Tests 1 and 3 compared very favorably to their corresponding target values. The only significant oxide that did not approach target at the end of Tests 1 and 3 was TiO_2, which was between 10 and 15% above target composition. The substantial deviations from target of iron and calcium observed in feed samples (see Section 2.4.3) are apparent in Figure 4.2. Notice the shift away from the iron target value of near 5.5 wt% iron oxide to a steady-state value of about 4 wt% iron oxide at the beginning of Test 2 (about 900 kg of production) and the return to target by the end of Test 3. The principal constituent in the simulant (sodium) and the most abundant constituent in the additives (silicon) vary significantly with the intended changes in the simulant-to-additives ratio. Notice in Figure 4.1 that the Na_2O concentrations stabilize near the target of 17.7 wt% during the production of the first 900 kg of glass as a consequence of using feed that is 15% low in simulant and, subsequently, increase towards the target of 22.2 wt% during the second test as a consequence of using feed that is 15% high in simulant. The inverse relationship is demonstrated for SiO_2. Sodium and silicon are farthest from target in Test 2. Another trend of note is the increase in potassium and titanium concentration as the melt pool transitions from about 0.5 wt% K_2O and 1.5 wt% TiO_2 towards target as shown in Figure 4.3. A systematic decrease in CaO concentration from a pretest value of about 4.5 wt% to the target value of about 2 wt% is shown in Figure 4.2. The chromium concentration in the glass is primarily from the melter refractories and, consequently, is highest at the start of a test after a period of idling and decreases during the course of the test, as shown in Figure 4.3.

The concentrations of chlorine, cesium, iodine, and sulfur, all of which are relatively volatile, are plotted over the course of the tests in Figure 4.4. The SO_3 percentage decreases from a higher initial concentration at the start of Test 1, then approaches the lower target (0.32 wt%),

increases towards the higher target (0.38 wt%) in Test 2 and finally decreases towards the nominal target of (0.35 wt%). The near target values for the nominal tests include over a day and half of processing at higher reductant ratios using formic acid as the reductant. In previous tests using sugar at such high reductant ratios, the level of sulfur dropped well below target (due to increased volatilization) and reduced sulfur was detected [4]. Formic acid, therefore, is not as effective a reductant as sugar with respect to sulfur. Chlorine concentrations were 54-64 percent of target throughout testing but were stable over the course of each test segment. Cesium concentrations also remained consistent throughout each test segment and were only 10 to 20 percent below target. All these trends are consistent with observations from the A1 melter tests [6] which employed a glass with several compositional similarities. The steady-state iodine concentration was 0.02 wt%, or twenty percent of target, in all three tests. This level of iodine retention in the product glass is similar to those obtained with other high-alkali glasses [6] and greater than obtained with low alkali glasses [5], supporting the expectation that iodine retention increases with glass alkali content. The drop in concentration of several volatile constituents between Tests 2 and 3 can be attributed to the near 2-month idling period between the tests.

Glass dip samples were obtained at the beginning and end of each test, primarily to ascertain if a secondary sulfate salt layer had formed on top 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. No dip samples at the beginning or end of any test showed visual evidence of sulfate, indicating that salt layers were not present on the melt surface. The analyzed compositions of the dip samples from the end of each segment were close to the target values with the exception of sulfur and chlorine, which have frequently been observed to be above target on dip samples as compared to discharged glass samples.

4.2 Iron Redox State

The iron oxidation state for glass samples from the end of each test segment was measured using colorimetric methods. The method detection limit for these measurements was 0.8% Fe^{2+}/Fe_{Total}. Sample information including name, test, and the amount of glass produced are given in Table 4.4. No measurable divalent iron was detected in any of the samples. This is somewhat surprising given the high levels of carbon (1 mole of NOx : 1.5 moles organic carbon) as formic acid used in the latter portion of Test 3. Comparable tests using sugar as a reductant resulted in divalent iron being as high as 45% of the total iron [4]. The lack of iron and sulfur reduction in the glass as well as the lack of NOx reduction in the emissions (Section 5.2) indicate that formic acid is not an effective reductant.

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 0.2 N NaOH was added to the sampling train to ensure complete scrubbing of all acid gases. The collected materials were analyzed using the following: direct current plasma optical emission spectroscopy (DCP) for the majority of the constituents, atomic absorption spectroscopy (AA) for cesium, and ion chromatography (IC) for anions. Prior to chemical analysis, filtered particles and rinses are digested in a nitric, hydrofluoric acid mixture with a microwave oven. In later tests, in an attempt to improve mass balances, a new method was employed, which involves dissolving a small aliquot of the particulate matter in water to permit the analysis of particulate fluoride and chloride as well as improve the recovery of sulfur and iodine (there is reduced potential for acid vapor escape with this room-temperature water dissolution as compared higher-temperature dissolution with mixed acids). Melter emission fluxes are compared to feed fluxes 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 0.45-μm heated filter.

The calculated isokinetic percentages were 106.3%, 120.6%, 108.9%, and 105.2% for the off-gas samples from Test 1, Test 2, Test 3b, and Test 3c, respectively (no sampling was performed for Test 3a). For regulatory purposes, Methods 5 isokinetic percentages are typically expected to be between 90 – 110%. Although one sample was outside of that range, the data are unlikely to be significantly impacted given the magnitude of the particle emissions as compared to most regulatory samples; consequently, the data are still believed to be representative of the off-gas stream in that test.

Particulate emissions from the melter were relatively high, ranging from 0.3 to 1% of feed solids. Typically, particulate melter emissions represent about 0.3% or less of melter feed [4, 5]. The difference is due to the higher alkali content of the Sub-Envelope A2 feed, which favors increased particulate emissions. Similar results were obtained with the Sub-Envelope A1 feed which has the same sodium content [6]. Elements exhibiting volatile behavior include halogens, sulfur, alkali metals, chromium, and, to a lesser degree, boron; chromium emission are likely biased high relative to the feed as a result of the high-chromium content of the melter

components (refractories, electrodes, etc.). Iodine was detected in the gaseous emissions in all four off-gas samples but as particulate only in the last two samples (Test 3). The detection of particulate iodine in the last two samples (Test 3) could be due to either the use of the water dissolution method for those samples or the formic acid in the feed. In samples from Test 3, as well as in the A1 melter tests [6], the vast majority of chlorine and fluorine emissions were particulate. The highest emission rates were observed while processing nominal feed with the highest formic acid content. Particulate emissions were significantly lowest in the test with less simulant (Test 1) due to the lower concentrations of some of these volatile elements. This trend is in keeping with observations from several previous studies [3-6, 8]. As expected, alkali metals showed increased volatility with increasing atomic weight (Na<K<Cs). 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. The off-gas residence time in the system prior to the FTIR sampling point is about 10 seconds, with a further 2 seconds in the FTIR sampling line; consequently, some re-equilibration may occur after the off-gas leaves the melter and prior to analysis, particularly for NOx. A summary of average concentrations monitored during each test is provided in Table 5.2. Concentrations of nitrogen species are plotted in Figures 5.1 - 5.4. The analytes listed in Table 5.2 are those that were thought likely 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 gas monitored was NO, which is consistent with previous tests in which nitrates and nitrites were present in the feed. The concentration of NO was about five times higher than that of NO_2 and significantly more than that for all other nitrogen oxide species. As expected, nitrogen oxide emissions for the test with excess simulant (Test 2) was higher than the test that was deficient in simulant (Test 1), since the simulant contains the nitrates and the increase was not compensated with additional sugar. Nitrogen and carbon oxide emissions increased substantially in tests using formic acid as the reductant. Conversely, byproducts typically associated with sugar additions to nitrate rich feeds, ammonia and hydrogen cyanide, decreased by an order of magnitude in the tests with formic acid. As expected, given the low- or below-detectable concentrations of gaseous chlorine, fluorine, and sulfur species observed using the Method 5-type sampling discussed earlier, little or no HF, HCl, or SO_2 were observed by FTIR. 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. The nominal reductant ratio that is typically used is 0.5, which results in about half of the nitrogen oxides being reduced to diatomic nitrogen. In the variation tests, the sugar additions were blind to the variations in nitrate-rich simulant (i.e., they assume that the feed is on-target when, in fact, it is off by ± 15%) and,

therefore, the actual ratios are less than 0.5 for excess-simulant feed and greater than 0.5 for simulant-deficient feed. The expected and obtained result was that more feed nitrates and nitrites were emitted as NOx in Test 2 than in Test 1. The unexpected result was the almost total lack of nitrogen oxide reduction in Test 3, even at a reductant ratio of one. Unlike previous tests with sugar [2, 4], the percentage of feed nitrates emitted as NOx remained constant as the amount of carbon in the feed was doubled. This is consistent with its lack of effect on glass redox state and sulfur emissions, all of which indicate that formic acid is a very poor reductant compared to sugar. A likely consequence is that melt pool foaming may be relatively poorly controlled unless much higher feed carbon contents (reductant ratios) are employed with formic acid.

5.3 Mass Balance of Volatile Constituents

Table 5.4 provides the percentages of volatile feed constituents (halides, sulfur, and cesium) that were retained in the glass product or identified in the various off-gas stream samples for each of the tests. The total recovery of sulfur and cesium was within 15% of that present in the batched feed. Table 5.4 shows that sulfur was retained in the glass at the highest rate, with 94 to 100 percent reporting to the glass. Cesium and chlorine were also retained in the glass in appreciable percentages ranging from 76-93 and 54-64, respectively. The chloride retention is remarkably consistent with LAW Sub-Envelope A1 results, even though the target chloride concentration was over four times higher (0.13 vs. 0.56 wt. %). Except for iodine, halide (Cl and F) and alkali emissions were almost exclusively particulate. The origin of the high recoveries in Test 3 with the highest formic acid concentration (last column in Table 5.4) is not known but may well be due to sporadic openings in the cold cap occurring during the 1-hour sampling period, resulting in an over-estimate of the steady-state particulate emissions. As observed in previous studies, iodine fell short of mass balance closure [4-6]. The lack of iodine mass balance closure suggests that the true decontamination factor (DF) for iodine is probably even lower than the emissions data indicate. Currently, additional methods are being pursued to trap forms of gaseous iodine that may be missed in the current off-gas sampling train. The water dissolution method will be used wherever possible in the future tests to determine particulate halide emissions.

SECTION 6.0
CONCLUSIONS

Two tests were conducted on a DM100 vitrification system to assess the robustness of the nominal LAW Sub-Envelope A2 formulation using an AP-101 waste simulant with respect to variations in feed make-up. The ± 15% variations investigated in the present tests are expected to conservatively bound the range of variations likely to be encountered in full-scale operations. The results showed that the nominal LAW Sub-Envelope A2 formulation is robust with respect to both a 15% excess and 15% deficit in the amount of waste simulant. The test results showed that the system tolerated the feed variations with respect to feed properties, processing behavior, glass production rate, sulfate formation tendency, and product quality. As a result, these formulations were subsequently accepted for larger-scale testing on the LAW Pilot Melter. Completion of the objectives for the tests performed in this work is detailed in Table 6.1.

During the present tests, total particulate emissions from the melter ranged from 0.3 to 1 wt% and DFs were determined for each element in the feed for the two tests that were performed. This high relative volatility can be attributed to the high concentration of volatile alkali halides in the feed. Of the more volatile species, DFs for halogens and cesium were between 1 and 10. Mass balance closure was found to be good for volatile constituents with the exception of iodine, despite the relatively high iodine retentions observed in the glass.

An additional test using the nominal feed with formic as the reductant at various reductant ratios indicated that formic acid is not an effective reductant with respect to sulfur, iron, or nitrates.

SECTION 7.0
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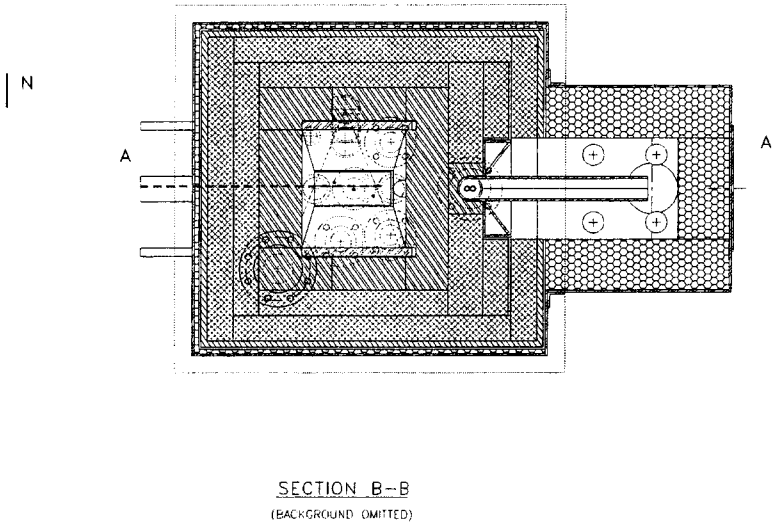

Figure 1.2(a). Cross-section through the DM100-WV melter—Plan View.

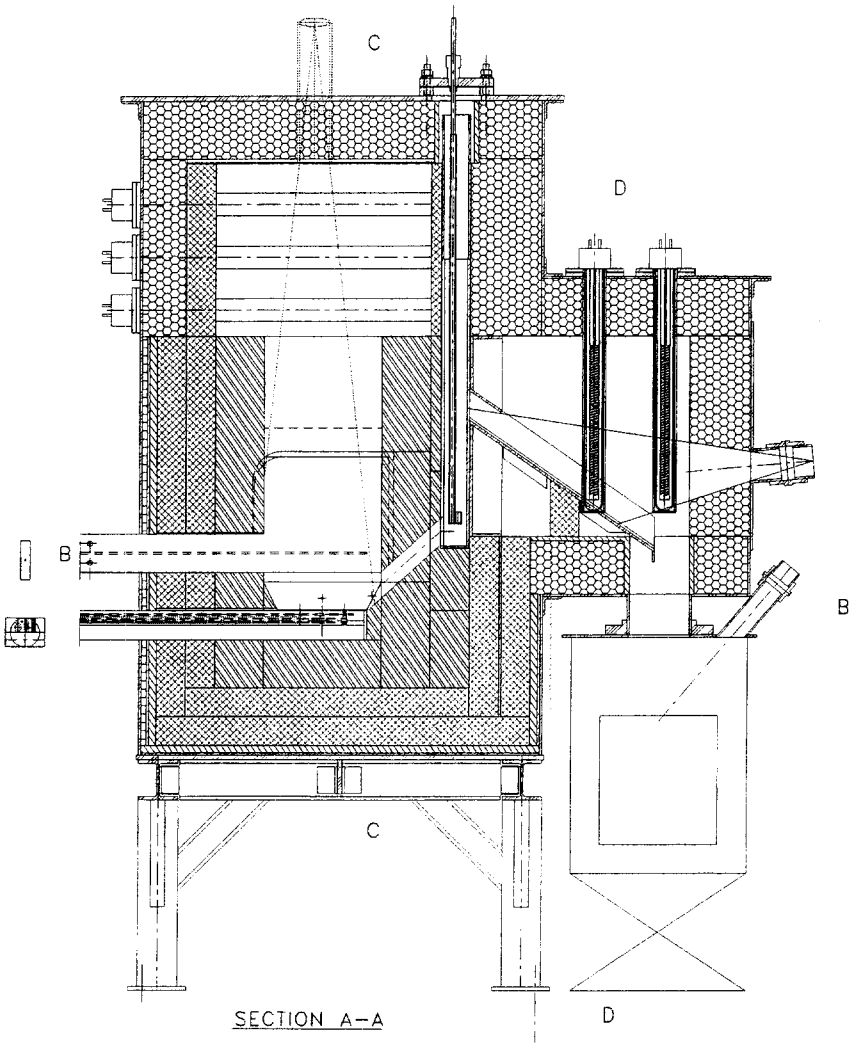

Figure 1.2(b). Cross-section through the DM100-WV melter—Section AA.

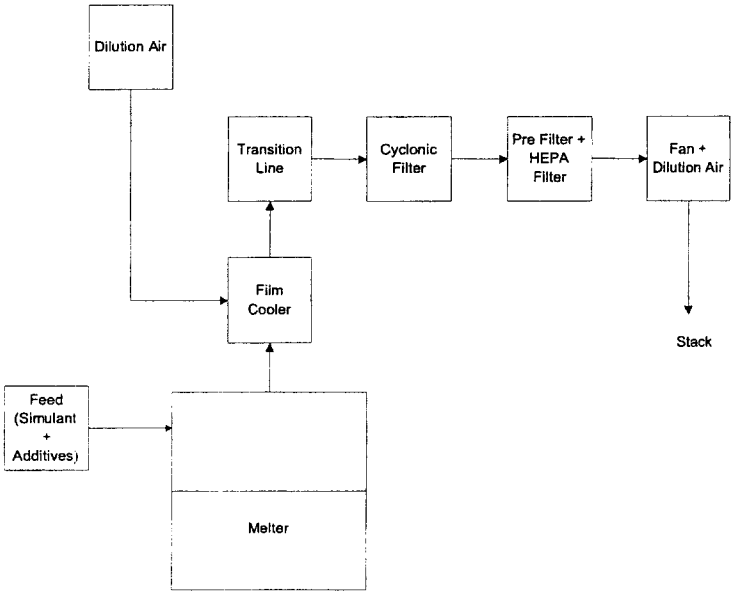

Figure 1.1. Schematic diagram of DuraMelter 100 vitrification system.

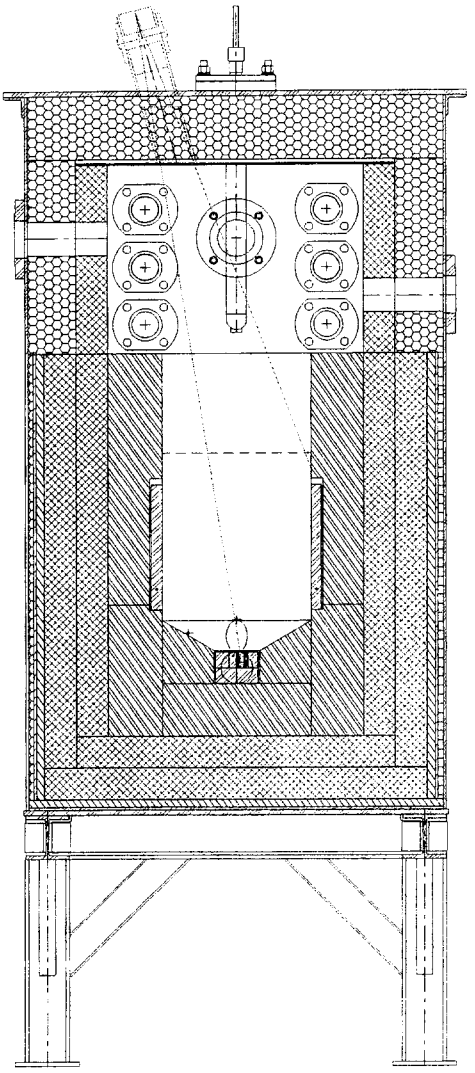

Figure 1.2(c). Cross-section through the DM100-WV melter—Section CC.

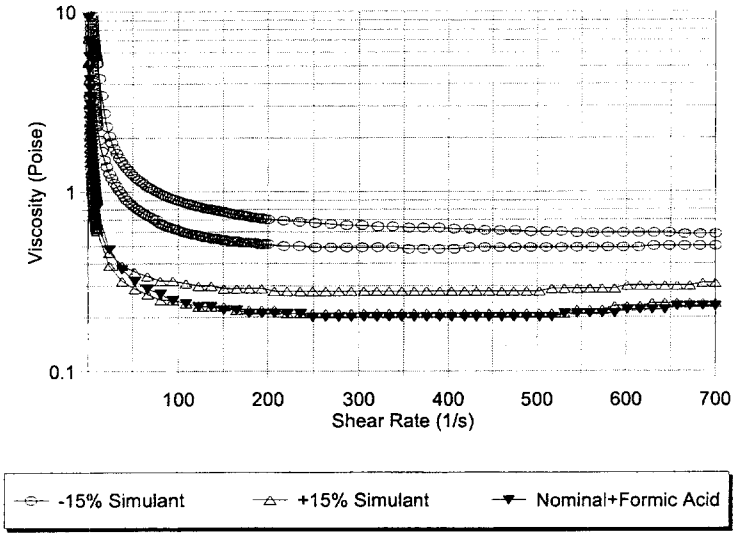

Figure 2.1. Measured viscosity of melter feed samples.

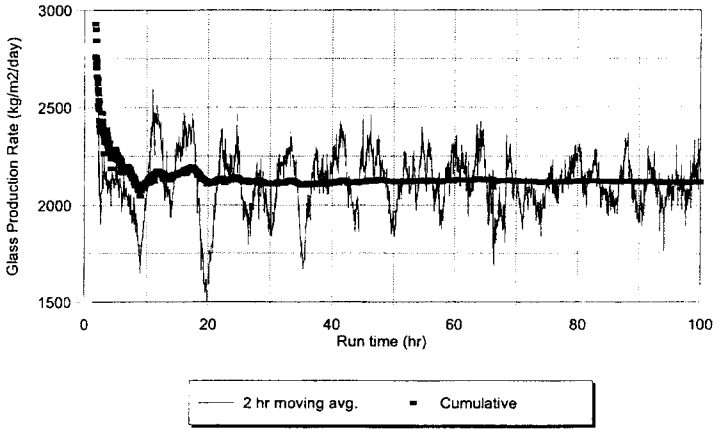

Figure 3.1. Glass production rates for Test 1 (-15% simulant).

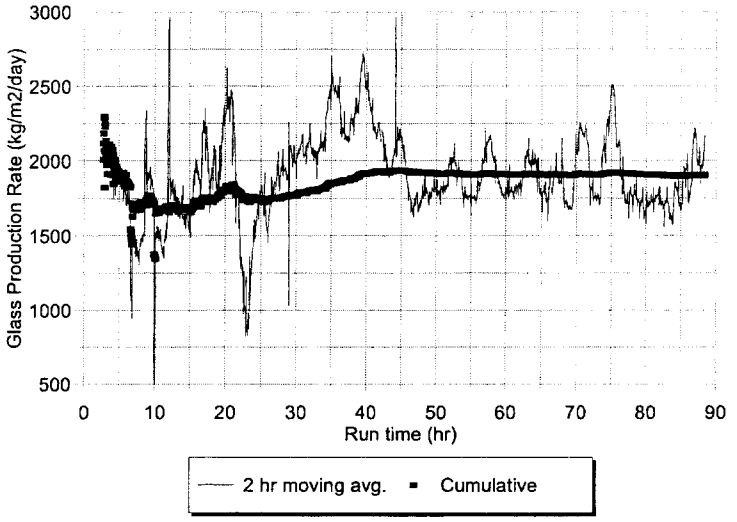

Figure 3.2. Glass production rates for Test 2 (+15% simulant).

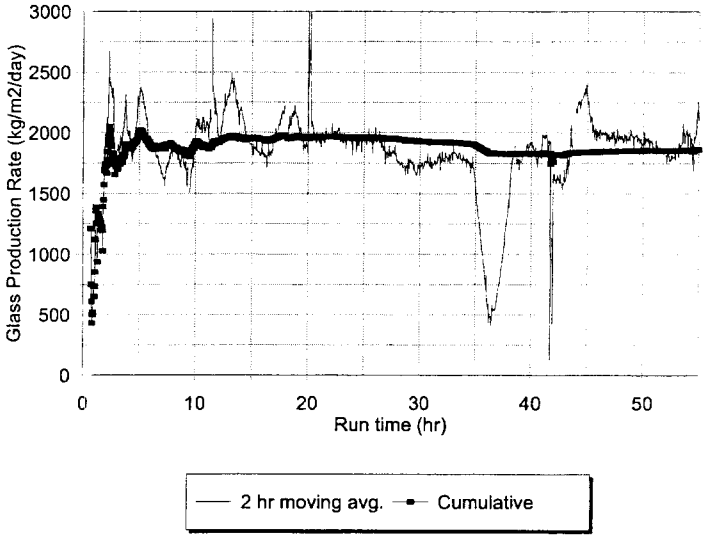

Figure 3.3. Glass production rates for Test 3 (nominal + formic acid).

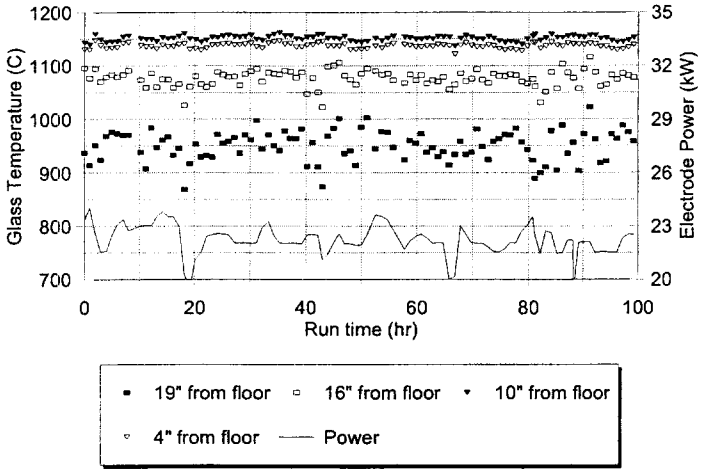

Figure 3.4. Glass temperatures and total electrode power for Test 1.

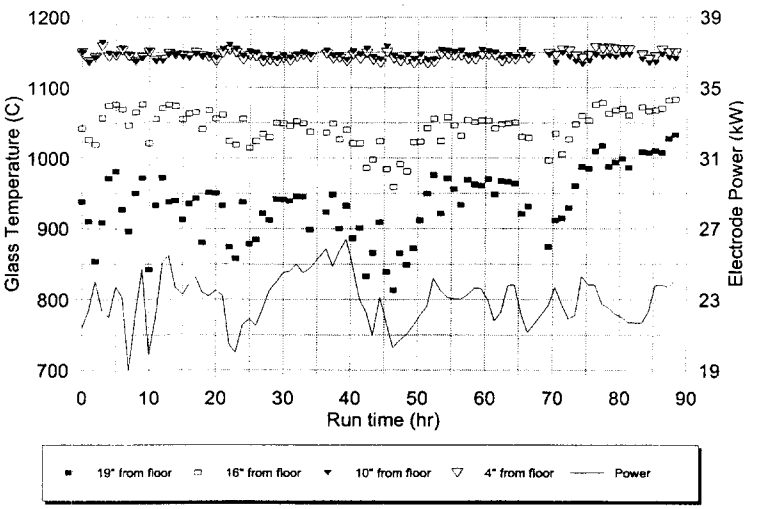

Figure 3.5. Glass temperatures and total electrode power for Test 2.

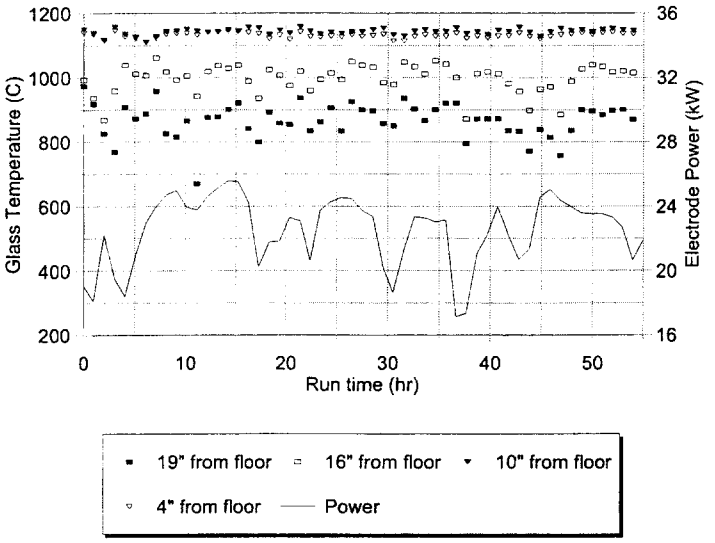

Figure 3.6. Glass temperatures and total electrode power for Test 3.

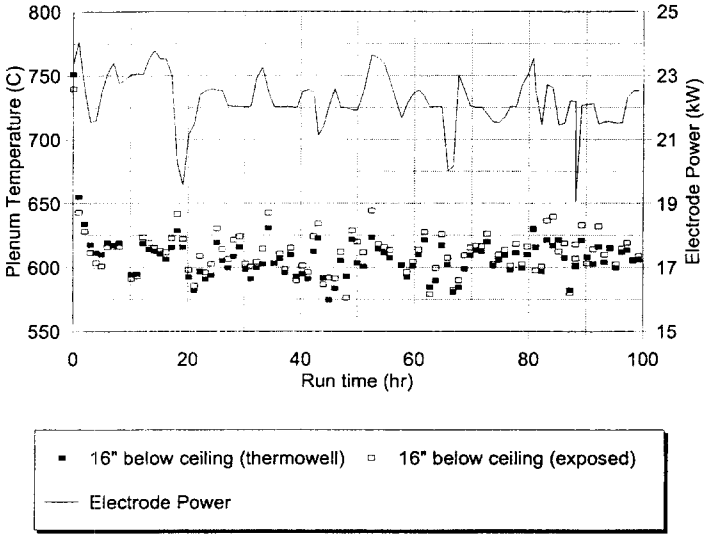

Figure 3.7. Plenum temperatures and electrode power for Test 1.

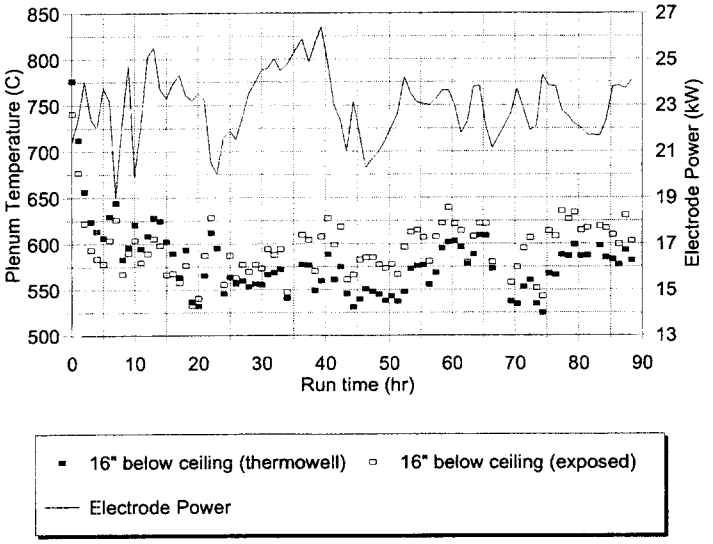

Figure 3.8. Plenum temperatures and electrode power for Test 2.

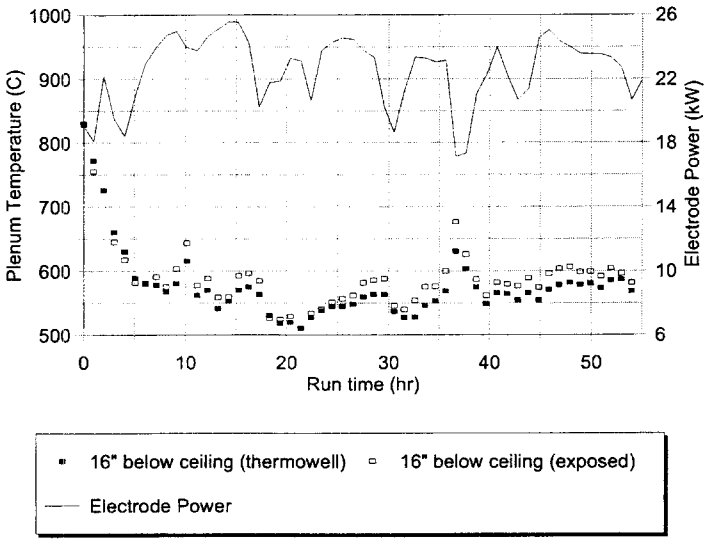

Figure 3.9. Plenum temperatures and electrode power for Test 3.

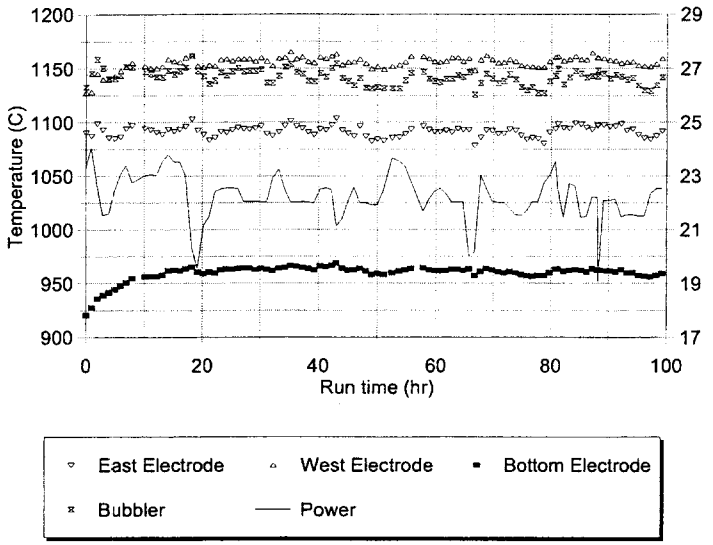

Figure 3.10. Electrode temperature and power plus bubbler temperature for Test 1.

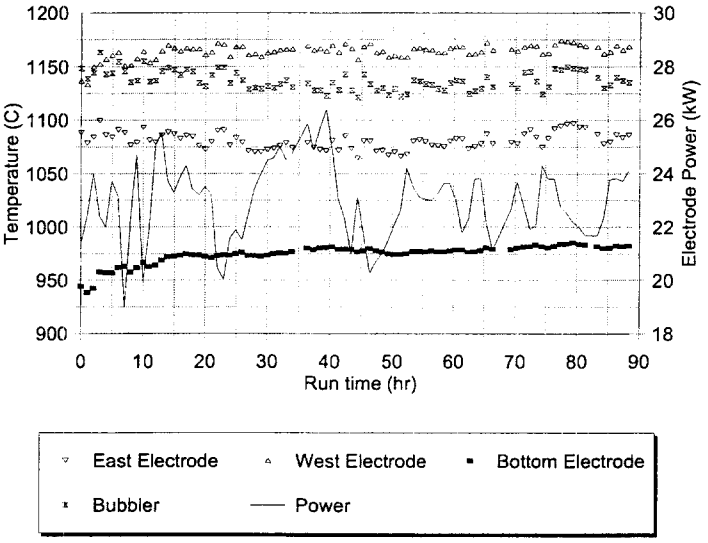

Figure 3.11. Electrode temperature and power plus bubbler temperature for Test 2.

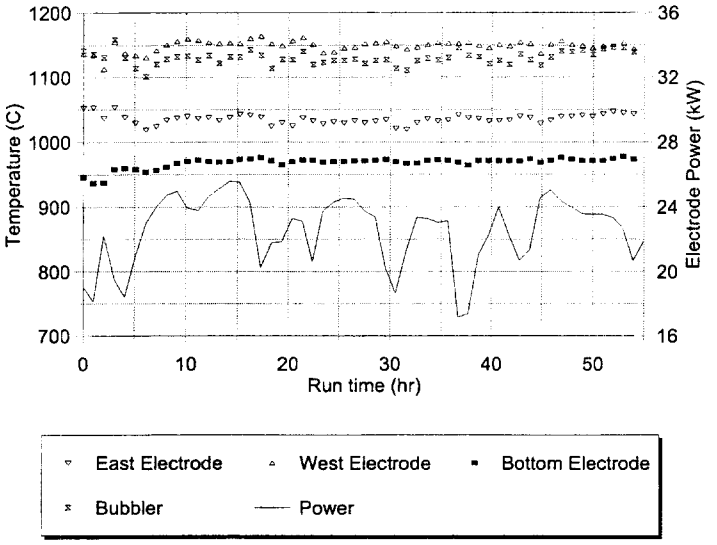

Figure 3.12. Electrode temperature and power plus bubbler temperature for Test 3.

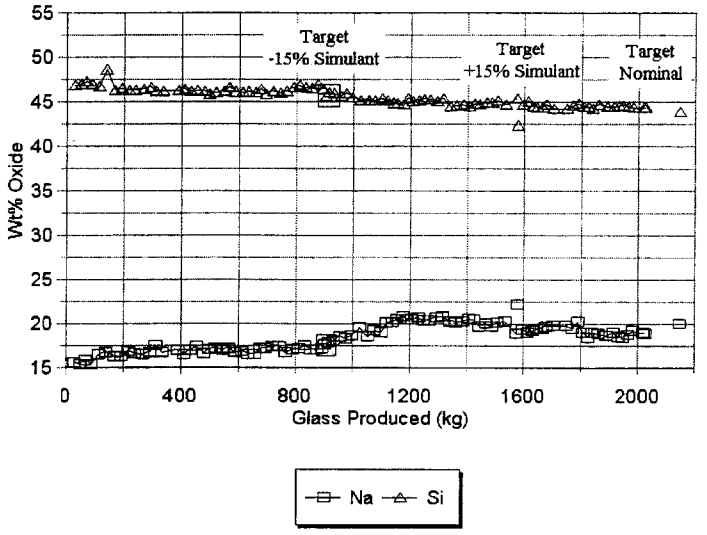

Figure 4.1. XRF analysis of Na_2O and SiO_2 in melter glasses.

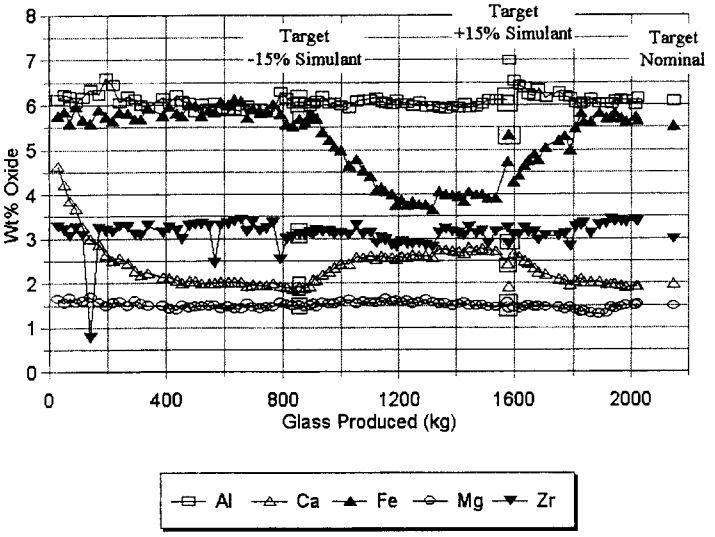

Figure 4.2. XRF analysis of select major oxides in product glasses.

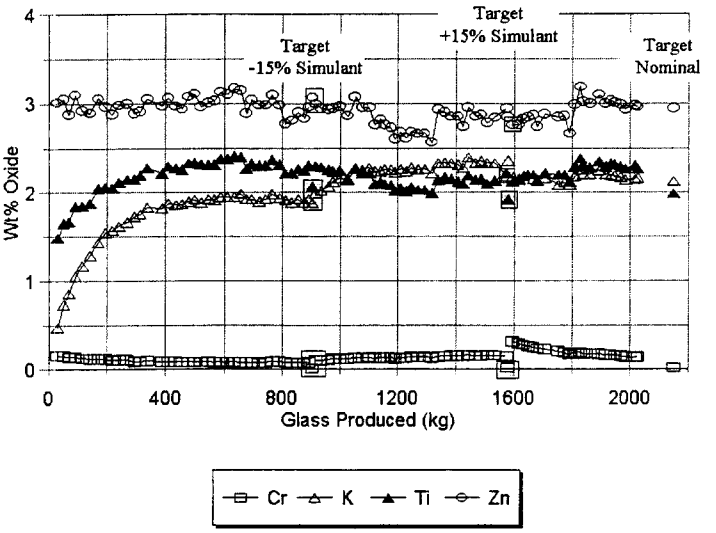

Figure 4.3. XRF analysis of select minor oxides in product glass.

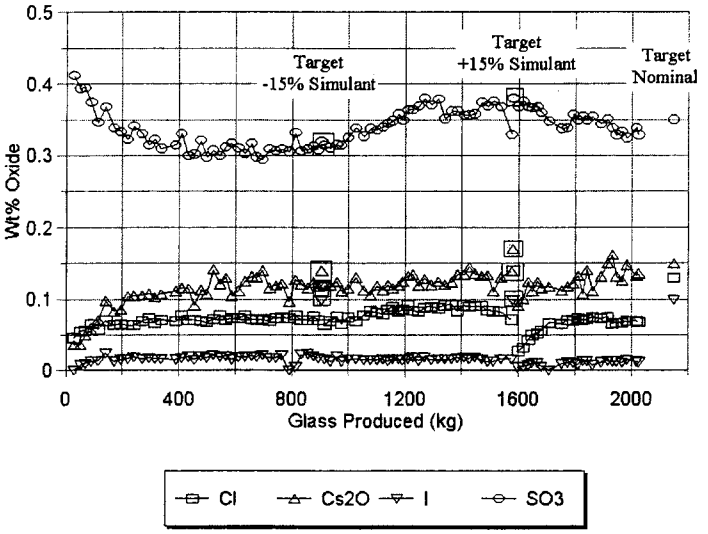

Figure 4.4. XRF analysis of volatile constituents in melter glass.

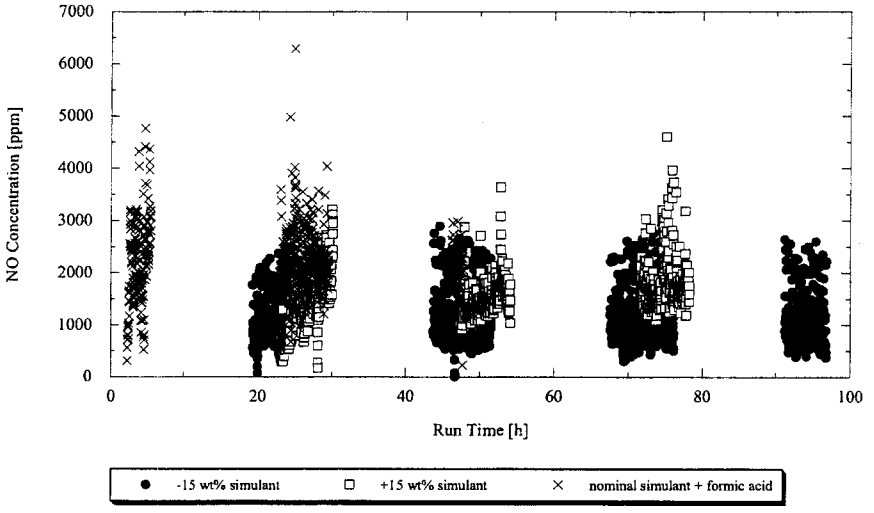

Figure 5.1. NO concentration in off-gas during monitoring intervals.

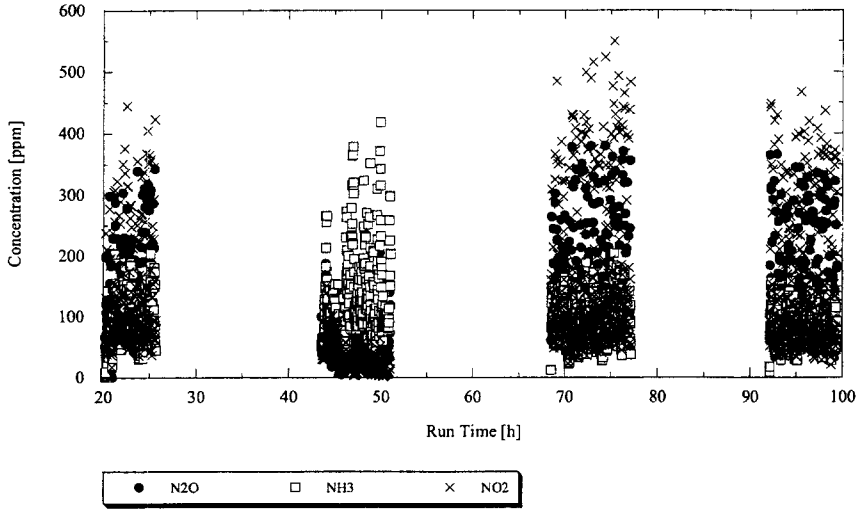

Figure 5.2. Concentration of selected species in off-gas during Test 1 (-15% simulant).

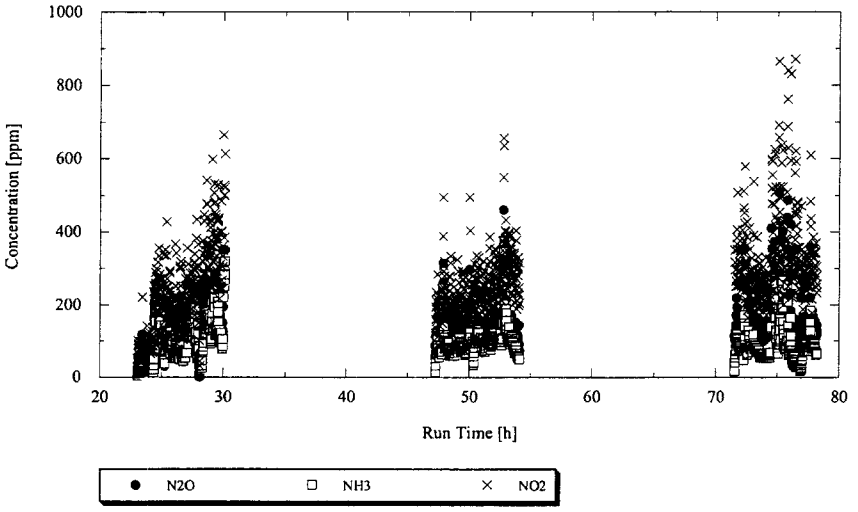

Figure 5.3. Concentration of selected species in off-gas during test 2 (+15 wt% simulant).

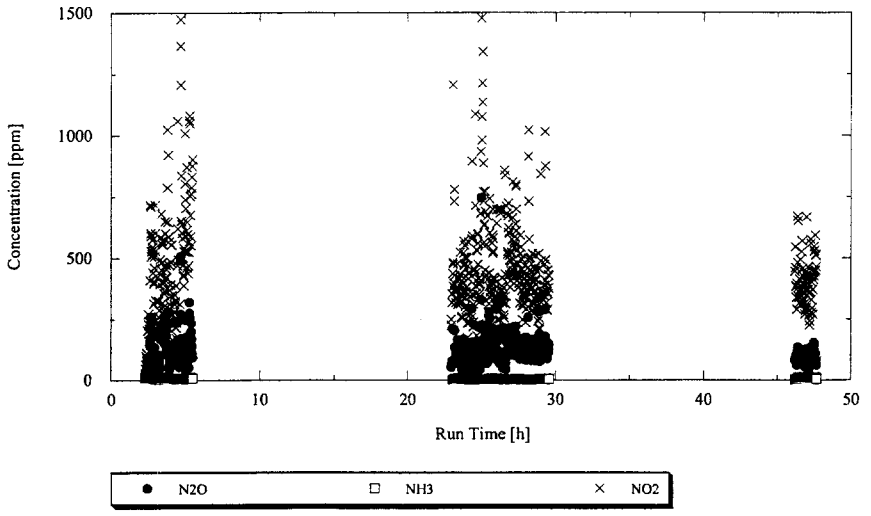

Figure 5.4. Concentration of selected species in off-gas during Test 3 (nominal simulant + formic acid).

Table 2.1. LAW Sub-Envelope A2 Simulant Recipe at 8 Molar Sodium.

Envelope Constituents	Simulant AP-101 including Pretreatment		GLASS Oxides	LAW A2 Simulant as Oxides (wt%)	Waste Contribution to Glass	Source in Simulant	Order for Addition	Formula Weight	Assay	Ratio	Target Weight (g)
	mg/l	M	Loading		24.831 %	In 395 ml water add following compounds in order listed below:					
Al	11850	0.439	Al_2O_3	7.274	1.806	$Al(NO_3)_3 \cdot 9H_2O$, 60% sol.	8	375.14	0.59	0.14	280.21
Ca	48	0.001	CaO	0.022	0.005	$Ca(NO_3)_2*4H_2O$	2	236.16	0.99	0.24	0.28
Cr	133	0.003	Cr_2O_3	0.063	0.016	Na2CrO4*4H2O	3	234.04	0.99	0.19	0..61
Cs (spike)	1798	0.014	Cs_2O	0.619	0.154	$CsNO_3$	4	194.91	1.00	0.72	2.64
Fe	5	0.0001	Fe_2O_3	0.002	0.001	$Fe(NO_3)_3*9H_2O$	5	404.01	1.00	0.20	0.03
K	21972	0.562	K_2O	8.599	2.135	KOH	7	56.10	0.85	0.84	37.09
Na	183920	8.000	Na_2O	80.543	20.000	NaOH, 50% sol. d=1.53	6	40.00	0.48	0.77	393.86
Ni	8	0.0001	NiO	0.003	0.001	NiO	13	74.69	1.00	1.00	0.01
PbO	4	0.0000	PbO	0.001	0.000	PbO	14	223.20	1.00	1.00	0.004
Cl	1614	0.046	Cl	0.524	0.130	NaCl	10	58.45	0.99	0.61	2.69
F	2814	0.148	F	0.914	0.227	NaF	11	42.00	0.99	0.45	6.28
PO_4	1216	0.013	P_2O_5	0.295	0.073	$Na_3PO_4*12H_2O$	9	380.12	0.99	0.19	4.92
SO_4	4206	0.044	SO_3	1.139	0.283	Na_2SO_4	12	142.06	0.99	0.56	6.28
NO_2	49444	1.075	NO_2			$NaNO_2$	24	69.00	0.97	0.55	76.46
NO_3	161402	2.603	NO_3			$NaNO_3$	25	84.99	0.99	0.73	108.98
CO_3	17136	0.286	CO_3			Na_2CO_3	26	105.99	1.00	0.58	30.27
OH	85049	5.003*	OH			From KOH + NaOH					
Org.Carbon	3861	0.322									
EDTA	900	0.037				$Na_2EDTA.2H_2O$ (C10)	15	372.24	0.99	0.32	1.12
HEDTA	900	0.039				$Na_3HEDTA .2H_2O$ (C10) – 41% sol.	16	380.24	0.45	0.32	3.30
Acetate	1000	0.040				Sodium Acetate (C2)	17	136.08	0.99	0.18	2.74
Formate	1000	0.026				Sodium Formate (C1)	18	68.01	0.99	0.18	1.79
Oxalate	500	0.013				Sodium Oxalate (C2)	19	134.00	0.99	0.18	0.90
Gluconate	700	0.026				Sodium Gluconate (C6)	1	218.14	0.99	0.06	0.94
Glycolic	1900	0.060				Glycolic Acid (C2)	20	76.05	0.67	0.32	3.40
NTA	700	0.026				Nitrilotriacetic Acid (C6)	21	191.14	0.98	0.38	0.86
Citric	2400	0.075				Citric Acid (C5)	22	192.12	0.99	0.12	2.91
Imidodiacetic	700	0.013				Iminodiacetic Acid (C2)	23	133.10	0.98	0.18	0.86
						Target Glass					1239.60
			SUM	99.998	24.831	Total simulant weight					1365.09

* OH concentration was targeted to be 5.003 M. Calculated OH concentration of the simulant is 5.239 M

Table 2.2. Oxide Composition of LAW Sub-Envelope A2 Simulant and Corresponding Glass Compositions

Glass Oxides	AP-101 in glass @ 20.0 % Na_2O	Additives Mix	Recycled Sodium Sulfate	LAWA88 Variations		
				Nominal	+15 wt% Simulant	- 15wt% Simulant
Loading	24.831 %	75.169 %		24.83%	27.52 %	21.93 %
Al_2O_3	1.806	4.289		6.09	6.13	6.04
B_2O_3	0.000	9.821		9.81	9.46	10.19
CaO	0.005	1.991		1.99	1.92	2.07
Cr_2O_3	0.016			0.02	0.02	0.01
Cs_2O	0.154			0.15	0.17	0.14
Fe_2O_3	0.001	5.544		5.54	5.34	5.75
K_2O	2.135			2.13	2.36	1.88
MgO	0.000	1.479		1.48	1.42	1.53
Na_2O	20.000		0.055	20.03	22.20	17.69
NiO	0.001			0.00	0.00	0.00
PbO	0.000			0.00	0.00	0.00
SiO_2	0.000	44.097		44.04	42.46	45.74
TiO_2	0.000	1.996		1.99	1.92	2.07
ZnO	0.000	2.957		2.95	2.85	3.07
ZrO_2	0.000	2.994		2.99	2.88	3.11
Cl	0.130			0.13	0.14	0.11
F	0.227			0.23	0.25	0.20
P_2O_5	0.073			0.07	0.08	0.06
SO_3	0.283		0.071	0.35	0.38	0.32
Total	24.831	75.168		100.00	100.00	100.00

Table 2.3. Glass Forming Additives for 1 Liter of Simulant (Nominal) and Corresponding Melter Feed Properties.

Additives Source	Feed LAW A88
Additives in Glass (wt%)	75.17 %
Kyanite (Al_2SiO_5) 325 Mesh (Kyanite Mining) (g)	99.44
H_3BO_3 (US Borax – Technical Granular) (g)	219.31
Wollanstonite NYAD 325 Mesh (NYCO Minerals) (g)	52.32
Fe_2O_3 (97% Alfa) (g)	64.34
Olivine (Mg_2SiO_4) 325 Mesh (#180 Unimin) (g)	38.57
SiO_2 (Sil-co-Sil 75 US Silica)) (g)	443.01
TiO_2 (Rutile Airfloated Chemaloy) (g)	25.94
ZnO (KADOX – 920 Zinc Corp. of America) (g)	36.77
Zircon $ZrSiO_4$ (Flour) Mesh 325 (AM. Mineral) (g)	55.74
Addition of Sucrose as Reductant (nominal) (g)	69.40
+Na_2SO_4 (from recycled off-gas) (g)	1.57
Simulant Weight for 1 liter (g)	1365
Sum of Additives (g)	1035
Sum of Complete Batch (g)	2401
Final Volume (l) (based on measured density)	1.412
Density – measured (g/ml)	1.70
Expected Glass Produced (g) ; i.e., Glass Yield (g/l of simulant)	1240
Weight % Water in Slurry Feed	37.7%
Weight % Additives in Slurry	43%
Glass Yield (g/kg of Feed)	516
Glass Yield – estimated (g/l of Feed)	878
Total Solids (g/l of Feed)	1059
Additives – estimated (g/l of Feed)	733

Table 2.4. Measured Properties of Melter Feed Samples.

Test #	Sampling Date	Sample Name	% Water	Density (g/ml)	Glass Yield (kg/kg)	Glass Yield (g/l)	pH	Yield Stress (Pa)	Viscosity (poise)	
									@ 1/s	@ 10/s
1	11/13/01	WVD-F-129A	36.6	1.73	0.506	875	11.79	4.1	23.1	2.3
	11/14/01	WVD-F-141A	36.6	1.71	0.502	859	11.72	NA	NA	NA
	11/14/01	WVD-F-144A	35.8	1.72	0.513	882	11.78	NA	NA	NA
	11/15/01	WVE-F-6A	35.6	1.72	0.515	885	11.76	NA	NA	NA
	11/16/01	WVE-F-22A	34.7	1.74	0.503	875	11.74	NA	NA	NA
	11/16/01	WVE-F-25A	35.0	1.72	0.516	888	11.77	7.2	37.3	5.2
2	11/27/01	WVE-F-58A	44.1	1.58	0.437	691	12.91	0.5	4.3	0.6
	11/28/01	WVE-F-76A	42.2	1.64	0.446	731	12.97	NA	NA	NA
	11/28/01	WVE-F-86A	41.6	1.65	0.453	747	12.96	NA	NA	NA
	11/29/01	WVE-F-102A	40.9	1.66	0.459	762	13.01	0.5	5.2	0.7
3	01/24/02	WVE-F-132A	37.3	1.67	0.472	788	10.15	1.7	6.5	0.8
	01/24/02	WVE-F-138A	39.5	1.66	0.472	783	10.00	NA	NA	NA
	01/24/02	WVE-F-142A	39.3	1.64	0.466	763	8.79	NA	NA	NA
	01/25/02	WVF-F-10A	39.8	1.56	0.450	702	7.29	NA	NA	NA

NA – Not Analyzed

Table 2.5. XRF Analyzed Compositions for Crucible-Melted Feed Samples (wt%).

Test #	1 (-15% Simulant)									2 (+15% Simulant)			
Element	Target	WVD-F-129A	WVD-F-141A	WVD-F-144A	WVE-F-6A	WVE-F-22A	WVE-F-25A	Average	%Dev.**	Target	WVE-F-58A	WVE-F-76A	WVE-F-86A
Al_2O_3	6.04	5.82	5.89	5.79	5.78	5.93	6.00	5.87	-2.74	6.13	6.16	6.06	6.03
B_2O_3*	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	NC	9.45	9.45	9.45	9.45
CaO	2.07	2.03	2.01	2.02	2.01	2.00	1.95	2.00	-3.27	1.92	2.64	2.81	2.82
Cl	0.11	0.05	0.06	0.05	0.06	0.04	0.05	0.05	NC	0.14	0.04	0.05	0.03
Cr_2O_3	0.01	0.04	0.03	0.04	0.04	0.04	0.04	0.04	NC	0.02	0.03	0.03	0.03
Cs_2O	0.14	0.10	0.11	0.10	0.11	0.10	0.09	0.10	NC	0.17	0.09	0.08	0.08
F	0.20	NA	NA	NA	NA	NA	NA	NA	NC	0.25	NA	NA	NA
Fe_2O_3	5.75	6.09	6.29	6.15	6.11	6.19	5.82	6.11	6.32	5.34	3.79	3.92	3.93
I	0.10	0.01	0.01	0.02	0.01	<0.01	0.01	0.01	NC	0.10	0.01	<0.01	<0.01
K_2O	1.88	2.05	2.02	1.94	1.93	1.98	1.88	1.97	4.66	2.36	2.15	2.37	2.30
MgO	1.53	1.16	1.01	1.36	1.34	1.13	1.40	1.23	-19.30	1.42	1.01	0.84	0.92
Na_2O	17.68	17.92	17.77	16.66	17.24	17.55	17.36	17.41	-1.48	22.18	21.57	21.36	21.00
NiO	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC	<0.01	<0.01	<0.01	<0.01
P_2O_5	0.06	0.07	0.09	0.08	0.09	0.10	0.09	0.09	NC	0.08	0.15	0.14	0.14
PbO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC	<0.01	<0.01	<0.01	<0.01
SiO_2	45.70	45.40	45.14	46.29	45.83	45.89	46.74	45.88	0.39	42.43	45.26	44.36	44.58
SO_3	0.32	0.21	0.28	0.24	0.27	0.25	0.23	0.25	NC	0.38	0.34	0.37	0.35
TiO_2	2.07	2.56	2.53	2.44	2.43	2.48	2.34	2.46	19.05	1.92	2.07	2.24	2.25
ZnO	3.07	3.12	3.31	3.21	3.17	3.24	2.99	3.17	3.48	2.85	2.81	2.97	2.98
ZrO_2	3.11	3.18	3.29	3.44	3.40	2.90	2.84	3.18	2.20	2.88	2.43	2.94	3.11
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC	100.00	100.00	100.00	100.00

*Target value
** % deviation from the target values
NA – Not Analyzed
NC – Not Calculated

Table 2.5. XRF Analyzed Compositions for Crucible-Melted Feed Samples (wt%).

Test #	2 (+15% Simulant)				3 (Nominal with Formic Acid)						
Element	Target	WVE-F-102A	Average	%Dev.**	Target	WVE-F-132A	WVE-F-138A	WVE-F-142A	WVF-F-10A	Average	%Dev.
Al_2O_3	6.13	5.92	6.04	-1.34	6.08	6.08	6.02	5.97	6.03	6.03	-0.92
B_2O_3*	9.45	9.45	9.45	NC	9.80	9.80	9.80	9.80	9.80	9.80	NC
CaO	1.92	2.76	2.76	43.67	1.99	1.96	1.90	1.95	1.88	1.92	-3.32
Cl	0.14	0.10	0.06	NC	0.13	0.02	0.03	0.03	0.02	0.03	NC
Cr_2O_3	0.02	0.03	0.03	NC	0.02	0.04	0.03	0.03	0.04	0.04	NC
Cs_2O	0.17	0.10	0.09	NC	0.15	0.09	0.10	0.08	0.09	0.09	NC
F	0.25	NA	NA	NC	0.23	<0.01	<0.01	<0.01	<0.01	<0.01	NC
Fe_2O_3	5.34	3.89	3.88	-27.29	5.54	5.82	5.62	5.81	5.73	5.74	3.77
I	0.10	0.01	0.01	NC	0.10	<0.01	0.01	<0.01	0.01	0.01	NC
K_2O	2.36	2.33	2.29	-2.99	2.13	2.12	2.12	2.11	2.03	2.09	-1.59
MgO	1.42	1.16	0.98	-30.78	1.48	1.14	1.03	1.12	1.41	1.18	-20.32
Na_2O	22.18	20.88	21.20	-4.41	20.01	19.08	20.22	19.26	19.35	19.48	-2.68
NiO	<0.01	<0.01	<0.01	NC	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
P_2O_5	0.08	0.15	0.15	NC	0.07	0.10	0.09	0.10	0.09	0.09	NC
PbO	<0.01	<0.01	<0.01	NC	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
SiO_2	42.43	44.59	44.70	5.35	44.00	44.88	44.39	44.87	44.66	44.70	1.59
SO_3	0.38	0.43	0.37	NC	0.35	0.27	0.30	0.31	0.27	0.29	NC
TiO_2	1.92	2.18	2.18	13.86	1.99	2.36	2.32	2.38	2.30	2.34	17.69
ZnO	2.85	2.90	2.91	2.27	2.95	3.07	3.00	3.06	2.94	3.01	2.27
ZrO_2	2.88	3.11	2.90	0.77	2.99	3.17	3.02	3.13	3.34	3.16	5.94
Sum	100.00	100.00	100.00	NC	100.00	100.00	100.00	100.00	100.00	100.00	NC

*Target value
** % deviation from the target values
NA – Not Analyzed
NC – Not Calculated

Table 3.1. Summary of Test Conditions and Results.

Sub-Envelope		A2	
LAW Simulant		AP-101	
Nominal Target Glass Formulation		LAWA88	
Simulant Content of Feed		- 15 wt%	+ 15 wt%
Target Glass	Target wt% SO_3	0.32	0.38
	Target wt% Na_2O	17.69	22.20
	Target wt% Cl	0.11	0.14
	Target wt% I	0.1	0.1
Time	Feed Start	11/12/01 15:33	11/26/01 13:06
	Feed End	11/16/01 19:32	11/30/01 05:32
	Water Feeding (hr)	1.2	2.7
	Net Slurry Feeding (hr)	98.8	85.7
Reductant	Type	Sugar	Sugar
	Reductant ratio	0.57#	0.44#
	Mol. NO_x : Mol. Total Organic Carbon	1: 0.78	1: 0.66
Measured Glass Yield (g/l)		877	733
Production Rate ($kg/m^2/day$)		2120	1907
Bubbling Rate (lpm)		21	17
Product*	Measured % Fe^{++}/Total Fe	< 0.8	< 0.8
	Measured wt% SO_3	0.31	0.37
	Measured wt% Cl	0.07	0.08
	Measured wt% I	0.02	0.02
	Test end Sulfate Gall	NO	NO

#Target ratio is 0.5 but the +15% or –15% variation results in the actual ratios given.
*SO_3, Cl, and I are steady-state values.

Table 3.2. Summary of Test Conditions and Results.

Sub-Envelope		A2		
LAW Simulant		AP-101		
Simulant Content of Feed		Nominal		
Glass	Name	LAWA88		
	Target wt% SO_3	0.35		
	Target wt% Na_2O	20.03		
Time	Feed Start	1/23/02 14:11	1/24/02 09:43	1/25/02 09:42
	Feed End	1/24/02 09:30	1/25/02 09:29	1/25/02 23:00
	Water Feeding (hr)	2.2	NA	NA
	Net Slurry Feeding (hr)	17.1	23.8	13.3
Reductant	Type	Formic Acid	Formic Acid	Formic Acid
	Reductant ratio	0.5	0.75	1.0
	NO_x : Total Org. Carbon	1: 0.75	1: 1	1: 1.5
Measured Glass Yield (g/l)		784	764	702
Production Rate ($kg/m^2/day$)		1975	1728	2095
Bubbling Rate (lpm)		22	22	21
Product	Measured % Fe^{++}	< 0.8	< 0.8	< 0.8
	Measured % SO_3	0.35	0.35	0.33
	Test end Sulfate Gall	NA	NA	NO

NA- Not applicable

Table 3.3. Summary of Measured Parameters.

			-15% Simulant			+15% Simulant			Nominal + Formic		
			AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX
Temperature (C)	Electrode	East	1092	1075	1107	1081	1063	1103	1035	1014	1059
		West	1156	1124	1173	1165	1139	1178	1150	1091	1172
		Bottom	960	923	972	976	945	986	969	930	979
	Glass	19" from bottom	950	826	1054	936	729	1056	864	570	1028
		16" from bottom	1076	1000	1120	1044	874	1102	999	758	1099
		10" from bottom	1152	1131	1169	1146	1074	1181	1143	1093	1175
		4" from bottom	1137	1116	1154	1144	1095	1167	1131	1100	1161
	Plenum	Exposed 16" from ceiling	611	530	674	593	489	721	582	493	765
		Thermowell 16" from ceiling	607	566	675	582	381	674	567	503	750
	Bubbler		1142	1122	1167	1137	1113	1175	1130	1088	1171
	Discharge Chamber		983	855	1021	983	860	1049	1029	1002	1051
	Film Cooler Outlet		303	76	340	300	261	329	296	147	334
	Transition Line Outlet		298	238	334	296	269	327	298	179	336
Lance Bubbling (lpm)			21	5	30	21	1	30	22	1	31
Melter Pressure (in. water)			-2.24	-4.51	2.02	-2.28	-5.24	1.86	-2.70	-5.26	5.05
Electrode	Voltage (V)		49.7	41.8	54.7	44.8	1.7	51.6	44.6	30.1	49.4
	Total Power (kW)		22.3	16.9	24.3	23.0	0.3	26.8	22.7	11.9	25.9

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

Test #	Discharge Date	Glass Name	Analysis Performed	Measured Mass (kg)	Cumulative Mass (kg)
1	11/12/01	WVD-G-121A		30.3	30.3
		WVD-G-121B	XRF		
		WVD-G-122A		21.8	52.1
		WVD-G-122B	XRF		
		WVD-G-122C		17.3	69.4
		WVD-G-123A	XRF		
	11/13/01	WVD-G-123B		22.4	91.8
		WVD-G-124A	XRF		
		WVD-G-124B		24.3	116.1
		WVD-G-128A	XRF		
		WVD-G-128B		26.2	142.3
		WVD-G-128C	XRF		
		WVD-G-128D		29.5	171.8
		WVD-G-129A	XRF		
		WVD-G-130A		23.5	195.3
		WVD-G-131A	XRF		
		WVD-G-131B		23.7	219.0
		WVD-G-132A	XRF		
		WVD-G-132B		22.6	241.6
		WVD-G-134A	XRF		
		WVD-G-134B		28.1	269.7
		WVD-G-134C	XRF		
		WVD-G-137A		24.6	294.3
		WVD-G-137B	XRF		
	11/14/01	WVD-G-137C		20.1	314.4
		WVD-G-138A	XRF		
		WVD-G-138B		23.1	337.5
		WVD-G-140A	XRF		
		WVD-G-140B		33.4	370.9
		WVD-G-140C			
		WVD-G-141A	XRF	18.4	389.3
		WVD-G-144A		21.6	410.9
		WVD-G-144B	XRF		
		WVD-G-146A		24.7	435.6
		WVD-G-146B	XRF		
		WVD-G-148A		20.4	456.0
		WVD-G-148B	XRF		
		WVD-G-148C		23.3	479.3
		WVD-G-151A	XRF		
		WVD-G-151B		20.4	499.7
		WVD-G-151C	XRF		

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

Test #	Dis. Date	Glass Name	Analysis Performed	Measured Mass(kg)	Cumulative Mass (kg)
1	11/15/01	WVD-G-152A		22.4	522.1
		WVD-G-154A	XRF		
		WVD-G-154B		24.7	546.8
		WVD-G-155A	XRF		
		WVD-G-155B		20.1	566.9
		WVD-G-155C	XRF		
		WVE-G-6A		21.1	588.0
		WVE-G-6B	XRF		
		WVE-G-6C		25.2	613.2
		WVE-G-10A	XRF		
		WVE-G-10B		21.9	635.1
		WVE-G-11A	XRF		
		WVE-G-11B		22.9	658.0
		WVE-G-11C	XRF		
		WVE-G-12A		19.2	677.2
		WVE-G-12B	XRF		
		WVE-G-16A		18.8	696.0
		WVE-G-16B	XRF		
		WVE-G-16C		24.9	720.9
		WVE-G-16D	XRF		
	11/16/01	WVE-G-17A		22.8	743.7
		WVE-G-18A	XRF		
		WVE-G-18B		22.7	766.4
		WVE-G-18C	XRF		
		WVE-G-20A		24.8	791.2
		WVE-G-20B	XRF		
		WVE-G-22A		21.6	812.8
		WVE-G-22B	XRF		
		WVE-G-25A		21.0	833.8
		WVE-G-25B	XRF		
		WVE-G-25C		22.1	855.9
		WVE-G-27A	XRF		
		WVE-G-27B		21.2	877.1
		WVE-G-27C	XRF		
		WVE-G-27D	XRF, Fe	15.6	892.7
2	11/26/01	WVE-G-44A		22.9	915.6
		WVE-G-44B	XRF		
		WVE-G-45A		19.3	934.9
		WVE-G-46A	XRF		
	11/27/01	WVE-G-50A		24.4	959.3
		WVE-G-51A	XRF		

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

Test	Dis. Date	Glass Name	Analysis Performed	Measured Mass(kg)	Cumulative Mass (kg)
2	11/27/01	WVE-G-52A		16.7	976.0
		WVE-G-54A	XRF		
		WVE-G-55A		23.4	999.4
		WVE-G-55B	XRF		
		WVE-G-58A		27.9	1027.3
		WVE-G-59A	XRF		
		WVE-G-63A		26.5	1053.8
		WVE-G-63B	XRF		
		WVE-G-64A		24.5	1078.3
		WVE-G-66A	XRF		
		WVE-G-66B		23.3	1101.6
		WVE-G-66C	XRF		
		WVE-G-68A		20.4	1122.0
		WVE-G-68B	XRF		
		WVE-G-68C		18.0	1140.0
		WVE-G-69A	XRF		
	11/28/01	WVE-G-72A		15.1	1155.1
		WVE-G-72B	XRF		
		WVE-G-72C		21.6	1176.7
		WVE-G-73A	XRF		
		WVE-G-73B		15.5	1192.2
		WVE-G-73C	XRF		
		WVE-G-74A		18.0	1210.2
		WVE-G-76A	XRF		
		WVE-G-77A		18.3	1228.5
		WVE-G-77B	XRF		
		WVE-G-78A		18.6	1247.1
		WVE-G-82A	XRF		
		WVE-G-82B		22.4	1269.5
		WVE-G-84A	XRF		
		WVE-G-85A		23.6	1293.1
		WVE-G-85B	XRF		
		WVE-G-85C		24.4	1317.5
		WVE-G-86A	XRF		
	11/29/01	WVE-G-86B		22.3	1339.8
		WVE-G-88A	XRF		
		WVE-G-89A		23.3	1363.1
		WVE-G-89B	XRF		
		WVE-G-92A		22.6	1385.7
		WVE-G-92B	XRF		

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

Test #	Dis. Date	Glass Name	Analysis Performed	Measured Mass(kg)	Cumulative Mass (kg)
2	11/29/01	WVE-G-93A		22.6	1408.3
		WVE-G-94A	XRF		
		WVE-G-96A		19.1	1427.4
		WVE-G-96B	XRF		
		WVE-G-97A		17.4	1444.8
		WVE-G-97B	XRF		
		WVE-G-100A		25.3	1470.1
		WVE-G-100B	XRF		
		WVE-G-102A		19.5	1489.6
		WVE-G-102B	XRF		
		WVE-G-103A		20.3	1509.9
		WVE-G-103B	XRF		
	11/30/01	WVE-G-104A		27.0	1536.9
		WVE-G-108A	XRF		
		WVE-G-109A		22.5	1559.4
		WVE-G-110A	XRF, Fe	16.9	1576.3
3	01/23/02	WVE-G-127A		21.5	1597.8
		WVE-G-127B	XRF		
		WVE-G-128A		19.1	1616.9
		WVE-G-128B	XRF		
		WVE-G-130A		17.3	1634.2
		WVE-G-130B	XRF,		
	01/24/02	WVE-G-130C		14.1	1648.3
		WVE-G-132A	XRF		
		WVE-G-133A		19.5	1667.8
		WVE-G-133B	XRF		
		WVE-G-134A		13.8	1681.6
		WVE-G-134B	XRF		
		WVE-G-134C		25.6	1707.2
		WVE-G-138A	XRF, Fe		
		WVE-G-139A		22.8	1730.0
		WVE-G-141A	XRF		
		WVE-G-142A		23	1753.0
		WVE-G-144A	XRF		
		WVE-G-144B		20.3	1773.3
		WVE-G-144C	XRF		
		WVE-G-145A		18.9	1792.2
		WVE-G-145B	XRF		
		WVE-G-149A		17.6	1809.8
		WVE-G-149B	XRF		

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

Test #	Dis. Date	Glass Name	Analysis Performed	Measured Mass(kg)	Cumulative Mass (kg)
3	01/24/02	WVE-G-150A		17.6	1827.4
		WVE-G-151A	XRF		
	01/25/02	WVE-G-151B		11.6	1839.0
		WVE-G-151C	XRF		
		WVE-G-152A		22.9	1861.9
		WVE-G-154A	XRF		
		WVE-G-155A		29.9	1891.8
		WVF-G-6A	XRF		
		WVF-G-6B		24.0	1915.8
		WVF-G-10A			
		WVF-G-12A	XRF		
		WVF-G-12B		17.5	1933.3
		WVF-G-12C	XRF		
		WVF-G-13A		14.1	1947.4
		WVF-G-13B	XRF		
		WVF-G-14A		20.0	1967.4
		WVF-G-14B	XRF		
		WVF-G-14C		17.4	1984.8
		WVF-G-20A	XRF		
	01/26/02	WVF-G-20B		32.8	2017.6
		WVF-G-20C			
		WVF-G-21A	XRF		
		WVF-G-21B	XRF, Fe	9.1	2026.7

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

Test #	1 (-15% Simulant)														
Glass (kg)		30.3	52.1	69.4	91.8	116.1	142.3	171.8	195.3	219	241.6	269.7	294.3	314.4	337.5
Element	Target	WVD-G-121B	WVD-G-122B	WVD-G-123A	WVD-G-124A	WVD-G-128A	WVD-G-128C	WVD-G-129A	WVD-G-131A	WVD-G-132A	WVD-G-134A	WVD-G-134C	WVD-G-137B	WVD-G-138A	WVD-G-140A
Al_2O_3	6.04	6.13	6.24	6.19	6.07	6.17	6.35	6.23	6.60	6.45	6.06	6.21	6.14	6.00	5.96
B_2O_3*	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18
CaO	2.07	4.63	4.23	3.86	3.70	3.27	3.00	2.88	2.65	2.51	2.57	2.46	2.28	2.19	2.23
Cl	0.11	0.05	0.06	0.06	0.07	0.06	0.07	0.06	0.07	0.06	0.06	0.07	0.07	0.07	0.07
Cr_2O_3	0.01	0.16	0.16	0.14	0.15	0.13	0.12	0.13	0.12	0.11	0.12	0.11	0.09	0.10	0.10
Cs_2O	0.14	0.04	0.04	0.05	0.06	0.07	0.10	0.08	0.09	0.10	0.11	0.11	0.11	0.10	0.11
F	0.20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	5.75	5.76	5.87	5.59	5.98	5.68	5.60	5.91	5.74	5.65	5.84	5.82	5.69	5.69	5.94
I	0.10	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
K_2O	1.88	0.47	0.73	0.86	1.05	1.17	1.29	1.43	1.54	1.57	1.62	1.66	1.73	1.75	1.83
MgO	1.53	1.65	1.56	1.66	1.56	1.61	1.69	1.56	1.50	1.55	1.58	1.50	1.60	1.54	1.50
Na_2O	17.68	15.59	15.40	15.86	15.45	16.48	16.81	16.31	16.31	16.90	16.62	16.48	16.77	17.51	16.74
NiO	<0.01	0.04	0.03	0.03	0.02	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P_2O_5	0.06	0.16	0.16	0.15	0.14	0.13	0.14	0.12	0.10	0.10	0.11	0.11	0.10	0.09	0.10
PbO	<0.01	0.02	0.01	0.01	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SiO_2	45.70	46.92	47.03	47.33	46.98	46.80	48.68	46.39	46.53	46.38	46.39	46.52	46.74	46.25	46.28
SO_3	0.32	0.41	0.39	0.39	0.37	0.35	0.37	0.34	0.33	0.32	0.34	0.33	0.31	0.32	0.31
TiO_2	2.07	1.49	1.65	1.67	1.84	1.85	1.88	2.04	2.06	2.05	2.12	2.15	2.16	2.19	2.28
ZnO	3.07	3.01	3.05	2.88	3.10	2.92	2.90	3.06	2.97	2.88	2.98	3.00	2.89	2.91	3.05
ZrO_2	3.11	3.28	3.21	3.07	3.25	3.10	0.78	3.23	3.18	3.15	3.28	3.27	3.11	3.08	3.30
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

*Target value
NA – Not Analyzed

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

Test #	1 (-15% Simulant)													
Glass (kg)		389.3	410.9	435.6	456	479.3	499.7	522.10	546.8	566.9	588.00	613.2	635.1	658
Element	Target	WVD-G-141A	WVD-G-144B	WVD-G-146B	WVD-G-148B	WVD-G-151A	WVD-G-151C	WVD-G-154A	WVD-G-155A	WVD-G-155C	WVE-G-6B	WVE-G-10A	WVE-G-11A	WVE-G-11C
Al_2O_3	6.04	6.16	6.04	6.23	6.09	6.05	5.84	6.04	5.92	6.05	5.91	5.88	5.90	5.88
B_2O_3*	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18
CaO	2.07	2.14	2.13	2.07	2.01	2.04	2.04	1.99	2.00	2.01	2.03	2.03	2.03	2.03
Cl	0.11	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.08	0.07
Cr_2O_3	0.01	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.08
Cs_2O	0.14	0.11	0.12	0.12	0.09	0.11	0.11	0.14	0.12	0.13	0.11	0.11	0.13	0.13
F	0.20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	5.75	5.77	5.97	5.81	5.76	6.00	5.98	5.75	5.90	5.86	6.07	6.00	6.13	6.10
I	0.10	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
K_2O	1.88	1.83	1.88	1.86	1.87	1.90	1.93	1.89	1.93	1.92	1.95	1.95	1.95	1.99
MgO	1.53	1.50	1.43	1.40	1.51	1.44	1.48	1.48	1.50	1.51	1.43	1.48	1.42	1.43
Na_2O	17.68	17.05	16.56	17.01	17.41	16.68	17.14	17.24	17.02	17.24	16.74	16.88	16.54	16.56
NiO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P_2O_5	0.06	0.10	0.10	0.09	0.09	0.09	0.10	0.10	0.10	0.09	0.08	0.08	0.09	0.09
PbO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SiO_2	45.70	46.33	46.47	46.29	46.31	46.29	45.94	46.08	46.24	46.73	46.19	46.11	46.18	46.14
SO_3	0.32	0.31	0.33	0.30	0.30	0.32	0.30	0.31	0.30	0.31	0.32	0.31	0.30	0.32
TiO_2	2.07	2.22	2.30	2.28	2.26	2.33	2.34	2.32	2.31	2.32	2.38	2.38	2.41	2.40
ZnO	3.07	2.97	3.06	2.97	2.94	3.08	3.11	2.97	3.01	3.03	3.13	3.10	3.17	3.15
ZrO_2	3.11	3.15	3.25	3.21	3.00	3.29	3.33	3.34	3.29	2.46	3.30	3.34	3.39	3.43
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

*Target value
NA – Not Analyzed

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

Test #	1 (-15% Simulant)													
Glass (kg)		677.2	696	720.9	743.7	766.4	791.2	812.8	833.8	855.9	877.1	892.7	Test 1	
Element	Target	WVE-G-12B	WVE-G-16B	WVE-G-16D	WVE-G-18A	WVE-G-18C	WVE-G-20B	WVE-G-22B	WVE-G-25B	WVE-G-27A	WVE-G-27C	WVE-G-27D	Average#	%Dev.**
Al_2O_3	6.04	5.99	5.91	5.91	5.90	5.85	6.29	6.15	6.05	6.08	6.05	5.98	6.03	-0.15
B_2O_3*	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	10.18	NC
CaO	2.07	1.93	1.97	1.95	1.95	2.00	1.94	1.91	1.87	1.92	1.90	1.93	2.10	1.40
Cl	0.11	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.08	0.07	0.07	NC
Cr_2O_3	0.01	0.08	0.08	0.08	0.08	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.9	NC
Cs_2O	0.14	0.13	0.14	0.12	0.12	0.12	0.10	0.13	0.12	0.12	0.12	0.12	0.12	NC
F	0.20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NC
Fe_2O_3	5.75	5.71	5.92	5.82	5.85	6.02	5.80	5.57	5.53	5.68	5.61	5.79	5.83	1.56
I	0.10	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.02	0.02	0.02	0.02	0.02	NC
K_2O	1.88	1.93	1.93	1.90	1.93	1.98	1.93	1.92	1.89	1.93	1.89	1.93	1.86	-1.22
MgO	1.53	1.53	1.45	1.43	1.45	1.47	1.55	1.52	1.49	1.51	1.45	1.49	1.48	-2.94
Na_2O	17.68	17.19	17.28	17.40	17.46	16.73	17.15	17.16	17.54	17.13	17.06	17.16	17.02	-3.71
NiO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
P_2O_5	0.06	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.09	0.09	0.10	0.09	0.10	NC
PbO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
SiO_2	45.70	46.52	45.93	46.26	46.06	46.25	46.66	46.89	46.68	46.61	46.98	46.44	46.38	1.47
SO_3	0.32	0.30	0.29	0.31	0.31	0.31	0.31	0.33	0.31	0.31	0.31	0.31	0.31	NC
TiO_2	2.07	2.27	2.32	2.31	2.31	2.37	2.31	2.21	2.22	2.27	2.25	2.31	2.27	9.74
ZnO	3.07	2.89	3.04	2.98	2.98	3.09	2.98	2.78	2.81	2.90	2.83	2.96	2.99	-2.48
ZrO_2	3.11	3.17	3.37	3.18	3.24	3.36	2.54	2.99	3.05	3.11	3.08	3.15	3.16	1.68
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	NC

*Target value
** % Deviation from target values
#Average was calculated for glass after initial 300 kg of glass production
NA – Not Analyzed
NC – Not Calculated

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

Test #	2(+15% Simulant)														
Glass (kg)		915.6	934.9	959.3	976	999.4	1027.3	1053.8	1078.3	1101.6	1122	1140	1155.1	1176.7	1192.2
Element	Target	WVE-G-44B	WVE-G-46A	WVE-G-51A	WVE-G-54A	WVE-G-55B	WVE-G-59A	WVE-G-63B	WVE-G-66A	WVE-G-66C	WVE-G-68B	WVE-G-69A	WVE-G-72B	WVE-G-73A	WVE-G-73C
Al_2O_3	6.13	6.08	6.19	6.03	6.05	5.99	5.94	6.09	6.11	6.12	6.16	6.07	6.05	6.01	6.11
B_2O_3*	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45
CaO	1.92	2.08	2.18	2.27	2.35	2.44	2.43	2.59	2.58	2.62	2.54	2.61	2.58	2.58	2.54
Cl	0.14	0.07	0.07	0.08	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.08	0.09
Cr_2O_3	0.02	0.11	0.10	0.11	0.12	0.12	0.12	0.13	0.13	0.14	0.13	0.13	0.14	0.14	0.12
Cs_2O	0.17	0.12	0.12	0.12	0.11	0.11	0.13	0.11	0.11	0.12	0.11	0.12	0.11	0.12	0.12
F	0.25	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	5.34	5.71	5.40	5.22	5.07	4.99	4.65	4.78	4.54	4.40	4.09	4.15	4.07	4.01	3.77
I	0.10	0.02	0.01	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.01
K_2O	2.36	2.00	2.02	2.07	2.12	2.16	2.14	2.27	2.25	2.28	2.24	2.24	2.26	2.26	2.23
MgO	1.42	1.47	1.56	1.53	1.54	1.59	1.63	1.54	1.58	1.56	1.55	1.57	1.64	1.58	1.61
Na_2O	22.18	17.87	18.11	18.61	18.37	18.67	19.59	18.59	19.21	19.05	20.15	20.17	20.46	20.84	20.55
NiO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P_2O_5	0.08	0.10	0.10	0.11	0.11	0.11	0.12	0.13	0.13	0.12	0.13	0.14	0.13	0.14	0.13
PbO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SiO_2	42.43	46.15	45.97	45.70	46.03	45.60	45.27	45.24	45.20	45.40	45.24	44.93	44.83	44.72	45.45
SO_3	0.38	0.31	0.31	0.31	0.31	0.32	0.34	0.33	0.34	0.34	0.34	0.34	0.35	0.36	0.35
TiO_2	1.92	2.30	2.29	2.26	2.24	2.25	2.15	2.28	2.22	2.21	2.10	2.13	2.10	2.09	2.02
ZnO	2.85	3.00	2.95	2.94	2.95	2.97	2.87	3.07	2.95	2.95	2.76	2.82	2.76	2.73	2.61
ZrO_2	2.88	3.18	3.15	3.17	3.09	3.13	3.09	3.31	3.10	3.14	2.90	3.02	2.97	2.87	2.82
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

*Target value
NA – Not Analyzed

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

Test #	2(+15% Simulant)														
Glass (kg)		1210.2	1228.5	1247.1	1269.5	1293.1	1317.5	1339.8	1363.1	1385.7	1408.3	1427.4	1444.8	1470.1	1489.6
Element	Target	WVE-G-76A	WVE-G-77B	WVE-G-82A	WVE-G-84A	WVE-G-85B	WVE-G-86A	WVE-G-88A	WVE-G-89B	WVE-G-92B	WVE-G-94A	WVE-G-96B	WVE-G-97B	WVE-G-100B	WVE-G-102B
Al_2O_3	6.13	6.04	6.04	5.98	6.08	5.96	5.97	5.94	5.92	5.97	5.94	6.03	5.93	5.95	6.02
B_2O_3*	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45
CaO	1.92	2.60	2.58	2.64	2.62	2.62	2.59	2.75	2.75	2.72	2.70	2.67	2.81	2.74	2.78
Cl	0.14	0.09	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.09	0.09	0.09	0.08
Cr_2O_3	0.02	0.14	0.13	0.14	0.14	0.15	0.13	0.15	0.15	0.16	0.16	0.16	0.16	0.15	0.16
Cs_2O	0.17	0.13	0.13	0.12	0.13	0.12	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.13	0.13
F	0.25	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	5.34	3.88	3.76	3.84	3.78	3.77	3.66	4.07	4.01	4.00	3.96	3.85	4.06	3.99	4.01
I	0.10	0.02	0.02	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01
K_2O	2.36	2.27	2.24	2.29	2.26	2.27	2.22	2.33	2.34	2.33	2.31	2.28	2.40	2.33	2.36
MgO	1.42	1.57	1.60	1.54	1.56	1.62	1.56	1.54	1.54	1.49	1.52	1.56	1.49	1.49	1.51
Na_2O	22.18	20.53	20.69	20.37	20.46	20.77	20.85	20.35	20.19	20.26	20.59	20.50	19.78	20.06	19.73
NiO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01
P_2O_5	0.08	0.13	0.14	0.13	0.14	0.15	0.15	0.13	0.14	0.14	0.14	0.13	0.14	0.13	0.14
PbO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SiO_2	42.43	45.13	45.27	45.40	45.30	45.12	45.43	44.49	44.62	44.73	44.51	44.85	44.77	44.98	45.04
SO_3	0.38	0.36	0.36	0.37	0.38	0.37	0.38	0.35	0.36	0.36	0.36	0.36	0.36	0.37	0.37
TiO_2	1.92	2.05	2.01	2.06	2.03	2.03	2.00	2.15	2.17	2.15	2.13	2.10	2.19	2.15	2.15
ZnO	2.85	2.68	2.62	2.69	2.67	2.66	2.57	2.93	2.90	2.85	2.85	2.74	2.96	2.86	2.87
ZrO_2	2.88	2.94	2.88	2.89	2.90	2.84	2.81	3.13	3.22	3.15	3.13	3.07	3.26	3.11	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	100.00	100.00	100.00

*Target value
NA – Not Analyzed

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

Test #	2 (+15% Simulant)						3 (Nominal)								
Glass (kg)		1509.9	1536.9	1576.3	Test 2			1597.8	1616.9	1634.2	1648.3	1667.8	1681.6	1707.2	1753
Element	Target	WVE-G-103B	WVE-G-108A	WVE-G-110A	Average#	%Dev.**	Target	WVE-G-127B	WVE-G-128B	WVE-G-130B	WVE-G-132A	WVE-G-133B	WVE-G-134B	WVE-G-138A	WVE-G-144A
Al_2O_3	6.13	6.11	6.11	6.10	6.00	-1.99	6.08	6.54	6.44	6.39	6.24	6.20	6.36	6.16	6.28
B_2O_3*	9.45	9.45	9.45	9.45	9.45	NC	9.80	9.80	9.80	9.80	9.80	9.80	9.80	9.80	9.80
CaO	1.92	2.74	2.73	2.43	2.68	39.63	1.99	2.66	2.59	2.50	2.45	2.34	2.24	2.20	2.09
Cl	0.14	0.08	0.08	0.07	0.09	NC	0.13	0.03	0.03	0.04	0.05	0.05	0.06	0.07	0.07
Cr_2O_3	0.02	0.16	0.16	0.15	0.15	NC	0.02	0.32	0.30	0.28	0.27	0.25	0.24	0.23	0.21
Cs_2O	0.17	0.11	0.13	0.14	0.13	NC	0.15	0.09	0.10	0.12	0.11	0.12	0.12	0.12	0.11
F	0.25	NA	NA	NA	NA	NC0	0.23	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	5.34	3.90	3.92	4.73	3.96	-25.86	5.54	4.29	4.42	4.65	4.76	4.89	4.77	5.05	5.21
I	0.10	0.01	0.02	0.02	0.02	NC	0.10	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01
K_2O	2.36	2.33	2.33	2.19	2.30	-2.43	2.13	2.18	2.16	2.19	2.20	2.16	2.13	2.17	2.09
MgO	1.42	1.46	1.45	1.55	1.53	7.83	1.48	1.45	1.43	1.46	1.51	1.46	1.47	1.46	1.45
Na_2O	22.18	20.15	20.24	18.88	20.24	-8.75	20.01	19.37	19.05	19.24	19.45	19.55	19.72	19.82	19.84
NiO	<0.01	0.01	0.01	<0.01	<0.01	NC	<0.01	0.04	0.03	0.03	0.02	0.01	0.01	0.01	0.01
P_2O_5	0.08	0.13	0.14	0.12	0.14	NC	0.07	0.13	0.14	0.12	0.12	0.12	0.11	0.11	0.11
PbO	<0.01	<0.01	<0.01	<0.01	<0.01	NC	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SiO_2	42.43	45.20	44.73	45.44	44.99	6.05	44.00	44.78	45.11	44.56	44.45	44.44	44.75	44.29	44.27
SO_3	0.38	0.38	0.37	0.33	0.36	NC	0.35	0.37	0.38	0.37	0.37	0.37	0.36	0.35	0.34
TiO_2	1.92	2.10	2.14	2.22	2.11	10.05	1.99	2.13	2.15	2.18	2.20	2.20	2.15	2.22	2.20
ZnO	2.85	2.79	2.84	2.94	2.80	-1.79	2.95	2.76	2.76	2.83	2.85	2.87	2.74	2.88	2.85
ZrO_2	2.88	2.88	3.15	3.24	3.05	6.07	2.99	3.07	3.09	3.24	3.14	3.14	2.97	3.07	3.05
Sum	100.00	100.00	100.00	100.00	100.00	NC	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

*Target value
** % deviation from target values
#Average was calculated for glass after initial 300 kg of glass production
NA – Not Analyzed
NC – Not Calculated

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

Test #	3 (Nominal)																
Glass (kg)		1773.3	1792.2	1809.8	1827.4	1839	1861.9	1891.8	1915.8	1933.3	1947.4	1967.4	1984.8	2017.6	2026.7	Test 3	
Element	Target	WVE-G-144C	WVE-G-145B	WVE-G-149B	WVE-G-151A	WVE-G-151C	WVE-G-154A	WVF-G-6A	WVF-G-12A	WVF-G-12C	WVF-G-13B	WVF-G-14B	WVF-G-20A	WVF-G-21A	WVF-G-21B	Average#	%Dev **
Al_2O_3	6.08	6.19	6.16	6.04	6.01	6.05	6.13	6.03	6.03	6.02	6.09	6.12	6.11	6.00	6.15	6.07	-0.27
B_2O_3*	9.80	9.80	9.80	9.80	9.80	9.80	9.80	9.80	9.80	9.80	9.80	9.80	9.80	9.80	9.80	9.80	NC
CaO	1.99	2.07	1.96	2.05	2.10	2.03	2.02	2.03	1.98	1.98	1.98	1.96	1.91	1.93	1.93	1.96	-1.34
Cl	0.13	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	NC
Cr_2O_3	0.02	0.19	0.17	0.19	0.20	0.18	0.18	0.18	0.17	0.17	0.17	0.16	0.15	0.14	0.15	0.16	NC
Cs_2O	0.15	0.12	0.12	0.13	0.11	0.14	0.11	0.13	0.15	0.16	0.13	0.13	0.15	0.13	0.14	0.14	NC
F	0.23	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NC
Fe_2O_3	5.54	5.30	5.00	5.49	5.81	5.63	5.61	5.82	5.70	5.73	5.82	5.71	5.61	5.74	5.65	5.72	3.36
I	0.10	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	NC
K_2O	2.13	2.12	2.09	2.19	2.26	2.21	2.21	2.25	2.20	2.20	2.19	2.18	2.14	2.15	2.17	2.18	2.66
MgO	1.48	1.40	1.46	1.40	1.33	1.37	1.32	1.30	1.31	1.44	1.42	1.46	1.49	1.50	1.53	1.43	-3.25
Na_2O	20.01	19.48	20.27	19.05	18.49	19.00	18.88	18.66	18.98	18.58	18.50	18.78	19.21	19.00	18.97	18.84	-5.88
NiO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
P_2O_5	0.07	0.11	0.10	0.11	0.10	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.09	0.08	0.10	0.09	NC
PbO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
SiO_2	44.00	44.63	44.83	44.59	44.49	44.37	44.80	44.52	44.52	44.62	44.69	44.55	44.38	44.43	44.42	44.52	1.17
SO_3	0.35	0.34	0.36	0.35	0.35	0.35	0.35	0.34	0.35	0.34	0.33	0.33	0.32	0.34	0.33	0.34	NC
TiO_2	1.99	2.20	2.12	2.29	2.39	2.31	2.29	2.35	2.30	2.32	2.31	2.29	2.27	2.30	2.27	2.30	15.78
ZnO	2.95	2.86	2.66	2.99	3.19	3.02	3.00	3.10	3.00	3.03	3.01	2.99	2.93	2.98	2.96	3.0	1.79
ZrO_2	2.99	3.11	2.82	3.25	3.29	3.35	3.11	3.29	3.33	3.44	3.37	3.38	3.36	3.40	3.38	3.37	12.78
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
** % deviation from target values
#Average was calculated for glass after initial 300 kg of glass production
NA – Not Analyzed
NC – Not Calculated

Table 4.3. XRF Analyzed Compositions for Glass Dip Samples (wt%).

Test #	1 (-15% Simulant)			2 (+15% Simulant)			3 (Nominal)			
Element	Target	WVD-D-109A	WVE-D-28A	Target	WVE-D-32A	WVE-D-110A	Target	WVE-D-112A	WVF-D-21A	WVF-D-21B
Al_2O_3	6.04	6.18	6.30	6.13	6.06	6.40	6.08	6.09	5.95	5.86
B_2O_3*	10.18	10.18	10.18	9.45	9.45	9.45	9.80	9.80	9.80	9.80
CaO	2.07	4.84	1.96	1.92	2.06	2.76	1.99	2.68	1.88	1.99
Cl	0.11	0.06	0.08	0.14	0.07	0.03	0.13	0.08	0.08	0.07
Cr_2O_3	0.01	0.23	0.16	0.02	0.12	0.31	0.02	0.21	0.14	0.15
Cs_2O	0.14	0.02	0.12	0.17	0.11	0.10	0.15	0.13	0.12	0.14
F	0.20	NA	NA	0.25	NA	NA	0.23	NA	NA	NA
Fe_2O_3	5.75	5.67	5.74	5.34	6.00	4.14	5.54	3.94	5.56	5.87
I	0.10	<0.01	0.02	0.10	0.01	<0.01	0.10	0.01	0.01	0.01
K_2O	1.88	0.28	1.92	2.36	1.90	2.21	2.13	2.25	2.09	2.20
MgO	1.53	1.68	1.41	1.42	1.44	1.53	1.48	1.45	1.59	1.49
Na_2O	17.68	15.81	16.69	22.18	17.45	20.19	20.01	20.33	19.71	18.29
NiO	<0.01	0.05	<0.01	<0.01	<0.01	0.04	<0.01	0.01	<0.01	<0.01
P_2O_5	0.06	0.17	0.10	0.08	0.10	0.14	0.07	0.14	0.10	0.10
PbO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SiO_2	45.70	46.78	46.47	42.43	46.22	44.36	44.00	44.61	44.31	44.62
SO_3	0.32	0.66	0.42	0.38	0.36	0.37	0.35	0.39	0.34	0.36
TiO_2	2.07	1.34	2.31	1.92	2.36	2.14	1.99	2.07	2.25	2.35
ZnO	3.07	2.93	2.99	2.85	3.06	2.75	2.95	2.78	2.88	3.12
ZrO_2	3.11	3.11	3.15	2.88	3.22	3.09	2.99	3.02	3.20	3.60
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulfate Presence?		NO	NO		NO	NO		NO	NO	NO

*Target value
NA – Not Analyzed

Table 4.4. Iron Redox State for Discharged Glass Samples.

Test #	Sampling Date	Sample Name	Cumulative Mass (kg)	%Fe^{2+}*/Total Fe
1	11/16/01	WVE-G-27D	892.7	<0.8
2	11/30/01	WVE-G-110A	1576.3	<0.8
3	01/24/02	WVE-G-138A	1707.2	<0.8
	01/25/02	WVE-G-154A	1861.9	<0.8
	01/26/02	WVF-G-21B	2026.7	<0.8

Table 5.1. Results from Melter Emission Samples.

		Test 1 11/15/01				Test 2 11/29/01				Test 3b 01/24/02				Test 3c 01/25/02			
		Feed Flux (mg/min)	Melter Outlet (mg/min)	% Emitted	Melter DF	Feed Flux (mg/min)	Melter Outlet (mg/min)	% Emitted	Melter DF	Feed Flux (mg/min)	Melter Outlet (mg/min)	% Emitted	Melter DF	Feed Flux (mg/min)	Melter Outlet (mg/min)	% Emitted	Melter DF
Particles	Total[$]	192667	574.5	0.30	335.4	156500	1301.3	0.83	120.3	185500	1100.2	0.59	168.6	151500	1495.1	0.99	101.3
	Al	6161	4.53	0.07	1360.5	5079	15.61	0.31	325.3	5981	7.62	0.13	784.9	4885	11.58	0.24	421.7
	B	6093	31.98	0.52	190.5	4595	67.61	1.47	68.0	5648	67.23	1.19	84.0	4612	35.86	0.78	128.6
	Ca	2851	2.06	0.07	1381.2	2148	8.19	0.38	262.3	2639	1.56	0.06	1688.4	2155	2.43	0.11	887.1
	Cl	212	NA	NA	NA	219	NA	NA	NA	241	101.33[#]	42.05	2.4	197	264.03[#]	134.05	0.8
	Cr	13	1.05	7.99	12.5	21	2.17	10.12	9.9	25	3.05	12.02	8.3	21	0.85	4.09	24.5
	Cs	254	3.36	1.32	75.7	251	30.66	12.22	8.2	262	28.61	10.90	9.2	214	35.83	16.72	6.0
	F	385	NA	NA	NA	391	NA	NA	NA	427	70.52[#]	16.52	6.1	348	202.44[#]	58.17	1.7
	Fe	7747	9.67	0.12	800.8	5844	17.20	0.29	339.8	7186	16.11	0.22	446.2	5869	22.33	0.38	262.8
	I	193	< 0.10	5.18	>1930	157	<0.10	6.37	>1570	186	4.08[#]	2.19	45.6	152	10.09[#]	6.64	15.1
	K	3007	36.69	1.22	82.0	3066	84.72	2.76	36.2	3280	78.70	2.40	41.7	2679	33.26	1.24	80.5
	Mg	1777	0.26	0.01	6832.6	1340	0.41	0.03	3252.6	1655	0.15	0.01	10968.3	1352	0.12	0.01	11555.3
	Na	25287	103.59	0.41	244.1	25777	235.76	0.91	109.3	27567	280.21	1.02	98.4	22514	288.45	1.28	78.1
	P	50	0.11	0.21	479.4	55	0.68	1.24	80.4	57	0.50	0.88	114.0	46	0.45	0.98	102.1
	S	247	24.71	10.00	10.0	238	11.92	5.00	20.0	260	22.92[#]	8.82	11.3	212	36.17[#]	17.06	5.9
	Si	41196	16.58	0.04	2484.6	31063	57.21	0.18	543.0	38189	12.62	0.03	3026.5	31190	22.24	0.07	1402.5
	Ti	2391	3.93	0.16	608.9	1801	10.48	0.58	171.8	2213	6.29	0.28	351.6	1807	7.91	0.44	228.5
	Zn	4752	7.49	0.16	634.0	3583	15.09	0.42	237.5	4396	11.09	0.25	396.6	3591	14.65	0.41	245.2
	Zr	4436	0.44	0.01	10080.6	3337	1.93	0.06	1731.6	4106	0.76	0.02	5435.9	3353	0.73	0.02	4570.1
GAS	B	6093	12.17	0.20	500.8	4595	1.44	0.03	3181.4	5648	0.71	0.01	7949.7	4612	0.89	0.02	5207.0
	Cl	212	1.17	0.55	181.4	219	< 0.10	< 0.04	>2190	241	< 0.10	< 0.04	> 2410	197	< 0.10	< 0.05	> 1970
	F	385	8.32	2.16	46.3	391	1.64	0.42	238.2	427	< 0.10	< 0.02	> 4270	348	< 0.10	< 0.03	> 3480
	I	193	49.65	25.77	3.9	157	16.21	10.36	9.7	186	1.79	0.96	103.9	152	0.91	0.60	165.8
	S	247	< 0.10	0.04	> 2470	238	< 0.10	< 0.04	>2380	260	0.44	0.17	588.7	212	0.19	0.09	1101.0

NA – Not Available
[$] - From gravimetric analysis of filters.
- Calculated from water dissolution.

Table 5.2 Concentrations of Gaseous Species Monitored by FTIR (ppmv).

Test	1	2	3		
	-15% Simulant	+15% Simulant	Nominal		
Reductant	Sugar	Sugar	Formic Acid		
Reductant Ratio	0.52	0.44	0.5	0.75	1.0
NOx: Organic Carbon	1: 0.78	1: 0.66	1: 0.75	1: 1	1: 1.5
NO	1100	1600	2240	2265	2159
NO_2	148	270	460	461	410
N_2O	127	138	128	122	85
HNO_2	< 1.0	2.2	1.5	2.9	1.7
HNO_3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
NH_3	85.7	94.4	9.0	4.2	9.9
SO_2	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
H_2O(%)	5.3	6.5	6.7	6.4	6.1
CO_2	3920	4180	4720	5730	7930
CO	54.7	63.2	350	438	680
Acetonitrile	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Acrylonitrile	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HCl	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HCN	1.8	1.2	< 1.0	< 1.0	< 1.0
HF	< 1.0	< 1.0	1.4	< 1.0	< 1.0

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

Test #	Feed [mol/h]	Reductant Ratio	Emissions [mol/h]			% Feed NO_x Emitted as Nitrogen Oxides
			NO_2 [mol/h]	NO [mol/h]	N_2O [mol/h]	
1	25.0	0.57	1.4	10.2	1.2	51.2
2	28.5	0.44	2.5	14.9	1.3	65.6
3	26.9	0.5	4.2	20.9	1.2	97.8
	26.9	0.75	4.3	21.1	1.1	98.5
	26.9	1.0	3.8	20.1	0.8	91.8

Table 5.4. Mass Balance of Volatile Constituents (% of Feed).

		-15 wt% Simulant	+15 wt% Simulant	Nominal + Formic Acid	Nominal + Formic Acid
Reductant Ratio		0.52	0.44	0.75	1.0
Glass	Cl	64	57	54	54
	Cs	86	76	87	93
	I	20	20	20	20
	S	97	97	100	94
Particle Emissions	Cl	NA	NA	42#	134#
	Cs	1.3	12	11	17
	I	< 0.1	< 0.1	2.2#	6.6#
	S	10	5.0	8.8#	17#
Gaseous Emissions	Cl	0.6	< 0.1	< 0.1	< 0.1
	Cs	< 0.1	< 0.1	< 0.1	< 0.1
	I	26	10	1.0	0.6
	S	< 0.1	< 0.1	0.4	< 0.1
Totals	Cl	64	57	96	135
	Cs	87	88	98	110
	I	46	30	23	27
	S	107	102	109	111

- Calculated from water dissolution.

Table 6.1. Completion of Test Objectives.

Test Objective	Objective Met?	Discussion Section
Demonstrate that Sub-Envelope A2 feed with -15% simulant is processable in the DM100	Yes	Section 3.0. Nominal operating conditions were maintained and the full test duration was completed.
Demonstrate that Sub-Envelope A2 feed with +15% simulant is processable in the DM100	Yes	Section 3.0. Nominal operating conditions were maintained and the full test duration was completed.
Demonstrate that no separate sulfate phase forms with Sub-Envelope A2 feed with -15% simulant in the DM100	Yes	Section 3.0. No separate sulfate phase was detected.
Demonstrate that no separate sulfate phase forms with Sub-Envelope A2 feed with +15% simulant in the DM100	Yes	Section 3.0. No separate sulfate phase was detected.
Demonstrate that target feed rate can be achieved with Sub-Envelope A2 feed with -15% simulant in the DM100	Yes	Section 3.0. Nominal operating temperature maintained and target glass production rate achieved.
Demonstrate that target feed rate can be achieved with Sub-Envelope A2 feed with +15% simulant in the DM100	Yes	Section 3.0. Nominal operating temperature maintained and target glass production rate achieved.
Demonstrate target product compositions are achieved for Sub-Envelope A2 feed with -15% and +15% stimulant in the DM100	Yes	Section 4.0. The analyzed glass product compositions agreed well with the target compositions.
Report melter emissions data for the DM100 with Sub-Envelope A2 feed with -15% and +15% stimulant	Yes	Section 5.0. Particulate and gaseous emissions were determined for a variety of species and DF values computed.
Characterize the properties of the melter feed for Sub-Envelope A2 feed with -15% and +15% stimulant	Yes	Section 2.0. Samples of the melter feeds were characterized with respect to chemical composition and physical properties, including rheology.
Per Test Exception, perform comparable tests using formic acid instead of sugar as the reductant at three reductant ratios.	Yes	Sections 3, 4, and 5. Nominal operating conditions were maintained and the full test durations were completed. The analyzed glass product compositions agreed well with the target compositions. Particulate and gaseous emissions were determined for a variety of species and DF values computed. Data on hydrogen emissions were collected and were reported separately [13].

Duratek

Duratek, Inc.
River Protection Project
345 Hills Street
Richland, Washington 99352
(509) 376-7055 - Phone
(509) 372-3830 - Fax

March 6, 2003
L-12057

WTP PDC Submittal Coordinator
Bechtel National, Inc.
2435 Stevens Center Place, H4-02 (MS5-K.1)
Richland, Washington 99352

SUBCONTRACT NO. 24590-101-TSA-W000-0009
DURATEK FEDERAL SERVICES, INC. RESEARCH AND TECHNOLOGY SUPPORT, TRANSMITTAL OF FINAL REPORT

Dear Sir or Madam:

Please find attached the following Final Report:

- Final Report – "Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A2 Feed (LAW A88 Glass) in Support of the LAW Pilot Melter." VSL-02R62N0-3, Rev. 1 dated January 31, 2003

Should you have any questions and/or concerns, please contact the undersigned on 376-9942.

Sincerely,

June Cram

for P. K. Brockman
Duratek, Inc.
Project Manager

Attachments

cc:	Steve Barnes w/o att	H4-02 (MS1-B)	Jeannette Doyle w/o att	H4-02 (MS1-B)
	Harvey Linn w/o att	H4-02 (MS14-3A)		
	Joe Perez w/o att	H4-02 (MS1-B)		
	Chris Musick w/o att	H4-02 (MS1-B)		
	Brad Bowan w/o att	Columbia		
	Glenn Diener w/o att	Columbia		
	Scot Jenkins w/o att	H4-02 (MS14-1B)		
	Chris Chapman w/o att	H1-11		
	Document Control file w/o att	Columbia		
	P. K. Brockman LB			

MASTER DISTRIBUTION SCHEDULE

Sheet 1 of 1

Project Name: RPP-WTP

Document Distribution: 24590-101-TSA-W000-0009

Document Number: **Revision:**

Insert rows as necessary ↑

Name	MSIN	Controlled	Uncontrolled	Size				Comments
				8 ½ x 11	11 x 17	Full	As Is	
JEANETTE, DOYLE	MS1-B							Review

Insert rows as necessary ↑

Jeanette Doyle
Approver's Name (Print)

Jeanette Doyle
Approver's Signature

09/06/02
Date

Morrey, Eugene

From: Jian-Shun_Shuen@RL.gov
Sent: Thursday, August 22, 2002 7:28 AM
To: Morrey, Eugene; Perez, Joseph
Cc: Jian-Shun_Shuen@rl.gov; Damerow, Frederick W; Doyle, Jeanette
Subject: ORP Acceptance of Comment Responses on Test Report VSL-02R62N0-3

Eugene and Joe,

The responses to ORP comments on the subject Test Report are acceptable. Please submit to ORP the revised report incorporating the comment resolutions as soon as practicable.

Regards,
Jian-Shun

-----Original Message-----
From: Morrey, Eugene [mailto:evmorrey@bechtel.com]
Sent: Wednesday, August 21, 2002 3:20 PM
To: 'Jian-Shun_Shuen (E-mail)'
Subject: Comment Responses on Test Report VSL-02R62N0-3

<< File: VSL-02R62N0-3 DOE Comments.doc >> Jian-Shun,

Attached are VSL responses to DOE comments on the following test report, VSL-02R62N0-3, Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A2 Feed (LAW A88 Glass) in Support of the LAW Pilot Melter. Please let me know if they are acceptable. If so, please provide approval by responding to this email.

A revised copy of the report incorporating the attached resolutions will be provided when it becomes available.

Thanks, Eugene

<<VSL-02R62N0-3 DOE Comments.doc>>

DOCUMENT REVIEW REQUEST

Sheet 1 of 1

TO BE COMPLETED BY DOCUMENT PREPARER

DOCUMENT NUMBER	DRAFT REVISION #	DOCUMENT TITLE
VSL-02R62N0-3	0	Final Report - Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A2 Feed (LAWA88 Glass) in Support of the LAW Pilot Melte

AB EVALUATION REQUIRED? ☐ YES ☒ NO (see document/procedure electronic index)

PREPARER:	Eugene Morrey	MS1-B	371-5191	07/10/02
	Name (Print)	MSIN	Telephone Number	Date

DISTRIBUTION

MSIN	REVIEWERS/REVIEWING ORGANIZATION'S MANAGER	ORGANIZATION (DEPARTMENT/ DISCIPLINE)	PURPOSE OF REVIEW	
			REQUIRED REVIEW	INFORMATION ONLY
MS1-B	S. Barnes	R&T Vitrification/WFQ	X	
MS6-P1	F. Beranek	ES&H	X	
MS1-C	O. Block	Vitrification Process Technology	X	
MS2-A2	G. Warner	Quality Assurance	X	
MS4-B1	K.L. Khianey	Area Project Manager – LAW	X	
MS3-B	I. G. Papp	Process Engineering	X	
MS3-A	D. Carl	Melter Systems Group	X	
MS1-B	J. Perez	R&T HLW Vitrification		X
MS1-B	S. Kelly	R&T Vitrification Offgas		X
MS9-A	L. S. Jenkins	Subcontracts		X
MS1-B	G. L. Smith	R&T Simulant Coordination	X	

Comments Due to Preparer by: 07/25/02 (Date)

NOTE: "Required Review" requires a response to the originator on whether or not there are comments.

TO BE COMPLETED BY REVIEWER

REVIEWER'S NAME/ORGANIZATION: D. Carl/Melter Systems DATE: 25JUL02

This document was reviewed per 24590-WTP-GPP-PADC-003, Internal Review and Approval of Documents, section 3.0, and is:

ACCEPTED, NO COMMENTS ☐ COMMENTS ON DOCUMENT ☐ COMMENTS ATTACHED ☒

Document maintains AB consistency? ☐ Yes ☐ No _____ INITIAL, ES&H

Document maintains QAM compliance? ☐ Yes ☐ No _____ INITIAL, QA

If the document is not compliant with the AB, an ABCN shall be approved and either the AB documents revised or a DTD approved before the document can be issued.

AB revised (date): _____ ABCN No. _____ Approval Date: _____

DTD No. _____ Approval Date: _____

Comments Resolved: D. C. Carl (Signature) 25JUL02 (Date)

Best Available Copy

Morrey, Eugene

From: Hyman, Marve
Sent: Wednesday, September 25, 2002 9:54 AM
To: Morrey, Eugene
Cc: Blodgett, Stephanie
Subject: FW: Comment Responses on A2 Variation DM100 Test Report

Eugene: All Process Engineering comments on subject doc made on behalf of Ivan Papp have been resolved.

Marve

-----Original Message-----
From: Morrey, Eugene
Sent: Wednesday, August 21, 2002 3:06 PM
To: Hyman, Marve; Papp, Ivan
Subject: Comment Responses on A2 Variation DM100 Test Report

Marve, Ivan;

Please review the attached comment responses and let me know if they are acceptable.

Thanks, Eugene

VSL-02R62N0-3 Papp Comments.d...

DOCUMENT REVIEW REQUEST

Sheet 1 of 1

TO BE COMPLETED BY DOCUMENT PREPARER

DOCUMENT NUMBER	DRAFT REVISION #	DOCUMENT TITLE
VSL-02R62N0-3	0	Final Report - Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A2 Feed (LAWA88 Glass) in Support of the LAW Pilot Melte

AB EVALUATION REQUIRED? ☐ YES ☒ NO (see document/procedure electronic index)

PREPARER:	Eugene Morrey	MS1-B	371-5191	07/10/02
	Name (Print)	MSIN	Telephone Number	Date

DISTRIBUTION

MSIN	REVIEWERS/REVIEWING ORGANIZATION'S MANAGER	ORGANIZATION (DEPARTMENT/ DISCIPLINE)	PURPOSE OF REVIEW	
			REQUIRED REVIEW	INFORMATION ONLY
MS1-B	S. Barnes	R&T Vitrification/WFQ	X	
MS6-P1	F. Beranek	ES&H	X	
MS1-C	O. Block	Vitrification Process Technology	X	
MS2-A2	G. Warner	Quality Assurance	X	
MS4-B1	K.L. Khianey	Area Project Manager – LAW	X	
MS3-B	I. G. Papp	Process Engineering	X	
MS3-A	D. Carl	Melter Systems Group	X	
MS1-B	J. Perez	R&T HLW Vitrification		X
MS1-B	S. Kelly	R&T Vitrification Offgas		X
MS9-A	L. S. Jenkins	Subcontracts		X
MS1-B	G. L. Smith	R&T Simulant Coordination	X	

Comments Due to Preparer by: 07/25/02 (Date)

NOTE: "Required Review" requires a response to the originator on whether or not there are comments.

TO BE COMPLETED BY REVIEWER

REVIEWER'S NAME/ORGANIZATION: K.L.KHIANEY LAW-APE DATE: 7/14/02

This document was reviewed per 24590-WTP-GPP-PADC-003, Internal Review and Approval of Documents, section 3.0, and is:

ACCEPTED, NO COMMENTS ☒ COMMENTS ON DOCUMENT ☐ COMMENTS ATTACHED ☐

Document maintains AB consistency? ☐ Yes ☐ No _____ INITIAL, ES&H

Document maintains QAM compliance? ☐ Yes ☐ No _____ INITIAL, QA

If the document is not compliant with the AB, an ABCN shall be approved and either the AB documents revised or a DTD approved before the document can be issued.

ABCN No. _____ Approval Date: _____

AB revised (date): _____ DTD No. _____ Approval Date: _____

Comments Resolved: _____ Signature _____ Date

Morrey, Eugene

From: Webb, Michael
Sent: Thursday, October 03, 2002 12:57 PM
To: Morrey, Eugene
Cc: WTP QA
Subject: RE: Comment Responses on A2 Variation DM100 Test Report

Eugene,

Your response is adequate at this time. If you have any additional questions, I can be reached at the number below.

Michael A. Webb
Quality Engineering
371-0255

-----Original Message-----
From: Morrey, Eugene
Sent: Wednesday, October 02, 2002 5:12 PM
To: Webb, Michael
Subject: FW: Comment Responses on A2 Variation DM100 Test Report

Mike,

According to my records, I still need a response from you on the attached comment resolutions. Please let me know if they are acceptable.

Thanks Eugene

-----Original Message-----
From: Morrey, Eugene
Sent: Wednesday, August 21, 2002 3:11 PM
To: Webb, Michael
Subject: Comment Responses on A2 Variation DM100 Test Report

Mike;

Please review the attached comment responses and let me know if they are acceptable.

Thanks, Eugene

<< File: VSL-02R62N0-3 QA Comments.doc >>

DOCUMENT REVIEW RECORD

Return to: Eugene Morrey 371-5191; MS1-B

Comments Due: 7/25/02

Document Title:	Document No.	Revision:	Date:
Final Report - Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A2 Feed (LAWA88 Glass) in Support of the LAW Pilot Melter	VSL-02R62N0-3	0	7/10/02

Reviewer:	Date:	Response by:	Date:	Comments Resolved:	Date:
Eugene Morrey/Joe Perez R&T	1/2/03			Eugene V. Morrey	2/12/03

Item No.	Section/ Paragraph	Comment	Response	Significance [a]	Resolution	Incorporated?
1	Section 7/ Reference 12	Correct Test Exception number is "24590-WTP-TEF-RT-02-05"	Agreed.			Yes
2	Table 4.2	Test averages are incorrect and need to be based on steady-state operation. Please recalculate.	Agreed.			Yes
3	Table 4.2	For future work the quantity of glass analyses (XRF) should be reduced: e.g., by 50%.	Comments applies to future Test Plans, not this report.			No
4	Table 6.1/ 4th test objective	The response indicates that a separate sulfate phase was detected in the first test with this feed and that sugar was increased to achieve operation without separate sulfate phase. I believe this was carried over from the C1 report. According to the text and Table 3.1, no sulfate gall was observed in any of the tests. Modify text in Table 6.1 to be consistent with results.	Agreed.			Yes
5	Approval Page	With changes made above, we are ready for the fully signed-off approval page.				

[a] **Significance**: M = Mandatory (must be resolved); E = Editorial (for consideration); I = Improvement (may be considered for next revision)

DOCUMENT REVIEW RECORD

Return to: Joe Perez

Comments Due: July12, 2002

Document Title: Duramelter 100 LAW Sub-Envelope A2 Variation Tests	Document No. VSL-02R62N0-3	Revision: 0	Date: June 26, 2002

Reviewer:	Date:	Response by:	Date:	Comments Resolved:	Date:
JM Perez RHT	8/10/02				10/3/02

Item No.	Section/ Paragraph	Comment	Response	Significance [a]	Resolution	Incorporated?
1	Pg. 5, 2nd Bullet	"product quality" is very broad and should be better described to clearly define the product properties to be examined, e.g., "…product quality, i.e., composition, no secondary salt phase.."	This will be clarified.	I	Ok	
2	Pg. 8, Sec. 2.1	1. 3rd sentence should have a reference supporting "per WTP direction" 2. general: perhaps the first para. is correct for testing conducted last November but this should ultimately be able to be simplified by simply referring to the WTP basis documents(s), i.e., test spec. simulant bases, etc. 3. Verify ref. 24 is the correct reference –the reference is not a project document but a subcontractor report. 4. The 2nd-to-last sentence also references a subcontractor report as the basis for sodium molarity. Although the subcontractor report may have supported the Project's establishment of the molarity limit, a Project basis document should be the reference.	1. Direction was provided through e-mail from E.V Morrey on 10/17/01. We can cite that reference or the implicit direction provided through approval of the test plan. 2. To our knowledge, no such WTP basis document was available for this work. 3. We have verified that Reference 24 is correct as cited. 4. To our knowledge, a WTP basis document that addresses this issue was not available.	M	Ok	
3	Pg. 8 footnote	Delete "Unfortunately" Delete last three sentences – conjecture and presumed future Project direction should not be in a	Agreed. The subject footnote is quoted from the approved Test Plan, which, in turn, included this	M	Ok	

Morrey, Eugene

From: Morrey, Eugene
Sent: Wednesday, February 12, 2003 5:51 PM
To: Block, Oliver U; Sauceda, Ermelinda; Smith, Gary L
Subject: No Comments Received on Test Report - A2 Variation DM100

Oli, ES&H, Gary;

Comments have not been received on, test report, VSL-02R62N0-3, Final Report - Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A2 Feed (LAWA88 Glass) in Support of the LAW Pilot Melter, by the due date. Issue of the document will proceed without your comments. If there are comments, they will be addressed / resolved / incorporated in the next revision of the document.

If you do not have comments, please respond as such to this message.

Thanks, Eugene

-----Original Message-----
From: Morrey, Eugene
Sent: Wednesday, July 10, 2002 11:06 AM
To: Barnes, Steven M; Block, Oliver U; Papp, Ivan; Carl, Daniel; Sauceda, Ermelinda; Jenkins, L. S (Scot); WTP QA; Khianey, Ken; Smith, Gary L
Cc: Perez, Jameilyn M; Perez, Joseph; Kelly, Sam
Subject: Test Report for Review and Comment - A2 Variation DM100 (Due July 25)

All

Duratek has submitted test report, "Final Report - Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A2 Feed (LAWA88 Glass) in Support of the LAW Pilot melter," VSL-02R62N0-3, rev. 0, for project review, comment, and acceptance. This report documents Sub-Anvelope A2 compositional variation testing in the DM100 melter to test impacts of typical process errors in the WTP and to support LAW Pilot melter operations.

The Document Review Request and Document Review Record are attached.

<< File: Document Review Request VSL-02R62N0-3.doc >> << File: Document Review Record VSL-02R62N0-3.doc >>

The report and the controlling test plan have been posted to the R&T share drive that everyone has access to. The folder address is: //Wtps0027/R&t/Vitrification/LAW Reports for Review/VSL-02R62N0-3 A2 Variation DM100

The test plan is titled: "Compositional Variation Tests on DuraMelter 100 with LAW Sub-envelope A2 Feed (LAWA88 glass) in Support of the LAW Pilot Melter," VSL-01T62N0-3, Rev. 0.

Comments are due to be submitted by me Thursday, July 25, 2002.

Please call if you have questions (371-5191).

Thanks, Eugene

Research and Technology Completion Form

R&T Scoping Statement(s): VL-4

Test Specification Number/Title: TSP-W375-00-00015/LAW DM10 and DM100 Melter Tests

Test Plan Number/Title: VSL-01T62N0-3, Rev. 1/Test Plan - Compositional Variation Tests on DuraMelter 100 with LAW Subenvelope A2 Feed (LAWA88 glass) in Support of the LAW Pilot Melter

Test Report Number/Title: VSL-02R62RN0-3, Rev. 1/Final Report - Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A2 Feed in Support of the LAW Pilot Melter

Prepared by: Eugene Morrey **Date:** 2/21/03

List Test Objectives:	State how objectives were met:
1) Demonstrate that Sub-Envelope A2 feed with ±15% waste loading is processable in the DM100 melter.	Target operating conditions were maintained and the full test duration was completed for both of the compositional variations.
2) Demonstrate that no separate sulfate phase forms with Sub-Envelope A2 feed with ±15% waste loading in the DM100 melter.	Both of the compositional variation feeds (±15% waste loading) processed without a sulfate layer.
3) Demonstrate that target feed rate can be achieved with Sub-Envelope A2 feed with ±15% waste loading in the DM100 melter.	Target feed rates, glass temperatures, and plenum temperatures were achieved and maintained for both compositional variation feeds. (see Table 3.3, and Figures 3.1 and 3.2)
4) Demonstrate target product compositions are achieved for Sub-Envelope A2 feed with ±15% waste loading in the DM100 melter.	Glass compositions as measured by XRF on the discharged glass analysis were within 10% of target for all major elements on Tests 1 and 3 (Tables 4.2). In Test 2 (+15% variation), the iron and calcium measured values deviated by as much as 25% to 40%, respectively, from target. The deviations are noted in the report text. The reason for the compositional deviations from target in Test 2 is that melter feed was transferred from Duratek. Duratek at the time of this test had been receiving GFCs low in iron. This problem has since been resolved with Duratek's GFC vendor and LAW Pilot melter feeds are now verified by analysis prior to use. The deviations are not expected to change the processing characteristics of this simulated feed, therefore the results should be accepted as is. Updated, correct compositions of the Sub-Envelope A2 feed were also processed through the DM100 and DM3300 melter during Sub-Envelope Changeover testing.
5) Collect melter emissions data to determine the effect of composition on melter emissions.	Melter emissions were sampled and analyzed during each of the tests. Total particulate emissions from the melter ranged from 0.3 wt% to 1.0 wt% and DFs were determined for each element in the feed. (Table 5.1)

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EAM 2/25/03

List Test Objectives:	**State how objectives were met:**
6) Provide supporting data necessary to ensure the success of the larger-scale Pilot Melter tests.	Each of the compositional variation feeds were successfully tested in the DM100 melter without processing problems and without formation of a separate sulfate layer. As a result, this formulation and accompanying waste loading variations were accepted for testing in the LAW Pilot Melter.
7) Perform comparable tests using formic acid instead of sugar as the reductant at three reductant ratios.	Nominal operating conditions were maintained and the sufficient test durations were completed. The analyzed glass product compositions agreed well with the target compositions. Particulate and gaseous emissions were determined for a variety of species and DF values reported. Formic acid was shown to be less effective than sugar in reducing iron, sulfur, or nitrates. Data on hydrogen emissions were collected and reported separately[a]. [a] K.S. Matlack, T.S. Schatz, and I.L. Pegg, Data Summary Report, *Off-Gas Hydrogen Concentrations in Tests on the DuraMelter 100 Melter System Using LAW Sub-Envelope A1 and A2 Simulants*," VSL-02S4100-1, Rev. 0
List any Test Exceptions:	**Did exceptions impact the objective?** ☒ Yes ☐ No (If Yes, explain)
1) Test Exception 24590-WTP-TEF-RT-02-05, Revision 0.	Tests with formic acid as a reductant were added to demonstrate safety differences between the Savannah River flowsheet with substantial hydrogen generation in the melter and the WTP flowsheet with very little hydrogen generation.
List Success Criteria	**Did the test meet the criteria?** ☒ Yes ☐ No (If No, explain)

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1) Determination that the processing characteristics of the Sub-envelope A2 formulation are satisfactory and that the stated variations in the amount of simulant in the feed do not affect key process characteristics, including production rate, secondary phase formation, cold cap and melting characteristics. This will be evidenced by stable operation for a sufficient period of time (defined here as a minimum of 8 hours) to determine and document the processing rate and melting characteristics. At the end of each test, the cold cap will be allowed to melt completely and the glass surface will be inspected for secondary phases, which, if present, will be sampled and analyzed. Glass samples will be examined for any liquid phase separation or crystalline phase formation. If processing rates are impacted negatively or secondary phase formations are observed, the RPP-WTP Project will determine whether to retest with different feed variations or glass formulations or to move forward with the LAW pilot-scale test.	Stable operation for periods of 90 hrs (-15% waste loading feed) and 45 hrs (+ 15% waste loading feed) were achieved for the compositional variation tests with nominal sugar. Production rates for each of the tests were acceptable and cold cap and melter characteristics were acceptable (i.e., no operational problems). Both of the compositional variation feeds (±15% waste loading) processed without a sulfate layer.
2) Collection of supporting off-gas characterization data. Samples of the off-gas particulate, semi-volatile, and condensable emissions will be collected during steady-state operation. Data on feed and process flows (flow rate, humidity, etc.) that are necessary to relate the off-gas sample data to the process operations will also be collected.	Samples of offgas particulate, semi-volatile, and condensable emissions were collected under steady-state conditions for each test and analyzed. Supporting data such as flow rates and humidity were also collected.

List QA Requirements:	**Did the subcontractor meet the requirements?** ☒ Yes ☐ No (If No, explain)
1) Per the test plan, work is to be conducted according to NQA-1 (1994).	Work prior to 8/01/01 was conducted in accordance with a VSL Project Quality Assurance Project Plan (QAPP), which complies with NQA-1 (1994).
2) Per direction of WTP QA in the summer of 2001, VSL was to transition to NQA-1 (1989) as quickly as possible.	Work after 8/01/01 was conducted in accordance with a VSL Project Quality Assurance Project Plan (QAPP), which complies with NQA-1 (1989).

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3) Per direction of WTP QA in the summer of 2001, VSL was to transition to NQA-2a (1990) Part 2.7 as quickly as possible.	Work after 8/01/01 was conducted in accordance with a VSL Project Quality Assurance Project Plan (QAPP), which complies with NQA-2a (1990) Part 2.7.
4) Verification of test conditions and properties determination.	Independent review of methods and results was performed by VSL.
List R&T Test Conditions:	**Were test conditions followed?** ☐ Yes ☒ No (If No, explain)
1) ±15% variation in simulant to additive ratios around the nominal with nominal sugar.	Compositional variations were generally met as evidenced by XRF analysis of the product glass and batching sheets. Glass compositions as measured by XRF on the discharged glass analysis were within 10% of target for all major elements for all tests, except in test 2 (+15% variation), where the iron and calcium measured values deviated by as much as 25% to 40%, respectively, from target. Nominal sugar was added, which results in non-nominal amounts in the variations, since sugar additions are made blind to the simulated process errors. he deviations are noted in the report text. The reason for the compositional deviations from target in Test 2 is that melter feed was transferred from Duratek. Duratek at the time of this test had been receiving GFCs low in iron. This problem has since been resolved with Duratek's GFC vendor and LAW Pilot melter feeds are now verified by analysis prior to use. The deviations are not expected to change the processing characteristics of this simulated feed, therefore the results should be accepted as is. Updated, correct compositions of the Sub-Envelope A2 feed were also processed through the DM100 and DM3300 melter during Sub-Envelope Changeover testing.
2) Bubbling Rate: fixed during each test at a rate selected to maintain a complete cold cap while maintaining the target feed rate.	Bubbler rates of 21 lpm for –15% variation and 17 lpm for +15% variation were adequate to achieve target glass production rates. The targeted glass production rate was 2.0 MT/m2/day based on glass conversion ratios of a nominal feed.

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3) Glass Temperature: 1150°C	The target glass temperature of 1150°C was successfully maintained for each of the tests.
4) Plenum Gas Temperature: 550±100°C	Plenum temperatures were maintained between 582-611°C (Section 3.0)
5) Target Glass Production Rate: 2.0 MT/m2/day assuming nominal glass conversion ratios. The 15% deviations in feed composition also affect the glass conversion ratios so the actual glass production rates may vary accordingly.	Target glass production rates were achieved for all tests. The –15% and +15% waste loading glass production rates were 2.12 MT glass /m2/day and 1.91 MT glass /m2/day, respectively, which when adjusted for glass yield are very close to the feed rate equivalent to 2.0 MT glass/m2/day for a nominal feed.
6) Per test exception, run the A2 nominal composition feed with NOx to carbon (formic acid and waste organics) ratios of 0.5, 0.75 and 1.0 for approximately 24 hours each.	All test conditions were met except for test duration, as test durations ranged from 13.5 to 24 hours. All test objectives and sampling needs were satisfied, so the tests were accepted as is.

Was testing performed with simulants? If yes, discuss how results compare to radioactive tests.	☒ Yes	☐ No
Rheological and vitrification data on Sub-envelope A2 (AP-101) actual pretreated waste and melter feed is not available at this time. The data was recently generated by Battelle and a draft report is in process, but the data is not yet approved for project use. Pilot-scale simulant data will be compared to actual waste data, when it is approved, and the results of the comparison will be included in a separate simulant verification report.		
Are all discrepancies resolved? If no, explain.	☒ Yes	☐ No
Are all subcontractor signoffs completed?	☒ Yes	☐ No
Is this work acceptable as completion for this activity?	☒ Yes	☐ No
Does the Testing or Report suggest any follow-on work? If yes, describe the suggested activity and attach a Request for Technology Development (RTD).	☐ Yes	☒ No

Approved by R&T Manager or Designee:	Date: 2/25/2003

MASTER DISTRIBUTION SCHEDULE

Sheet 1 of 1

Project Name: RPP-WTP

Document Distribution: Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A2 Feed (LAW A88 Glass) in Support of the LAW Pilot Melter

Document Number: VSL-02R62N0-3

Revision: 1

Insert rows as necessary ↑

Name	MSIN	Controlled	Uncontrolled	Size				Comments
				8 ½ x 11	11 x 17	Full	As Is	
Gary Smith	MS1-B							Info Only
Chris Musick	MS1-B							Info Only
Joe Perez	MS1-B							Info Only
Eugene Morrey	MS1-B							Info Only
Paul Rutland	MS1-C							Info Only
Eggie Berrios	MS1-C							Info Only
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Jeanette Doyle
Approver's Name (Print)

Jeanette Doyle
Approver's Signature

4/14/03
Date