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Enhanced LAW Glass Correlation-Phase 1, VSL-16R4000-1, Rev 0

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

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Enhanced LAW Glass Correlation-Phase 1, VSL-16R4000-1, Rev 0

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VSL-16R4000-1

Final Report

Enhanced LAW Glass Correlation-Phase 1

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Test Plan: Enhanced LAW Glass Correlation-Phase 1, VSL-15T3680-1, Rev. 0

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

I.L. Pegg: ______________________ **Date:** 12/1/16
VSL Program Director/Principal Investigator

I. Joseph: Innocent Joseph **Date:** 12/1/16
Atkins Sub-Contract Manager

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List of Abbreviations

ANL-LRM	Argonne National Laboratory-Low Activity Waste Reference Material
ASTM	American Society for Testing and Materials
CUA	Catholic University of America
DCP-AES	Direct Current Plasma Atomic Emission Spectroscopy
DF	Decontamination Factor
DM	DuraMelter®
DOE	Department of Energy
DWPF-EA	Defense Waste Processing Facility-Environmental Assessment
dscf	Dry standard cubic foot
dscfm	Dry standard cubic foot per minute
FTIR	Fourier Transform Infrared Spectroscopy
GFC	Glass Forming Chemical
IC	Ion Chromatography
ICP-MS	Induction Coupled Plasma – Mass Spectroscopy
HEPA	High-Efficiency Particulate Air
HLW	High Level Waste
IHLW	Immobilized High Level Waste
ILAW	Immobilized Low Activity Waste
LAW	Low Activity Waste
NIST	National Institute of Standards and Technology
NQA	Nuclear Quality Assurance
ORP	Office of River Protection
PCT	Product Consistency Test
PVC	Polyvinyl Chloride
QAPP	Quality Assurance Project Plan
SEM-EDS	Scanning Electron Microscopy - Energy Dispersive X-ray Spectroscopy
VHT	Vapor Hydration Test
VSL	Vitreous State Laboratory
WTP	Hanford Tank Waste Treatment and Immobilization Plant
XRF	X-Ray Fluorescence

SECTION 1.0
INTRODUCTION

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

Acceptable glass formulations for vitrification of Hanford low activity waste (LAW) must meet a variety of product quality, processability, and waste loading requirements. To this end, The Vitreous State Laboratory (VSL) at The Catholic University of America (CUA) developed and tested a number of glass formulations during Part A [1], Part B1 [2] and Part B2 [3, 4] of the WTP development program. The testing resulted in the selection of target glass compositions for the processing of eight of the Phase I LAW tanks. The selected glass compositions were tested at the crucible scale to confirm their compliance with ILAW performance requirements. Duramelter 100 (DM100) [5-16] and LAW Pilot Melter [17-28] tests were then conducted to demonstrate the viability of these glass compositions for LAW vitrification at high processing rates.

Glass formulation development work for the WTP was based on Hanford tank waste composition data [29-32] that have evolved over time. As a result, the target glass compositions for waste processing also were adjusted to accommodate the changes in LAW compositions. The major components of interest in the LAW streams, from a waste loading perspective, are sodium, sulfur, and to a lesser extent potassium. Melter testing included composition variations involving the nominal feed and ± 15% variations in the amount of waste simulant added to the melter feed. As a result of these efforts, the WTP has a series of glass compositions with different sodium, potassium, and sulfur concentrations that have been tested and validated over a range of melter scales, including the LAW Pilot Melter.

In support of the WTP Project, VSL developed and tested feed and glass formulations to provide data to meet the WTP contract requirements and to support system design activities. This included developing property-composition models for Product Consistency Test (PCT), Vapor Hydration Test (VHT), melt viscosity, and melt electrical conductivity [33, 34], and additive blends for each LAW stream to generate melter feeds with acceptable rheological properties for processing at the WTP [35, 36].

This extensive glass formulation development work underpinning the WTP baseline LAW glasses was captured in a correlation developed by VSL and Atkins that permits the calculation of the glass formulation required for each particular batch of LAW delivered to the LAW vitrification facility [37]. The correlation is based on the baseline LAW glasses developed for the WTP with particular emphasis on those subjected to melter testing, especially in the LAW Pilot Melter. The composition outputs from the LAW correlation are designed such that they can tolerate expected process variations without adversely affecting properties relevant to processing and product quality. This LAW correlation, along with the LAW glass property-composition models, will be used to control glass compositions for LAW vitrification at the WTP. Given the composition of any LAW stream, the correlation permits the calculation of a suitable glass composition and the required glass forming additives such that all processing, waste loading, and product quality requirements would be met. Confirmation of the proposed correlation was based on a set of seven glass compositions tested in the DuraMelter 100 (DM100) [38]. The formulation selection also included an assessment of the process control uncertainties (in terms of composition variations) expected for the LAW vitrification process. Melter testing included LAW glasses that extend from the alkali-limited region through the sulfate-limited region with decreasing alkali contents. The DM100 melter testing provided reliable information on sulfate incorporation and secondary phase accumulation in the dynamic melter environment, which could not be obtained using laboratory crucible melts alone.

1.1 ORP Enhanced LAW Glass Formulations and Correlation

The Office of River Protection is examining options to optimize the LAW facility and LAW glass waste form. VSL and Atkins have evaluated several potential incremental improvements for ORP in support of its evaluation of WTP LAW facility optimization [39]. Many of these incremental improvements have been tested at VSL, including increasing the waste loading, increasing the processing temperature, and increasing the fraction of the sulfur in the feed that is partitioned to the off-gas (assuming that the present WTP recycle loop can be broken) [40-42]. These approaches successfully demonstrated increases in glass production rates and significant increases in sulfate incorporation at the nominal melter operating temperature of 1150°C and at slightly higher than nominal glass processing temperatures. Subsequent tests demonstrated further improvements in glass waste loading for all of the LAW waste envelopes, thereby reducing the amount of glass to be produced by the WTP for the same amount of waste processed [43, 44]. Subsequent testing determined the applicability of these improvements over the expected range of sodium and sulfur concentrations for Hanford LAW [45] and to a wider range of LAW wastes types, including those with high potassium concentration [46, 47]. The extent of these waste loading increases over the range of LAW waste streams is summarized in Table 1.1 and Figure 1.1.

Thus, since the Baseline LAW Correlation was developed for WTP, VSL and Atkins have developed considerably higher waste loading LAW glass formulations under a program directed by ORP [39]. These glass formulations explored the limits of waste loading achievable in LAW glasses for various LAW streams with varying alkali and sulfate concentrations [40-47]. While these glasses provide much higher waste loadings, which result in substantial reduction in the amount of LAW glass to be produced at Hanford, in order to utilize them for LAW processing at the WTP new LAW glass property-composition models and a new LAW correlation that incorporates these enhanced glass formulations are required. Enhanced LAW glass property-composition models that incorporate these higher waste loading ORP compositions are being developed under separate tasks in the ORP program [48-51]. The present report presents the results of the first phase of a program of work that is intended to lead to the development of an Enhanced LAW Glass Correlation, which along with the enhanced LAW glass property-composition models can be used to control LAW processing at the WTP using the higher waste loading LAW glasses. This work is Phase 1 of a multi-year effort, as described in the Test Plan [52] and the corresponding ORP statement of work [53].

The present work involved generation of an initial Enhanced LAW Glass Correlation, preparation and characterization of crucible melts to further develop this correlation, and DM100 melter tests using selected formulations based on the results of crucible melt testing. The correlation employs waste composition information to determine the appropriate waste loading, glass composition, and amounts and types of glass forming additives to prepare the melter feed. Similar to the development of the Baseline LAW Glass Correlation, in the development of the Enhanced LAW Glass Correlation emphasis was given to the fifteen high-waste-loading LAW compositions that have been subjected to melter testing (Figure 1.1). However, while a number of the glass compositions used in the development of the Baseline LAW Glass Correlation were processed in the larger DM100, DM1200, and LAW Pilot melters, the ORP LAW glass compositions have only been processed in the smaller DM10 melter. Since the ORP LAW glass compositions explored the limits of LAW loading, the Enhanced LAW Glass Correlation is also designed to define the practical limits of LAW loading in these glasses. Once expected process variations in the WTP LAW vitrification facility are better defined, waste loadings in the Enhanced LAW Glass Correlation generated glass compositions can be adjusted accordingly.

1.2 Test Objectives

The objective of the present work was to initiate the development of an Enhanced LAW Glass Correlation that can be used to determine the appropriate waste loading, glass composition, and amounts and types of glass former additives for LAW processing at the WTP based on the LAW composition that will be delivered to the LAW vitrification facility. The intent is that this correlation, along with the enhanced LAW glass property-composition models, can be used for LAW processing at the WTP with the higher waste loading LAW glass formulations that have been developed for ORP at the VSL.

The primary objectives of this work were:

- Review relevant high waste loading ORP LAW glass compositions to identify compositional trends and to generate an initial Enhanced LAW Glass Correlation.

- Generate 25 glass formulations, spanning the range of alkali and sulfur concentrations in Hanford LAW, based on the initial Enhanced LAW Glass Correlation and existing LAW glass property-composition models.

- Prepare and characterize 25 crucible glasses with respect to properties affecting processability and product quality (melt viscosity, melt electrical conductivity, VHT, PCT, crystallization, refractory corrosion, and sulfate incorporation).

- Analyze the results from the crucible tests to determine the effectiveness of the initial Enhanced LAW Glass Correlation and to select four compositions for DM100 melter tests.

- Conduct DM100 melter tests with the four selected compositions to determine their processing characteristics and tendency to form secondary sulfate phases.

- Refine the Enhanced LAW Glass Correlation based on the results from the crucible and melter tests.

The objectives of this work were accomplished through a combination of crucible scale tests and DM100 melter tests. The starting point for the glass formulation development work was the previously developed glass formulations for ORP LAW regions A, B, C, D, E, F, and G (see Table 1.1 and Figure 1.1). The glass formulations developed previously for these wastes and processed in melters, along with other relevant LAW compositions, were analyzed to identify composition trends and to generate the initial Enhanced LAW Glass Correlation, presented in Section 2. Based on this initial correlation and ORP LAW glass property-composition models [49-51], 28 formulations were generated for testing. Crucible melts (~400 g) of these formulations were prepared and characterized with respect to properties affecting processability and product quality (melt viscosity, melt electrical conductivity, VHT, PCT, crystallization, refractory corrosion, and sulfate incorporation). Testing was designed such that properties that were expected to be most constraining were measured first, so that glasses failing one property were not characterized further. The crucible test results were reviewed and four glass compositions were selected for DM100 melter tests. While the crucible melts prepared and characterized span the range of sodium, potassium, and sulfur concentrations in Hanford LAW, the DM100 melter tests in this phase of the work concentrated on the high sodium and high potassium, but lower sulfate LAW compositions. DM100 melter tests with lower sodium, higher sulfur feeds are planned for Phase 2 of this work [54]. Samples of the glass product from melter testing were collected and characterized to provide comparison to the results obtained from the crucible glasses. Data from melter testing on processing rates and any processing difficulties, secondary sulfate phase formation, off-gas composition, and system operating parameters were also collected for each of the four processed compositions.

1.3 DM100 Melter System Description

1.3.1 Feed System

A schematic diagram of the DM100 vitrification system is shown in Figure 1.2. 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 recirculation loop extends to the top of the melter where feed is diverted from the recirculation loop through a peristaltic pump and into the melter through a Teflon-lined feed line and vertical water-cooled feed tube.

1.3.2 Melter System

Cross-sectional diagrams through the DM100-WV melter are shown in Figures 1.3.a-c. The DM100-WV unit is a ceramic refractory-lined melter fitted with a pair of opposing Inconel 690 plate electrodes as well as a bottom electrode. The melter can be operated with either three-phase or single-phase power. However, the standard mode of operation, which was used for these tests, is single-phase with voltage applied to the side electrodes only. The bubbler used for stirring the melt pool enters from the top and is removable. The glass product is removed from the melter by means of an air-lift discharge system. The DM100-WV has a melt surface of 12 × 14 inches, giving a melt surface area of 0.108 m^2. The nominal depth of the melt pool is about 19 inches, which gives a typical glass inventory of between 115 and 120 kg. The plenum height is 27.5 inches. Temperatures are monitored by means of a series of thermocouples located in the melt pool, the electrodes, the plenum space, and the discharge chamber.

1.3.3 Off-Gas System

For operational simplicity, the DM100-WV is equipped with a dry off-gas treatment system involving gas filtration operations only. Exhaust gases leave the melter plenum through a film cooler device that minimizes the formation of solid deposits. The film-cooler air has constant flow rate and its temperature is thermostatically controlled. Consequently, under steady-state operating conditions, the exhaust gases passing through the transition line (between the melter and the first filtration device) can be sampled at constant temperature and airflow rate. The geometry of the transition line conforms to the requirements of the 40-CFR-60 air sampling techniques. Immediately downstream of the transition line are cyclonic filters followed by conventional pre-filters and high efficient particulate air (HEPA) filters. The temperature of the cyclonic filters is maintained above 150°C while the temperatures in the HEPAs are kept sufficiently high to prevent moisture condensation. The entire train of gas filtration operations is duplicated and each train is used alternately. An induced draft fan completes the system.

1.4 Quality Assurance

This work was conducted under a quality assurance program compliant with 10 CFR 830 Subpart A, Nuclear Quality Assurance (NQA)-1 (2004), and DOE Order 414.1C. This program is supplemented by a Quality Assurance Project Plan (QAPP) for ORP work that is conducted at VSL [55]. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work [56]. Requirements of DOE/RW-0333P were not applicable to this work.

SECTION 2.0
ENHANCED LAW GLASS CORRELATION DEVELOPMENT

2.1 Selection of Composition Data Set

Sixteen glass compositions were used to underpin the preliminary ORP Enhanced LAW Glass Correlation presented in this report. These glass compositions are based on the composition data for Hanford tanks AN-105, AP-101, AN-107, AN-104, AN-102, AZ-101 and AZ-102 as given in a WTP Test Specification [32]. These LAW compositions were previously used in the development of the respective high waste loading LAW glass compositions for each of these waste streams [40-47]. The sodium concentrations in the simulants developed for these tests included an increase to account for sodium additions in pretreatment [57]. Sulfate concentrations in the simulants were adjusted to meet the target SO_3 concentration defined for each glass composition generated for testing. The concentrations of halides (Cl, F) and some other minor components (Ni, Pb, P) were set at constant values for the present tests. The effect of variation of these components on secondary sulfate phase formation will be determined and incorporated at a later date, once the correlation has been developed, in a manner similar to that employed earlier [38, 58-60]. Fifteen of the sixteen glass compositions used in the development of the Enhanced LAW Glass Correlation were previously subjected to DM10 melter tests. These compositions are identified in Table 1.1 and Figure 1.1, and are described below. The remaining composition is ORPLA51, which is the best performing glass composition out of twenty formulations designed for high alkali LAW glasses [61].

All of the glasses listed in Table 1.1 were prepared and characterized at crucible scale to confirm that they meet all of the WTP processing and product quality requirements. The “Bechtel Baseline” and “Bechtel Correlation” glasses listed in Table 1.1 were used in melter tests at the DM100 and/or the LAW Pilot melter scale. At the end of the melter tests, dip samples were taken from the melt pool and examined for the presence of secondary sulfate phases. The SO_3 concentrations listed in Table 1.1 are concentrations at which secondary sulfate phase accumulation was not observed in the melt pool. The same methodology was used in the selection ORP-LAW glasses listed in Table 1.1, except that the melter tests were conducted at the smaller DM10 melter scale.

2.2 Enhanced LAW Glass Correlation Development

2.2.1 Compositional Basis

In previous work for ORP [40-47] high waste loading LAW glass compositions were developed and tested on the DM10 melter for each of the Hanford LAW tanks listed above in Section 2.1. These compositions, given in Table 2.1, were the primary compositions that were used to define compositional trends and to generate an initial Enhanced LAW Glass Correlation. During the latter part of the LAW glass formulation development for ORP, the Hanford LAW composition range was divided into seven regions termed A, B, C, D, E, F and G. The sulfur to sodium ratio increases from Region A to Region F such that sodium is the waste loading limiting component in Region A, whereas it is sulfur in Region F. Region G has significant amounts of K in addition to Na, so that a combination of the two becomes the waste loading limiting factor; the potassium to sodium ratio was tested in Region G up to the contractual maximum K/Na molar ratio of 0.18. Early development of higher waste loading LAW glass compositions for ORP were based on the Envelope A, B, and C LAW composition definitions used in the baseline WTP LAW glass development. These ORP LAW glasses were also considered in the evaluation of compositional trends used to develop the present correlation. The LAW compositions considered in the development of the ORP LAW glasses span the range of sulfur and alkali concentrations in Hanford LAW as well as the potassium to sodium ratio [62]:

- Region A is represented by Tank AN-105, for which waste loading in the glass is limited by sodium. Compared to the Baseline LAW Correlation glass LAWE4H [38], Na_2O loading in the ORP LAW glasses increased from 21 wt% to 24 wt% and the SO_3 concentration increased from 0.35 wt% to 0.8 wt%. Higher waste loading ORP LAW glass formulations that have been processed for Region A in the DM10 melter include LAWA161 [40], LAWA187 [44] (DM10 and DM100), ORPLA15 [45], ORPLA20 [46] and ORPLA38-1 [47].

- Region G is represented by LAW from Tank AP-101, for which waste loading is limited by a combination of Na_2O and K_2O. Waste loading improvements in the ORP LAW glasses resulted in an increase in the Na_2O concentration from 18.2 wt% to 21 wt% and K_2O concentration from 5.0 to 5.8 wt%, as compared to the Baseline LAW Correlation glass LAWE3 [38]. The ORP LAW glass formulations that have been processed in the DM10 melter for Region G are ORPLG9 [46] and ORPLG27 [47].

- Region B is represented by LAW from Tank AN-107, which has higher S/Na ratio than Region A along with higher organic content. The higher waste loading ORP LAW glass has a Na_2O concentration of 24 wt%, as compared to 19 wt% in the Baseline LAW Correlation glass LAWE5H [38] and a SO_3 content of 0.9 wt% compared to 0.5 wt% for the baseline composition. The ORP LAW formulation that has been processed in the DM10 melter for Region B is ORPLB4 [45].

- Region C is represented by LAW from Hanford Tank AN-104. Compared to the ORPLB4 glass composition developed for Region B, ORPLC5 developed for Region C has slightly lower Na_2O and SO_3 concentrations of 23.6 wt% and 0.7 wt%, respectively. The target K_2O concentration in the ORPLC5 glass is 0.54 wt% compared to 0.11 wt% in ORPLB4. The ORP LAW formulations that have been processed in the DM10 melter for Region C are LAWC100 [43] and ORPLC5 [45].

- Region D is represented by LAW from Hanford Tank AN-102. Compared to the corresponding Baseline LAW Correlation glass composition LAWE7H [38], Na_2O increased from 13.5 wt% to 22 wt% in ORP LAW glass composition ORPLD6, and SO_3 increased from 0.6 wt% to 1.2 wt%. The ORP LAW formulations that have been processed in the DM10 melter for Region D are ORPLD1 [45] and ORPLD6 [46].

- Region E is represented by LAW from Tank AZ-101, which has one of the highest S/Na ratios. Glass formulation development work for ORP resulted in a Na_2O increase from 8.9 wt% in the Baseline LAW Correlation glass LAW9H [38] to 16 wt% in the ORP LAW glass ORPLE12, along with a SO_3 increase from 0.7 wt% to 1.5 wt%. The ORP LAW formulation that has been processed in the DM10 melter for Region E is ORPLE12 [45].

- Region F is represented by LAW from Tank AZ-102, which has the highest S/Na ratio. Compared to the Baseline LAW Correlation glass LAWE10H [38], the ORP LAW glass ORPLF7 has increased Na_2O loading from 5.7 wt% to 12 wt% and increased SO_3 loading from 0.8 wt% to 1.5 wt%. The ORP LAW formulation that has been processed in the DM10 melter for Region F is ORPLF7 [46]. Finally, glass LAWB99 was the first high waste loading formulation for LAW from Tank AZ-102 that was developed and successfully processed in DM10 and DM100 melter systems without the formation of secondary sulfate phases.

In addition to the above LAW glass compositions subjected to melter tests, ORPLA51, which is a recently developed composition for the high alkali Region A but which has not undergone melter processing, was also used in the development of the initial Enhanced LAW Glass Correlation. This formulation does not contain Cr_2O_3 as an additive to control K-3 refractory corrosion; instead, this formulation employs higher concentrations of Al_2O_3 (as was used in LAWA187) and TiO_2 to meet all of the WTP processing and product quality requirements while achieving a K-3 refractory corrosion neck loss of 0.032″ compared to a target maximum of 0.04″.

The waste alkali concentration in the selected glasses as a function of SO_3 concentration is plotted in Figure 2.1 along with the identifications of the LAW tanks tested and the composition Regions from A to G. The blue lines in Figure 2.1 show the Baseline WTP LAW Correlation and the red curve shows the initial ORP Enhanced Law Glass Correlation. Any LAW stream can be represented by a line that passes through the origin with a slope equal to the Na_2O/SO_3 ratio specific to that waste. Accordingly, as the loading of this stream into the glass is increased, the sodium and sulfate concentrations from waste in the glass will increase in this fixed ratio. An increase in the sodium loading in high sulfate LAW results in a much larger increase in SO_3 loading than is the case for low sulfate LAW.

2.2.2 Waste Loading Estimation

As noted above, the LAW waste compositions are conveniently characterized by their molar ratios of sulfate to sodium (SO_4/Na). Consequently, LAW glass waste loading as a function of SO_4/Na ratio in the waste is a major factor of interest in the LAW Glass Correlation development. Another factor that affects waste loading is the molar ratio of potassium to sodium in the LAW, such as is the case for LAW AP-101.

The LAW Glass Correlation should be capable of calculating a glass formulation for LAW processing based on the LAW composition supplied to the LAW vitrification facility that includes the effects of pretreatment and recycle. Various pretreatment and recycle assumptions were used in the formulation of the glasses that form the basis for the LAW Glass Correlation development. For the purposes of the LAW Glass Correlation, the target Na_2O and SO_3 concentrations in the feeds used in melter tests are used to underpin the correlation, or in the case of crucible melt ORPLA51, the target Na_2O and SO_3 concentrations in the batched glass. Even though the pretreatment and recycle assumptions may change as the flow-sheet evolves, the LAW Glass Correlation is designed to be capable of calculating the LAW glass composition for waste processing once the sodium, potassium, and sulfur concentrations in the LAW are known.

2.3 Enhanced LAW Glass Correlation Outline

2.3.1 Enhanced LAW Glass Composition Range

The enhanced LAW glass composition range in terms of alkali and sulfur concentrations is illustrated in Figure 2.1. The alkali oxide concentration in the glass in terms of ALK is plotted as a function of sulfur concentration in terms of SO_3 (wt%), all of which originate from the LAW. ALK is defined in the same way as in the WTP baseline correlation [37]:

$$\mathrm{ALK} = \mathrm{Na_2O}\ (\mathrm{wt\%}) + 0.66\ \mathrm{K_2O}\ (\mathrm{wt\%}), \tag{2.1}$$

where 0.66 is the ratio of the molecular weights of Na_2O and K_2O.

ALK is defined in this manner because the two alkali oxides from the waste (Na_2O and K_2O) on a molar basis have similar effects on the properties of the LAW glass, and therefore waste loading. The entire enhanced LAW glass composition range can be divided into three regions.

1. The straight line high alkali portion of the composition region with ALK value of 24.33 wt% is termed the *Alkali Limited Region (AL).*

2. The curved portion where both Na_2O and SO_3 concentrations need to be managed to optimize waste loading is termed the *Alkali & Sulfate Limited Region (ASL).*

3. As sulfate concentration in the LAW increases further, waste loading in the glass is limited by sulfate alone at a value of 1.5 wt% SO_3. This portion of the composition range is termed the *Sulfate Limited Region (SL).*

The variation in sodium to potassium ratio in the LAW was studied in the *AL* region because in this region the ALK value is maintained at 24.33 wt%, while the SO_3 concentration may vary with the variation in the sodium to potassium ratio. In the *ASL* region, both ALK and SO_3 can change with the sodium to potassium ratio, and therefore the direct effect of the variation in sodium to potassium ratio on waste loading is of lesser importance. In the *SL* region, potassium to sodium ratio in the LAW has little or no effect on waste loading in the glass.

The intent is to define the Enhanced LAW Glass Correlation in terms of ALK and SO_3 concentrations in the LAW glass (as was done for the Baseline LAW Glass Correlation) such that it provides the highest acceptable loadings of the waste loading limiting LAW components Na_2O,

K_2O and SO_3. Since Hanford LAW contains much higher concentrations of Na than K, parts of the discussion below use sulfur to sodium ratios instead of sulfur to sodium plus potassium ratios. The composition regions and the glass compositions that were considered in the development of the Enhanced LAW Glass Correlation in terms of ALK and sulfur concentrations in the glass are given below.

- **Alkali Limited Glasses**

  The alkali limited glasses were developed to treat LAW with high alkali, but low to moderate sulfur content. The sulfur to sodium ratio in these LAW streams and the glasses developed to treat these waste streams are given below. Most of these LAW streams contain sodium as the major alkali component with smaller amounts of potassium, but a few contain higher concentrations of potassium. These LAW streams cover the ORP LAW composition regions A, B and G. The Na_2O and ALK contents in glasses developed to treat these LAW streams have $Na_2O \leq 24$ wt% and ALK = 24.33 wt%. Glass development for Region A was based on the LAW composition from Hanford Tank AN-105. This LAW has high sodium concentration, with low potassium and sulfur concentrations. The glasses from Region A that were used in the development of the Enhanced LAW Glass Correlation have $0 < SO_3 \leq 0.40$ wt% and $Na_2O = 24$ wt%.

  Of the glasses from Region A that were used in in the development of the Enhanced LAW Glass Correlation, ORPLA15, ORPLA20, and ORPLA38-1 were subjected to melter tests, and ORPLA51 was tested at crucible scale.

  Glass development for Region G of the LAW composition range was based on the LAW composition from Hanford Tank AP-101. This LAW has high sodium and potassium, and lower sulfur concentrations. The glasses from Region G that were used in the development of the Enhanced LAW Glass Correlation have $0 < SO3 \leq 0.40$ wt% and $Na_2O = 24.33 - 0.66\ K_2O$ wt%.

  Two glasses from Region G, ORPLG9 and ORPLG27, which were used in the development of the Enhanced LAW Glass Correlation, were both subjected to melter tests.

  Glass development for Region B of the LAW composition range was based on the LAW composition from Hanford Tank AN-107. This LAW has high sodium and moderate sulfur concentrations. The glasses from Region B that were used in the development of the Enhanced LAW Glass Correlation generally have $0.40 < SO_3 \leq 0.80$ wt% and $Na_2O = 24$ wt%. The high alkali and sulfur concentrations in the glasses developed to treat these LAW required the addition of a new glass former additive (V_2O_5) to increase sulfur loading. Some of the glasses developed for Region B could accommodate SO_3 concentrations slightly higher than 0.8 wt% in the melter test feeds.

  The glass from Region B, ORPLB4, which was used in the development of the Enhanced LAW Glass Correlation, was subjected to melter tests.

- **Alkali and Sulfate Limited Glasses**

  The alkali and sulfate limited glasses were developed to treat LAW with moderate to high sulfur content in the ORP LAW composition regions C, D and E. The sulfur to sodium ratio in these LAW streams is such that 0.035 < mass ratio SO_3 /Na_2O ≤ 0.097 or, equivalently, 0.0135 < mole ratio SO_4 /Na ≤ 0.0375. The target SO_3 concentrations in these glasses generally range from 0.80 to 1.50 wt%, but slightly lower values were sometimes used in melter test feeds to avoid secondary sulfate phase formation.

  Glass development for Region C of the LAW composition range was based on the LAW composition from Hanford Tank AN-104. The glass from Region C that was used in the development of the Enhanced LAW Glass Correlation, ORPLC5, was used in melter tests. LAW from Hanford Tank AN-102 was the basis for development of glass formulations for Region D. The glasses from Region D that were used in the development of the Enhanced LAW Glass Correlation are LAWC100, LAWA161, ORPLD1, and ORPLD6. All of these glass formulations were used in melter tests. Glass development for Region E of the LAW composition range was based on the LAW composition from Hanford Tank AZ-101. The glass from Region E that was used in the development of the Enhanced LAW Glass Correlation, ORPLE12, was also used in melter tests.

- **Sulfate Limited Glasses**

  The sulfate limited glasses were developed to treat LAW with very high sulfur content in the ORP LAW composition Region F. The sulfur to sodium ratio in these LAW streams is such that mass ratio SO_3 /Na_2O ≥ 0.097 or, equivalently, mole ratio SO_4 /Na ≥ 0.0375. The target SO_3 concentration in these glasses is 1.50 wt%.

  Glass development for Region F of the LAW composition range was based on the LAW composition from Hanford Tank AZ-102. The glasses from Region F that were used in the development of the Enhanced LAW Glass Correlation, LAWB99 and ORPLF7, were also used in melter tests. Glasses LAWB99 and ORPLF7 contain 10.0 wt% and 12.0 wt% Na_2O, respectively, along with 1.50 wt% SO_3. However, Region E glass, ORPLE12, can accommodate 16.0 wt% Na_2O along with 1.50 wt% SO_3. Therefore, glass ORPLE12 was given more importance in the Enhanced LAW Glass Correlation development as compared to LAWB99 and ORPLF7.

2.3.2 Glass Forming Chemical Additives

Thirteen glass forming chemical (GFC) additives were considered in glass formulation development for the higher waste loading ORP LAW glasses. These are Al_2O_3, B_2O_3, CaO, Cr_2O_3, Fe_2O_3, Li_2O, MgO, SiO_2, SnO_2, TiO_2, V_2O_5, ZnO and ZrO_2. The same approach used in the development of the WTP Baseline LAW Glass Correlation [37] was used in the development of the present initial Enhanced LAW Glass Correlation. The overall objective of this effort was to develop a correlation for the higher waste loading ORP LAW glasses that would allow definition of waste loading and types and amounts of glass former additives once the LAW composition is known. The GFC additives considered for the Enhanced LAW Glass Correlation include all of the additives used in the WTP Baseline LAW Glass Correlation (Al_2O_3, B_2O_3, CaO, Fe_2O_3, Li_2O, MgO, SiO_2, TiO_2, ZnO, and ZrO_2) as well as three new additives (Cr_2O_3, SnO_2, and V_2O_5) used only in the higher waste loading ORP glasses. Based on the sixteen ORP LAW glass compositions given in Table 2.1, compositional variations in the GFC additives were identified as the compositions move from the high alkali Region A to the high sulfate Region F. The GFC additives were either kept constant throughout or varied smoothly with ALK and/or SO_3. Once the appropriate glass compositions have been defined, it is straightforward to calculate the GFC additions to prepare the melter feed.

The variation of each additive was based on the glass compositions given in Table 2.1 and LAW glass property-composition models [49-51]. Property-composition models for Product Consistency Test (PCT)-Na, PCT-B, Vapor Hydration Test (VHT) alteration rate, melt electrical conductivity, melt viscosity, sulfate solubility and K-3 refractory corrosion were used in the development of the Enhanced LAW Glass Correlation. The LAW glass processing and product quality requirements for the WTP are given in Table 2.2 [63]. PCT-Na and PCT-B were not found to be challenging, nor were melt viscosity and melt electrical conductivity. Glass formulations that showed the highest SO_3 solubility often challenged either the K-3 refractory corrosion or the VHT requirement, or both. Of the twenty eight formulations designed with the support of these models and predicted to meet all seven property requirements, two each failed K-3 refractory corrosion and VHT alteration limits. This is not surprising as the evaluation of replicate datasets used to develop these two models showed rather large relative standard deviations inherent to these property measurements (32%RSD and 40%RSD for the K-3 and VHT models, respectively).

2.3.2.1 Glass Former Additives with Fixed Concentrations

Similar to the strategy utilized in the development of the WTP Baseline LAW Glass Correlation, some of the components such as B_2O_3, MgO, and ZnO were held at fixed concentrations in all of the glasses in the initial Enhanced LAW Glass Correlation.

The concentrations of B_2O_3 in the sixteen glasses are illustrated in Figure 2.2 as functions of ALK and SO_3. B_2O_3 varies from 7.9 to 13.8 wt% with an average of about 10 wt%. The variation is neither a function of ALK nor SO_3 and its effect was found to remain small in most predictive property models. For this reason, it was set at its average concentration of 10 wt% in the 28 new ORLEC glasses, as also shown in the figure.

As evident in Figures 2.3, the concentrations of magnesium and zinc oxides vary little from one glass to another among the sixteen ORP glasses considered (averages of 1.0 and 2.9 wt%, respectively, for MgO and ZnO). The only exception is the crucible glass LAWA51 in which MgO was tested at nearly 2 wt%. In this glass, MgO was found to be much less effective in preventing K-3 corrosion than Al_2O_3 or TiO_2 [61]. Based on the above observations, the concentrations of MgO and ZnO were fixed at 1.0 and 3.0 wt%, respectively, in the 28 new ORLEC glasses.

2.3.2.2 Glass Former Additives with Variable Concentrations

The additives used in the WTP LAW Glass Correlation, Al_2O_3, CaO, Fe_2O_3, Li_2O, TiO_2, and ZrO_2, as well as the three new additives Cr_2O_3, SnO_2 and V_2O_5, are varied depending on the sulfur to alkali ratio in the LAW stream, as described below. The objective was to define smooth variations through the existing data set on which to base the design of new crucible melts that would ultimately be used to define the quantitative relationships in the final Enhanced LAW Glass Correlation.

Al_2O_3: In the sixteen glasses considered, Al_2O_3 varies from 6.0 to 10.6 wt%, with an average of about 9.0 wt% (see Figure 2.4). The median and mode of Al_2O_3 concentration in these glasses is 10 wt%. The strong decrease in K-3 corrosion with higher Al_2O_3 concentrations indicates that Al_2O_3 concentration should be maintained at high levels in high alkali glasses in order to mitigate high K-3 corrosion. Consequently, Al_2O_3 was first set at a value of 10 wt% when ALK is above 21 wt% and at 7.8 wt% below it (applied to glasses ORLEC1 to ORLEC9 described in Section 3). This strategy yielded glasses with lower K-3 corrosion than predicted by the model in the region of intermediate ALK (20 to 22.3 wt% ALK), leaving room for changes to improve sulfate solubility. Accordingly, Al_2O_3 was decreased linearly between ALK = 22.3 and 20.3 wt% and set to 7.8 wt% below that range, as shown in Figure 2.4.

CaO: In the sixteen glasses considered, CaO varies from 1.0 to 10.1 wt%, with an average of 5.5 wt%. There is a strong dependence of CaO concentration with ALK and with SO_3, which can be seen in the two plots in Figure 2.5. Several glasses were formulated with a smooth variation in CaO over this range, as shown in Figure 2.5. Although their predicted K-3 neck corrosion values were below the limit of 0.040” (0.035” and 0.036” for glasses ORLEC8 and ORLC9, respectively), two of these formulations at the lower alkali/higher sulfate range failed (measured K-3 neck corrosion of 0.043” and 0.045”, respectively). Also, some of the measured sulfate solubility values (ORLEC4 and ORLEC6) were lower than predicted. Therefore, a second series of glasses with slightly higher CaO concentrations was defined and tested, as shown in Figure 2.5.

Cr_2O_3: In the sixteen glasses considered, Cr_2O_3 varies from 0.02 to 0.59 wt%. In the three early glasses (LAWA161, LAWC100, and LAWB99), only the waste contributes to the chromium content of the glass. All other glasses formulated at enhanced waste loading for ORP melter testing include an addition of 0.5 wt% Cr_2O_3 to reduce K-3 refractory corrosion. Since chromium decreases sulfate solubility in the glass, a new glass formulation without Cr_2O_3 addition, but with higher Al_2O_3, TiO_2 and ZrO_2 was tested in LAWA51 and was found to meet all WTP processing and product quality requirements. This glass formulation was not, however, subjected to melter tests. In the present initial ORP Enhanced LAW Glass Correlation, 0.5 wt%

Cr_2O_3 was added to glasses with the lowest sulfate content (target of 0.1 wt% SO_3) but none was added at sulfate concentrations above 1.0 wt%; thus in the latter case it is fixed at 0.08 wt%, all of which is from the waste contribution in the current ORLEC series of glasses. The amount of Cr_2O_3 additive is increased linearly as the SO_3 concentration decreases from 1.0 to 0.1 wt%, reaching a maximum of 0.5 wt% at 0.1 wt% SO_3 (0.58 wt% including the contribution from waste), as shown in Figure 2.6.

Fe_2O_3: In the sixteen glasses considered, Fe_2O_3 varies from 0.19 to 1.13 wt%, without any particular relationship to sulfate or alkali concentration. In the initial series of Enhanced LAW Correlation glasses (ORLEC1-12, see Section 3), Fe_2O_3 was fixed at 1 wt%. Since two glasses in the series failed the K-3 refractory corrosion criterion, iron was decreased to the minimum of 0.2 wt% in these glasses, thus making room for more silica. In the remaining glasses, Fe_2O_3 was kept at 1 wt% in the higher alkali/low sulfate glasses and decreased linearly as sulfate increases, as shown in Figure 2.7. The minimum was estimated to be 0.2 wt% from its concentration as impurities in various GFC additives.

Li_2O: Li_2O concentrations in the glasses are plotted as a function of ALK in Figure 2.8. Lithium is not used in glasses with high alkali content (high Na_2O and K_2O). For this reason, the Li_2O concentration was set to zero for ALK values above 19.6 wt%. It is one of the most effective additives to improve sulfate solubility; however, high Li_2O concentrations in glasses have been found to cause cracking of K-3 refractory coupons in laboratory tests in glasses containing higher than about 4.3 wt% Li_2O [3, 64]. The maximum Li_2O concentration was, therefore, set to 4.3 wt% in the Baseline LAW Correlation. The Li_2O concentrations in the initial series of Enhanced LAW Correlation glasses were adjusted to fit glasses ORPLE12 and LAWB99 at 2.5 and 3.5 wt%, respectively, as shown in Figure 2.8.

SnO_2: Tin oxide is a new additive introduced in high alkali ORP glasses to improve chemical durability, especially performance on the VHT. This is evident from Figure 2.9 where SnO_2 concentrations in the sixteen ORP glasses are plotted as a function of ALK. In the initial Enhanced LAW Glass Correlation SnO_2 is added only to glasses with an ALK value above 22 wt%. In the ALK range of 22 to 24.33 wt% SnO_2 increases linearly from 0 wt% to 2.33 wt%, as shown in Figure 2.9.

TiO_2: Titanium oxide concentrations in the sixteen glasses used as the basis for the initial Enhanced LAW Glass correlation, illustrated in Figure 2.10, show that only one of the glasses contains TiO_2 (ORPLA51 at 4.0 wt%). Results from characterization of ORPLA51 showed that TiO_2 is beneficial in reducing refractory corrosion in high alkali LAW glasses. Therefore, the TiO_2 concentration in the initial series of Enhanced LAW Correlation glasses (ORPLEC1 to ORPLEC12 in Section 3) was set at 1.0 wt%, similar to the concentration in the WTP Baseline LAW Glass Correlation of 1.4 wt%. The TiO_2 concentration in glasses that were formulated subsequently was varied from zero in glasses with more than 0.85 wt% SO_3, increasing linearly from 0 to 1.0 wt% as the SO_3 concentration decreases from 0.85 to 0.1 wt%, and staying fixed at 1.0 wt% in glasses with less than 0.1 wt% SO_3, as shown in Figure 2.10.

V_2O_5: In the sixteen glasses considered in the development of the initial enhanced LAW Glass Correlation, V_2O_5 varies from 0 to 2.5 wt%, with higher amounts at higher SO_3 concentrations, as shown in Figure 2.11. Based on the property-composition model developed from 372 glass formulations, V_2O_5 has the second strongest effect on improving sulfate solubility (after Li_2O). In the present initial ORP Enhanced LAW Glass Correlation, V_2O_5 was not added to glasses with SO_3 concentrations of 0.4 wt% or less. V_2O_5 was increased linearly from 0 to 1.93 wt% as the SO_3 concentration increased from 0.4 to 1.5 wt%, as shown in Figure 2.11.

ZrO_2: In the sixteen glasses considered in the development of the initial enhanced LAW Glass Correlation, ZrO_2 varies from 3.0 to 6.4 wt%. As evident in Figure 2.12, the ZrO_2 concentration is lower (3 to 3.9 wt%) in lower alkali glasses, but is high ($\geq$ 5.7 wt%) in high alkali glasses. For the initial Enhanced LAW Glass Correlation ZrO_2 was kept at 3.5 wt% in glasses with an ALK value of 21.8 wt% or lower and was increased linearly from 3.5 to 6.03 wt% as the ALK value increased from 21.8 to 24.33 wt%, as shown in Figure 2.12.

SiO_2: As was done for the Baseline LAW Glass Correlation, once the concentrations of all of the other glass components are defined and summed, SiO_2 is added to make up the remainder such that the total is 100 wt%. In this way, variations in the minor waste components (such as Cr_2O_3, Cl, F, P_2O_5), the sum of which typically averages about 0.5 wt%, are absorbed by a corresponding variation in the silica addition. As shown in Figure 2.13, SiO_2 varies from 34 to 42 wt% in the sixteen ORP glasses considered, and from 36 to 45 wt% in the initial Enhanced LAW Glass Correlation design.

Halides (Cl, F), P_2O_5, NiO, and PbO present in the Hanford LAW at various levels are kept constant at the concentrations given in Table 2.3. These components are included in the initial Enhanced LAW Glass Correlation as a grouped component termed "Others" at a total concentration of 0.5 wt%. The effects of Cl, Cr, and P on secondary sulfate phase formation, which are known to be significant as demonstrated in melter tests [38, 58-60], will be addressed separately at a later date in a manner similar to that employed for the WTP Baseline LAW Glass Correlation [38, 58].

2.3.3 Formulation of Enhanced LAW Correlation Glasses

Using the above guidelines, 28 glasses were formulated and tested to support the initial Enhanced LAW Glass Correlation. The compositions of these glasses are presented and discussed in Section 3.0. Glasses in the first series, ORLEC1 to ORLEC9, were designed with 24 to 16 wt% Na_2O in steps of 1 wt%, following the strategies described above, with the generally lower level of CaO in the intermediate region (Figure 2.5) and with Fe_2O_3 and TiO_2 fixed at 1 wt%. ORLEC1 is the end member of this series with high Na_2O concentration (24.0 wt%) and the lowest sulfate concentration (0.1 wt% SO_3). ORLEC10, ORLEC11, and ORLEC12 were formulated with an ALK value of 24.33 wt% but with varying Na_2O and K_2O concentrations, all with 0.1 wt% SO_3.

In the next set of formulations (ORLEC13 to ORLEC23), CaO levels were generally higher in the intermediate region (Figure 2.5). Glass formulations ORLEC24 and ORLEC25 were designed to improve sulfate loading of ORLEC10 and ORLEC12 and required the addition of V_2O_5. The last three glasses, ORLEC26, ORLEC27, and ORLEC28, were formulated with an ALK value of 24.33 wt% but with varying Na_2O and K_2O concentrations and with 0.4 wt% SO_3.

SECTION 3.0
CRUCIBLE GLASS TESTING

Twenty-eight glass formulations developed using the initial ORP Enhanced LAW Glass Correlation were prepared and characterized to support the selection of glass compositions for DM100 melter tests and to refine the correlation.

The experimental procedures used in the preparation and characterization of the simulated LAW glasses are presented in this section. The following subsections discuss the preparation of glass batches, crucible glass melting, glass composition analysis, and test procedures for PCT, VHT melt electrical conductivity, melt viscosity, K-3 refractory corrosion, sulfate solubility, and secondary phase analysis. Results of testing are also presented and discussed. Properties that are expected to be most constraining were measured first, so that glasses failing one property were not characterized further.

3.1 Glass Batching and Preparation

The target glass compositions (see Table 3.1) were used to create the batching sheets providing information on the required starting materials and their weights for glass melting. These batch sheets include identification of the chemicals according to vendors and catalog numbers with the associated purity and the amounts necessary to produce a batch size of approximately 450 to 480 g of glass. All glass samples were prepared using reagent grade or higher purity chemicals according to VSL standard operating procedures. A blender was used to mix and homogenize the starting materials before they were loaded into platinum-5% gold crucibles (Pt-Au) that are engraved with individual identification numbers.

The crucibles were placed inside a Deltech DT-29 furnace with a Eurotherm 2404 temperature controller. Glasses were melted for 75 minutes after the melt reaches a temperature of 1200°C. Mixing of the melt was accomplished mechanically using a platinum stirrer, beginning 15 minutes after the furnace reaches the target temperature and continuing for the next 60 minutes. At the end of melting, the molten glass was poured onto a graphite plate to cool. The glass sample was collected and analyzed for composition before distribution for property measurements.

3.2 Analysis of Glass Compositions

The compositions of the glasses were determined using X-ray fluorescence (XRF) spectroscopy and direct current plasma atomic emission spectroscopy (DCP-AES), as described below.

The primary method used for glass composition analysis was XRF spectroscopy on powdered glass samples. Powdered samples of the glasses (–200 mesh) were analyzed with a

PANalytical Axios^{mAX}-Advanced XRF spectrometer. The spectrometer was calibrated over a range of glass compositions using standard reference materials traceable to National Institute of Standards and Technology (NIST), as well as waste glasses including the Argonne National Laboratory-Low Activity Waste Reference Material (ANL-LRM) [65], the Defense Waste Processing Facility-Environmental Assessment (DWPF-EA) glass [66], and Hanford WTP glasses. Analysis by XRF provides data for all glass components of interest except lithium and boron, which are analyzed by DCP-AES, as described below.

The glass samples were analyzed by DCP-AES after being subjected to microwave-assisted total acid dissolution in Teflon vessels according to VSL standard operating procedures. Twenty milliliters of a 1:5 mixture of concentrated HF:HNO_3 was diluted to 50 ml and used for the dissolution. This procedure is similar to the American Society for Testing and Materials (ASTM) Test Method C 1412-99, which also employs a mixture of concentrated HF and HNO_3 in microwave digestion of pulverized glass samples. However, supplemental use of HCl/H_3BO_3 is not included in the VSL procedure because boron is normally one of the analytes. The resulting solutions were analyzed by DCP-AES for all constituents except anionic species such as sulfur and halogens, which were determined by XRF.

XRF and DCP-AES (for B_2O_3 and Li_2O) analyzed compositions of the glasses are given in Table 3.1 together with the respective target compositions. The relative deviations from the target composition do not exceed 10% for any of the major oxides (those present at > 1 wt% target). With the exception of volatile components such as Cl and SO_3, the batched (target) glass compositions are expected to be more accurate than the analyzed compositions because the batched compositions are derived from simple weighings of pure chemicals. Hence, the target compositions for all major constituents, except SO_3, are believed to provide the best compositional representations of the tested glasses. All of the glasses were found to be on target and were accepted for subsequent testing.

3.3 Secondary Phase Evaluation

The glasses collected from the crucible melt were visibly clear, generally lime green in color, or emerald green when chromium was used as an additive. They showed no evidence of secondary phases, but indications of the formation of some separate sulfate phase were visible at the surface of glasses formulated at the highest target SO_3 concentrations (> 1 wt% SO_3).

All glass samples were also heat-treated for 20 hours at 950°C after a one-hour pre-melt at 1200°C; all heat-treated samples remained clear and free of crystals under optical microscopy (up to 112.5 X magnification). Small (10 µm) triangular crystals, which are probably a chrome-spinel, were seen in the heat-treated sample of ORLEC1 but the quantity was clearly less than 0.1 vol% (Table 3.2). Glasses considered for melter testing were also heat-treated according to the WTP LAW canister centerline cooling (CCC) profile [67]. Among the resulting glass samples only two (ORLEC14CCC and ORLEC16CCC) appeared slightly opalescent and were further evaluated by scanning electron microscopy coupled with energy dispersive X-ray spectroscopy (SEM-EDS). Traces of a secondary phase lazurite were identified at estimated concentrations of less than 0.2 vol% and much less than 0.01 vol% in ORLEC14CCC and ORLEC16CCC, respectively.

3.4 Sulfate Solubility

Sulfate solubility was determined by over-saturation tests on all ORLEC crucible glasses. In this method, sulfate solubility is determined by re-melting a small amount of the glass batch with an excess of sulfate such that a molten salt phase forms on the surface of the glass melt. The sulfate solubility is then determined by analyzing the chemical composition of the glass melt in equilibrium with the molten sulfate phase at the designated test temperature. The glass sample is ground and sieved to pass 40-mesh and then thoroughly mixed with reagent grade sodium sulfate. The amount of sulfate added was equivalent to 4 wt% SO_3 in the glass if all of the sulfur was retained in the glass. The glass/sulfate mixture was loaded into a Pt/Au crucible with a cover and re-melted at 1150ºC for 1 hour. The crucible was then cooled naturally to room temperature and the glass recovered for examination. Washing of glass pieces to remove the salt phase was followed by grinding (<200 mesh) and then washing of the glass powder to ensure removal of all sulfate salts. Analysis of SO_3 in the powdered glass samples (denoted S4 after grinding and S4W after powder-washing) provides an estimate of sulfate solubility. Results are provided in Table 3.3 and shown in Figure 3.1 where a clear trend of higher sulfate solubility with lower ALK is visible.

The sulfate solubility was also investigated by gas bubbling experiments for three selected compositions. In this method, SO_3 is loaded into the glass melt gradually by bubbling a gaseous mixture of SO_2, O_2, and N_2 through the molten glass. The partial pressure of SO_3 is controlled through the chemical reaction between SO_2 and O_2 at the test temperature in the presence of a catalyst (the platinum bubbling tube). Gases are mixed and the flow is regulated using a gas proportioner with the flow tubes calibrated for each individual gas stream. The mixed gas is then transported through flexible polyvinyl chloride (PVC) tubing connected to a Pt bubbling tube, the other end of which is immersed in the molten glass. The flow rate of the mixed gas is normally 30 ml/min (at room temperature). The sulfate solubility is then determined by analyzing the chemical composition of the glass melt in equilibrium with a molten sulfate phase at the designated test temperature. For each test, 100 grams of the test glass is placed into a 200 ml Pt crucible and covered by a Pt sheet furnished with a slot for introducing the gas bubbling tube. The crucible is loaded in the center of the platform of a preheated Del-Tech furnace. The gas mixture is introduced through the roof of the furnace using a Pt tube. For each prescribed gas mixture of controlled partial pressure of SO_3, the test glass melt is bubbled for 3.5 hours. At the end of each bubbling period, the setup is removed from the furnace for inspection for the development of a sulfate layer and sampling (~3-5 grams). A complete bubbling experiment usually involves 6 to 9 bubbling cycles, with stepwise increases in the partial pressure of SO_3. Typically, two to three more bubbling cycles are conducted after the onset of a sulfate layer in order to ensure saturation. Glass sampled from gas-bubbled experiments is powdered (<200 mesh) and then washed to remove possible inclusions of segregated sulfate salt prior to analysis by XRF for chemical composition. The solvents used for washing include dilute (0.75 wt%) HNO_3 (to remove alkali and calcium sulfate) and de-ionized water.

Results of sulfate solubility measurements by bubbling are provided in Table 3.3 and shown in Figure 3.1 along with the results from sulfate over-saturation tests. In this phase of testing, sulfate solubility by bubbling was measured only for the high alkali glasses with varying Na_2O and K_2O concentrations because these are the glass compositions that were selected for DM100 melter testing. Sulfate solubility by bubbling for glasses from other LAW composition regions will be measured in the future phases of this work. All three of the measured SO_3 solubility values by bubbling (0.51, 0.59, and 0.61 wt%) are above the target of 0.4 wt%. Also, as can be seen in Table 3.3, sulfate solubility values from bubbling tests are somewhat higher than those from over-saturation tests, which is consistent with previous observations [51].

3.5 Product Consistency Test

The PCT was conducted using 4 g of crushed glass (100-200 mesh, 75-149 μm) placed in 40 ml of test solution (de-ionized water) inside 304L stainless steel vessels. These test conditions result in a ratio of the glass surface area to the solution volume of about 2000 m^{-1}. The PCT was performed at 90ºC for 7 days according to ASTM C 1285 [68], in accordance with the current WTP contract requirement [63]. All tests were conducted in triplicate, in parallel with the ANL-LRM glass standard for LAW glasses [65] included in each test set. Leachates were sampled after seven days: one milliliter of sampled leachate was mixed with 20 ml of 1M HNO_3 and the resulting solution analyzed by DCP-AES. Another 3 ml of sampled leachate was used for pH measurement.

Results of PCT are summarized in Table 3.4 and shown in Figure 3.2. From the figure it is clear that all of the normalized PCT releases are well below the contractual limit of 2 g/m^2 [63]. The three glasses with the highest PCT releases are ORLEC12, ORLEC25, and ORLEC27, which all have the highest ALK value and contain 5.64 wt% of K_2O. These results are consistent with predictions from PCT models [50].

3.6 Vapor Hydration Test

The vapor hydration tests were run in Parr series 4700 screw-cap pressure vessels made of 304L stainless steel and having either 22 or 45 ml capacity, in accordance with the corresponding VSL procedure which conforms to ASTM C 1663 [69]. Glass coupons were cut and polished, dimensional measurements were taken to permit calculation of the area, and the coupons were weighed before and after the VHT on a balance having a resolution of 100 μg. Coupons were suspended from a hanger in the pressure vessel and enough de-ionized water was added to the vessel to saturate the volume at the test temperature of 200ºC and to allow for a non-dripping layer covering the coupon. The pressure vessels were sealed, weighed on a high capacity balance having a resolution of 1 mg, and placed in an oven held at 200ºC. The temperature was monitored continuously with an independent calibrated thermocouple. At the completion of the test, the pressure vessels were removed and immediately partially immersed in an ice/water bath to condense the water vapor near the bottom of the vessel. Once cool and dry, the vessel was weighed. If the difference in the mass of the sealed pressure vessel before and after the test indicated a water loss in excess of 50% of the original amount, the test results were discarded (none were discarded in the set reported here). If the weighing indicated an acceptable test, the pressure vessel was then opened and if the coupon had not fallen from its hanger during the test, it was removed and weighed. Post-VHT coupons were placed on an optical scanner and the scanned images examined and stored for future reference. Coupons were mounted whole in epoxy in a standard 1-inch diameter SEM mounting cup with the broad surfaces supported vertically so that subsequent grinding and polishing would produce a representative cross-section of the reacted layer and the remaining glass for SEM examination and measurement. For consistency with existing data, the nominal test duration was 24 days.

For an average reacted layer thickness greater than 100 microns, the layer thickness (which can be uneven) was determined by measuring the remaining glass thickness at ten points throughout the cross-section of the coupon and subtracting the average remaining thickness from the original thickness of the coupon and dividing that value by 2. For average layer thicknesses less than or equal to about 100 microns, the thickness of the altered layer was measured directly at 3 points in each of 6 evenly spaced regions of the coupon using the digital caliper in the SEM software package and the resulting set of 18 measurements was averaged.

WTP Contract Specification 2 [63] requires that the VHT alteration rate determined from tests of seven days or longer duration be below 50 g/m^2/day. If it is assumed that the altered layer density is not appreciably different from that of the glass, the mean glass alteration rate over the test interval (r in $g/m^2/d$) is related to the measured altered layer thickness D in microns by:

$$r = \rho D/t,$$

where ρ is the glass density in g/cm^3 and t is the test duration. Under this assumption, for a typical density of 2.65 g/cm^3, a layer thickness of 453 microns in a 24-day VHT would correspond to a mean glass alteration rate of 50 g/m^2/day.

The VHT alteration depths (in μm) and alteration rates (in $g/m^2/d$) are given in Table 3.5 for the 28 ORLEC glasses (ORLEC1-28). The model-predicted alteration rates are also given in the last column of the table and compared to the measured values in Figure 3.3. While the predicted values were all below 50 $g/m^2/d$, the VHT alteration depths and rates measured for these glasses vary from 5 to 714 μm (0.6 to 78.8 g/m^2/day), with the VHT alteration rates exceeding the contractual limit for two glasses. The measured VHT alteration rate of 52.2 $g/m^2/d$ for glass ORLEC2 exceeded the contractual limit of 50 $g/m^2/d$ [63] even though the predicted alteration rate was only 20 $g/m^2/d$. ORLEC16, a reformulation of ORLEC2 with 1.5 wt% more SiO_2 at the expense of Fe_2O_3 and TiO_2, showed a measured VHT alteration rate of 20.9 $g/m^2/d$ versus a predicted value of 18.8 $g/m^2/d$. Triplicate VHT alteration rate measurements on formulation ORLEC25 showed a consistently high value averaging 76 $g/m^2/d$ versus a predicted value of 50 $g/m^2/d$. This particular formulation is designed for LAW with the maximum contractual molar ratio for K/Na of 0.18, along with sufficiently high sulfate concentrations to yield 0.60 wt% SO_3 in the glass (SO_4 /Na ratio of greater than 0.01). An evaluation of the LAW inventory described in the TFCOUP [62] indicates that such a LAW may not exist at Hanford. The waste analytical data for LAW from tank AP-101 identifies it as the LAW with the highest K/Na molar ratio (0.14) and in this case, the molar ratio of SO_4/Na is 0.0075. For this LAW composition, the waste contributions to the glass calculated by the initial Enhanced LAW Glass Correlation would be 21.29 wt% Na_2O, 4.61 wt% K_2O, and 0.41 wt% SO_3. Prior to considering further improvement to the LAW formulation ORLEC25 (20.61 wt% Na_2O, 5.64 wt% K_2O, and 0.60 wt% SO_3), it may be prudent to determine whether a LAW stream with such high potassium and sulfur concentrations is likely to be a credible feed to the WTP LAW vitrification facility.

Examination of alteration layers with SEM showed large re-deposited crystals of Na-aluminosilicate (likely analcime) or Na-K-aluminosilicate (possibly zeolite) on top of sodium-depleted alteration layers. These were particularly evident in glasses ORLEC25 and ORLEC27, the two glasses with the highest K_2O content and currently one of the more challenging LAW streams for which to formulate glass compositions.

3.7 Melt Viscosity and Melt Electrical Conductivity

The melt viscosity (η) of each glass was measured using a Brookfield viscometer with a platinum-rhodium spindle and crucible. The relative torque of a rotating spindle immersed in molten glass was measured as a function of rotational velocity (revolutions per minute (RPM)) at temperatures around 950, 1050, 1150 and 1250ºC. The viscosity of the molten glass was then calculated from the collected data of torque versus RPM. The equipment was calibrated using viscosity standard oils and checked periodically using a NIST traceable standard reference glass. To facilitate comparison, the viscosity data were interpolated to standard temperatures (e.g., from 950 ºC to 1250ºC) using the Vogel-Fulcher equation:

$$\ln \eta = [A/(T\text{-}T_o)] + B,$$

where A, B, and T_o are fitting parameters.

Per current WTP requirements, glass melts should satisfy the viscosity limits of 10 to 150 poise at 1100 ºC, with the preferred range being 40-80 poise at 1150ºC [70]. LAW viscosity model predicted values of the melt viscosities at 1100 ºC and 1150 ºC for the 28 ORLEC glasses given in Table 3.6 show that the glasses were generally designed to fit the preferred range.

The electrical conductivity (EC) of each glass was determined by measuring the impedance of the glass melt at temperatures around 950, 1050, 1150 and 1250ºC as a function of AC frequency using a calibrated platinum-rhodium electrode probe attached to a Hewlett-Packard model 4194A impedance analyzer. The collected impedance data were analyzed to obtain the DC electrical conductivity. The probe (analyzer along with the crucible to assure that the geometry is replicated) was calibrated and checked periodically using NIST traceable standard reference materials. To facilitate glass to glass comparison, the electrical conductivity data were interpolated to standard temperatures (e.g., 1150ºC) using the Vogel-Fulcher equation:

$$\ln \text{EC} = [A/(T\text{-}T_o)] + B$$

where A, B, and T_o are fitting parameters.
The current WTP requirement is that glass melt EC be in the range of 0.1 - 0.7 S/cm at 1100 - 1200 ºC [70]. The LAW electrical conductivity model predicted EC values at 1150 ºC for the 28 ORLEC glasses also are given in Table 3.6.

The measured values of viscosity and electrical conductivity interpolated to standard temperatures from 950 ºC to 1250ºC are given in Table 3.6 for the 28 ORLEC glasses. The melt viscosity at the melter operating range varies from 21 Poise at 1150ºC for ORLEC9 to 139 poise at 1100ºC for ORLEC17. EC ranges from 0.295 at 1100°C for ORLEC19 to 0.670 S/cm at 1200°C for ORLEC15. All of the glasses meet the melt viscosity and electrical conductivity requirements for the WTP [70].

3.8 Refractory Corrosion

The K-3 refractory corrosion tests were conducted using a modified ASTM refractory corrosion test procedure (ASTM C621 [71]). The primary modification is the addition of gas bubbling during testing in order to better represent the conditions in the bubbled WTP melters.

For this test, Monofrax K-3 test coupons are cut from K-3 refractory bricks. Since the material that forms fused-cast K-3 varies from the surface of the brick to its interior (e.g., the interior material tends to contain larger and more numerous pores), the test coupons are cut from material within one inch of the brick surface. All sides of the K-3 coupons are ground parallel with a precision of better than 1 mil (0.001”). A typical K-3 coupon measures 0.395 × 0.595 inches in cross-section and is long enough (~ 3 inches) to be immersed in the molten glass to a depth of one inch.

For each test, the K-3 test coupon is first cemented to a crucible cover made of Zirmul and baked. Before starting the corrosion test, the baked coupons are preheated and then positioned in a 200 ml platinum crucible containing 170 grams of pre-melted glass. A platinum sheet covers the glass to ensure that it cannot be contaminated by Zirmul. The platinum crucible containing the K-3 coupon and molten glass is set inside a quartz crucible holder, which is then placed in a box furnace preheated to about 800°C. After the furnace reaches the designated test temperature (nominally 1208°C), a platinum bubbling tube is introduced into the molten glass from above through a slot in the Zirmul/platinum cover. Dry, room temperature air is bubbled through the molten glass at a constant rate of 8 cc/minute controlled by a precision flow meter. The bubbling rate, i.e., the number of gas bubbles generated inside the melt per minute, is monitored using a pressure transducer interfaced to a computer via an A/D converter. The temperature of the furnace is monitored using an S-type thermocouple positioned above the crucible inside the furnace and checked before each test against a calibrated S-type thermocouple. The standard glass-contact corrosion test is run for six days at 1208°C with continuous air bubbling. All K-3 corrosion tests are performed at the same *refractory surface area (S) / melt volume (V)* ratio of about 0.20 cm^{-1}, which is 74% less than the S/V ratio specified by the ASTM C-621-84 for static glass contact corrosion tests. Fresh K-3 test coupons are used for each corrosion test. At the end of each test, the K-3 coupon is removed from the melt and cooled to room temperature in a clean quartz crucible. The coupon is then sectioned lengthwise to facilitate measurement of dimensional changes. Per ASTM C-621, the dimension losses at the “neck” (the glass-air interface) and the “half-down” (half of the immersed length of the coupon below the neck) locations are reported.

The acceptability of the corrosion characteristics of a glass composition is somewhat subjective because a glass composition that shows slightly higher K-3 corrosion, but which allows higher waste loading, may be a more economical choice than one with lower K-3 corrosion and lower waste loading. However, for WTP LAW glass formulation development, a neck corrosion of 0.035 inches on a 6-day K-3 coupon corrosion test at 1208°C has been used as an acceptance limit. A temperature about 50°C higher than the nominal melter operating temperature of 1150°C was selected for these tests so that a measurable amount of corrosion will be observed on a 6-day test. For the ORP LAW glass formulations, since higher waste loading compositions are being explored, a slightly higher neck corrosion value of 0.040 inches has been used as a guide for acceptable refractory corrosion characteristics. The corrosion limits were adopted based on the observations given below.

The K-3 corrosion limits specified for the LAW glasses can be correlated to the observed refractory corrosion in the one-third scale LAW Pilot Melter, in which more than 15 LAW glass compositions were processed. These glasses had neck corrosion losses ranging from about 0.009 to 0.0334 inches with a mean of about 0.025 inches per the modified ASTM procedure. After nearly five years of operations, K-3 refractory loss at the neck region in the LAW Pilot melter ranged from 4 to 5 inches through a combination of uniform corrosion and spalling [72]. Similar results regarding contact K-3 refractory corrosion rates were obtained from the M-Area melter operated by Atkins at SRS, even though it was operated for only about one year. With a total K-3 refractory thickness of 17 inches for the WTP LAW Melter (12 inch glass contact K-3 refractory with 5 inch backup K-3 brick) the proposed corrosion rate limits are adequate for the melter design life of five or more years. With the proposed K-3 refractory corrosion rate limits, the melter failure mechanism is highly unlikely to be the glass contact refractory.

K-3 corrosion tests were conducted on 26 of the 28 ORLEC glasses and the results are given in Table 3.7. K-3 refractory corrosion tests were not performed on ORLEC5 and ORLEC25; ORPLEC5 because the calcium addition strategy was revised and this formulation was predicted to show low corrosion, and ORLEC25 because it failed VHT. Predicted and measured K-3 neck corrosion losses for twenty six ORLEC glasses are given in Figure 3.4.

Among the first series of the Enhanced LAW Correlation glasses (ORLEC1-9), two glasses formulated to accommodate high SO_3 concentrations, ORLEC8 (1.4 wt% SO_3) and ORLEC9 (1.5 wt% SO_3), showed K-3 refractory corrosion exceeding 0.040". Both glasses contain high Li_2O and CaO concentrations (2.08 and 7.91 wt% in ORLEC8 and 2.48 and 9.17 wt% in ORLEC9, respectively). Also, in both cases, the measured K-3 neck corrosion was about 20% above the predicted values, demonstrating that it will be useful to update the K-3 refractory corrosion model once more data are collected. Reformulation of these glasses with lower Li_2O and/or CaO reduced the K-3 refractory corrosion to within the acceptable limit of 0.040".

3.9 Selection of Four Glass Compositions for Melter Tests

Waste composition data from TFCOUP, Rev. 5 [62] were used to examine the distribution of these streams in terms of ALK and SO_3 with respect to the initial ORP Enhanced LAW Glass Correlation, as illustrated in Figure 3.5. More than a third of these streams lead to alkali limited glasses in composition regions A and G. Glasses from this region were therefore selected for the Phase 1 DM100 melter tests. Since the ORP LAW glass formulations explored simultaneously higher Na_2O and SO_3 loadings as compared to the baseline WTP LAW glass formulations, the same LAW streams that were tested for the WTP baseline were, in some cases, tested at higher sulfate concentrations for the ORP LAW glass formulation work. As a result, some of the LAW tank waste compositions used in the development of the ORP LAW glasses are shown at different SO_3 concentrations as compared to the same tank waste compositions used in the development of the WTP baseline LAW glasses

The formulations selected for DM100 melter tests, ORLEC12, ORLEC26, ORLEC27, and ORLEC28, are shown in Figure 3.6 and Table 3.8 in terms of their Na_2O, K_2O, and SO_3 concentrations. A summary of their properties and comparison to the WTP requirements is provided in Table 3.9. Each of the four glass compositions and the relative contributions from waste and GFC additives are given in Tables 3.10 – 3.13. The four selected compositions are also compared in Figure 3.6 to 66 LAW compositions identified as the highest in alkalis and the lowest in sulfate content in TFCOUP, Rev. 5 [62]. The yellow circles in Figure 3.6 show the positions of these high alkali LAW streams. Also shown in the figure are green triangles which show the projected SO_3 concentrations in the glass for the same 66 LAW streams. The blue squares identify the four glass compositions selected for DM100 melter testing. The potassium concentration in the AP-101 LAW simulant that was used as a basis for these formulations was increased so that glasses ORLEC12 and ORLEC27 could be tested at the contract maximum K_2O concentration of 5.64 wt%.

3.10 Feed Formulations

Feed recipes for the four waste compositions are given in Table 3.14. Each feed was produced using reagent grade chemicals and the same glass forming chemical additives planned for use at the WTP, with the exception of chromium and tin, which are new additives. Optima Chemicals, which has supplied all of the LAW simulants for the previous DM100 tests, LAW Pilot Melter tests, and testing for enhancements of LAW glass formulations for ORP, prepared the feed. Upon receipt at VSL, the feed was homogenized, sampled, and analyzed to verify chemical composition and physical properties. Prior to each test, sugar and perrhenic acid were added to each drum of feed. Based on previous testing [73], the amount of rhenium spiked into the feed corresponded to a ReO_2 concentration of 0.01 wt% in the glass product assuming total retention.

3.10.1 LAW Compositions

LAW simulants used in the Enhanced LAW Glass Correlation development work were based on the composition data for Hanford tanks AN-105, AP-101, AN-107, AN-104, AN-102, AZ-101, and AZ-102 as given in a WTP Test Specification [32]. The DM100 melter tests in Phase 1 concentrated on LAW from Hanford tanks AN-105 and AP-101, as well as an intermediate composition corresponding to a mixture of 48% AN-105 and 52% AP-101. The LAW simulant compositions given in Tables 3.15 – 3.18 are close to the compositions previously used in the development of the respective high waste loading ORP LAW glass formulations [40-47]. Some of the LAW simulants used in earlier tests contained Cs spikes that are not included in the present tests. The base waste composition incorporates early Tank Farm Contractor Operation and Utilization Plan (TFCOUP) [31] data, actual waste analysis data, and WTP flow sheet information. The sodium concentration in the simulant includes an increase to account for sodium additions in pretreatment [57]. The sulfate concentration in the simulant is adjusted to meet the target SO_3 concentration of 0.1 wt% in ORLEC12 and 0.4 wt% in the other three glass formulations. The concentrations of halides (Cl, F) and some other minor components (Ni, Pb, P) is set at the constant values given in Table 2.3.

3.10.2 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 Atkins for the vitrification of high-sodium-nitrate feeds at Savannah River's M-Area and has been successfully applied to the processing of a wide variety of simulated WTP feeds. In developing this approach, we elected to conservatively adopt the most reducing potential reaction as the basis for the *definition* of a "sugar" or stoichiometric 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 sugar ratio of 1.0 corresponds to one mole of sucrose per eight moles of nitrate or, more generally, 1.5 moles of organic carbon per mole of nitrate. It is then expected that significantly less sugar than this will be required in practice. The empirically determined amount required to successfully control melt foaming without significantly reducing the glass melt was found to correspond to a ratio of 0.5 when any nitrites present were counted as nitrates (i.e., 0.75 moles of organic carbon per mole of nitrate + nitrite). This approach has been employed for all WTP melter testing [7-28, 38, 58] and several optimization tests conducted for ORP [40, 41, 43-47, 59, 60, 73-75]. 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 LAW AN-105 (Region A) feed to achieve a sugar ratio of 0.5 proceeds as follows:

- One liter of 8 molar sodium simulant contains 1.857 moles of nitrite and 2.048 moles of nitrate, giving a total of 3.905 moles of NOx (see Table 3.15)
- The required total amount of organic carbon for a sugar ratio of 0.5 is $3.905 \times 0.75 = 2.929$ moles

- One liter of simulant contains 0.174 moles of organic carbon (see Table 3.15)
- Therefore, 2.929 – 0.174 = 2.755 moles of organic carbon must be added.

Since the molecular weight of sucrose is 342 g, 2.755 × 342/12 = 78.5 g sugar must be added per liter of simulant, as shown in Table 3.14.

SECTION 4.0
DM100 MELTER OPERATIONS

A series of four tests were conducted on the DM100-WV melter between 11/16/15 and 12/16/15 to determine feed processing properties and potential for secondary phase formation while processing waste simulants and additives corresponding to the four glass compositions described in Section 3.0. Each feed was processed at the nominal glass temperature of 1150°C and the bubbling rate was adjusted to target a glass production rate of 2250 $kg/m^2/day$. These four tests were conducted in nominally 50-hour test segments and produced seventeen hundred kilograms of glass from nearly two metric tons of feed. Summaries for all of the tests are provided in Table 4.1. The tests are distinguished by changes to the waste composition, sulfur content, and glass composition as follows:

- **ORLEC26:** LAW AN-105 waste, Target glass – 0.4 wt% SO_3, 0.54 wt% K_2O, 24 wt% Na_2O
- **ORLEC12:** LAW AP-101 waste, Target glass – 0.1 wt% SO_3, 5.64 wt% K_2O, 20.61 wt% Na_2O
- **ORLEC27:** LAW AP-101 waste, Target glass – 0.4 wt% SO_3, 5.64 wt% K_2O, 20.61 wt% Na_2O
- **ORLEC28:** 51.66% AP-101 + 48.34% AN-105 waste, Target glass – 0.4 wt% SO_3, 3.36 wt% K_2O, 22.11 wt% Na_2O.

Attempts were made to replicate the melter configuration and operating conditions used in previous LAW Sub-Envelope [5-16, 38, 43, 44, 58, 74, 75] tests on the DM100-WV melter. These conditions include a near complete cold cap, which is between 80-95% melt surface coverage for the DM100 since a 100% cold cap tends to lead to "bridging" in smaller melters. Cold cap conditions were mostly similar to those experienced in previous DM100 tests with LAW simulants. Deposits formed along the walls of the melter after discharging glass, which lowered the glass level in the melter leaving material adhering to the walls out of contact with the molten glass. Manual methods used after many of the glass discharges readily removed these soft deposits from the walls, returning them to the cold cap surface. Occasionally, liquid would pond on the cold cap surface and abruptly flow to the melt pool surface causing minor excursions in melter pressure. The extent to which these deposits formed and manual methods for removal were required was dependent on the feed being processed: feeds containing the LAW AN-105 waste required deposit removal after every other discharge while feeds containing only the LAW AP-101 waste required only a couple of removal procedures over the entire test. Short, routine interruptions were required during testing to transfer feed to the feed tank; longer interruptions of about half an hour occurred eight hours into each test to permit dip sampling of the melt pool and after about four hours during the test with ORLEC27 due to the temporary loss of cooling water. No foamy glass was observed in any of the glass discharges. No secondary phases were observed on any samples taken before, during, or after any of the tests.

Glass production rates as moving hourly and cumulative averages (calculated from target glass conversion ratio and feed rate data) while processing the four different glass compositions and waste blends are illustrated in Figures 4.1.a to 4.1.d. Instantaneous glass production rates are compared for the four tests in Figure 4.1.e. Average and steady glass production rates were calculated with both the target and measured glass conversion ratios and compared to average glass productions rates calculated from the amount of glass discharged in Table 4.1. Measured glass conversion ratios were six to seven percent lower than the target glass conversion ratios and therefore glass productions rates calculated with the measured glass conversion ratios are correspondingly lower. Average glass production rates calculated from the amounts of glass discharged approximate the average production rates calculated with the measured glass conversion ratios. Steady state processing rates were typically a little higher than average processing rates since down time during each test for sampling and other events is not included in the estimation of the steady state rate. Based on the target glass conversion ratio, which was used as guide during each test, steady state production rates approximated the 2250 kg/m^2/day for three of the four tests. During the first test with the ORLEC26 composition, accumulation of feed material in the cold cap necessitated reduction of the feed rate to a steady state production rate of 2000 kg/m^2/day.

The results of various operational measurements that were made during these tests are given in Table 4.2. Melt pool bubbling rates are shown in Figures 4.2.a - 4.2.e, glass temperatures in Figures 4.3.a - 4.3.d, plenum temperatures and power supplied to the electrodes in Figures 4.4.a - 4.4.d, and electrode temperatures and melt pool resistance in Figures 4.5.a - 4.5.d. The amount of bubbling required during steady state processing of ORLEC26 and ORLEC28 was 16 lpm whereas only 11 lpm was required while processing ORLEC12 and ORLEC27 suggesting that feeds with the AP-101 waste and corresponding glasses are more readily processed than feeds containing the AN-105 waste and corresponding glass compositions. Test average bulk glass temperatures, as indicated by the thermocouples located at four and ten inches from the bottom of the melt pool, were within five degrees of the target glass temperature of 1150°C for all four tests. Glass temperatures near the top of the melt pool at sixteen inches from the melter floor are significantly lower (between 800 and 1000°C during the first test and around 1100°C for the other tests) as a result of gradients near the cold cap and therefore are not reliable indicators of bulk glass temperatures. The glass level in the melter ranged from sixteen to nineteen inches from the melter floor and therefore temperatures measured in the thermowell at nineteen inches above the floor are actually above the glass pool and thus reflect the temperature within the cold cap or plenum space and not the molten glass. Measured temperatures sixteen and nineteen inches from the melter floor are also strongly affected by cold cap thickness and glass level and therefore are more variable over the course of the tests than those in the bulk glass pool. This is particularly evident during the first test which showed temperatures nineteen inches from the melter floor that were about a hundred degrees below the corresponding plenum temperatures, indicating a thick cold cap surrounding the thermal well nineteen inches from the melter floor. The lowest glass levels were measured before and after the initial test (See Table 5.10) and therefore the lower temperatures at the upper thermocouples were measured during the first test.

Plenum temperatures typically ranged from around 400 to 500°C once the cold cap was established, indicating near complete coverage of the melt pool surface with melter feed. Higher plenum temperatures occurred at the beginning of each test as the cold cap was established, after eight hours of feeding in the last three tests while sampling the melt pool (Figures 4.4.b - 4.4.d), and at twelve to sixteen hours run time during the test with ORLEC27 (Figure 4.4.c) in response to idling mandated by a loss of cooling water. Measured plenum temperatures were typically lower during the test with ORLEC27 than for the other feed compositions (400 as opposed to 500°C) indicating a thicker more extensive cold cap during this test. Plenum temperatures measured by the exposed thermocouple were on average about 15°C higher than those measured in the thermowell due to more direct exposure to the glass surface.

The east electrode temperatures averaged between 1105 – 1111ºC, which was about 60ºC higher than the temperature of the west electrode and 260ºC higher than the temperature of the bottom electrode. The difference in temperature between the side electrodes is probably due to the sensitivity to the placement of thermocouples in the electrodes and therefore not reflective of an overall temperature difference between the sides of the melter. The lower temperature of the bottom electrode is expected since it was not powered during the tests. Power supplied to the electrodes was relatively constant throughout the tests in response to similar feed water contents, processing rates, and operating conditions. Test average power ranged from 17.8 kW to 19.7 kW; it is difficult to ascribe the small differences in power usage to differences in feed composition or other minor differences. However, a discernable decrease in power usage can be observed during the latter portion of the initial test in response to decreases in feed rate to the melter. The melt pool resistance also remained relatively constant over the course of the tests due to only minor compositional changes in the glass pool as well as consistency in feed water content and operational conditions over the course of the tests. Once the steady state conditions were achieved half way through the initial test, glass resistance ranged mainly between 0.065 and 0.07 ohms, as shown in test average melt pool resistance values of 0.066, 0.067, and 0.068 ohms for the last three tests.

The gas temperature at the film cooler averaged between 291 and 301°C and depended on the plenum temperature, the amount of added film cooler air, and the temperature of the added film cooler air. A small drop of about ten to twenty degrees in gas temperature was observed across the (insulated) transition line; the high temperature is maintained in order to prevent condensation in the downstream filtration units.

In summary, the results from DM100 testing demonstrate that all four feeds can be processed without the formation of secondary phases or significant processing difficulties. Feeds formulated with only the AP-101 simulated waste were more readily processed, as evidenced by the use of less bubbling to achieve the target feed rate and minimal need to manually remove deposits adhering to the melter walls after discharging. There were no discernable differences in processing the two compositions with the AP-101 simulated waste (ORLEC12 and ORLEC27) in response to the increase in SO_3 and SiO_2 at the expense of Fe_2O_3, TiO_2, and Cr_2O_3 in the form of additives. Feeds formulated with only the AN-105 simulated waste were more difficult to process, as evidenced by the inability to achieve the target glass production rate despite the use of high levels of bubbling and the use of manual methods to remove deposits adhering to the melter walls after every other discharge. The most significant difference between the two waste streams and corresponding glass compositions is the higher concentration of potassium in the AP-101 waste at the expense primarily of sodium. In previous high level waste (HLW) testing, glass production rates were observed to increase with higher concentrations of potassium in the waste [76] and potassium was used as an additive to increase processing rates and suppress crystallization in the glass melt [77].

SECTION 5.0
DM100 FEED AND GLASS PRODUCTS

5.1 Analysis of Feed Samples

5.1.1 General Properties

Feed samples from each test were analyzed to confirm physical properties and chemical composition. Samples were taken from as-received drums and at the beginning and end of each melter test from an inline sampling port in the feed line. Sample names, sampling dates, measured properties, and comparison to target glass yield values are given in Table 5.1. Glass yield analysis results for the as-received feeds were mostly within three percent of the target values and therefore did not require the addition of water. Measured glass yields of melter test samples were up to seven and half percent below the target values as a result of the addition of sugar, perrhenic acid solution, and small amounts of water added during transfer to the feed tank. The closeness of the measured and target glass yields for the as-received feed samples led to the use of target glass yield values for the purposes of calculating glass production rates over the course of each test. Production rates were also calculated using the measured conversion ratio of the melter test samples, which show the corresponding near seven percent lower glass production rate as a point of comparison (see Table 5.1). The amount of glass produced in each of the melter tests was consistent with the amount of feed consumed and the measured glass yield, confirming the feed solids content analysis. Measured feed densities and water contents for as-received and test samples varied within narrow ranges for each sampling type and sampling location illustrating the uniformity of the feed during each test. Measured feed pH ranged between 12.5 and 11.8 for all the samples; these values were typically slightly lower for the melter test samples than for the as-received feed samples as a result of sugar and water additions associated with feed transfers.

5.1.2 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). The XRF analysis of rhenium is based on a calibration derived from solution analysis of dissolved glass samples that were analyzed by inductively coupled plasma mass spectroscopy ICP-MS [73]; the XRF detection limit for rhenium in powdered glass samples was reduced to about 0.001 wt% ReO_2 by employing element-specific analysis using a LiF220 crystal to measure the intensity of the Re Lβ1spectral line. Boron and lithium concentrations were determined by direct current plasma atomic emission spectroscopy (DCP-AES) analysis of solutions generated by microwave aided acid dissolution. Feed sample data are compared to the target composition in Tables 5.2 – 5.5 for each of the four tests. The results generally corroborate the consistency of the feed oxide composition and show good agreement with the target composition for the major and minor components.

Of the oxides with a target concentration of greater than one percent in as-received feed samples, deficits of greater than 10% from the target composition of tin, calcium, and zinc oxides were measured and addressed by the addition of the appropriate additive to the feed prior to melter testing. Deficits of magnesium oxide were also detected in the as-received feed due to olivine settling to the bottom of drums; magnesium deficits were smaller in melter test feed samples and discharged glass as a result of more extensive feed mixing and homogenization associated with removal of feed from drums. Of the oxides with a target concentration of greater than one percent in melter test feed samples, only aluminum, boron, and tin oxides for the ORLEC26 composition and zinc, zirconium, and tin oxides for the ORLEC27 composition deviated from the target concentration by more than ten percent. In all but the tin analysis, all these deviations were less than fifteen percent from the target and mostly not observed in the glasses discharged at the end of the respective tests. Although most of the measured boron concentrations were within ten percent of the target value for most of the compositions, the concentrations measured in feed samples by DCP-AES were used to calculate the amounts in the discharged glasses and renormalize the XRF data. Measured concentrations of tin in the melter feed samples varied from the target composition, the as-received feed samples, and the product glasses (see Section 5.2), as well as between melter feed samples taken from a given test suggesting segregation of the tin dioxide additive in the feed, similar to the observation in preceding tests with this additive [74, 75].

As in previous tests with LAW feeds [35, 58, 73, 78-81], small surpluses of titanium (0.05 – 0.2 wt% TiO_2) were observed in feed and glass samples due to its presence as a contaminant in the glass forming additives, most notably kyanite [82]. Similarly, small surpluses of iron (0.02 – 0.1 wt% Fe_2O_3) were also observed in feed samples in these low iron compositions due to low level contamination in the glass forming additives and chemicals used to formulate the waste simulant. Low concentrations (0.01 – 0.03 wt% oxide) of lithium and manganese in the feed samples were also detected, even though they were not included in the target composition, presumably originating from trace level contamination of feed additives and chemicals used to produce the waste simulant. None of these minor deviations from the target compositions are expected to have any significant effect on glass properties, feed processing characteristics, or partitioning of constituents to the exhaust stream. The volatile minor elements rhenium, chlorine, and to a lesser extent sulfur are, as expected, below target due to loss during crucible melting; an exception being the ORLEC12 samples which contained 0.14 as opposed to 0.10 wt% SO_3 due to assumed low level contamination in the feed.

5.2 Compositional Analysis of Discharged and Dip Glass Samples

Almost two metric tons of glass was produced during the four tests. The glass was discharged from the DM100 melter periodically into 5-gallon carbon steel pails using an air lift system. The discharged product glass was sampled by removing sufficient glass from the top of each pail for total inorganic analysis. Product glass masses and discharge date are given in Tables 5.6 – 5.9. Sets of five glass samples were also obtained by dipping a rod into the glass pool during and at the end of each test, as listed in Table 5.10. These “dip” samples serve to document the composition of the glass pool before, during, and after each test as well as to detect secondary phases on the glass pool surface. All of the "dip samples" underwent visual examination to detect the presence of a separate sulfate phase on the glass surface; select samples were also subjected to complete chemical analysis. No macroscopic secondary phases were observed in any of the discharged glasses or dip glass samples.

All discharge glass samples were crushed and analyzed directly by XRF. Since boron and lithium are not determined by XRF, boron and lithium concentrations were calculated from the measured feed concentrations, the initial concentrations measured in the melt pool, and the nominal glass volume of the melter. A separate XRF analysis for rhenium calibrated to values measured by ICP-MS (see Section 5.1.2 [73]) and for fluorine on polished solid samples was performed. The XRF analyzed compositions of discharged glass samples are provided in Tables 5.11 - 5.18. The vast majority of the XRF analysis results compare favorably to their corresponding target values and feed sample analyses (see Section 5.1.2). All oxide values from glass discharged at the end of each with a target concentration of greater than or equal to one weight percent showed less than 10% deviation from the target values except for oxides of potassium, zinc, and zirconium for the ORLEC12 composition and zirconium for the ORLEC27 composition. These deviations are all less than 14% and in the case of zinc and zirconium not observed in the average analyzed composition from the respective tests. Average glass analysis of glasses from each test are also close to the target values except for oxides that have concentrations disparate from target composition at the onset of testing, as observed for aluminum and calcium during the initial test and potassium in the second and final tests.

Manganese was measured in the product glass at low concentrations despite not being included in the target composition as a result of its presence in the feed as a contaminant. Also, consistent with the feed sample analysis, iron and titanium present in the target compositions at relatively low concentrations, were measured at above target concentrations as a result of being present as impurities in additives and chemicals used to produce the waste simulant. More chromium and nickel were measured in the discharged and melt pool glasses than in the target due to corrosion of refractory and Inconel components in the melter. Measured rhenium, chlorine, and sulfur concentrations in discharged and melt pool glasses reflect the concentrations measured in feed samples: lower than target values due to volatilization except for sulfur in the ORLEC12 composition. XRF is used for Re analysis at concentrations of about 0.001 wt% or higher and ICP-MS is used for lower concentrations. The XRF Re analysis is calibrated using samples that are analyzed both by XRF and ICP-MS (glass powders for XRF analysis and dissolved glass samples for ICP-MS). At Re concentrations that are high enough for analysis by XRF, that is the preferred analysis technique because it is faster and more economical. However, during future work select samples will be analyzed for Re concentration by both XRF and ICP-MS.

Compositional trends for selected constituents shown in Figures 5.1 - 5.8 illustrate the changes in glass pool composition over the course of the tests. Over four metric tons of the ORPLA20 glass composition was processed in the preceding tests [74, 75], which is similar to the first composition processed, ORLEC26, for many of the elements. At the onset of testing, modest increases in aluminum, boron, sodium, zinc, zirconium, iron, and titanium at the expense of silicon and calcium were observed. Target concentrations of aluminum, boron, calcium, zinc, zirconium, phosphorus, tin, magnesium, and chlorine are the same for each of the four compositions and therefore significant changes in their concentrations are not observed in product glasses once target concentrations are approximated during the initial test. The most notable change in concentration over the course of testing is for potassium oxide, which increases from 0.5 wt% in the initial test to 5.6 wt% in the second and third tests, and falls to 3.4 wt% in the final test with corresponding changes in sodium and silicon. Other noticeable changes over the course of the tests are the intended increases in iron, titanium, and chromium concentrations in response to decreases in sulfur content during the test with the ORLEC12 composition.

Excess chromium and nickel are observed in the glass pool due to corrosion of melter refractory and metal components, particularly after idling periods. Readily apparent in the graphical data is the volatilization of rhenium and chlorine from the glass over the course of the tests. The amounts of chlorine and rhenium lost during each test was relatively constant between the tests at about 0.06 weight percent chlorine and 0.007 weight percent rhenium oxide; exceptions are rhenium during the initial test when rhenium was not added to the feed, and chlorine during the last test in which about half the chlorine in the feed was lost. About 0.05 wt% SO_3 appears to be lost from the glass during three of the four tests, with the test processing the ORLEC12 composition showing excess sulfur due to presumed trace level contamination of the feed.

5.3 Glass Pool Samples

Glass dip samples were obtained primarily to ascertain whether a secondary sulfate layer had formed on the surface of the glass melt. A list of all dip samples taken including sample names, target glass identification, measured melt pool depth, sampling date, and visual observations, is given in Table 5.10. Samples were taken in groups of five by dipping metal rods into the melter and placing the rods with adhering glass into steel pails to cool. After about ten minutes, the glass was sufficiently cool to observe separated phases, if present, on the surface of the glass as well as adhering to the threads of the metal rod. An example of cooled glass on the metal rods is shown in Figure 5.9. After the glass cooled and observations of secondary phases on the rod were noted, the glass was broken off the rod and placed in Petri dishes for closer examination, as shown in Figure 5.10. Typically secondary phases strongly adhere to the rod [38, 58-60]; no secondary phases were observed on any of the rods during these tests. Visual observations of the dip samples indicated that secondary phases were not present on the melt surface before, during, or after of any of the tests.

Select glass pool samples were crushed and analyzed directly by XRF or dissolved in acid and the resulting solutions analyzed by DCP-AES for boron and lithium determination. The analyzed compositions of the dip samples are provided in Tables 5.19 - 5.22. The vast majority of the XRF analysis results compare favorably to their corresponding discharged glasses. Dip samples from the end of tests and feed sample analyses compare very favorably (see Section 5.1.2). Boron concentrations measured by DCP-AES on solutions generated from glass pool samples taken prior to and during testing approximate the concentrations calculated from the feed sample analysis, supporting the use of feed sample analyzed values for normalizing the XRF data for the discharge glasses. Lithium was measured in the product glass at low concentrations despite not being included in the target composition as a result of its presence in the feed as a contaminant.

5.4 Glass Property Testing

Glass property measurements, including product quality testing, were performed on four glasses taken from at or near the end of each of the tests. These selections permit direct comparisons with the corresponding crucible melt results for melt viscosity, melt electrical conductivity, sodium and boron Product Consistency Test (PCT; ASTM C 1285) releases, Vapor Hydration Test (VHT) alteration rate, and secondary phases in both as melted and canister cooled glasses. The data are also presented in Table 5.23 for viscosity and electrical conductivity, Table 5.24 and Figure 5.11 for PCT, Table 5.26 and Figure 5.12 for VHT, and Figure 5.13 for secondary phases in canister cooled glass.

All of the measured properties of the crucible and melter glasses are within acceptable limits for processing and product quality except for one VHT of melter glass replicate. The viscosities and electrical conductivities of the crucible and melter glasses are close but the measured values for melter glasses are all lower than those for the corresponding crucible glass. The PCT releases for the crucible and melter glasses are close but the measured values for melter glasses are higher than for the corresponding crucible glass. The lower viscosities and electrical conductivities as well as the higher PCT releases for the melter glasses are attributable to small deficiencies in aluminum, silicon, and zirconium with corresponding surpluses of boron and sodium as compared to the target compositions [49, 50]. VHT alteration rates for the crucible and melter glasses are similar, with no distinct pattern between the differences. Replicate VHT analysis differed by a factor approaching two, showing the typical large variations inherent in the VHT test results.

Samples of the as-melted and heat treated crucible and melter glasses were examined for the presence of secondary phases. Glass samples were heat treated at 950°C for 20 hours, and also according to the canister centerline cooling (CCC) curve [67]. No crystalline phases were observed in the as-melted or heat treated samples. Photographs of the heat treated glasses are presented in Figure 5.13, showing them to be clear and green in color, without the presence of any secondary phases.

SECTION 6.0
MONITORED OFF-GAS EMISSIONS

6.1 Particulate Sampling

The melter exhaust was sampled for metals/particles/acid gases according to 40-CFR-60 Methods 3, 5, 26, 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 dry standard cubic feet (dscf) was taken at a rate of between 0.5 and 0.75 dry standard cubic feet per minute (dscfm). Total particulate loading was determined by combining gravimetric analysis of the standard particle filter and chemical analysis of probe rinse solutions. An additional impinger containing 2 N NaOH was added to the sampling train to ensure complete scrubbing of all acid gases and to distinguish between halogens in the form of acids or homonuclear molecular gases. The collected materials were analyzed using direct current plasma atomic emission spectroscopy (DCP-AES) for the majority of the constituents and ion chromatography (IC) for anions. Melter emission fluxes are compared to feed fluxes in Table 6.1 for the four tests. Notice the distinction that is made between constituents sampled as particles and as "gas". The "gaseous" constituents are operationally defined as those species that are scrubbed in the impinger solutions after the air stream has passed through a 0.3 μm heated filter. All samples were well within the 90 – 110% limits for isokinetic sampling.

Solids carryover from the melter ranged from 0.19 to 0.61 percent of feed solids for the four new compositions tested. This is less than the 0.77 and 1.0 percent carryover for other feeds formulated with the same LAW waste compositions [38] suggesting that the additives used in these formulations result in lower carryover than the blend used in the BNI baseline formulations. Carryover was also less than the 0.65 percent carryover for feed formulated for an AN-105 waste blended with similar additives [74] due primarily to the higher concentration of chlorine in the waste simulant (0.2 vs. 0.68 wt%) than for the present tests. Solids carryover from the melter while processing the ORLEC26 composition was about one-third of that measured while processing the other three compositions (0.19% vs. 0.53-0.61%) due to the much lower concentration of potassium and the lack of rhenium in the ORLEC26 melter feed. Potassium, sodium, and chlorine constitute the majority of the particulate matter sampled during the tests.

As expected, the feed elements emitted at the lowest melter decontamination factor (DF), in ascending order, were rhenium, chlorine, fluorine, potassium, sulfur, chromium, and boron. Emissions of chlorine and sulfur were particulate, consistent with previous tests conducted at high sodium contents [38, 58, 74, 75]. Fluorine and boron were the only elements detected in the impinger solutions collected downstream of the heated particle filter in the sampling train, which constitute the “gas” fraction of the melter emissions.

6.2 Particulate Sampled from Off-Gas System

Material accumulated in the cyclones downstream of the film cooler was removed, quantified, and analyzed after each test; the amounts and analysis results are provided in Table 6.2. The amount of material removed from the cyclone is not indicative of the amount of particulate emitted from the melter for any one test since much of the particulate emitted is fine particulate, which is not captured in the cyclones. Pre-filters for HEPA filters downstream of the cyclones are routinely changed three times a day while processing high alkali LAW feeds. This finding is consistent with tests processing high alkali LAW on the DM1200 in which significant amounts of fine alkali salts are captured downstream of the submerged bed scrubber in the wet electrostatic precipitator, which is designed to remove fine particulate from the exhaust stream [83-85].

Analysis of material accumulated in the cyclones shows all of the feed components in similar proportions to the feed for many of the elements, enrichments over feed for volatile elements, most notably rhenium, chlorine, sodium, potassium, boron, chromium, and sulfur, as well as depletions of non-volatile constituents including aluminum, silicon, iron, magnesium, zirconium, as well as contamination with ruthenium and rhenium from earlier tests. Chlorine and rhenium, which had the lowest measured DF across the melter, have the greatest enrichment (about 30X) in the cyclone powders over their amounts in the target glass. The relative amounts of potassium in the target glass compositions is reflected in the cyclone particulate collected after each of the four tests. The mineral phases detected by XRD analysis show carryover of minerals in the feed (quartz, zircon, and rutile) as well as salts volatilized from the glass pool and cold cap (halite and sylvine). The proportion of these volatile elements and minerals would be even higher if particulates passing through the cyclones were included.

6.3 Mass Balance of Volatile Constituents

Table 6.3 provides the elemental mass balance around the melter for sulfur, rhenium, and chlorine for the present tests and for previous tests with the same waste compositions [38]. The total recovery of these volatile feed constituents was good for the present tests except for sulfur while processing the low sulfur ORLEC12 composition; mass balance closures were between 84 and 115% except for the one sulfur value. Mass balance closure is typically very difficult to achieve for halides and SO_3 concentrations below about 0.4 wt% in the target glass due to the ubiquity of these constituents as trace level contaminants in glass forming additives and chemicals used to produce the waste simulant [38, 58, 73, 78-82].

As described in Section 5.1.1, chlorine, sulfur, and rhenium retentions in the glass were typically 50-70%, 88% (with the exception of the test with the ORLEC12 composition), and 30%, respectively, with no obvious influence of the other feed constituents. Chlorine retention while vitrifying high alkali LAW compositions is typically about 50% with the balance being emitted as particulate [8, 10, 12, 38, 58-60, 73, 78-82]; higher measured chlorine retention in some of the present tests is probably attributable to trace level contamination of the feed, which is targeted at only 0.2 wt% chlorine on a glass basis. The sulfur retention of 88% in three of the four tests is consistent with previous tests with high alkali LAW compositions, which showed near complete retention of sulfur in the product glass [8, 10, 12, 38, 58-60, 73, 78-81].

The rhenium retention in the glass product of 30% is within the range measured for glasses formulated for the same waste processed through the same melter [38] suggesting the differences in glass formulations do not significantly influence rhenium retention. Other tests with the same waste processed through the same melter showed a doubling of rhenium retention in the glass product with the use of ferric oxalate as an additive [80]. Testing on the DM10 with feed with the same rhenium feed concentration (0.01 wt% ReO_2 on a glass basis), high alkali LAW stream, and the new additives used to enhance waste loading also showed a higher rhenium retention (42%) than in the present tests [73]. Melter emissions of rhenium, chlorine, and sulfur were exclusively particulate in keeping with numerous measurements of melter exhaust while processing high alkali LAW streams, showing that the vast majority of these volatiles are particulate [8, 10, 12, 38, 58-60, 73, 78-81]. Rhenium retention values based on glass analyses would be expected to have much lower variation because these values are based on multiple glass sample analyses over the course of the test, whereas the off-gas data are collected over a one-hour period, typically towards the end of the test, and off-gas emissions vary over the course of the test.

6.4 Gases Monitored by FTIR

Melter emissions were monitored in each test for a variety of gaseous components, most notably CO and nitrogen species, by Fourier Transform Infra-Red Spectroscopy (FTIR). The off-gas system temperature is maintained well above 100°C beyond the sampling port downstream of the HEPA filter to prevent analyte loss due to condensation prior to monitoring. A summary of average and range of concentrations monitored during each test is provided in Table 6.4. Concentrations of various monitored species during DM100 tests are plotted in Figures 6.1. – 6.6. The analytes listed in Table 6.4 are those that were thought likely to be observed during the tests based on previous work; no other species were detected in the off-gas stream by FTIR. The most abundant nitrogen species monitored was NO, which is consistent with previous tests [5-16, 58-60, 38, 73, 78-81] in which nitrates and nitrites were present in the feed. The NO_2 concentration was more than 10 times less than the NO concentration during each of the tests, in keeping with previous DM100 tests with LAW simulants containing high concentrations of nitrates.

As expected, concentrations of nitrogen oxides and by-products of incomplete organic combustion, such as ammonia and carbon monoxide were relatively constant between the tests given the similarity in feed processing rate and amounts of nitrates, nitrites, and organic carbon in each feed. One discernable difference between the data from the tests is the lower concentration of nitrogen oxides during the first test as a result of the lower (approximately 10%) steady state processing rate. Another discernable difference is the greater degree of variability (higher peak concentrations) in the data from the tests with the ORLECE26 and ORLEC28 compositions as compared to tests with the ORLEC12 and ORLEC27 compositions due to a more irregular cold cap and the need to manually remove residual deposits after some of the glass discharges. These variations in emissions over the course of each test, which may be as high as an order of magnitude, are due in part to changes in the cold cap.

The measured water contents averaged 5.8 to 7.1%, which is about half the amount measured by the Method 5-type sampling discussed earlier, as a result of dilution air introduction between the two sampling points. Little or no HCl was observed by FTIR in these tests, in keeping with the gaseous emission rates measured by the Method 5-type sampling.

SECTION 7.0
SUMMARY AND CONCLUSIONS

Data from the development of high waste loading glasses were analyzed in order to begin the definition of an initial Enhanced LAW Glass Correlation that will systematize the variation of the glass formulations over the expected range of LAW compositions. Such a correlation is needed for eventual use to determine the appropriate waste loading, glass composition, and amounts and types of glass former additives for LAW processing at the WTP based on the analysis of the LAW composition that is delivered to the LAW vitrification facility. The development of this correlation for the higher waste loading ORP LAW glasses followed a methodology similar to that used in the development of the WTP Baseline LAW Glass Correlation for the lower waste loading baseline glasses [37]. Sixteen previously developed glass compositions covering the LAW composition regions A to G were used as the basis for the development of the new correlation. Fifteen of these high waste loading LAW glasses have been previously subjected to DM10 melter testing; the remaining glass is a high-alkali formulation that meets all of the WTP processing and product quality requirements but without the use of Cr as an additive to control K-3 refractory corrosion.

The types and amounts of GFC additives in the above sixteen glasses were analyzed to support development of the initial Enhanced LAW Glass Correlation. Based on this analysis, B_2O_3, CaO, and MgO were held at fixed concentrations in all of the correlation glasses. The concentrations of Al_2O_3, CaO, Cr_2O_3, Fe_2O_3, Li_2O, SnO_2, TiO_2, V_2O_5, and ZrO_2 were varied systematically with the alkali or SO_3 content of the glass, as described in Section 2. Based on the initial correlation that was developed and property-composition models for higher waste loading LAW glasses [49-51], a total of 28 glass formulations were prepared and characterized in the present work. Sulfate solubility and K-3 refractory corrosion results from the first batch of about ten crucible melts suggested modifications to the strategy to calculate Al_2O_3 and CaO additions, which were implemented in the formulation of the remaining crucible glasses. Characterization results from the 28 crucible melts showed that the majority of the measured properties were in agreement with model predictions, except for two each that failed VHT alteration rate and K-3 refractory corrosion criteria. This is not surprising considering the large uncertainties in these models.

In a manner similar to that employed in the development of the WTP Baseline LAW Glass Correlation, the approach for the development of the Enhanced LAW Glass Correlation includes preparation and characterization of crucible glasses developed using the correlation to confirm that they meet all WTP processing and product quality requirements, and DM100 melter tests with selected formulations to confirm their processing characteristics. In the present Phase 1 of the work, 28 formulations covering the LAW composition range (in terms of Na_2O, K_2O and SO_3 concentrations) were prepared and characterized and the results will be used to refine the initial correlation by modifying the strategy to calculate the concentrations of specific GFC additives. DM100 melter tests in Phase 1 of the work were limited to the high alkali portion of the LAW composition space (Region A and G). Accordingly, as described in Section 3.7, four glass compositions (ORLEC12, ORLEC26, ORLEC27 and ORLEC28) were selected for melter tests.

These compositions cover LAW composition spaces with higher Na and/or K, but lower S concentrations, which represents about one-third of all LAW at Hanford. These glasses meet all of the WTP processing and product quality requirements, as can be seen in Table 3.9. DM100 melter tests using formulations that cover the rest of the Hanford LAW composition space are planned for subsequent phases of this work.

A series of four tests were conducted on the DM100-WV melter to determine feed processing properties and the potential for secondary phase formation while processing waste simulants and additives corresponding to four glass compositions (ORLEC26, ORLEC12, ORLEC27, and ORLEC28) developed for these tests. Each feed was processed at the nominal glass temperature of 1150°C and the bubbling rate was adjusted to target a glass production rate of 2250 $kg/m^2/day$ in nominally 50-hour tests. The melter configuration and operating conditions used in previous LAW tests [5-16, 38, 43, 44, 58, 74, 75] were replicated including a near complete cold cap, which is between 80-95% melt surface coverage for the DM100 since a 100% cold cap tends to lead to "bridging" in smaller melters. Cold cap conditions were mostly similar to those experienced in previous DM100 tests with LAW simulants.

The results from the DM100 tests demonstrate that all four feeds can be processed without the formation of secondary phases or significant processing difficulties. Feeds formulated with only the AP-101 simulated waste were more readily processed, as evidenced by the use of less bubbling to achieve the target feed rate and minimal need to manually remove deposits adhering to the melter walls after discharging. There were no discernable differences in processing the two compositions with the AP-101 simulated waste (ORLEC12 and ORLEC27) in response to the increase in SO_3 and SiO_2 at the expense of Fe_2O_3, TiO_2, and Cr_2O_3 in the form of additives. Feeds formulated with only the AN-105 simulated waste were more difficult to process, as evidenced by the inability to achieve the target glass production rate despite the use of high levels of bubbling and the use of manual methods to remove deposits adhering to the melter walls after every other discharge. The most significant difference between the two waste streams and corresponding glass compositions is the higher concentration of potassium in the AP-101 waste at the expense primarily of sodium.

Analysis of the feed samples and product glasses confirmed the composition of the feed and showed the intended transitions between the various compositions. Glass property measurements on four glasses taken from at or near the end of each of the tests permit direct comparisons with the corresponding crucible melt results for melt viscosity, melt electrical conductivity, sodium and boron PCT releases, VHT alteration rate, and secondary phases in both as melted and canister cooled glasses. All of the measured properties of the crucible and melter glasses are within acceptable limits for processing and product quality (with the exception of one VHT replicate on one melter glass). Although similar to crucible glasses, melter glasses were found to be slightly less electrically conductive and viscous and have higher PCT releases than crucible glasses due to small differences in aluminum, boron, sodium, silicon, and zirconium content.

The melter exhaust was sampled during each test for particulate and gaseous species to determine the effect of different glass formulations and waste compositions on emissions as well as to enable mass balance determinations for select elements of interest. Solids carryover from the melter ranged from 0.19 to 0.61 percent of feed solids for the four new compositions tested. This is less than the 0.77 and 1.0 percent carryover for baseline feeds formulated with the same LAW waste compositions [38], suggesting that the additives used in these formulations result in lower carryover than the blend used in the BNI baseline formulation. Solids carryover from the melter while processing the ORLEC26 feed was about one-third of that measured while processing the other three compositions (0.19% vs. 0.53-0.61%) due to the much lower concentration of potassium and the lack of rhenium in the ORLEC26 melter feed. Potassium, sodium, and chlorine constitute the majority of the particulate matter sampled during the tests.

The feed elements emitted at the lowest melter DF, in ascending order, were rhenium, chlorine, sulfur, potassium, chromium, boron, and sodium. These findings were confirmed by the analysis of material accumulated in the cyclone filters downstream of the melter exhaust sampling point, which contained all of the feed components in similar proportions to the feed for many of the elements, enrichments over feed for volatile elements, most notably rhenium, chlorine, sodium, potassium, boron, chromium, and sulfur, as well as depletions of non-volatile species including aluminum, silicon, iron, magnesium, and zirconium. Chlorine and rhenium, which had the lowest measured DF across the melter have the greatest enrichment (about 30X) in the cyclone powders over the amounts in the target glass. The total recovery of sulfur, rhenium, and chlorine was good for the present tests except for sulfur while processing the low sulfur ORLEC12 composition: mass balance closures were between 84 and 115% except for the one sulfur value. Retentions of chlorine, sulfur, and rhenium in the glass were 50-70%, 88% (with the exception of the test with the ORLEC12 composition), and 30%, respectively, with the balance being emitted from the melter as particulate. The most abundant nitrogen species monitored was NO followed by NO_2, which was about an order of magnitude lower in concentration. Concentrations of nitrogen oxides and by-products of incomplete organic combustion, such as ammonia and carbon monoxide were very similar between the four tests.

SECTION 8.0
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Table 1.1. Waste Loading Improvements in LAW Glass Formulations Developed for WTP and ORP.

Waste ID	Loading	Bechtel Baseline [7, 11, 13-16]		Bechtel Correlation (2007) [38]		ORP (2006) [43, 44]		ORP (2007) [45]		ORP (2008) [46]		ORP (2010) [47]		ORP Summary	
AN-105	**Waste**	**Glass LAWA44**	**26.0%**	**Glass LAWE4H**	**27.2%**	**Glass LAWA187**	**30.5%**	**Glass ORPLA15**	**31.6%**	**Glass ORPLA20**	**31.6%**	**Glass ORPLA38-1**	**31.5%**	**Glass ORPLA38-1**	**31.5%**
	Na_2O		**20.0%**		**21.3%**		**22.9%**		**24.0%**		**24.0%**		**24.0%**		**24.0%**
	K_2O		**0.5%**		**0.5%**		**0.5%**		**0.5%**		**0.5%**		**0.5%**		**0.5%**
	SO_3		**0.2%**		**0.4%**		**1.0%**		**0.6%**		**0.7%**		**0.8%**		**0.8%**
AP-101	**Waste**	**Glass LAWA126**	**24.5%**	**Glass LAWE3**	**25.4%**	-		-		**Glass ORPLG9**	**29.1%**	**Glass ORPLG27**	**29.1%**	**Glass ORPLG27**	**29.1%**
	Na_2O		**18.5%**		**18.2%**						**21.0%**		**21.0%**		**21.0%**
	K_2O		**3.8%**		**5.0%**						**5.8%**		**5.8%**		**5.8%**
	SO_3		**0.4%**		**0.4%**						**0.2%**		**0.5%**		**0.5%**
AN-107	Waste	Glass LAWC22	16.2%	Glass LAWE5H	20.6%	-		Glass ORPLB4	26.2%	-		-		Glass ORPLB4	26.2%
	Na_2O		14.4%		19.0%				24.0%						24.0%
	K_2O		0.1%		0.5%				0.1%						0.1%
	SO_3		0.4%		0.5%				0.9%						0.9%
AN-104	Waste	Glass LAWA137	20.0%	Glass LAWE6H	20.9%	-		Glass ORPLC5	31.0%	-		-		Glass ORPLC5	31.0%
	Na_2O		14.6%		15.8%				23.6%						23.6%
	K_2O		0.3%		0.5%				0.5%						0.5%
	SO_3		0.4%		0.5%				0.7%						0.7%
AN-102	**Waste**	**Glass LAWC35**	**14.0%**	**Glass LAWE7H**	**16.2%**	**Glass LAWC100**	**24.1%**	**Glass ORPLD1**	**24.9%**	**Glass ORPLD6**	**25.9%**	-		**Glass ORPLD6**	**25.9%**
	Na_2O		**12.0%**		**13.5%**		**20.0%**		**21.0%**		**22.0%**				**22.0%**
	K_2O		**0.1%**		**0.5%**		**0.2%**		**0.2%**		**0.2%**				**0.2%**
	SO_3		**0.6%**		**0.6%**		**1.1%**		**1.1%**		**1.2%**				**1.2%**
AZ-101	Waste	Glass LAWB83	7.3%	Glass LAWE9H	11.3%	-		Glass ORPLE12	19.8%	-		-		Glass ORPLE12	19.8%
	Na_2O		5.5%		8.9%				16.0%						16.0%
	K_2O		0.2%		0.5%				0.6%						0.6%
	SO_3		0.7%		0.7%				1.5%						1.5%
AZ-102	**Waste**	**Glass LAWB96**	**3.7%**	**Glass LAWE10H**	**6.2%**	**Glass LAWB99**	**11.9%**	-		**Glass ORPLF7**	**14.3%**	-		**Glass ORPLF7**	**14.3%**
	Na_2O		**5.5%**		**5.7%**		**10.0%**				**12.0%**				**12.0%**
	K_2O		**0.1%**		**0.5%**		**0.4%**				**0.5%**				**0.5%**
	SO_3		**0.7%**		**0.8%**		**1.5%**				**1.5%**				**1.5%**

- Empty data field

Table 2.1. Compositions of Selected ORP LAW Glasses (wt%).

Glass ID	LAWA187	ORPLA15	ORPLA20	ORPLA38-1	ORPLA51	ORPLB4	ORPLC5	LAWC100
Composition Region	Region A	Region A	Region A	Region A	Region A	Region B	Region C	Region D
Al_2O_3	10.57	9.45	6.65	6.95	10.15	9.98	10.02	10.16
B_2O_3	12.77	8.60	8.74	8.22	8.02	8.48	8.50	13.68
CaO	6.47	3.32	3.32	3.13	1.00	1.89	1.91	8.02
Cr_2O_3	0.52	0.49	0.50	0.49	0.02	0.52	0.53	0.02
Cs_2O	-	0.14	-	-	-	0.14	0.14	
Fe_2O_3	0.90	0.92	0.19	0.26	0.19	0.96	0.97	1.00
K_2O	0.51	0.54	0.53	0.52	0.53	0.11	0.54	0.15
MgO	0.90	0.92	0.92	0.98	1.93	0.93	0.93	1.00
MnO_2	-	-	-	-	-	0.05	-	-
Na_2O	23.00	24.00	24.00	24.00	24.00	24.00	23.57	20.00
NiO	-	-	-	-	-	0.04	-	0.03
PbO	-	-	-	-	-	-	-	0.01
SiO_2	34.80	39.25	42.33	41.55	39.03	39.88	40.01	36.62
SnO_2	1.00	2.73	2.74	2.67	1.00	1.00	1.00	-
TiO_2	-	-	-	-	4.00	-	-	-
V_2O_5	0.97	-	-	0.92	0.00	1.99	2.00	1.00
ZnO	2.99	2.43	2.74	2.82	2.80	2.36	2.36	3.00
ZrO_2	2.99	5.91	5.96	6.03	5.96	6.02	6.02	3.00
Cl	0.64	0.68	0.67	0.66	0.67	0.11	0.62	0.65
F	0.00	0.00	0.00	0.00	-	0.47	0.01	0.19
P_2O_5	0.00	0.00	0.00	0.00	-	0.22	0.18	0.27
SO_3	0.95*	0.60*	0.70*	0.80*	0.70	0.85*	0.70*	1.20*
SUM	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

- Empty data field
* SO_3 values were varied during melter tests

Table 2.1. Compositions of Selected ORP LAW Glasses (wt%) (continued).

Glass ID	LAWA161	ORPLD1	ORPLD6	ORPLE12	ORPLF7	LAWB99	ORPLG9	ORPLG27
Composition Region	Region D	Region D	Region D	Region E	Region F	Region F	Region G	Region G
Al_2O_3	10.18	10.15	10.09	7.58	8.65	10.06	6.76	6.02
B_2O_3	13.78	12.02	9.85	9.82	9.54	10.91	8.51	7.91
CaO	8.05	8.01	7.89	10.02	9.78	10.11	2.70	2.68
Cr_2O_3	0.02	0.50	0.50	0.50	0.56	0.11	0.59	0.59
Cs_2O	0.15	0.13	-	0.15	-	-	-	-
Fe_2O_3	1.01	1.00	0.28	0.24	0.23	1.14	0.20	0.28
K_2O	0.45	0.16	0.17	0.55	0.43	0.40	5.76	5.74
Li_2O	-	-	-	2.49	4.37	3.52	-	-
MgO	1.01	1.00	1.00	1.04	0.98	1.14	0.96	0.44
Na_2O	19.90	21.00	22.00	16.00	12.00	9.96	21.00	21.00
NiO	-	0.04	0.04	-	-	-	0.01	0.01
PbO	-	0.01	0.01	-	-	-	0.01	0.01
SiO_2	36.77	37.11	37.24	41.27	42.50	42.79	40.92	42.05
SnO_2	-	-	-	-	-	-	2.84	3.18
TiO_2	-	-	-	0.01	-	-	-	-
V_2O_5	1.01	1.00	1.96	1.74	2.50	1.23	-	-
ZnO	3.01	3.00	2.96	3.21	2.92	3.51	3.40	2.68
ZrO_2	3.01	3.00	3.98	3.53	3.92	3.51	5.68	6.43
Cl	0.56	0.33	0.35	0.02	0.01	0.01	0.23	0.23
F	<0.01	0.17	0.18	0.20	0.07	0.07	0.09	0.09
P_2O_5	-	0.28	0.30	0.12	0.03	0.03	0.14	0.14
SO_3	1.10*	1.10*	1.20*	1.50*	1.50*	1.50	0.20*	0.50*
SUM	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

- Empty data field

* SO_3 values were varied during melter tests

Table 2.2. Glass Processing and Product Quality Requirements.

Property	**Requirement(s) [63]**
Density	< 3.7 g/ml
Liquidus Temperature	< 950°C
LAW Canister Centerline Cooling Heat Treatment	Report amount of crystals
PCT per ASTM C1285 Test conducted at glass to water ratio of 1 gram of glass (-100 +200 mesh) per 10 ml of water at 90°C PCT-B$ PCT-Na$ PCT-Si	< 2.0 g/m^2
VHT$ at 200°C for 24 days	< 50 g/m^2/day
Viscosity$ at 1100°C	10 to 150 P
Electrical Conductivity$ at 1100°C	0.1 to 0.7 S/cm
Glass Transition T_G (onset)	Report T_G
K-3 Refractory Corrosion$	For WTP LAW glass formulation development, a neck corrosion of 0.035 inches on 6-day K-3 coupon corrosion test at 1208°C has been used as an acceptance limit. For the current LAW glass formulation development work for ORP, since higher waste loading compositions are being explored, a slightly higher neck corrosion value of 0.040 inches was used as a guide for acceptable corrosion characteristics.

$Identifies properties for which a model has been developed.

Table 2.3. Composition of the Grouped Component "Others".

Component	Relative Concentration (wt%)	Concentration in Initial ORP Enhanced LAW Correlation Glasses (wt%)
Cl	40.00	0.200
F	16.00	0.080
NiO	1.60	0.008
PbO	1.60	0.008
P_2O_5	40.8	0.204
Total	100.00	0.500

Table 3.1. Target and Analyzed Compositions (wt%) of Twenty Eight ORLEC Crucible Glasses.

Glass	ORLEC1		ORLEC2		ORLEC3		ORLEC4		ORLEC5	
Oxides	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*
Al_2O_3	10.00	9.51	10.00	9.44	10.00	9.52	10.00	9.50	7.80	7.43
B_2O_3	10.00	10.05	10.00	10.12	10.00	10.14	10.00	10.00	10.00	10.27
CaO	1.95	2.07	2.22	2.28	2.63	2.70	3.25	3.33	4.12	4.31
Cr_2O_3	0.58	0.58	0.08	0.13	0.08	0.14	0.08		0.08	0.11
Fe_2O_3	1.00	1.09	1.00	1.01	1.00	1.01	1.00	1.01	1.00	1.08
K_2O	0.50	0.53	0.50	0.54	0.50	0.55	0.50	0.52	0.50	0.47
Li_2O	-	-	-	-	-	-	-	-	-	-
MgO	1.00	0.72	1.00	0.93	1.00	0.98	1.00	0.94	1.00	0.92
Na_2O	24.00	24.21	23.00	24.05	22.00	22.85	21.00	22.07	20.00	20.25
NiO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
PbO	0.01	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
SiO_2	38.09	37.90	39.37	39.26	41.68	41.33	42.73	42.78	44.85	45.10
SnO_2	2.33	2.22	1.33	1.21	0.33	0.35	-	-	-	-
TiO_2	1.00	1.07	1.00	1.03	1.00	1.03	1.00	1.07	1.00	1.05
V_2O_5	-	-	1.05	1.03	1.23	1.23	1.35	1.29	1.49	1.53
ZnO	3.00	3.02	3.00	2.89	3.00	2.98	3.00	2.87	3.00	2.99
ZrO_2	6.03	6.18	5.03	4.93	4.03	4.08	3.50	3.49	3.50	3.67
Cl	0.20	0.15	0.20	0.14	0.20	0.14	0.20	0.13	0.20	0.15
F	0.08	NA	0.08	NA	0.08	NA	0.08	NA	0.08	NA
P_2O_5	0.12	0.16	0.12	0.17	0.12	0.16	0.12	0.14	0.12	0.13
SO_3	0.10	0.10	1.00	0.78	1.10	0.83	1.17	0.75	1.25	0.73
Sum	100.0	99.6	100.0	100.0	100.0	100.0	100.0	99.9	100.0	100.2

*– Analyzed by X-ray fluorescence except for boron and lithium which were measured by DCP
NA = Not Analyzed
- Empty data field

Table 3.1. Target and Analyzed Compositions (wt%) of Twenty Eight ORLEC Crucible Glasses (continued).

Glass	ORLEC6		ORLEC7		ORLEC8		ORLEC9		ORLEC10	
Oxides	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*
Al_2O_3	7.80	7.51	7.80	7.49	7.80	7.35	7.80	7.50	10.00	9.49
B_2O_3	10.00	10.07	10.00	10.03	10.00	10.08	10.00	10.11	10.00	10.08
CaO	5.24	5.43	6.55	6.75	7.91	8.17	9.17	9.37	1.95	1.87
Cr_2O_3	0.08	0.09	0.08	0.12	0.08	0.09	0.08	0.08	0.58	0.52
Fe_2O_3	1.00	1.07	1.00	1.05	1.00	0.99	1.00	1.02	1.00	0.98
K_2O	0.50	0.49	0.50	0.48	0.50	0.48	0.50	0.49	1.42	1.34
Li_2O	0.36	0.42	1.52	1.59	2.08	2.21	2.48	2.64	-	-
MgO	1.00	0.98	1.00	0.99	1.00	0.97	1.00	0.96	1.00	0.98
Na_2O	19.00	19.53	18.00	18.01	17.00	17.76	16.00	16.57	23.39	25.10
NiO	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
PbO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SiO_2	44.21	44.39	42.56	43.15	41.50	41.63	40.71	40.69	37.78	37.45
SnO_2	-	-	-	-	-	-	-	-	2.33	2.27
TiO_2	1.00	1.12	1.00	1.05	1.00	1.06	1.00	1.05	1.00	1.03
V_2O_5	1.59	1.63	1.70	1.69	1.79	1.73	1.87	1.88	-	-
ZnO	3.00	3.03	3.00	2.94	3.00	2.91	3.00	2.96	3.00	2.80
ZrO_2	3.50	3.68	3.50	3.55	3.50	3.51	3.50	3.56	6.03	5.63
Cl	0.20	0.13	0.20	0.13	0.20	0.12	0.20	0.13	0.20	0.14
F	0.08	NA	0.08	NA	0.08	NA	0.08	NA	0.08	NA
P_2O_5	0.12	0.13	0.12	0.12	0.12	0.13	0.12	0.13	0.12	0.13
SO_3	1.31	0.70	1.37	0.88	1.42	0.99	1.47	1.03	0.10	0.13
Sum	100.0	100.4	100.0	100.0	100.0	100.2	100.0	100.2	100.0	99.9

*– Analyzed by X-ray fluorescence except for boron and lithium which were measured by DCP
NA = Not Analyzed
- Empty data field

Table 3.1. Target and Analyzed Compositions (wt%) of Twenty Eight ORLEC Crucible Glasses (continued).

Glass	ORLEC11		ORLEC12		ORLEC13		ORLEC14		ORLEC15		ORLEC16	
Oxides	Target	Analyzed*	Target	Analyzed*	Target	Target	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*
Al_2O_3	10.00	9.64	10.00	9.47	10.00	9.29	10.00	9.36	10.00	9.40	10.00	9.44
B_2O_3	10.00	10.05	10.00	10.05	10.00	10.08	10.00	10.05	10.00	10.12	10.00	10.15
CaO	1.95	1.96	1.95	1.91	1.95	2.06	1.95	2.07	1.95	2.03	2.50	2.65
Cr_2O_3	0.58	0.61	0.58	0.54	0.49	0.51	0.34	0.37	0.23	0.25	0.15	0.24
Fe_2O_3	1.00	1.04	1.00	1.02	0.73	0.81	0.34	0.37	0.20	0.24	0.20	0.21
K_2O	3.36	3.24	5.64	5.29	0.50	0.48	0.50	0.49	0.50	0.50	0.50	0.51
Li_2O	-	-	-	-	-	-	-	-	-	-	-	-
MgO	1.00	0.96	1.00	0.96	1.00	0.93	1.00	0.92	1.00	0.90	1.00	0.90
Na_2O	22.11	22.73	20.61	21.91	24.00	24.39	24.00	24.31	24.00	24.43	23.00	23.23
NiO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
PbO	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SiO_2	37.12	36.93	36.34	36.53	38.52	38.26	38.81	38.71	38.72	38.51	40.82	40.72
SnO_2	2.33	2.37	2.33	2.23	2.33	2.35	2.33	2.33	2.33	2.38	1.33	1.40
TiO_2	1.00	1.03	1.00	1.05	0.73	0.80	0.34	0.41	0.02	0.08	0.00	0.05
V_2O_5	-	-	-	-	-	-	0.35	0.36	0.77	0.81	1.05	1.09
ZnO	3.00	2.95	3.00	2.86	3.00	3.03	3.00	3.04	3.00	3.03	3.00	3.06
ZrO_2	6.03	5.97	6.03	5.70	6.03	6.30	6.03	6.26	6.03	6.30	5.03	5.34
Cl	0.20	0.14	0.20	0.13	0.20	0.16	0.20	0.17	0.20	0.17	0.20	0.14
F	0.08	NA	0.08	NA	0.08	NA	0.08	NA	0.08	NA	0.08	NA
P_2O_5	0.12	0.13	0.12	0.14	0.12	0.13	0.12	0.13	0.12	0.13	0.12	0.14
SO_3	0.10	0.11	0.10	0.12	0.30	0.31	0.60	0.54	0.84	0.68	1.00	0.79
Sum	100.0	99.9	100.0	99.9	100.0	99.9	100.0	99.9	100.0	100.0	100.0	100.1

*– Analyzed by X-ray fluorescence except for boron and lithium which were measured by DCP
NA = Not Analyzed
- Empty data field

Table 3.1. Target and Analyzed Compositions (wt%) of Twenty Eight ORLEC Crucible Glasses (continued).

Glass	ORLEC17		ORLEC18		ORLEC19		ORLEC20		ORLEC21		ORLEC22	
Oxides	Target	Analyzed*	Target	Analyzed*	Target	Target	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*
Al_2O_3	10.00	9.44	9.07	8.59	8.12	7.69	7.80	7.36	7.80	7.34	7.80	7.42
B_2O_3	10.00	10.07	10.00	10.07	10.00	10.01	10.00	10.09	10.00	10.04	10.00	10.00
CaO	3.64	3.93	4.58	4.78	5.49	5.63	6.22	6.56	6.94	7.18	7.58	7.83
Cr_2O_3	0.10	0.12	0.08	0.16	0.08	0.10	0.08	0.10	0.08	0.11	0.08	0.08
Fe_2O_3	0.20	0.24	0.20	0.25	0.20	0.22	0.20	0.25	0.20	0.24	0.20	0.23
K_2O	0.50	0.52	0.50	0.50	0.50	0.51	0.50	0.49	0.50	0.49	0.50	0.51
Li_2O	-	-	-	-	-	-	0.37	0.42	1.45	1.56	2.14	2.25
MgO	1.00	0.91	1.00	0.93	1.00	0.96	1.00	0.98	1.00	0.96	1.00	0.93
Na_2O	22.00	21.97	21.00	21.52	20.00	20.63	19.00	19.26	18.00	18.54	17.00	17.42
NiO	0.01	0.01	0.01		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
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
SiO_2	42.46	42.46	44.13	43.81	44.96	44.84	45.01	44.94	44.04	44.02	43.57	43.63
SnO_2	0.33	0.32	-	-	-	-	-	-	-	-	-	-
TiO_2	0.00	0.06	0.00	0.04	0.00	0.05	0.00	0.04	0.00	0.04	0.00	0.05
V_2O_5	1.22	1.30	1.35	1.40	1.49	1.50	1.59	1.60	1.70	1.71	1.79	1.81
ZnO	3.00	3.14	3.00	3.09	3.00	2.92	3.00	3.08	3.00	2.97	3.00	2.98
ZrO_2	4.03	4.36	3.50	3.75	3.50	3.65	3.50	3.77	3.50	3.66	3.50	3.69
Cl	0.20	0.14	0.20	0.14	0.20	0.15	0.20	0.14	0.20	0.14	0.20	0.15
F	0.08	NA	0.08	NA	0.08	NA	0.08	NA	0.08	NA	0.08	NA
P_2O_5	0.12	0.13	0.12	0.12	0.12	0.14	0.12	0.13	0.12	0.13	0.12	0.12
SO_3	1.10	0.87	1.17	0.81	1.25	0.87	1.31	0.82	1.37	0.93	1.42	1.00
Sum	100.0	100.0	100.0	100.0	100.0	99.9	100.0	100.1	100.0	100.1	100.0	100.1

*– Analyzed by X-ray fluorescence except for boron and lithium which were measured by DCP
NA = Not Analyzed
- Empty data field

Table 3.1. Target and Analyzed Compositions (wt%) of Twenty Eight ORLEC Crucible Glasses (continued).

Glass	ORLEC23		ORLEC24		ORLEC25		ORLEC26		ORLEC27		ORLEC28	
Oxides	Target	Analyzed*	Target	Analyzed*	Target	Target	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*
Al_2O_3	7.80	7.25	10.00	9.34	10.00	9.57	10.00	9.44	10.00	9.42	10.00	9.48
B_2O_3	10.00	10.06	10.00	10.07	10.00	10.08	10.00	9.75	10.00	9.33	10.00	9.62
CaO	8.19	8.42	1.95	2.00	1.95	1.93	1.95	2.00	1.95	2.04	1.95	2.00
Cr_2O_3	0.08	0.07	0.34	0.36	0.34	0.34	0.44	0.43	0.44	0.43	0.44	0.44
Fe_2O_3	0.20	0.21	0.34	0.38	0.34	0.36	0.60	0.64	0.60	0.65	0.60	0.66
K_2O	0.50	0.49	1.42	1.41	5.64	5.33	0.50	0.50	5.64	5.58	3.36	3.40
Li_2O	2.45	2.60	-	-	-	-	-	-	-	-	-	-
MgO	1.00	0.93	1.00	0.91	1.00	0.94	1.00	0.92	1.00	0.88	1.00	0.94
Na_2O	16.00	16.26	23.39	23.84	20.61	22.02	24.00	24.48	20.61	20.99	22.11	22.48
NiO	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
PbO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
SiO_2	43.51	43.89	38.49	38.61	37.06	37.04	38.73	38.71	36.98	37.13	37.76	37.58
SnO_2	-	-	2.33	2.25	2.33	2.14	2.33	2.30	2.33	2.24	2.33	2.23
TiO_2	0.00	0.04	0.34	0.38	0.34	0.39	0.60	0.67	0.60	0.65	0.60	0.70
V_2O_5	1.88	1.91	0.35	0.38	0.35	0.35	-	-	-	-	-	-
ZnO	3.00	2.94	3.00	3.01	3.00	2.84	3.00	3.00	3.00	3.00	3.00	3.06
ZrO_2	3.50	3.61	6.03	6.14	6.03	5.80	6.03	6.10	6.03	6.15	6.03	6.23
Cl	0.20	0.14	0.20	0.17	0.20	0.14	0.20	0.15	0.20	0.14	0.20	0.16
F	0.08	NA	0.08	NA	0.08	NA	0.08	NA	0.08	NA	0.08	NA
P_2O_5	0.12	0.13	0.12	0.14	0.12	0.15	0.12	0.14	0.12	0.14	0.12	0.13
SO_3	1.47	1.16	0.60	0.55	0.60	0.51	0.40	0.38	0.40	0.39	0.40	0.37
Sum	100.0	100.1	100.0	99.9	100.0	100.0	100.0	99.6	100.0	99.2	100.0	99.5

*– Analyzed by X-ray fluorescence except for boron and lithium which were measured by DCP
NA = Not Analyzed
- Empty data field

Table 3.2. Descriptions of Twenty Eight Heat Treated ORLEC Crucible Glasses.

Glass ID	**Heat Treatment - Glass remelted at 1200°C for 1 hour, heat treated for 20 hours at 950°C, then quenched.**
ORLEC1	Clear emerald green glass - small (10 µm) triangular crystals , possibly spinel –less than 0.1 vol%
ORLEC2	Clear bright lime green glass
ORLEC3	Clear bright lime green glass
ORLEC4	Clear bright lime green glass
ORLEC5	Clear bright lime green glass
ORLEC6	Clear bright lime green glass
ORLEC7	Clear bright lime green glass
ORLEC8	Clear bright lime green glass
ORLEC9	Clear bright lime green glass
ORLEC10	Clear emerald green glass
ORLEC11	Clear emerald green glass
ORLEC12	Clear emerald green glass
ORLEC13	Clear emerald green glass
ORLEC14	Clear emerald green glass
ORLEC15	Clear bright lime green glass
ORLEC16	Clear bright lime green glass
ORLEC17	Clear bright lime green glass
ORLEC18	Clear bright lime green glass
ORLEC19	Clear bright lime green glass
ORLEC20	Clear bright lime green glass
ORLEC21	Clear bright lime green glass
ORLEC22	Clear bright lime green glass
ORLEC23	Clear bright lime green glass
ORLEC24	Clear emerald green glass
ORLEC25	Clear emerald green glass
ORLEC26	Clear emerald green glass
ORLEC27	Clear emerald green glass
ORLEC28	Clear emerald green glass

Table 3.3. Measured Sulfate Solubility in Twenty Eight ORLEC Crucible Glasses.

Sample ID	SO$_3$ Content (wt%)		
	Batch Saturation		Bubbling
	As-Melted	After Acid Wash	
ORLEC1S4	0.29	0.27	Not measured
ORLEC2S4	0.78	0.75	
ORLEC3S4	0.81	0.78	
ORLEC4S4	0.76	0.67	
ORLEC5S4	0.77	0.76	
ORLEC6S4	0.74	0.77	
ORLEC7S4	0.97	0.95	
ORLEC8S4	1.16	1.06	
ORLEC9S4	1.30	1.21	
ORLEC10S4	0.35	0.33	
ORLEC11S4	0.31	0.31	
ORLEC12S4	0.28	0.28	
ORLEC13S4	0.43	0.43	
ORLEC14S4	0.64	0.61	
ORLEC15S4	0.76	0.75	
ORLEC16S4	0.80	0.77	
ORLEC17S4	0.88	0.77	
ORLEC18S4	0.86	0.76	
ORLEC19S4	0.83	0.79	
ORLEC20S4	0.94	0.82	
ORLEC21S4	0.98	1.02	
ORLEC22S4	1.18	1.14	
ORLEC23S4	1.31	1.25	
ORLEC24S4	0.61	0.61	
ORLEC25S4	0.59	0.57	
ORLEC26S4	0.47	0.45	0.59 (onset at 0.40)
ORLEC27S4	0.46	0.43	0.51 (onset at 0.36)
ORLEC28S4	0.48	0.46	0.61 (onset at 0.43)

Table 3.4. Results of 7-day PCT (at 90ºC) for Twenty Eight ORLEC Crucible Glasses.

Glass ID	ORLEC1	ORLEC2	ORLEC3	ORLEC4	ORLEC5	ORLEC6	ORLEC7	ORLEC8	ORLEC9	ORLEC10
7-Day PCT, Stainless Steel Vessel; S/V=2000 m^{-1} (ppm)										
B	30.56	28.04	25.5	19.69	19.33	18.67	18.49	18.62	17.69	22.35
Na	186.95	156.52	134.83	102.78	95.35	89.6	100.68	98.63	87.17	155.77
Si	59.81	54.04	52.85	53.28	56.51	51.89	56.83	54.28	47.6	52.78
Normalized Concentrations (g/L)										
B	0.98	0.90	0.82	0.63	0.62	0.60	0.60	0.60	0.57	0.72
Na	1.05	0.92	0.83	0.66	0.64	0.64	0.75	0.78	0.73	0.90
Si	0.34	0.29	0.27	0.27	0.27	0.25	0.29	0.28	0.25	0.30
pH	11.40	11.21	10.87	11.10	11.15	11.02	11.31	11.46	11.30	11.46
7-Day PCT Normalized Mass Loss (g/m^2)										
B	0.49	0.45	0.41	0.32	0.31	0.30	0.30	0.30	0.28	0.36
Na	0.52	0.46	0.41	0.33	0.32	0.32	0.38	0.39	0.37	0.45
Si	0.17	0.15	0.14	0.13	0.13	0.13	0.14	0.14	0.13	0.15

Table 3.4. Results of 7-day PCT (at 90°C) for Twenty Eight ORLEC Crucible Glasses (continued).

Glass ID	ORLEC11	ORLEC12	ORLEC13	ORLEC14	ORLEC15	ORLEC16	ORLEC17	ORLEC18	ORLEC19
7-Day PCT, Stainless Steel Vessel; S/V=2000 m^{-1} (ppm)									
B	25.28	39.44	26.04	29.52	30.52	27.1	26.49	22.32	20.54
Na	153.75	185.35	168.64	171.75	175.62	149.02	135.06	119.17	108.6
Si	48.56	48.57	58.41	58.43	55.73	52.95	56.47	58.41	58.52
Normalized Concentrations (g/L)									
B	0.81	1.27	0.84	0.95	0.98	0.87	0.85	0.72	0.66
Na	0.94	1.21	0.95	0.96	0.99	0.87	0.83	0.76	0.73
Si	0.28	0.29	0.32	0.32	0.31	0.28	0.28	0.28	0.28
pH	11.34	11.07	10.90	10.81	10.81	11.05	11.20	11.30	11.37
7-Day PCT Normalized Mass Loss (g/m^2)									
B	0.41	0.64	0.42	0.48	0.49	0.44	0.43	0.36	0.33
Na	0.47	0.61	0.47	0.48	0.49	0.44	0.41	0.38	0.37
Si	0.14	0.14	0.16	0.16	0.15	0.14	0.14	0.14	0.14

Table 3.4. Results of 7-day PCT (at 90°C) for Twenty Eight ORLEC Crucible Glasses (continued).

Glass ID	ORLEC20	ORLEC21	ORLEC22	ORLEC23	ORLEC24	ORLEC25	ORLEC26	ORLEC27	ORLEC28
7-Day PCT, Stainless Steel Vessel; S/V=2000 m^{-1} (ppm)									
B	18.48	19.23	17.43	16.34	28.54	50.37	22.81	42.38	31.61
Na	103	106.4	98.95	85.47	163.92	218.82	157.68	196.03	166.96
Si	55.88	57.75	55.56	48.45	54.61	52.59	55.35	53.32	52.83
Normalized Concentrations (g/L)									
B	0.60	0.62	0.56	0.53	0.92	1.62	0.73	1.36	1.02
Na	0.73	0.80	0.78	0.72	0.94	1.43	0.89	1.28	1.02
Si	0.27	0.28	0.27	0.24	0.30	0.30	0.31	0.31	0.30
pH	11.41	11.53	11.32	11.33	11.35	11.17	11.11	11.01	10.86
7-Day PCT Normalized Mass Loss (g/m^2)									
B	0.30	0.31	0.28	0.26	0.46	0.81	0.37	0.68	0.51
Na	0.37	0.40	0.39	0.36	0.47	0.72	0.44	0.64	0.51
Si	0.13	0.14	0.14	0.12	0.15	0.15	0.15	0.15	0.15

Table 3.5. Results of VHT (at 200ºC for 24 Days) for Twenty Eight ORLEC Crucible Glasses.

Glass ID	Alteration Depth (µm)	Rate (g/m²/d) Calculated for Estimated Average Density of 2.65 g/cc	Comparison to Limit of 50 g/m²/d	Predicted Rate (g/m²/d)
ORLEC1	237.0	26.2	52%	20.5
ORLEC2	472.4	52.2	104%	20.0
ORLEC3	302.0	33.3	67%	16.5
ORLEC4	243.5	26.9	54%	9.9
ORLEC5	24.8	2.7	5%	3.0
ORLEC6	6.1	0.7	1%	3.4
ORLEC7	196.5	21.7	43%	15.4
ORLEC8	231.0	25.5	51%	19.2
ORLEC9	188.5	20.8	42%	18.9
ORLEC10	11.5	1.3	3%	13.6
ORLEC11	266.5	29.4	59%	12.8
ORLEC12	372.5	41.1	82%	47.3
ORLEC13	41.4	4.6	9%	20.3
ORLEC14	14.1	1.6	3%	21.5
ORLEC15	22.7	2.5	5%	23.5
ORLEC16	189.0	20.9	42%	18.8
ORLEC17	347.5	38.4	77%	16.0
ORLEC18	214.0	23.6	47%	9.1
ORLEC19	162.5	17.9	36%	4.0
ORLEC20	200.5	22.1	44%	4.5
ORLEC21	307.0	33.9	68%	16.6
ORLEC22	321.5	35.5	71%	25.4
ORLEC23	368.5	40.7	81%	22.6
ORLEC24	20.9	2.3	5%	14.3
ORLEC25-T1	673.8	74.4	149%	49.6
ORLEC25-T2	713.8	78.8	158%	
ORLEC25-T3	685.7	75.7	151%	
ORLEC26	5.1	0.6	1%	20.2
ORLEC27	351.6	38.8	78%	46.7
ORLEC28	58.9	6.5	13%	12.7

Table 3.6. Viscosities and Electrical Conductivities for Twenty Eight ORLEC Crucible Glasses.

Glass ID			ORLEC1	ORLEC2	ORLEC3	ORLEC4	ORLEC5	ORLEC6	ORLEC7	ORLEC8	ORLEC9	ORLEC10
Viscosity (P)	Predicted at 1100°C		104	104	120	131	120	98	52	38	30	103
	Predicted at 1150°C		60	62	72	79	72	59	33	24	19	60
	Interpolated	950°C	777	936	879	931	964	756	332	224	184	821
		1000°C	349	425	415	444	452	357	168	116	96	366
		1050°C	174	214	215	232	233	186	93	65	54	182
		1100°C	94	117	121	131	130	105	55	40	33	98
		1150°C	55	69	73	79	78	63	35	25	21	57
		1200°C	34	43	46	50	49	40	23	17	14	35
		1250°C	22	28	31	33	33	27	16	12	10	23
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.649	0.269	0.582	0.507	0.445	0.398	0.370	0.414	0.419	0.617
	Interpolated	950°C	0.251	0.257	0.232	0.209	0.178	0.167	0.177	0.174	0.153	0.248
		1000°C	0.309	0.318	0.283	0.257	0.225	0.210	0.228	0.223	0.199	0.307
		1050°C	0.374	0.387	0.341	0.311	0.277	0.260	0.284	0.280	0.254	0.374
		1100°C	0.446	0.465	0.405	0.371	0.333	0.317	0.346	0.346	0.319	0.449
		1150°C	0.523	0.551	0.475	0.438	0.393	0.381	0.413	0.421	0.393	0.532
		1200°C	0.606	0.645	0.552	0.511	0.456	0.453	0.484	0.506	0.478	0.623
		1250°C	0.695	0.747	0.634	0.590	0.521	0.532	0.560	0.601	0.574	0.722

Table 3.6. Viscosities and Electrical Conductivities for Twenty Eight ORLEC Crucible Glasses (continued).

Glass ID			ORLEC11	ORLEC12	ORLEC13	ORLEC14	ORLEC15	ORLEC16	ORLEC17	ORLEC18	ORLEC19	ORLEC20
Viscosity (P)	Predicted at 1100°C		102	101	109	112	111	123	125	123	120	103
	Predicted at 1150°C		60	62	63	65	64	72	75	74	72	62
	Interpolated	950°C	782	879	1017	1143	988	1056	1051	982	979	820
		1000°C	350	393	433	465	429	477	490	458	449	383
		1050°C	174	195	209	219	208	240	251	236	229	198
		1100°C	95	105	111	115	111	131	139	132	127	111
		1150°C	55	60	64	66	64	77	82	79	76	67
		1200°C	34	37	40	41	39	48	52	50	48	42
		1250°C	22	24	26	27	25	32	34	33	32	28
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.649	0.269	0.582	0.507	0.445	0.398	0.370	0.414	0.419	0.617
	Interpolated	950°C	0.230	0.189	0.265	0.269	0.288	0.255	0.231	0.218	0.161	0.156
		1000°C	0.286	0.238	0.327	0.331	0.350	0.313	0.280	0.266	0.200	0.197
		1050°C	0.350	0.294	0.397	0.401	0.419	0.378	0.334	0.319	0.244	0.245
		1100°C	0.422	0.358	0.475	0.480	0.496	0.451	0.394	0.378	0.295	0.299
		1150°C	0.502	0.431	0.561	0.567	0.579	0.531	0.459	0.443	0.350	0.360
		1200°C	0.591	0.511	0.656	0.662	0.670	0.619	0.529	0.513	0.411	0.428
		1250°C	0.688	0.600	0.758	0.766	0.767	0.713	0.605	0.588	0.478	0.503

Table 3.6. Viscosities and Electrical Conductivities for Twenty Eight ORLEC Crucible Glasses (continued).

Glass ID			ORLEC21	ORLEC22	ORLEC23	ORLEC24	ORLEC25	ORLEC26	ORLEC27	ORLEC28
Viscosity (P)	Predicted at 1100°C		63	48	45	112	109	112	108	110
	Predicted at 1150°C		39	30	28	64	63	65	62	63
	Interpolated	950°C	419	317	284	985	896	958	910	989
		1000°C	208	163	146	437	401	419	406	436
		1050°C	113	91	81	214	198	204	200	213
		1100°C	66	54	49	114	107	109	107	113
		1150°C	41	34	31	65	61	62	61	65
		1200°C	27	22	20	40	37	38	37	39
		1250°C	18	15	14	25	24	24	24	25
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.649	0.269	0.582	0.507	0.445	0.398	0.370	0.414
	Interpolated	950°C	0.169	0.167	0.166	0.262	0.197	0.250	0.192	0.222
		1000°C	0.214	0.213	0.212	0.314	0.248	0.306	0.240	0.276
		1050°C	0.265	0.266	0.265	0.373	0.307	0.368	0.296	0.338
		1100°C	0.324	0.326	0.327	0.436	0.373	0.438	0.360	0.408
		1150°C	0.390	0.393	0.397	0.504	0.448	0.514	0.431	0.485
		1200°C	0.463	0.469	0.476	0.578	0.531	0.597	0.510	0.570
		1250°C	0.543	0.552	0.564	0.656	0.623	0.686	0.597	0.664

Table 3.7. Results of K-3 Corrosion Testing for Twenty Six ORLEC Crucible Glasses.

Glass ID	Neck loss (inches)	Depth of altered zone (inches)	Half-down loss (inches)
ORLEC1	0.0250	0.0325	0.0003
ORLEC2	0.0315	0.0295	expanded
ORLEC3	0.0130	0.0225	0.0010
ORLEC4	0.0045	0.0175	expanded
ORLEC6	0.0130	0.0180	0.0005
ORLEC7	0.0340	0.0240	0.0015
ORLEC8	0.0430	0.0290	0.0035
ORLEC9	0.0445	0.0325	0.0015
ORLEC10	0.0160	0.0270	0.0000
ORLEC11	0.0315	0.0280	expanded
ORLEC12	0.0315	0.0250	0.0010
ORLEC13	0.0110	0.0285	expanded
ORLEC14	0.0235	0.0260	expanded
ORLEC15	0.0270	0.0280	expanded
ORLEC16	0.0175	0.0245	0.0020
ORLEC17	0.0270	0.0225	0.0000
ORLEC18	0.0230	0.0210	0.0017
ORLEC19	0.0105	0.0210	0.0005
ORLEC20	0.0090	0.0200	expanded
ORLEC21	0.0260	0.0245	0.0025
ORLEC22	0.0330	0.0260	0.0040
ORLEC23	0.0265	0.0255	0.0020
ORLEC24	0.0290	0.0255	0.0020
ORLEC26	0.0275	0.0250	0.0010
ORLEC27	0.0295	0.0240	0.0005
ORLEC28	0.0300	0.0230	0.0015

Table 3.8. Waste Compositions and Corresponding Waste Loadings in Glass.

ORP Composition Region Designation	WTP Baseline LAW Glass Correlation			ORP Enhanced LAW Glass Correlation				
	Tank / Sub-Envelope Identification	Glass Identification	Target Minimum Waste Loading (wt%)	ORP Glass Identification	Na_2O (wt%)	K_2O (wt%)	SO_3 (wt%)	Waste Loading (wt%)
A	AN-105/ Sub-Envelope A1	LAWE4H	27.18	ORLEC26	24.00	0.54	0.40	31.08
Transition from A to G	51.66% AP-101 + 48.34% AN-105 at K/Na molar ratio of 0.1	Not tested		ORLEC28	22.11	3.36	0.40	29.74
G with low SO_3	AP-101/ Sub-Envelope A2	LAWE3	25.41	ORLEC12	20.61	5.64	0.10	28.39
G with high SO_3				ORLEC27	20.61	5.64	0.40	28.69

Table 3.9. Summary of Test Results for Four Selected ORLEC Glass Formulations and Comparison to ILAW Requirements.

Test	**Requirement [63, 70]**	**Test Results for ORLEC26, Region A**	**Test Results for ORLEC12, Region G Low SO_3**	**Test Results for ORLEC27, Region G High SO_3**	**Test Results for ORLEC28, Intermediate Region A/G High SO_3**
Waste description		Tank AN-105 (24 wt% Na_2O, 0.5 wt% K_2O, 0.4 wt% SO_3)	Tank AP-101 (20.6 wt% Na_2O, 5.6% wt% K_2O, 0.1 wt% SO_3)	Tank AP-101 (20.6 wt% Na_2O, 5.6 wt% K_2O, 0.4 wt% SO_3)	Mixed AP-101/AN-105 at K/Na molar ratio of 0.1 (22.1 wt%, Na_2O, 3.4 wt% K_2O, 0.4 wt% SO_3)
Density of glass	< 3.7 g/cc	Not measured – used 2.65 g/cc as average for LAW glasses in VHT alteration rate calculation.			
Crystalline Phase	Phase identification	Clear homogeneous glass after heat treatment at 950°C for 20 hours	Clear homogeneous glass after heat treatment at 950°C for 20 hours	Clear homogeneous glass after heat treatment at 950°C for 20 hours	Clear homogeneous glass after heat treatment at 950°C for 20 hours
Liquidus	< 950°C	< 950°C	< 950°C	< 950°C	< 950°C
PCT B (g/m^2)	< 2.0 g/m^2	0.37 g/m^2	0.64 g/m^2	0.68 g/m^2	0.51 g/m^2
PCT Na (g/m^2)	< 2.0 g/m^2	0.44 g/m^2	0.61 g/m^2	0.64 g/m^2	0.51 g/m^2
PCT Si (g/m^2)	< 2.0 g/m^2	0.15 g/m^2	0.14 g/m^2	0.15 g/m^2	0.15 g/m^2
VHT at 200°C (g/m^2/day)	< 50 g/m^2/day	0.6 g/m^2/day	41 g/m^2/day	39 g/m^2/day	7 g/m^2/day
Viscosity (poise) at 1100°C	10 to 150 P	94 P	109 P	107 P	113 P
Conductivity (S/cm) at 1100°C	0.2 to 0.7 S/cm	0.446 S/cm	0.438 S/cm	0.360 S/cm	0.408 S/cm

Table 3.10. Oxide Composition of AN-105 Simulant and ORLEC26 Glass Composition Used in DM100 Melter Tests (wt%).

Components	AN-105 waste contribution	Glass former additives	ORLEC26 (for AN-105)
Loading	31.05%	68.95%	
Al_2O_3	5.59	4.41	10.00
B_2O_3	0.02	9.98	10.00
CaO		1.95	1.95
Cr_2O_3	0.08	0.36	0.44
Fe_2O_3		0.60	0.60
K_2O	0.54		0.54
MgO		1.00	1.00
Na_2O	24.00	-	24.00
NiO	0.01	-	0.01
PbO	0.01	-	0.01
SiO_2		38.69	38.69
SnO_2		2.33	2.33
TiO_2		0.60	0.60
ZnO		3.00	3.00
ZrO_2		6.03	6.03
Cl	0.20	-	0.20
F	0.08	-	0.08
P_2O_5	0.12	-	0.12
SO_3	0.40	-	0.40
Sum	31.05	68.95	100.00

- Empty data field

Table 3.11. Oxide Composition of AP-101 Simulant Adjusted to 0.1 wt% SO_3 and ORLEC12 Glass Composition Used in DM100 Melter Tests (wt%).

Components	AP-101 waste contribution	Glass former additives	ORLEC12 (for AP-101)
Loading	28.39%	71.61%	-
Al_2O_3	1.51	8.49	10.00
B_2O_3	0.00	10.00	10.00
CaO		1.95	1.95
Cr_2O_3	0.08	0.50	0.58
Fe_2O_3		1.00	1.00
K_2O	5.64		5.64
MgO		1.00	1.00
Na_2O	20.61		20.61
NiO	0.01		0.01
PbO	0.01		0.01
SiO_2	0.03	36.31	36.34
SnO_2		2.33	2.33
TiO_2		1.00	1.00
ZnO		3.00	3.00
ZrO_2		6.03	6.03
Cl	0.20		0.20
F	0.08		0.08
P_2O_5	0.12		0.12
SO_3	0.10		0.10
Sum	28.39	71.61	100.00

- Empty data field

Table 3.12. Oxide Composition of AP-101 Simulant at Nominal 0.4 wt% SO_3 and ORLEC27 Glass Composition Used in DM100 Melter Tests (wt%).

Components	AP-101 waste contribution	Glass former additives	ORLEC27 (for AP-101)
Loading	28.69%	71.31%	-
Al_2O_3	1.51	8.49	10.00
B_2O_3	0.00	10.00	10.00
CaO		1.95	1.95
Cr_2O_3	0.08	0.36	0.44
Fe_2O_3		0.60	0.60
K_2O	5.64		5.64
MgO		1.00	1.00
Na_2O	20.61		20.61
NiO	0.01		0.01
PbO	0.01		0.01
SiO_2	0.03	36.95	36.98
SnO_2		2.33	2.33
TiO_2		0.60	0.60
ZnO		3.00	3.00
ZrO_2		6.03	6.03
Cl	0.20		0.20
F	0.08		0.08
P_2O_5	0.12		0.12
SO_3	0.40		0.40
Sum	28.69	71.31	100.00

- Empty data field

Table 3.13. Oxide Composition of Intermediate Waste AN-105/AP-101 Simulant at K/Na molar ratio of 0.1 and ORLEC28 Glass Composition Used in DM100 Melter Tests (wt%).

Components	AP-101/AN105 waste contribution	Glass former additives	ORPLEC28 (for 51.66% AP-101 + 48.34% AN-105)
Loading	29.74%	70.26%	
Al_2O_3	3.33	6.67	10.00
B_2O_3	0.01	9.99	10.00
CaO		1.95	1.95
Cr_2O_3	0.08	0.36	0.44
Fe_2O_3		0.60	0.60
K_2O	3.36		3.36
MgO		1.00	1.00
Na_2O	22.11		22.11
NiO	0.01		0.01
PbO	0.01		0.01
SiO_2	0.03	37.73	37.76
SnO_2		2.33	2.33
TiO_2		0.60	0.60
ZnO		3.00	3.00
ZrO_2		6.03	6.03
Cl	0.20		0.20
F	0.08		0.08
P_2O_5	0.12		0.12
SO_3	0.40		0.40
Sum	29.74	70.26	100.00

- Empty data field

Table 3.14. Glass Former Additives for 1 Liter of Waste and Corresponding Glass Yields.

Waste Description	AN-105	AP-101	AP-101	51.66% AP-101 + 48.34% AN-105
Glass Formulation	ORLEC26	ORLEC12	ORLEC27	ORLEC28
Additives in Glass (wt%)	68.95%	71.61%	71.31%	70.26%
Kyanite (Al_2SiO_5) 325 Mesh (Kyanite Mining) (g)	80.18	179.08	179.08	130.92
H_3BO_3 (US Borax – Technical Granular) (g)	183.22	213.59	213.59	198.91
Wollastonite NYAD 325 Mesh (NYCO Minerals) (g)	42.43	51.61	51.61	48.11
Cr_2O_3	3.79	6.14	4.42	4.12
Fe_2O_3	3.95	8.98	4.14	4.08
Olivine (Mg_2SiO_4) 325 Mesh (#180 Unimin) (g)	21.73	24.42	24.42	22.77
SiO_2 (Sil-co-Sil 75 US Silica) (g)	304.25	287.59	295.30	299.25
SnO_2 - Stannic Oxide - Mason Color	24.25	28.24	28.24	26.32
TiO_2 (Rutile Airfloated Chemaloy) (g)	6.20	12.04	7.22	6.73
ZnO (KADOX – 920 Zinc Corp. of America) (g)	31.02	36.09	36.09	33.64
Zircon $ZrSiO_4$ (Flour) Mesh 325 (AM. Mineral) (g)	93.56	109.41	109.41	101.98
Addition of Sucrose as Reductant (g)	78.50	83.66	83.66	81.17
Simulant Weight for 1 liter (g)	1359	1403	1402	1487
Sum of Additives (g)	873	1041	1037	958
Sum of Complete Batch (g)	2232	2443	2439	2445
Target Glass Produced (g)	1033	1203	1203	1121

Table 3.15. AN-105 LAW Simulant Recipe at 8 Molar Sodium for ORLEC26 Melter Test at 0.4 wt% SO_3.

Envelope Constituents	Simulant for AN-105 including pretreatment		Glass Oxides	AN-105 Simulant as Oxides (wt%)	Source in Simulant	Order for Addition	Formula Weight	Assay*	Target Weight (g)
-	mg/L	M	-	-	In 270 ml water add following compounds in the order listed below				
Al	30554	1.132	Al_2O_3	17.98	$Al(NO_3)_3.9H_2O$, 60% sol.	1	375.14	0.61	422.01
					$Al(OH)_3$	6	78.00	1.00	35.22
B	79	0.007	B_2O_3	0.08	H_3BO_3	2	61.83	0.99	0.45
Cr	565	0.011	Cr_2O_3	0.26	$Na_2CrO_4.4H_2O$	5	234.04	0.99	2.58
K	4608	0.118	K_2O	1.73	KOH	4	56.10	0.91	7.28
Na	183920	8.000	Na_2O	77.21	NaOH, 50% sol. d=1.53	3	40.00	0.50	463.20
Ni	65	0.001	NiO	0.03	NiO	7	74.69	1.00	0.08$
Pb	77	0.0004	PbO	0.03	PbO	8	223.20	1.00	0.08$
Si	157	0.006	SiO_2	0.10	SiO_2	9	60.09	0.99	0.34
Cl$	2066	0.058	Cl	0.64	NaCl	10	58.45	0.99	3.44
F$	826	0.043	F	0.26	NaF	11	42.00	0.99	1.84
$PO_4$$	1714	0.018	P_2O_5	0.49	$Na_3PO_4.12H_2O$	13	380.12	0.99	6.93$
$SO_4$$	4958	0.052	SO_3	1.29	Na_2SO_4	12	142.06	0.99	7.41
NO_2	85428	1.857	-	-	$NaNO_2$	17	69.00	0.97	128.79
NO_3	126988	2.048	-	-	$NaNO_3$	-	84.99	0.99	0.00
TOC	2093	0.174	-	-	-	-	-	-	-
Acetate	2251	0.038	-	-	Sodium Acetate (C2)	14	136.08	0.99	5.24
Formate	2135	0.047	-	-	Sodium Formate (C1)	15	68.01	0.99	3.26
Glycolate	1936	0.025	-	-	Glycolic Acid (C2)	16	76.05	0.71	2.73
-	-	-	SUM	100.0	Total simulant wt.				1358.6

- Empty data field.

* Assay refers to the purity of the raw material as specified by the vendor.

$ SO_4, Cl, F, NiO, PbO and PO_4 values were adjusted to meet the level fixed for the Enhanced LAW Glass Correlation.

Table 3.16. LAW Simulant Recipe at 8 Molar Sodium for Transition from Region A to Region G (51.66% AP-101 + 48.34% AN-105 at K/Na molar ratio of 0.1) for ORLEC28 Melter Test at 0.4 wt% SO_3.

Envelope Constituents	Simulant AP-101 Including Pretreatment		Glass Oxides	Simulant as Oxides (wt%)	Source in Simulant	Order for Addition	Formula Weight	Assay*	Target Weight (g)
-	mg/L	Molarity	Loading	100%	In 378.28 ml water add following compounds in the order listed below				
Al	19742	0.732	Al_2O_3	5.26	$Al(NO_3)_3.9H_2O$, 60% sol.	1	375.14	0.61	452.30
B	44	0.004	B_2O_3	0.01	H_3BO_3	2	61.83	0.99	0.25
Cr	613	0.012	Cr_2O_3	0.32	$Na_2CrO_4.4H_2O$	5	234.04	0.99	2.80
K	31313	0.801	K_2O	19.61	KOH	4	56.10	0.91	49.48
Na	183920	8.000$^{\$}$	Na_2O	71.67	NaOH, 50% sol. d=1.53	3	40.00	0.50	392.71
Ni	70	0.001	NiO	0.03	NiO	6	74.69	1.00	0.09$^{\$}$
Pb	83	0.0005	PbO	0.03	PbO	7	223.20	1.00	0.09$^{\$}$
Si	157	0.006	SiO_2	0.10	SiO_2	8	60.09	0.99	0.34
Cl$^{\$}$	2242	0.077	Cl	0.79	NaCl	9	58.45	0.99	3.73$^{\$}$
F$^{\$}$	1083	0.063	F	0.31	NaF	10	42.00	0.99	2.00$^{\$}$
$PO_4$$^{\$}$	1860	0.020	P_2O_5	0.49	$Na_3PO_4.12H_2O$	12	380.12	0.99	7.52$^{\$}$
$SO_4$$^{\$}$	5374	0.056	SO_3	1.39	Na_2SO_4	11	142.06	0.99	8.03$^{\$}$
NO_2	71315	1.550	-	-	$NaNO_2$	17	69.00	1.00	107.51
NO_3	155958	2.515	-	-	$NaNO_3$	18	84.99	0.99	27.49
CO_3	23131	0.385	-	-	Na_2CO_3	19	105.99	1.00	40.85
Org. Carbon	2416	0.201	-	-	-	-	-	-	-
Acetate	2416	0.045	-	-	Sodium Acetate (C2)	13	136.08	0.99	6.17
Formate	2651	0.048	-	-	Sodium Formate (C1)	14	68.01	0.99	3.32
Oxalate	1715	0.019	-	-	Sodium Oxalate (C2)	15	134.00	0.99	2.64
	936	0.012			Glycolic Acid (C2)	16	76.05	0.71	1.32
-	-	-	SUM	100.0	Total simulant Weight				1486.9

- Empty data field.

* Assay refers to the purity of the raw material as specified by the vendor.

$^{\$}$ SO_4, Cl, F, NiO, PbO and PO_4 values were adjusted to meet the level fixed in the Enhanced LAW Glass Correlation glasses.

Table 3.17. AP-101 LAW Simulant Recipe at 8 Molar Sodium for Region G for ORLEC12 Melter Test at 0.1 wt% SO_3.

Envelope Constituents	Simulant AP-101 Including Pretreatment		Glass Oxides	Simulant as Oxides (wt%)	Source in Simulant	Order for Addition	Formula Weight	Assay*	Target Weight (g)
-	mg/L	Molarity	Loading	100%	In 494 ml water add following compounds in the order listed below				
Al	9625	0.357	Al_2O_3	5.33	$Al(NO_3)_3.9H_2O$, 60% sol.	1	375.14	0.61	220.51
B	12	0.001	B_2O_3	0.01	H_3BO_3	2	61.83	0.99	0.07
Cr	658	0.013	Cr_2O_3	0.28	$Na_2CrO_4.4H_2O$	8	234.04	0.99	3.01
K	56301	1.440	K_2O	19.86	KOH	7	56.10	0.91	88.97
Na	183920	8.000$	Na_2O	72.59	NaOH, 50% sol. d=1.53	6	40.00	0.50	235.33
Ni	76	0.001	NiO	0.03	NiO	3	74.69	1.00	0.10
Pb	89	0.0004	PbO	0.03	PbO	4	223.20	1.00	0.10
Si	157	0.006	SiO_2	0.10	SiO_2	5	60.09	0.99	0.34
Cl$	2406	0.068	Cl	0.70	NaCl	10	58.45	0.99	4.01
F$	963	0.051	F	0.28	NaF	11	42.00	0.99	2.15
$PO_4$$	1996	0.021	P_2O_5	0.44	$Na_3PO_4.12H_2O$	9	380.12	0.99	8.07
$SO_4$$	1441	0.015	SO_3	0.35	Na_2SO_4	12	142.06	0.99	2.15$
NO_2	58110	1.263	-	-	$NaNO_2$	16	69.00	1.00	87.60
NO_3	183067	2.953	-	-	$NaNO_3$	17	84.99	0.99	161.61
CO_3	44775	0.746	-	-	Na_2CO_3	18	105.99	1.00	79.08
Org. Carbon	2718	0.227	-	-	-	-	-	-	-
Acetate	3025	0.051	-	-	Sodium Acetate (C2)	13	136.08	0.99	7.04
Formate	2213	0.049	-	-	Sodium Formate (C1)	14	68.01	0.99	3.38
Oxalate	3321	0.038	-	-	Sodium Oxalate (C2)	15	134.00	0.99	5.11
-	-	-	SUM	100.0	Total simulant Weight				1402.6

- Empty data field.

* Assay refers to the purity of the raw material as specified by the vendor.

$ SO_4, Cl, F, NiO, PbO and PO_4 values were adjusted to meet the level fixed in the Enhanced LAW Glass Correlation glasses.

Table 3.18. AP-101 LAW Simulant Recipe at 8 Molar Sodium for Region G for ORLEC27 Melter Test at the nominal 0.4 wt% SO_3.

Envelope Constituents	Simulant AP-101 Including Pretreatment		Glass Oxides	Simulant as Oxides (wt%)	Source in Simulant	Order for Addition	Formula Weight	Assay*	Target Weight (g)
-	mg/L	Molarity	Loading	100%	In 494 ml water add following compounds in the order listed below				
Al	9625	0.357	Al_2O_3	5.26	$Al(NO_3)_3.9H_2O$, 60% sol.	1	375.14	0.61	220.51
B	12	0.001	B_2O_3	0.01	H_3BO_3	2	61.83	0.99	0.07
Cr	658	0.013	Cr_2O_3	0.32	$Na_2CrO_4.4H_2O$	8	234.04	0.99	3.01
K	56301	1.440	K_2O	19.65	KOH	7	56.10	0.91	88.97
Na	183920	8.000[\$]	Na_2O	71.84	NaOH, 50% sol. d=1.53	6	40.00	0.50	228.15
Ni	76	0.001	NiO	0.03	NiO	3	74.69	1.00	0.10
Pb	89	0.0004	PbO	0.03	PbO	4	223.20	1.00	0.10
Si	157	0.006	SiO_2	0.10	SiO_2	5	60.09	0.99	0.34
Cl[\$]	2406	0.068	Cl	0.79	NaCl	10	58.45	0.99	4.01
F[\$]	963	0.051	F	0.31	NaF	11	42.00	0.99	2.15
PO_4[\$]	1996	0.021	P_2O_5	0.49	$Na_3PO_4.12H_2O$	9	380.12	0.99	8.07
SO_4[\$]	5764	0.060	SO_3	1.39	Na_2SO_4	12	142.06	0.99	8.61[\$]
NO_2	58110	1.263	-	-	$NaNO_2$	16	69.00	1.00	87.60
NO_3	183067	2.953	-	-	$NaNO_3$	17	84.99	0.99	161.61
CO_3	44775	0.746	-	-	Na_2CO_3	18	105.99	1.00	79.08
Org. Carbon	2718	0.227	-	-	-	-	-	-	-
Acetate	3025	0.051	-	-	Sodium Acetate (C2)	13	136.08	0.99	7.04
Formate	2213	0.049	-	-	Sodium Formate (C1)	14	68.01	0.99	3.38
Oxalate	3321	0.038	-	-	Sodium Oxalate (C2)	15	134.00	0.99	5.11
-	-	-	SUM	100.0	Total simulant Weight				1401.9

- Empty data field.

* Assay refers to the purity of the raw material as specified by the vendor.

[\$] SO_4, Cl, F, NiO, PbO and PO_4 values were adjusted to meet the level fixed in the Enhanced LAW Glass Correlation glasses.

Table 4.1. Summary of Test Conditions and Results for DM100 Tests.

Glass Formulation		ORLEC26	ORLEC12	ORLEC27	ORLEC28
Waste Description		AN-105	AP-101	AP-101	51.66% AP-101 + 48.34% AN-105
Target Glass	Sulfur (wt.% SO_3)	0.40	0.10	0.40	0.40
	Potassium (wt% K_2O)	0.54	5.64	5.64	3.36
	Sodium (wt% Na_2O)	24	20.61	20.61	22.11
Time	Feed Start	11/16/15 10:45	12/2/15 8:30	12/7/15 10:00	12/14/15 10:10
	Feed End	11/18/15 21:00	12/4/15 12:00	12/9/15 18:00	12/16/15 15:00
	Water Feeding (hr)	1.1	1.0	1.0	1.1
	Net Slurry Feeding (hr)	57.2	50.5	55.0	51.7
	Total (hr)	58.3	51.5	56.0	52.8
	Interruptions (min)	13	43	280	62
Feed	Target Glass Yield (kg/kg)	0.48	0.51	0.51	0.47
	Measured Glass Yield (kg/kg)	0.448	0.480	0.474	0.443
	Used (kg)	1084	987	993	1078
Avg. Bubbling Rate (lpm)		16.1	13.9	14.1	14.0
Number of rodding events		16	2	4	22
Glass Discharged (kg)		479	466	467	479
Avg. Production Rate based on feed consumed (kg/m^2/day)	Target Yield	2023	2214	2044	2186
	Measured Yield	1888	2084	1900	2060
Avg. Production Rate based on glass discharged (kg/m^2/day)		1862	2051	1887	2064
Steady State Production Rate based on feed consumed (kg/m^2/day)	Target Yield	2000	2250	2250	2200
	Measured Yield	1867	2118	2091	2074

Table 4.2. Summary of Measured Melter Parameters for DM100 Tests.

Test			ORLEC26			ORLEC12		
			AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (C)	Electrode	East	1105	1053	1125	1113	1051	1127
		West	1055	948	1079	1054	964	1068
		Bottom	855	759	886	860	790	878
	Glass	19” from bottom	437	226	849	903	476	1006
		16” from bottom	932	646	1096	1111	964	1143
		10” from bottom	1148	1117	1184	1148	1114	1173
		4” from bottom	1155	1116	1210	1155	1118	1188
	Plenum	Exposed	441	234	757	560	480	787
		Thermowell	437	326	747	544	484	780
	Discharge Chamber		1031	876	1058	1042	952	1067
	Film Cooler Outlet		291	277	304	299	282	310
	Transition Line Outlet		276	237	300	280	264	308
Lance Bubbling (lpm)			16.1	1.3	25.9	11.4	1.2	12.4
Melter Pressure (inches water)			-1.05	-2.15	0.49	-0.79	-4.18	-0.08
Electrode Voltage (V)			36.3	33.6	40.9	35.7	30.8	37.8
Total Power (kW)			17.8	15.3	19.8	19.3	16.2	20.6
Glass Resistance (ohms)			0.074	0.065	0.094	0.066	0.058	0.072

Table 4.2. Summary of Measured Melter Parameters for DM100 Tests (continued).

Test			ORLEC27			ORLEC28		
			AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (C)	Electrode	East	1107	1067	1123	1111	1063	1130
		West	1046	1004	1062	1060	1014	1075
		Bottom	845	781	861	858	811	874
	Glass	19” from bottom	885	336	1047	817	545	1001
		16” from bottom	1109	1054	1151	1105	847	1146
		10” from bottom	1147	1130	1174	1151	1127	1175
		4” from bottom	1152	1129	1181	1155	1107	1181
	Plenum	Exposed	558	447	851	507	353	763
		Thermowell	543	451	823	494	396	762
	Discharge Chamber		1026	787	1064	1049	1029	1072
	Film Cooler Outlet		301	282	322	298	286	311
	Transition Line Outlet		283	269	306	277	266	295
Lance Bubbling (lpm)			10.0	1.0	12.7	15.2	1.6	18.3
Melter Pressure (inches water)			-0.74	-3.35	-0.04	-0.73	-3.24	1.09
Electrode Voltage (V)			35.1	29.8	38.0	36.7	31.2	40.0
Total Power (kW)			18.5	14.5	21.1	19.7	16.2	22.0
Glass Resistance (ohms)			0.067	0.059	0.074	0.068	0.060	0.080

Table 5.1. Characteristics of Melter Feed Samples from DM100 Tests.

	Source	Date	Name	% Water	pH	Density (g/ml)	Glass Yield			
							(g/l)	Measured (kg/kg)	Target (kg/kg)	%Dev.
ORLEC26	As Received	11/10/15	OWV-F-70A	42.6	12.5	1.60	749	0.468	0.48	-2.42
	Feed Tube	11/16/15	OWV-F-71A	40.3	12.5	1.62	730	0.451	0.48	-6.10
	Feed Tube	11/18/15	OWV-F-109A	39.5	12.3	1.62	719	0.444	0.48	-7.52
ORLEC12	As Received	11/19/15	OWV-F-110A	37.9	12.0	1.69	835	0.494	0.51	-3.12
	As Received	11/19/15	OWV-F-110B	37.7	12.0	1.7	858	0.505	0.51	-1.02
	Feed Tube	12/2/2015	OWV-F-127A	35.7	11.8	1.69	823	0.487	0.51	-4.55
	Feed Tube	12/4/2015	OWV-F-147A	36.7	11.9	1.68	795	0.473	0.51	-7.22
ORLEC27	As Received	11/19/15	OWV-F-110C	35.7	12.1	1.69	840	0.497	0.51	-2.72
	As Received	11/19/15	OWV-F-110D	36.4	12.2	1.71	849	0.496	0.51	-2.90
	Feed Tube	12/7/2015	PWV-F-22A	36.4	11.9	1.64	780	0.476	0.51	-6.71
	Feed Tube	12/9/2015	PWV-F-46A	37.5	11.9	1.58	747	0.473	0.51	-7.51
ORLEC28	As Received	11/12/15	OWV-F-70B	43.2	12.0	1.62	718	0.443	0.47	-5.66
	As Received	11/13/15	OWV-F-70C	41.9	11.9	1.62	752	0.464	0.47	-1.21
	As Received	11/13/15	OWV-F-70D	42.4	12.0	1.63	754	0.463	0.47	-1.60
	As Received	11/13/15	OWV-F-70E	41.5	12.0	1.62	749	0.463	0.47	-1.60
	Feed Tube	12/10/15	PWV-F-52A	40.2	11.9	1.58	714	0.452	0.47	-3.89
	Feed Tube	12/16/15	PWV-F-93A	42.3	11.9	1.58	685	0.434	0.47	-7.70

Table 5.2. XRF Analyzed Compositions for Vitrified Feed Samples from DM100 Melter Tests with ORLEC26 (wt%).

	ORLEC26	As Received		From Test			
		OWV-F-70A	% Dev.	OWV-F-71A	OWV-F-109A	Avg.	% Dev.
Al_2O_3	10.00	9.11	-8.92	9.12	8.79	8.95	-10.46
B_2O_3#	10.00	11.52	15.20	11.09	11.09	11.09	10.90
CaO	1.95	1.97	1.12	1.87	1.97	1.92	-1.59
Cl	0.20	0.11	NC	0.12	0.11	0.11	NC
Cr_2O_3	0.44	0.49	NC	0.48	0.49	0.49	NC
F*	0.08	0.08	NC	0.08	0.08	0.08	NC
Fe_2O_3	0.60	0.67	NC	0.74	0.66	0.70	NC
K_2O	0.50	0.50	NC	0.56	0.53	0.54	NC
Li_2O#	&	0.03	NC	0.03	0.03	0.03	NC
MgO	1.00	0.81	-19.26	0.95	0.81	0.88	-12.03
MnO	&	0.01	NC	< 0.01	0.01	0.01	NC
Na_2O	24.00	25.02	4.26	23.83	25.11	24.47	1.98
NiO	0.01	0.03	NC	0.02	0.02	0.02	NC
P_2O_5	0.12	0.14	NC	0.14	0.14	0.14	NC
PbO	0.01	0.00	NC	0.01	0.02	0.01	NC
$ReO_2$$	&	< 0.001	NC	< 0.001	< 0.001	< 0.001	NC
SO_3	0.40	0.47	NC	0.34	0.37	0.36	NC
SiO_2	38.73	37.47	-3.25	38.18	36.86	37.52	-3.13
SnO_2	2.33	2.19	-6.09	2.60	3.82	3.21	37.84
TiO_2	0.60	0.70	NC	0.73	0.62	0.68	NC
ZnO	3.00	2.98	-0.64	3.01	3.07	3.04	1.36
ZrO_2	6.03	5.72	-5.15	6.09	5.40	5.74	-4.76
Sum	100.00	100.00	-	100.00	100.00	-	-

- DCP Analysis of B_2O_3 and Li_2O
& - Not a target constituent
*- Target value
$- Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS [78].
NC – Not calculated
- Empty data field

Table 5.3. XRF Analyzed Compositions for Vitrified Feed Samples from DM100 Melter Tests with ORLEC12 (wt%).

		As Received				From Test			
	ORLEC12	OWV-F-110A	OWV-F-110B	Avg.	% Dev.	OWV-F-127A	OWV-F-147A	Avg.	% Dev.
Al_2O_3	10.00	9.31	9.39	9.35	-6.49	9.58	9.12	9.35	-6.46
B_2O_3#	10.00	10.62	10.38	10.50	5.00	10.74	10.90	10.82	8.20
CaO	1.95	1.76	2.12	1.94	-0.18	1.94	2.02	1.98	1.74
Cl	0.20	0.15	0.15	0.15	NC	0.10	0.09	0.10	NC
Cr_2O_3	0.58	0.54	0.50	0.52	NC	0.58	0.60	0.59	NC
F%	0.08	0.08	0.08	0.08	NC	0.08	0.08	0.08	NC
Fe_2O_3	1.00	1.04	1.08	1.06	6.10	1.12	1.07	1.09	9.43
K_2O	5.64	5.86	5.53	5.70	0.94	5.23	5.67	5.45	-3.37
Li_2O#	&	0.03	0.03	0.03	NC	0.03	0.03	0.03	NC
MgO	1.00	0.63	0.95	0.79	-20.89	1.17	0.73	0.95	-5.13
MnO	&	0.02	0.01	0.02	NC	0.01	0.01	0.01	NC
Na_2O	20.61	22.31	21.73	22.02	6.86	21.31	21.95	21.63	4.96
NiO	0.01	0.02	0.02	0.02	NC	0.02	0.02	0.02	NC
P_2O_5	0.12	0.18	0.17	0.17	NC	0.14	0.17	0.16	NC
PbO	0.01	< 0.01	0.01	< 0.01	NC	0.01	0.01	0.01	NC
$ReO_2$$	0.010	< 0.001	< 0.001	< 0.001	NC	0.002	0.002	0.002	NC
SO_3	0.10	0.14	0.13	0.13	NC	0.13	0.15	0.14	NC
SiO_2	36.33	35.72	35.98	35.85	-1.33	35.74	35.21	35.48	-2.36
SnO_2	2.33	1.90	2.13	2.02	-13.38	2.36	2.47	2.42	3.67
TiO_2	1.00	1.14	1.10	1.12	12.11	1.24	1.16	1.20	20.13
ZnO	3.00	2.83	2.87	2.85	-4.86	2.69	2.90	2.80	-6.83
ZrO_2	6.03	5.70	5.64	5.67	-6.00	5.77	5.62	5.70	-5.55
Sum	100.00	100.00	100.00	-	-	100.00	100.00	-	-

- DCP Analysis of B_2O_3 and Li_2O
& - Not a target constituent
*- Target value
$- Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS [78].
NC – Not calculated
- Empty data field

Table 5.4. XRF Analyzed Compositions for Vitrified Feed Samples from DM100 Melter Tests with ORLEC27 (wt%).

	ORLEC27	As Received				From Test			
		OWV-F-110C	OWV-F-110D	Avg.	% Dev.	PWV-F-22A	PWV-F-46A	Avg.	% Dev.
Al_2O_3	10.00	9.31	9.50	9.41	-5.95	9.45	9.48	9.46	-5.37
$B_2O_3^{\#}$	10.00	10.99	10.79	10.89	8.90	10.96	10.94	10.95	9.50
CaO	1.95	1.51	1.57	1.54	-21.14	1.77	1.83	1.80	-7.83
Cl	0.20	0.09	0.08	0.09	NC	0.12	0.08	0.10	NC
Cr_2O_3	0.44	0.44	0.43	0.43	NC	0.43	0.40	0.42	NC
$F^{\%}$	0.08	0.08	0.08	0.08	NC	0.08	0.08	0.08	NC
Fe_2O_3	0.60	0.64	0.64	0.64	NC	0.64	0.60	0.62	NC
K_2O	5.64	5.50	5.63	5.57	-1.36	5.52	5.30	5.41	-4.18
$Li_2O^{\#}$	&	0.03	0.03	0.03	NC	0.03	0.03	0.03	NC
MgO	1.00	0.82	0.87	0.85	-15.41	0.97	0.88	0.93	-7.22
MnO	&	0.02	0.01	0.02	NC	0.01	0.01	0.01	NC
Na_2O	20.61	21.97	22.25	22.11	7.29	21.82	22.53	22.18	7.63
NiO	0.01	0.02	0.02	0.02	NC	0.02	0.02	0.02	NC
P_2O_5	0.12	0.15	0.17	0.16	NC	0.15	0.16	0.15	NC
PbO	0.01	0.01	< 0.01	0.01	NC	0.01	0.01	0.01	NC
$ReO_2^{\$}$	0.010	< 0.001	< 0.001	< 0.001	NC	0.002	0.002	0.002	NC
SO_3	0.40	0.37	0.39	0.38	NC	0.35	0.40	0.38	NC
SiO_2	36.97	36.63	36.22	36.42	-1.48	36.78	37.51	37.15	0.47
SnO_2	2.33	2.11	2.08	2.10	-10.09	1.94	1.66	1.80	-22.75
TiO_2	0.60	0.75	0.73	0.74	NC	0.74	0.65	0.70	NC
ZnO	3.00	2.87	2.88	2.87	-4.24	2.74	2.61	2.68	-10.78
ZrO_2	6.03	5.69	5.63	5.66	-6.14	5.47	4.81	5.14	-14.76
Sum	100.00	100.00	100.00	100.00	-	100.00	100.00	-	-

- DCP Analysis of B_2O_3 and Li_2O
& - Not a target constituent
*- Target value
$- Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS [78].
NC – Not calculated
- Empty data field

Table 5.5. XRF Analyzed Compositions of Vitrified Feed Samples from DM100 Melter Tests with ORLEC28 (wt%).

	ORLEC 28	As Received						From Test			
		OWV-F-70B	OWV-F-70C	OWV-F-70D-	OWV-F-70E	Avg.	% Dev.	PWV-F-52A	PWV-F-93A	Avg.	% Dev.
Al_2O_3	10.00	9.32	9.52	9.34	9.60	9.45	-5.54	9.46	8.96	9.21	-7.91
$B_2O_3^{\#}$	10.00	13.23	10.58	10.77	10.65	11.31	13.08	10.28	11.26	10.77	7.70
CaO	1.95	1.91	1.95	2.11	2.04	2.00	2.62	2.03	2.02	2.03	4.02
Cl	0.20	0.09	0.08	0.09	0.09	0.09	NC	0.09	0.07	0.08	NC
Cr_2O_3	0.44	0.44	0.46	0.47	0.45	0.46	NC	0.44	0.47	0.45	NC
$F^{\%}$	0.08	0.08	0.08	0.08	0.08	0.08	NC	0.08	0.08	0.08	NC
Fe_2O_3	0.60	0.52	0.62	0.68	0.65	0.62	NC	0.69	0.60	0.64	NC
K_2O	3.36	3.61	3.11	3.24	3.25	3.30	-1.79	3.07	3.31	3.19	-5.23
$Li_2O^{\#}$	&	0.03	0.03	0.03	0.03	0.03	NC	0.03	0.03	0.03	NC
MgO	1.00	0.29	0.85	0.77	0.84	0.69	-30.96	1.12	0.61	0.87	-13.12
MnO	&	< 0.01	0.01	0.01	0.01	0.01	NC	0.02	0.01	0.02	NC
Na_2O	22.11	24.81	23.64	22.92	23.16	23.63	6.89	21.92	24.19	23.06	4.29
NiO	0.01	0.02	0.02	0.01	0.02	0.02	NC	0.03	0.02	0.02	NC
P_2O_5	0.12	0.16	0.17	0.15	0.16	0.16	NC	0.15	0.17	0.16	NC
PbO	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	NC	< 0.01	0.01	< 0.01	NC
$ReO_2^{\$}$	0.010	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	NC	0.004	0.003	0.003	NC
SO_3	0.40	0.40	0.38	0.39	0.38	0.39	NC	0.36	0.39	0.38	NC
SiO_2	37.75	35.64	38.11	38.27	37.94	37.49	-0.67	38.72	36.09	37.41	-0.90
SnO_2	2.33	1.32	1.67	1.68	1.62	1.57	-32.55	2.22	2.31	2.26	-2.88
TiO_2	0.60	0.60	0.73	0.71	0.74	0.70	NC	0.76	0.67	0.72	NC
ZnO	3.00	2.31	2.39	2.47	2.49	2.41	-19.58	2.91	3.09	3.00	-0.07
ZrO_2	6.03	5.21	5.60	5.79	5.79	5.60	-7.18	5.61	5.64	5.62	-6.73
Sum	100.00	100.00	100.00	100.00	100.00	-	-	100.00	100.00	-	-

- DCP Analysis of B_2O_3 and Li_2O
& - Not a target constituent
*- Target value
$- Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS [78].
NC – Not calculated
- Empty data field

Table 5.6. List of Glass Discharged and Masses during Melter Tests with ORLEC26 Composition.

Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
11/16/15	OWV-G-71A	22.34	22.34
	OWV-G-83A		
	OWV-G-83B	21.70	44.04
	OWV-G-83C		
	OWV-G-84A	24.58	68.62
	OWV-G-84B		
	OWV-G-84C	23.84	92.46
	OWV-G-86A		
	OWV-G-86B	30.48	122.94
11/17/15	OWV-G-86C		
	OWV-G-86D	18.98	141.92
	OWV-G-89A		
	OWV-G-89B	22.10	164.02
	OWV-G-89C		
	OWV-G-89D	29.54	193.56
	OWV-G-89E		
	OWV-G-92A	13.94	207.50
	OWV-G-92B		
	OWV-G-92C	21.52	229.02
	OWV-G-92D		
	OWV-G-92E	16.22	245.24
	OWV-G-95A		
	OWV-G-96A	24.86	270.10
	OWV-G-96B		
	OWV-G-97A	18.78	288.88
	OWV-G-97B		
	OWV-G-97C	30.26	319.14
11/18/15	OWV-G-97D		
	OWV-G-99A	25.40	344.54
	OWV-G-99B		
	OWV-G-99C	31.68	376.22
	OWV-G-99D		
	OWV-G-99E	21.42	397.64
	OWV-G-99F		
	OWV-G-99G	27.64	425.28
	OWV-G-104A		
	OWV-G-104B		
	OWV-G-104C	17.84	443.12
	OWV-G-104D		
	OWV-G-107A	28.62	471.74
	OWV-G-109A		
	OWV-G-109B	7.74	479.48

Table 5.7. List of Glass Discharged and Masses during Melter Tests with ORLEC12 Composition.

Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
12/2/15	OWV-G-128A	26.64	26.64
	OWV-G-128B		
	OWV-G-128C	37.42	64.06
	OWV-G-129A		
	OWV-G-129B	29.46	93.52
	OWV-G-129C		
	OWV-G-131A	31.56	125.08
	OWV-G-131B		
12/3/15	OWV-G-131C	27.56	152.64
	OWV-G-134A		
	OWV-G-134B	28.06	180.70
	OWV-G-134C		
	OWV-G-134D	27.24	207.94
	OWV-G-134E		
	OWV-G-136A	26.78	234.72
	OWV-G-136B		
	OWV-G-136C	29.04	263.76
	OWV-G-136D		
	OWV-G-141A	26.34	290.10
	OWV-G-141B		
	OWV-G-141C	25.08	315.18
	OWV-G-141D		
	OWV-G-141E	29.06	344.24
	OWV-G-144A		
12/4/15	OWV-G-144B	29.78	374.02
	OWV-G-144C		
	OWV-G-144D	30.24	404.26
	OWV-G-144E		
	OWV-G-144F	23.50	427.76
	OWV-G-144G		
	OWV-G-147A	21.76	449.52
	OWV-G-147B		
	OWV-G-147C	16.06	465.58

Table 5.8. List of Glass Discharged and Masses during Melter Tests with ORLEC27 Composition.

Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
12/7/15	PWV-G-23A	34.50	34.50
	PWV-G-23B		
	PWV-G-23C	27.20	61.70
	PWV-G-24A		
	PWV-G-24B	20.96	82.66
	PWV-G-24C		
	PWV-G-25A	23.48	106.14
12/8/15	PWV-G-29A		
	PWV-G-29B	33.80	139.94
	PWV-G-30A		
	PWV-G-30B	23.64	163.58
	PWV-G-30C		
	PWV-G-30D	25.84	189.42
	PWV-G-32A		
	PWV-G-32B	28.50	217.92
	PWV-G-32C		
	PWV-G-32D	29.62	247.54
	PWV-G-32E		
	PWV-G-35A	27.50	275.04
	PWV-G-35B		
	PWV-G-35C	28.80	303.84
12/9/15	PWV-G-35D		
	PWV-G-35E	25.64	329.48
	PWV-G-35F		
	PWV-G-40A	31.16	360.64
	PWV-G-40B		
	PWV-G-40C	27.88	388.52
	PWV-G-40D		
	PWV-G-40E	26.84	415.36
	PWV-G-43A		
	PWV-G-43B	25.40	440.76
	PWV-G-43C		
	PWV-G-43D	26.16	466.92
	PWV-G-43E		

Table 5.9. List of Glass Discharged and Masses during Melter Tests with ORLEC28 Composition.

Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
12/14/15	PWV-G-65A	26.88	26.88
	PWV-G-65B		
	PWV-G-65C	22.52	49.40
	PWV-G-65D		
	PWV-G-66A	29.38	78.78
	PWV-G-67A		
	PWV-G-67B	26.82	105.60
	PWV-G-67C		
12/15/15	PWV-G-71A	24.64	130.24
	PWV-G-71B		
	PWV-G-71C	23.88	154.12
	PWV-G-71D		
	PWV-G-72A	27.76	181.88
	PWV-G-72B		
	PWV-G-72C	21.76	203.64
	PWV-G-78A		
	PWV-G-78B	15.74	219.38
	PWV-G-78C		
	PWV-G-78D	26.52	245.90
	PWV-G-79A		
	PWV-G-79B	20.40	266.30
	PWV-G-79C		
	PWV-G-79D	31.86	298.16
	PWV-G-80A		
	PWV-G-80B		
	PWV-G-80C	34.42	332.58
	PWV-G-80D		
12/16/15	PWV-G-83A	20.34	352.92
	PWV-G-83B		
	PWV-G-83C	23.84	376.76
	PWV-G-85A		
	PWV-G-85B	25.06	401.82
	PWV-G-85C		
	PWV-G-87A	29.60	431.42
	PWV-G-87B		
	PWV-G-87C	26.24	457.66
	PWV-G-87D		
	PWV-G-87E	21.56	479.22
	PWV-G-93A		

Table 5.10. Listing of Glass Pool Samples and Secondary Phase Observations during DM100 Tests.

Test	Date	Time	Sample Name	Location	Depth of Glass Pool (inches)	Secondary Phases Observed
ORLEC26	11/16/15	Before	OWV-D-71A	-	16.0	None
	11/18/15	After	OWV-D-109A	NW	16.5	None
			OWV-D-109B	NE	16.5	None
			OWV-D-109C	Center	16.5	None
			OWV-D-109D	SW	16.5	None
ORLEC12	12/2/15	Before	OWV-D-127A	-	17	None
		During	OWV-D-129A	NE	18.5	None
			OWV-D-129B	NW	18.5	None
			OWV-D-129C	Center	18.5	None
			OWV-D-129D	SE	18.5	None
			OWV-D-129E	SW	18.5	None
	12/4/15	After	OWV-D-147A	Center	16.5	None
			OWV-D-147B	SE	16.5	None
			OWV-D-147C	NE	16.5	None
			OWV-D-147D	NW	16.5	None
			OWV-D-147E	SW	16.5	None
ORLEC27	12/7/15	Before	PWV-D-22A	-	17.5	None
		During	PWV-D-24A	NW	19.0	None
			PWV-D-24B	NE	19.0	None
			PWV-D-24C	Center	19.0	None
			PWV-D-24D	SW	19.0	None
			PWV-D-24E	SE	19.0	None
	12/9/15	After	PWV-D-46A	NW	17.5	None
			PWV-D-46B	NE	17.5	None
			PWV-D-46C	Center	17.5	None
			PWV-D-46D	SW	17.5	None
			PWV-D-46E	SE	17.5	None

Table 5.10 Listing of Glass Pool Samples and Secondary Phase Observations during DM100 Tests (continued).

Test	Date	Time	Sample Name	Location	Depth of Glass Pool (inches)	Secondary Phase
ORLEC28	12/14/15	Before	PWV-D-52A	-	17.8	None
		During	PWV-D-66A	NW	18.5	None
			PWV-D-66B	NE	18.5	None
			PWV-D-66C	Center	18.5	None
			PWV-D-66D	SW	18.5	None
			PWV-D-66E	SE	18.5	None
	12/16/15	After	PWV-D-93A	NW	18.8	None
			PWV-D-93B	NE	18.8	None
			PWV-D-93C	Center	18.8	None
			PWV-D-93D	SW	18.8	None
			PWV-D-93E	SE	18.8	None

Table 5.11. XRF Analyzed Compositions of Glass Samples Discharged during DM100 Melter Test with ORLEC26 Glass Composition (wt%).

	Glass (kg)	22.34	44.04	68.62	92.46	122.94	141.92	164.02	193.56
	Target	OWV-G-83A	OWV-G-83C	OWV-G-84B	OWV-G-86A	OWV-G-86C	OWV-G-89A	OWV-G-89C	OWV-G-89E
Al_2O_3	10.00	6.17	6.46	6.94	7.31	7.73	7.72	7.97	8.25
$B_2O_3^{\#}$	10.00	8.89	9.29	9.65	9.93	10.21	10.35	10.48	10.63
CaO	1.95	2.81	2.68	2.52	2.43	2.28	2.29	2.24	2.14
Cl	0.20	0.07	0.08	0.09	0.11	0.11	0.12	0.12	0.12
Cr_2O_3	0.44	0.58	0.53	0.52	0.54	0.50	0.55	0.52	0.54
$F^{\%}$	0.08	0.01	0.02	0.03	0.03	0.04	0.04	0.05	0.05
Fe_2O_3	0.60	0.37	0.41	0.42	0.51	0.47	0.58	0.60	0.60
K_2O	0.50	0.46	0.49	0.43	0.51	0.50	0.52	0.52	0.52
$Li_2O^{\#}$	&	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.04
MgO	1.00	0.89	0.88	0.90	0.90	0.93	0.93	0.91	0.94
MnO	&	0.02	0.02	0.02	0.01	0.02	0.01	0.02	0.01
Na_2O	24.00	21.42	21.81	22.02	22.38	23.08	23.63	22.97	23.71
NiO	0.008	0.24	0.23	0.17	0.17	0.14	0.13	0.13	0.11
P_2O_5	0.12	0.04	0.05	0.07	0.08	0.10	0.10	0.11	0.11
PbO	0.008	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	0.01	0.01
$ReO_2^{\$}$	&	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SO_3	0.40	0.35	0.35	0.35	0.35	0.35	0.33	0.33	0.36
SiO_2	38.73	47.48	46.32	45.45	44.27	43.51	41.94	42.05	40.99
SnO_2	2.33	2.25	2.30	2.31	2.18	2.07	2.12	2.18	2.16
TiO_2	0.60	0.15	0.20	0.27	0.34	0.38	0.43	0.50	0.53
ZnO	3.00	2.39	2.43	2.45	2.53	2.43	2.64	2.67	2.68
ZrO_2	6.03	5.33	5.40	5.32	5.37	5.12	5.52	5.60	5.51
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.2) using a simple well-stirred tank model.

& - Not a target constituent.

\$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]

%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.11. XRF Analyzed Compositions for Glass Samples Discharged during DM100 Melter Test with ORLEC26 Glass Composition (wt%) (continued).

	Glass (kg)	207.50	229.02	245.24	270.10	288.88	319.14	344.54	376.22
	Target	OWV-G-92B	OWV-G-92D	OWV-G-95A	OWV-G-96B	OWV-G-97B	OWV-G-97D	OWV-G-99B	OWV-G-99D
Al_2O_3	10.00	8.21	8.48	8.42	8.64	8.66	8.63	8.73	8.75
B_2O_3[#]	10.00	10.68	10.75	10.80	10.86	10.90	10.94	10.97	11.00
CaO	1.95	2.14	2.12	2.07	2.13	2.13	2.11	2.10	2.08
Cl	0.20	0.12	0.12	0.12	0.14	0.13	0.14	0.12	0.11
Cr_2O_3	0.44	0.52	0.54	0.53	0.54	0.58	0.57	0.59	0.53
F[%]	0.08	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06
Fe_2O_3	0.60	0.62	0.59	0.59	0.61	0.66	0.67	0.66	0.68
K_2O	0.50	0.50	0.49	0.51	0.49	0.56	0.52	0.52	0.55
Li_2O[#]	&	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03
MgO	1.00	0.94	0.95	0.97	0.95	0.91	0.94	0.95	0.94
MnO	&	0.01	< 0.01	0.02	0.02	0.01	0.01	0.02	0.01
Na_2O	24.00	23.78	23.48	23.72	23.72	23.51	23.30	23.98	23.59
NiO	0.008	0.11	0.11	0.10	0.09	0.10	0.08	0.09	0.06
P_2O_5	0.12	0.11	0.13	0.13	0.13	0.13	0.13	0.13	0.12
PbO	0.008	< 0.01	0.01	< 0.01	0.01	< 0.01	0.01	0.01	0.01
ReO_2[$]	&	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SO_3	0.40	0.36	0.36	0.35	0.37	0.37	0.36	0.34	0.34
SiO_2	38.73	41.04	40.88	40.83	40.08	39.95	39.74	39.32	39.27
SnO_2	2.33	2.17	2.20	2.10	2.25	2.23	2.28	2.17	2.27
TiO_2	0.60	0.51	0.54	0.52	0.60	0.60	0.64	0.62	0.66
ZnO	3.00	2.64	2.70	2.68	2.71	2.79	2.89	2.84	2.94
ZrO_2	6.03	5.44	5.46	5.45	5.59	5.70	5.94	5.74	5.98
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.2) using a simple well-stirred tank model.

& - Not a target constituent.

$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]

%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.11. XRF Analyzed Compositions for Glass Samples Discharged during DM100 Melter Test with ORLEC26 Glass Composition (wt%) (continued).

	Glass (kg)	397.64	425.28	443.12	471.74	479.48
	Target	OWV-G-99F	OWV-G-104B	OWV-G-104D	OWV-G-109A	OWV-G-109B
Al_2O_3	10.00	8.82	8.75	9.00	9.00	9.08
B_2O_3#	10.00	11.02	11.03	11.04	11.05	11.06
CaO	1.95	2.10	2.07	2.02	2.01	2.04
Cl	0.20	0.13	0.13	0.12	0.13	0.14
Cr_2O_3	0.44	0.57	0.55	0.55	0.55	0.59
F%	0.08	0.06	0.06	0.06	0.06	0.06
Fe_2O_3	0.60	0.71	0.72	0.66	0.70	0.77
K_2O	0.50	0.54	0.57	0.51	0.52	0.53
Li_2O#	&	0.03	0.03	0.03	0.03	0.03
MgO	1.00	0.97	1.04	0.99	1.00	0.98
MnO	&	0.02	< 0.01	0.02	0.02	0.03
Na_2O	24.00	23.68	23.44	24.08	23.97	23.93
NiO	0.008	0.07	0.07	0.06	0.07	0.07
P_2O_5	0.12	0.13	0.13	0.12	0.13	0.13
PbO	0.008	0.01	0.01	< 0.01	0.01	0.01
$ReO_2$$	&	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SO_3	0.40	0.35	0.35	0.34	0.34	0.35
SiO_2	38.73	38.80	39.00	38.89	38.72	38.31
SnO_2	2.33	2.28	2.31	2.18	2.29	2.17
TiO_2	0.60	0.66	0.69	0.67	0.68	0.68
ZnO	3.00	2.97	2.97	2.88	2.90	3.00
ZrO_2	6.03	6.08	6.08	5.77	5.82	6.07
Sum	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.2) using a simple well-stirred tank model.
& - Not a target constituent.
$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]
%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.12. XRF Analyzed Compositions for Glass Samples Discharged during DM100 Melter Test with ORLEC12 Glass Composition (wt%).

	Glass (kg)	506.12	543.54	573.00	604.56	632.12	660.18
	Target	OWV-G-128B	OWV-G-129A	OWV-G-129C	OWV-G-131B	OWV-G-134A	OWV-G-134C
Al_2O_3	10.00	9.10	9.18	9.03	9.25	9.25	9.35
$B_2O_3^{\#}$	10.00	11.00	10.95	10.92	10.90	10.88	10.87
CaO	1.95	1.98	2.06	2.07	2.03	1.99	1.98
Cl	0.20	0.10	0.12	0.13	0.12	0.12	0.13
Cr_2O_3	0.58	0.59	0.62	0.63	0.62	0.61	0.69
$F^{\%}$	0.08	0.06	0.06	0.06	0.06	0.06	0.06
Fe_2O_3	1.00	0.78	0.92	0.90	0.94	0.96	0.99
K_2O	5.64	1.37	2.25	2.96	3.43	3.31	3.91
$Li_2O^{\#}$	&	0.03	0.03	0.03	0.03	0.03	0.03
MgO	1.00	0.96	0.94	0.91	0.94	0.90	0.97
MnO	&	0.02	0.01	0.02	< 0.01	0.02	0.02
Na_2O	20.61	23.62	22.79	22.14	22.08	22.21	21.90
NiO	0.008	0.13	0.11	0.12	0.11	0.10	0.10
P_2O_5	0.12	0.15	0.14	0.16	0.13	0.14	0.15
PbO	0.008	0.01	< 0.01	0.01	0.01	0.01	0.01
$ReO_2^{\$}$	0.010	< 0.001	0.002	0.002	0.002	0.002	0.003
SO_3	0.10	0.31	0.30	0.29	0.26	0.22	0.21
SiO_2	36.33	38.37	37.57	37.40	37.27	37.24	36.80
SnO_2	2.33	2.25	2.24	2.44	2.23	2.30	2.36
TiO_2	1.00	0.73	0.87	0.91	0.92	0.95	1.00
ZnO	3.00	2.79	2.92	2.90	2.82	2.86	2.79
ZrO_2	6.03	5.66	5.92	5.97	5.84	5.84	5.69
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.3) using a simple well-stirred tank model.
& - Not a target constituent.
$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]
%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.12. XRF Analyzed Compositions for Glass Samples Discharged during DM100 Melter Test with ORLEC12 Glass Composition (wt%) (continued).

	Glass (kg)	687.42	714.20	743.24	769.58	794.66	823.72
	Target	OWV-G-134E	OWV-G-136B	OWV-G-136D	OWV-G-141B	OWV-G-141D	OWV-G-144A
Al_2O_3	10.00	9.31	9.44	9.30	9.29	9.39	9.28
B_2O_3[#]	10.00	10.86	10.85	10.84	10.84	10.83	10.83
CaO	1.95	2.02	1.92	2.04	2.00	2.00	1.96
Cl	0.20	0.14	0.15	0.14	0.13	0.15	0.13
Cr_2O_3	0.58	0.66	0.63	0.66	0.63	0.64	0.63
F[%]	0.08	0.06	0.06	0.06	0.06	0.06	0.06
Fe_2O_3	1.00	1.04	0.98	1.04	1.02	1.01	1.04
K_2O	5.64	4.34	4.22	4.65	4.67	4.76	4.79
Li_2O[#]	&	0.03	0.03	0.03	0.03	0.03	0.03
MgO	1.00	1.03	0.97	0.93	0.91	0.97	1.01
MnO	&	0.01	0.01	0.02	< 0.01	0.02	0.01
Na_2O	20.61	21.55	22.15	21.46	21.80	21.69	21.86
NiO	0.008	0.09	0.08	0.09	0.07	0.07	0.06
P_2O_5	0.12	0.15	0.15	0.15	0.15	0.15	0.15
PbO	0.008	0.01	0.01	0.01	0.01	0.01	0.01
ReO_2[\$]	0.010	0.003	0.003	0.003	0.003	0.003	0.003
SO_3	0.10	0.21	0.18	0.17	0.17	0.18	0.18
SiO_2	36.33	36.47	36.84	36.00	36.60	36.10	36.22
SnO_2	2.33	2.31	2.15	2.49	2.33	2.37	2.44
TiO_2	1.00	1.04	1.06	1.13	1.05	1.13	1.09
ZnO	3.00	2.88	2.70	2.90	2.72	2.79	2.70
ZrO_2	6.03	5.82	5.41	5.90	5.52	5.65	5.51
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.3) using a simple well-stirred tank model.

& - Not a target constituent.

\$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]

%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.12. XRF Analyzed Compositions for Glass Samples Discharged during DM100 Melter Test with ORLEC12 Glass Composition (wt%) (continued).

	Glass (kg)	853.50	883.74	907.24	929.00	945.06
	Target	OWV-G-144C	OWV-G-144E	OWV-G-144G	OWV-G-147B	OWV-G-147C
Al_2O_3	10.00	9.26	9.27	9.32	9.32	9.42
B_2O_3#	10.00	10.83	10.83	10.82	10.82	10.82
CaO	1.95	2.00	1.99	1.95	2.02	1.98
Cl	0.20	0.15	0.15	0.14	0.14	0.14
Cr_2O_3	0.58	0.68	0.66	0.60	0.68	0.59
F%	0.08	0.06	0.06	0.06	0.06	0.06
Fe_2O_3	1.00	1.08	1.07	1.05	1.13	0.98
K_2O	5.64	4.87	5.19	4.99	5.27	5.04
Li_2O#	&	0.03	0.03	0.03	0.03	0.03
MgO	1.00	1.01	0.97	1.03	0.95	0.95
MnO	&	0.02	0.02	0.02	0.02	< 0.01
Na_2O	20.61	21.77	20.80	22.00	21.19	21.76
NiO	0.008	0.06	0.06	0.06	0.07	0.04
P_2O_5	0.12	0.15	0.15	0.14	0.15	0.15
PbO	0.008	< 0.01	0.01	0.01	0.01	0.02
$ReO_2$$	0.010	0.003	0.003	0.003	0.003	0.003
SO_3	0.10	0.17	0.17	0.15	0.15	0.15
SiO_2	36.33	35.80	36.20	36.04	35.99	36.66
SnO_2	2.33	2.48	2.48	2.26	2.46	2.27
TiO_2	1.00	1.07	1.14	1.09	1.09	1.08
ZnO	3.00	2.83	2.88	2.74	2.79	2.64
ZrO_2	6.03	5.69	5.87	5.49	5.65	5.21
Sum	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.3) using a simple well-stirred tank model.

& - Not a target constituent.

$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]

%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.13. XRF Analyzed Compositions for Glass Samples Discharged during DM100 Melter Test with ORLEC27 Glass Composition (wt%).

	Glass (kg)	979.56	1006.76	1027.72	1051.20	1085.00	1108.64
	Target	PWV-G-23B	PWV-G-24A	PWV-G-24C	PWV-G-29A	PWV-G-30A	PWV-G-30C
Al_2O_3	10.00	9.37	9.51	9.41	9.49	9.50	9.42
$B_2O_3^{\#}$	10.00	10.86	10.88	10.89	10.90	10.91	10.92
CaO	1.95	1.93	1.95	1.96	1.83	1.96	1.90
Cl	0.20	0.13	0.13	0.13	0.13	0.13	0.14
Cr_2O_3	0.44	0.65	0.65	0.62	0.60	0.59	0.55
$F^{\%}$	0.08	0.06	0.06	0.06	0.06	0.06	0.06
Fe_2O_3	0.60	1.02	0.98	0.88	0.88	0.82	0.80
K_2O	5.64	5.23	5.24	5.30	5.15	5.32	5.50
$Li_2O^{\#}$	&	0.03	0.03	0.03	0.03	0.03	0.03
MgO	1.00	0.93	0.94	0.92	0.95	0.96	0.94
MnO	&	< 0.01	0.02	< 0.01	0.01	0.01	< 0.01
Na_2O	20.61	21.15	21.24	21.27	21.59	21.19	21.19
NiO	0.008	0.07	0.08	0.08	0.07	0.07	0.07
P_2O_5	0.12	0.15	0.15	0.14	0.15	0.16	0.15
PbO	0.008	0.01	0.01	0.01	0.01	0.01	< 0.01
$ReO_2^{\$}$	0.010	0.002	0.003	0.003	0.003	0.003	0.003
SO_3	0.40	0.19	0.21	0.24	0.26	0.27	0.30
SiO_2	36.97	36.61	36.17	36.44	36.30	36.40	36.84
SnO_2	2.33	2.31	2.31	2.23	2.29	2.15	2.18
TiO_2	0.60	1.05	1.02	0.98	0.96	0.95	0.86
ZnO	3.00	2.75	2.80	2.80	2.79	2.83	2.73
ZrO_2	6.03	5.50	5.65	5.61	5.53	5.66	5.41
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00

\# - B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.4) using a simple well-stirred tank model.

& - Not a target constituent.

$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]

%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.13. XRF Analyzed Compositions for Glass Samples Discharged during DM100 Melter Test with ORLEC27 Glass Composition (wt%) (continued).

	Glass (kg)	1134.48	1162.98	1192.60	1220.10	1248.90	1274.54
	Target	PWV-G-32A	PWV-G-32C	PWV-G-32E	PWV-G-35B	PWV-G-35D	PWV-G-35F
Al_2O_3	10.00	9.49	9.45	9.55	9.47	9.38	9.39
B_2O_3#	10.00	10.93	10.93	10.94	10.94	10.94	10.94
CaO	1.95	1.78	1.81	1.92	1.85	1.90	1.85
Cl	0.20	0.14	0.13	0.15	0.13	0.13	0.13
Cr_2O_3	0.44	0.60	0.53	0.51	0.52	0.55	0.53
F%	0.08	0.06	0.06	0.06	0.06	0.06	0.06
Fe_2O_3	0.60	0.84	0.81	0.78	0.69	0.73	0.75
K_2O	5.64	5.33	5.37	5.52	5.41	5.49	5.44
Li_2O#	&	0.03	0.03	0.03	0.03	0.03	0.03
MgO	1.00	0.97	0.94	0.92	0.95	0.92	1.01
MnO	&	0.02	0.02	0.02	0.01	0.01	0.01
Na_2O	20.61	21.83	21.86	21.10	21.57	21.29	21.85
NiO	0.008	0.06	0.06	0.07	0.06	0.07	0.06
P_2O_5	0.12	0.15	0.16	0.16	0.15	0.15	0.14
PbO	0.008	0.01	< 0.01	0.01	< 0.01	0.01	< 0.01
$ReO_2$$	0.010	0.003	0.003	0.003	0.003	0.003	0.003
SO_3	0.40	0.28	0.31	0.34	0.31	0.36	0.36
SiO_2	36.97	36.33	36.53	36.54	36.76	36.49	36.49
SnO_2	2.33	2.07	2.02	2.09	2.05	2.22	2.04
TiO_2	0.60	0.89	0.83	0.87	0.83	0.85	0.77
ZnO	3.00	2.74	2.73	2.81	2.72	2.82	2.70
ZrO_2	6.03	5.46	5.40	5.63	5.47	5.60	5.42
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.4) using a simple well-stirred tank model.

& - Not a target constituent.

$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]

%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.13. XRF Analyzed Compositions for Glass Samples Discharged during DM100 Melter Test with ORLEC27 Glass Composition (wt%) (continued).

	Glass (kg)	1305.70	1333.58	1360.42	1385.82	1411.98
	Target	PWV-G-40B	PWV-G-40D	PWV-G-43A	PWV-G-43C	PWV-G-43E
Al_2O_3	10.00	9.39	9.56	9.43	9.52	9.38
B_2O_3#	10.00	10.95	10.95	10.95	10.95	10.95
CaO	1.95	1.84	1.84	1.89	1.72	1.84
Cl	0.20	0.14	0.16	0.15	0.15	0.15
Cr_2O_3	0.44	0.49	0.49	0.52	0.50	0.52
F%	0.08	0.06	0.06	0.06	0.06	0.06
Fe_2O_3	0.60	0.69	0.69	0.76	0.68	0.72
K_2O	5.64	5.58	5.52	5.63	5.42	5.68
Li_2O#	&	0.03	0.03	0.03	0.03	0.03
MgO	1.00	0.96	0.94	0.94	0.93	0.93
MnO	&	0.02	0.01	0.01	0.02	0.02
Na_2O	20.61	21.52	21.97	21.29	22.28	21.64
NiO	0.008	0.06	0.05	0.06	0.06	0.05
P_2O_5	0.12	0.14	0.14	0.15	0.16	0.15
PbO	0.008	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
$ReO_2$$	0.010	0.003	0.003	0.003	0.003	0.003
SO_3	0.40	0.35	0.35	0.34	0.35	0.38
SiO_2	36.97	36.75	36.47	36.48	36.64	36.40
SnO_2	2.33	2.09	1.98	2.04	1.96	2.17
TiO_2	0.60	0.74	0.81	0.82	0.74	0.78
ZnO	3.00	2.76	2.70	2.83	2.63	2.75
ZrO_2	6.03	5.42	5.30	5.61	5.21	5.41
Sum	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.4) using a simple well-stirred tank model.
& - Not a target constituent.
$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]
%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.14. XRF Analyzed Compositions for Glass Samples Discharged during DM100 Melter Test with ORLEC28 Glass Composition (wt%).

	Glass (kg)	1438.86	1461.38	1490.76	1517.58	1542.22	1566.10	1593.86
	Target	PWV-G-65B	PWV-G-65D	PWV-G-67A	PWV-G-67C	PWV-G-71B	PWV-G-71D	PWV-G-72B
Al_2O_3	10.00	9.50	9.41	9.43	9.27	9.40	9.41	9.29
B_2O_3[#]	10.00	10.91	10.88	10.86	10.84	10.82	10.81	10.80
CaO	1.95	1.90	1.87	1.93	1.93	1.92	1.93	1.93
Cl	0.20	0.08	0.10	0.09	0.09	0.10	0.10	0.10
Cr_2O_3	0.44	0.53	0.50	0.51	0.53	0.53	0.57	0.52
F[%]	0.08	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Fe_2O_3	0.60	0.74	0.72	0.76	0.81	0.81	0.77	0.92
K_2O	3.36	5.16	4.88	4.62	4.32	4.39	4.07	3.97
Li_2O[#]	&	0.03	0.03	0.03	0.03	0.03	0.03	0.03
MgO	1.00	0.97	1.04	1.05	1.11	1.07	1.11	1.09
MnO	&	< 0.01	< 0.01	0.02	0.01	0.02	0.02	0.02
Na_2O	22.11	21.24	21.66	21.77	22.00	21.58	21.59	21.30
NiO	0.008	0.09	0.08	0.07	0.07	0.06	0.07	0.07
P_2O_5	0.12	0.15	0.15	0.16	0.14	0.13	0.14	0.15
PbO	0.008	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.01	0.01
ReO_2[$]	0.010	0.002	0.002	0.002	0.002	0.002	0.003	0.003
SO_3	0.40	0.37	0.33	0.37	0.34	0.35	0.36	0.36
SiO_2	37.75	36.63	36.74	36.61	36.62	36.72	36.88	37.00
SnO_2	2.33	2.32	2.30	2.36	2.44	2.44	2.54	2.55
TiO_2	0.60	0.77	0.76	0.75	0.78	0.78	0.75	0.76
ZnO	3.00	2.94	2.96	3.00	3.06	3.12	3.19	3.27
ZrO_2	6.03	5.61	5.51	5.56	5.56	5.65	5.58	5.81
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.5) using a simple well-stirred tank model.

& - Not a target constituent.

$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]

%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.14. XRF Analyzed Compositions for Glass Samples Discharged during DM100 Melter Test with ORLEC28 Glass Composition (wt%) (continued).

	Glass (kg)	1615.62	1631.36	1657.88	1678.28	1710.14	1744.56
	Target	PWV-G-78A	PWV-G-78C	PWV-G-79A	PWV-G-79C	PWV-G-80B	PWV-G-80D
Al_2O_3	10.00	9.21	9.33	9.39	9.50	9.23	9.36
B_2O_3#	10.00	10.80	10.79	10.79	10.79	10.78	10.78
CaO	1.95	1.96	1.97	1.93	1.90	1.97	1.93
Cl	0.20	0.10	0.11	0.09	0.10	0.10	0.10
Cr_2O_3	0.44	0.48	0.50	0.52	0.51	0.53	0.51
F%	0.08	0.06	0.06	0.06	0.06	0.06	0.06
Fe_2O_3	0.60	0.73	0.71	0.72	0.68	0.72	0.70
K_2O	3.36	3.83	3.81	3.66	3.59	3.54	3.43
Li_2O#	&	0.03	0.03	0.03	0.03	0.03	0.03
MgO	1.00	1.09	1.18	1.17	1.25	1.16	1.17
MnO	&	0.01	0.02	0.02	0.02	0.02	0.01
Na_2O	22.11	21.68	21.92	21.65	22.28	22.05	22.73
NiO	0.008	0.06	0.06	0.06	0.06	0.05	0.05
P_2O_5	0.12	0.14	0.15	0.13	0.14	0.15	0.16
PbO	0.008	0.01	0.01	< 0.01	< 0.01	0.01	0.01
$ReO_2$$	0.010	0.003	0.003	0.003	0.003	0.003	0.003
SO_3	0.40	0.37	0.34	0.34	0.34	0.37	0.35
SiO_2	37.75	36.96	36.74	37.30	36.92	36.80	36.97
SnO_2	2.33	2.69	2.57	2.57	2.57	2.70	2.46
TiO_2	0.60	0.76	0.80	0.76	0.73	0.73	0.71
ZnO	3.00	3.29	3.27	3.22	3.13	3.30	3.11
ZrO_2	6.03	5.75	5.64	5.60	5.41	5.71	5.36
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00

\# - B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.5) using a simple well-stirred tank model.
& - Not a target constituent.
$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]
%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.14. XRF Analyzed Compositions for Glass Samples Discharged during DM100 Melter Test with ORLEC28 Glass Composition (wt%) (continued).

	Glass (kg)	1764.90	1788.74	1813.80	1843.40	1869.64	1891.20
	Target	PWV-G-83B	PWV-G-85A	PWV-G-85C	PWV-G-87B	PWV-G-87D	PWV-G-93A
Al_2O_3	10.00	9.23	9.23	9.39	9.32	9.17	9.33
B_2O_3#	10.00	10.78	10.78	10.77	10.77	10.77	10.77
CaO	1.95	2.01	2.01	1.97	1.98	1.97	2.01
Cl	0.20	0.09	0.08	0.10	0.11	0.10	0.10
Cr_2O_3	0.44	0.58	0.55	0.49	0.50	0.50	0.53
F%	0.08	0.06	0.06	0.06	0.06	0.06	0.06
Fe_2O_3	0.60	0.74	0.72	0.75	0.72	0.71	0.70
K_2O	3.36	3.54	3.46	3.33	3.39	3.34	3.39
Li_2O#	&	0.03	0.03	0.03	0.03	0.03	0.03
MgO	1.00	1.11	1.12	1.16	1.16	1.07	1.06
MnO	&	0.01	0.01	0.02	0.02	0.02	0.02
Na_2O	22.11	21.53	21.44	22.46	22.05	22.08	21.85
NiO	0.008	0.06	0.06	0.05	0.07	0.05	0.07
P_2O_5	0.12	0.16	0.14	0.16	0.14	0.15	0.14
PbO	0.008	< 0.01	0.01	< 0.01	0.01	0.01	< 0.01
$ReO_2$$	0.010	0.003	0.003	0.003	0.003	0.003	0.003
SO_3	0.40	0.35	0.36	0.35	0.35	0.38	0.34
SiO_2	37.75	37.28	37.49	37.02	37.14	37.38	37.52
SnO_2	2.33	2.61	2.68	2.56	2.52	2.59	2.52
TiO_2	0.60	0.77	0.76	0.72	0.74	0.76	0.76
ZnO	3.00	3.26	3.26	3.16	3.24	3.20	3.21
ZrO_2	6.03	5.79	5.77	5.44	5.70	5.67	5.60
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.5) using a simple well-stirred tank model.

& - Not a target constituent.

$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]

%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.15. Comparison of XRF Analyzed Discharged Glasses to ORLEC26 Glass Composition (wt%).

	Target	Test Average Glass		Terminal Discharge	
		Average	% Dev. from target	OWV-G-109B	% Dev. from target
Al_2O_3	10.00	8.18	-18.23	9.08	-9.17
B_2O_3#	10.00	10.55	NC	11.06	NC
CaO	1.95	2.21	13.53	2.04	4.54
Cl	0.20	0.12	NC	0.14	NC
Cr_2O_3	0.44	0.55	NC	0.59	NC
F%	0.08	0.05	NC	0.06	NC
Fe_2O_3	0.60	0.60	NC	0.77	NC
K_2O	0.50	0.51	NC	0.53	NC
Li_2O#	&	0.04	NC	0.03	NC
MgO	1.00	0.94	-5.63	0.98	-2.22
MnO	&	0.02	NC	0.03	NC
Na_2O	24.00	23.29	-2.94	23.93	-0.30
NiO	0.01	0.11	NC	0.07	NC
P_2O_5	0.12	0.11	NC	0.13	NC
PbO	0.01	0.01	NC	0.01	NC
$ReO_2$$	&	< 0.001	NC	< 0.001	NC
SO_3	0.40	0.35	NC	0.35	NC
SiO_2	38.73	41.28	6.58	38.31	-1.09
SnO_2	2.33	2.21	-5.06	2.17	-7.08
TiO_2	0.60	0.52	NC	0.68	NC
ZnO	3.00	2.72	-9.34	3.00	-0.08
ZrO_2	6.03	5.63	-6.57	6.07	0.60
Sum	100.00	-	-	100.00	-

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.2) using a simple well-stirred tank model.
& - Not a target constituent.
$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]
%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.16. Comparison of XRF Analyzed Discharged Glasses to ORLEC12 Glass Composition (wt%).

	Target	Test Average Glass		Terminal Discharge	
		Avg.	% Dev. from target	OWV-G-147C	% Dev. from target
Al_2O_3	10.00	9.28	-7.19	9.42	-5.81
B_2O_3#	10.00	10.86	NC	10.82	NC
CaO	1.95	2.00	2.79	1.98	1.70
Cl	0.20	0.13	NC	0.14	NC
Cr_2O_3	0.58	0.64	NC	0.59	NC
F%	0.08	0.06	NC	0.06	NC
Fe_2O_3	1.00	1.00	-0.48	0.98	-2.06
K_2O	5.64	4.12	-27.02	5.04	-10.64
Li_2O#	&	0.03	NC	0.03	NC
MgO	1.00	0.96	-3.74	0.95	-5.23
MnO	&	0.01	NC	< 0.01	NC
Na_2O	20.61	21.93	6.41	21.76	5.60
NiO	0.01	0.08	NC	0.04	NC
P_2O_5	0.12	0.15	NC	0.15	NC
PbO	0.01	0.01	NC	0.02	NC
$ReO_2$$	0.010	0.003	NC	0.003	NC
SO_3	0.10	0.20	NC	0.15	NC
SiO_2	36.33	36.68	0.95	36.66	0.90
SnO_2	2.33	2.34	0.59	2.27	-2.67
TiO_2	1.00	1.02	2.00	1.08	8.15
ZnO	3.00	2.80	-6.56	2.64	-12.14
ZrO_2	6.03	5.68	-5.73	5.21	-13.55
Sum	100.00	-	-	100.00	-

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.3) using a simple well-stirred tank model.
& - Not a target constituent.
$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]
%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.17. Comparison of XRF Analyzed Discharged Glasses to ORLEC27 Glass Composition (wt%).

	Target	Test Average Glass		Terminal Discharge	
		Avg.	% Dev. from target	PWV-G-43E	% Dev. from target
Al_2O_3	10.00	9.45	-5.47	9.38	-6.20
B_2O_3#	10.00	10.92	NC	10.95	NC
CaO	1.95	1.87	-4.17	1.84	-5.73
Cl	0.20	0.14	NC	0.15	NC
Cr_2O_3	0.44	0.56	NC	0.52	NC
F%	0.08	0.06	NC	0.06	NC
Fe_2O_3	0.60	0.80	NC	0.72	NC
K_2O	5.64	5.42	-3.97	5.68	0.57
Li_2O#	&	0.03	NC	0.03	NC
MgO	1.00	0.94	-5.56	0.93	-7.05
MnO	&	0.01	NC	0.02	NC
Na_2O	20.61	21.52	4.43	21.64	5.03
NiO	0.01	0.06	NC	0.05	NC
P_2O_5	0.12	0.15	NC	0.15	NC
PbO	0.01	0.01	NC	< 0.01	NC
$ReO_2$$	0.010	0.003	NC	0.003	NC
SO_3	0.40	0.31	NC	0.38	NC
SiO_2	36.97	36.51	-1.25	36.40	-1.53
SnO_2	2.33	2.13	-8.65	2.17	-6.97
TiO_2	0.60	0.87	NC	0.78	NC
ZnO	3.00	2.76	-8.04	2.75	-8.43
ZrO_2	6.03	5.49	-8.98	5.41	-10.29
Sum	100.00	-	-	100.00	-

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.4) using a simple well-stirred tank model.

& - Not a target constituent.

$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]

%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.18. Comparison of XRF Analyzed Discharged Glasses to ORLEC28 Glass Composition (wt%).

	Target	Test Average Glass		Terminal Discharge	
		Avg.	% Dev. from target	PWV-G-93A	% Dev. from target
Al_2O_3	10.00	9.34	-6.63	9.33	-6.75
B_2O_3#	10.00	10.81	NC	10.77	NC
CaO	1.95	1.95	-0.06	2.01	3.22
Cl	0.20	0.10	NC	0.10	NC
Cr_2O_3	0.44	0.52	NC	0.53	NC
F%	0.08	0.06	NC	0.06	NC
Fe_2O_3	0.60	0.74	NC	0.70	NC
K_2O	3.36	3.88	15.34	3.39	0.65
Li_2O#	&	0.03	NC	0.03	NC
MgO	1.00	1.11	11.32	1.06	5.85
MnO	&	0.02	NC	0.02	NC
Na_2O	22.11	21.83	-1.25	21.85	-1.18
NiO	0.01	0.06	NC	0.07	NC
P_2O_5	0.12	0.15	NC	0.14	NC
PbO	0.01	0.01	NC	< 0.01	NC
$ReO_2$$	0.010	0.003	NC	0.003	NC
SO_3	0.40	0.35	NC	0.34	NC
SiO_2	37.75	36.98	-2.02	37.52	-0.60
SnO_2	2.33	2.52	8.33	2.52	8.09
TiO_2	0.60	0.75	NC	0.76	NC
ZnO	3.00	3.17	5.55	3.21	7.14
ZrO_2	6.03	5.62	-6.85	5.60	-7.17
Sum	100.00	-	-	100.00	-

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (OWV-D-71A) and feed sample analysis (see Table 5.5) using a simple well-stirred tank model.

& - Not a target constituent.

$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]

%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.19. XRF Analyzed Compositions for Melt Pool Samples from DM100 Melter Tests with ORLEC26 Glass Composition (wt%).

	Target	Before	After				
		OWV-D-71A	OWV-D-109A	OWV-D-109B	OWV-D-109C	OWV-D-109D	OWV-D-109E
Al_2O_3	10.00	5.62	8.93	8.95	8.75	8.98	9.02
$B_2O_3^{\#}$	10.00	8.40	10.72	10.81	10.58	10.62	10.66
CaO	1.95	2.98	2.09	1.99	2.06	2.01	2.05
Cl	0.20	0.07	0.14	0.14	0.14	0.14	0.14
Cr_2O_3	0.44	0.54	0.61	0.74	0.77	0.61	0.59
$F^{\%}$	0.08	0.00	0.06	0.06	0.06	0.06	0.06
Fe_2O_3	0.60	0.32	0.75	0.74	0.75	0.72	0.72
K_2O	0.50	0.45	0.57	0.52	0.53	0.55	0.56
$Li_2O^{\#}$	&	0.08	0.04	0.04	0.05	0.04	0.04
MgO	1.00	0.81	1.00	0.93	0.95	0.97	0.98
MnO	&	0.02	0.02	0.02	0.01	0.01	0.02
Na_2O	24.00	21.00	23.95	24.41	23.70	24.03	24.21
NiO	0.01	0.27	0.06	0.07	0.09	0.06	0.07
P_2O_5	0.12	0.03	0.14	0.14	0.13	0.16	0.14
PbO	0.01	< 0.01	< 0.01	0.01	0.01	0.01	0.01
$ReO_2^{\$}$	&	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SO_3	0.40	0.36	0.37	0.45	0.38	0.37	0.35
SiO_2	38.73	49.26	38.30	38.31	39.03	38.83	38.76
SnO_2	2.33	2.33	2.32	2.14	2.32	2.27	2.25
TiO_2	0.60	0.05	0.69	0.68	0.67	0.68	0.69
ZnO	3.00	2.23	3.07	2.97	3.04	2.96	2.91
ZrO_2	6.03	5.17	6.17	5.87	5.99	5.94	5.78
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- DCP Analysis of B_2O_3 and Li_2O
& - Not a target constituent
$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]
%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.20. XRF Analyzed Compositions for Melt Pool Samples from DM100 Melter Tests with ORLEC12 Glass Composition (wt%).

	Target	Before	During	After	
		OWV-D-127A	OWV-D-129A	OWV-D-147B	OWV-D-147C
Al_2O_3	10.00	9.06	9.21	9.49	9.39
B_2O_3[#]	10.00	10.77	10.48	10.62	10.47
CaO	1.95	1.98	1.99	1.93	1.93
Cl	0.20	0.09	0.10	0.15	0.15
Cr_2O_3	0.58	0.58	0.64	0.61	0.67
F[%]	0.08	0.06	0.06	0.06	0.06
Fe_2O_3	1.00	0.72	0.91	1.01	0.98
K_2O	5.64	0.50	2.55	5.21	5.12
Li_2O[#]	&	0.06	0.05	0.04	0.04
MgO	1.00	0.98	0.94	0.97	0.92
MnO	&	0.02	0.02	< 0.01	0.01
Na_2O	20.61	24.19	23.09	21.68	22.33
NiO	0.01	0.16	0.12	0.05	0.05
P_2O_5	0.12	0.14	0.14	0.15	0.14
PbO	0.01	< 0.01	< 0.01	< 0.01	0.01
ReO_2[$]	0.010	< 0.001	0.002	0.003	0.003
SO_3	0.10	0.36	0.27	0.17	0.15
SiO_2	36.33	38.71	37.63	36.46	36.13
SnO_2	2.33	2.24	2.26	2.30	2.34
TiO_2	1.00	0.66	0.91	1.06	1.11
ZnO	3.00	2.88	2.86	2.69	2.66
ZrO_2	6.03	5.83	5.77	5.32	5.32
Sum	100.00	100.00	100.00	100.00	100.00

- DCP Analysis of B_2O_3 and Li_2O
& - Not a target constituent
$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [783
%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.21. XRF Analyzed Compositions for Melt Pool Samples from DM100 Melter Tests with ORLEC27 Glass Composition (wt%).

	Target	Before	During		After
	ORLEC27	PWV-D-22A	PWV-D-24C	PWV-D-46A	PWV-D-46C
Al_2O_3	10.00	9.42	9.48	9.31	9.51
B_2O_3[#]	10.00	10.66	10.83	10.91	10.98
CaO	1.95	2.02	1.87	1.83	1.83
Cl	0.20	0.13	0.13	0.16	0.15
Cr_2O_3	0.44	0.62	0.66	0.54	0.48
F[%]	0.08	0.06	0.06	0.06	0.06
Fe_2O_3	0.60	1.06	0.87	0.67	0.67
K_2O	5.64	5.16	5.22	5.53	5.60
Li_2O[#]	&	0.04	0.04	0.03	0.03
MgO	1.00	0.94	0.93	0.94	0.93
MnO	&	0.02	0.02	0.01	0.02
Na_2O	20.61	21.36	21.28	21.73	21.66
NiO	0.01	0.08	0.08	0.05	0.04
P_2O_5	0.12	0.15	0.15	0.14	0.15
PbO	0.01	0.01	0.01	< 0.01	0.01
ReO_2[$]	0.010	0.003	0.003	0.003	0.003
SO_3	0.40	0.15	0.24	0.40	0.37
SiO_2	36.97	36.38	36.85	36.95	36.79
SnO_2	2.33	2.31	2.16	1.98	1.90
TiO_2	0.60	1.16	0.97	0.73	0.80
ZnO	3.00	2.79	2.72	2.70	2.70
ZrO_2	6.03	5.48	5.40	5.31	5.32
Sum	100.00	100.00	100.00	100.00	100.00

\# - DCP Analysis of B_2O_3 and Li_2O
& - Not a target constituent
$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]
%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.22. XRF Analyzed Compositions for Melt Pool Samples from DM100 Melter Tests with ORLEC28 Glass Composition (wt%).

	Target	Before	During		After	
	ORLEC28	PWV-D-52A	PWV-D-66A	PWV-D-66E	PWV-D-93A	PWV-D-93C
Al_2O_3	10.00	9.46	9.50	9.54	9.32	9.38
B_2O_3#	10.00	11.04	10.93	10.42	10.33	10.72
CaO	1.95	1.89	1.84	1.93	1.98	1.97
Cl	0.20	0.14	0.11	0.10	0.13	0.12
Cr_2O_3	0.44	0.51	0.59	0.55	0.51	0.51
F%	0.08	0.06	0.06	0.06	0.06	0.06
Fe_2O_3	0.60	0.73	0.75	0.73	0.72	0.69
K_2O	3.36	5.46	4.67	4.76	3.32	3.29
Li_2O#	&	0.04	0.04	0.04	0.03	0.03
MgO	1.00	0.95	1.07	1.08	1.11	1.07
MnO	&	0.02	0.02	0.01	0.02	0.02
Na_2O	22.11	21.30	21.56	21.41	22.74	22.21
NiO	0.01	0.08	0.07	0.08	0.04	0.05
P_2O_5	0.12	0.16	0.14	0.15	0.14	0.14
PbO	0.01	0.01	< 0.01	0.01	0.01	< 0.01
$ReO_2$$	0.010	0.002	0.003	0.002	0.003	0.003
SO_3	0.40	0.36	0.36	0.36	0.39	0.35
SiO_2	37.75	37.06	36.55	37.00	37.22	37.42
SnO_2	2.33	1.96	2.35	2.28	2.48	2.41
TiO_2	0.60	0.76	0.74	0.78	0.74	0.73
ZnO	3.00	2.69	3.09	3.09	3.10	3.20
ZrO_2	6.03	5.32	5.55	5.62	5.60	5.62
Sum	100.00	100.00	100.00	100.00	100.00	100.00

- DCP Analysis of B_2O_3 and Li_2O
& - Not a target constituent
$ - Rhenium concentration based on calibration of samples analyzed by ICP-MS [73]
%- Fluorine estimated from independent XRF analysis of select samples.

Table 5.23. Measured Viscosities and Electrical Conductivities for Crucible and Melter Glasses.

			ORLEC12		ORLEC26		ORLEC27		ORLEC28	
			Crucible	OWV-G-144E	Crucible	OWV-G-109B	Crucible	PWV-G-43E	Crucible	PWV-G-93A
Viscosity (P)	**Interpolated**	950°C	936	696	958	799	910	667	989	611
		1000°C	425	315	419	355	406	305	436	358
		1050°C	214	158	204	176	200	154	213	176
		1100°C	117	87	109	96	107	85	113	94
		1150°C	69	51	62	56	61	50	65	55
		1200°C	43	32	38	35	37	31	39	34
		1250°C	28	21	24	23	24	20	25	22
Electrical Conductivity (S/ cm)	**Interpolated**	950°C	0.257	0.192	0.250	0.192	0.192	0.205	0.222	0.213
		1000°C	0.318	0.246	0.306	0.246	0.240	0.254	0.276	0.265
		1050°C	0.387	0.306	0.368	0.308	0.296	0.310	0.338	0.323
		1100°C	0.465	0.378	0.438	0.378	0.360	0.373	0.408	0.388
		1150°C	0.551	0.455	0.514	0.455	0.431	0.442	0.485	0.461
		1200°C	0.645	0.540	0.597	0.540	0.510	0.518	0.570	0.541
		1250°C	0.747	0.631	0.686	0.631	0.597	0.602	0.664	0.628

Table 5.24. Results of 7-Day PCT (at 90°C) for DM-100 Melter Glasses Compared to Crucible Glasses.

		Crucible ORLEC 12	**Melter** **OWV-G-144E**	Crucible ORLEC 26	**Melter** **OWV-G-109B**	Crucible ORLEC 27	**Melter** **PWV-G-43E**	Crucible ORLEC 28	**Melter** **PWV-G-93A**
7-Day PCT, Stainless Steel Vessel; S/V=2000 m^{-1} (ppm)	B	39.44	52.20	22.81	38.34	42.38	86.44	31.61	47.62
	Na	185.35	186.41	157.68	182.79	196.03	288.42	166.96	191.88
	Si	48.57	51.62	55.35	59.49	53.32	55.39	52.83	51.59
Normalized Concentrations (g/L)	B	1.27	1.68	0.73	1.23	1.36	2.78	1.02	1.53
	Na	1.21	1.22	0.89	1.03	1.28	1.89	1.02	1.17
	Si	0.29	0.30	0.31	0.33	0.31	0.32	0.30	0.29
	pH	11.07	11.3	11.11	11.11	11.01	11.51	10.86	11.26
7-Day PCT Normalized Mass Loss (g/m^2)	B	0.64	0.84	0.37	0.62	0.68	1.39	0.51	0.77
	Na	0.61	0.61	0.44	0.51	0.64	0.94	0.51	0.58
	Si	0.14	0.15	0.15	0.16	0.15	0.16	0.15	0.15

Table 5.25. Results of VHT (at 200ºC for 24 Days) for DM-100 Melter Glasses Compared to Crucible Glasses.

		Alteration Depth (µm)	Rate (g/m^2/d) Calculated for Estimated Average Density of 2.65 g/cc	Comparison to Limit of 50 g/m^2/d	Predicted Rate (g/m^2/d)
ORLEC12	Crucible	372.45	41.1	82.2%	47.3
	OWV-G-144E-T1	198.7	21.9	43.9%	
	OWV-G-144E-T2	252	27.8	55.7%	
ORLEC26	Crucible	5.09	0.6	1.1%	20.2
	OWV-G-109B-T1	15.4	1.7	3.4%	
	OWV-G-109B-T2	7.7	0.9	1.7%	
ORLEC27	Crucible	351.55	38.8	77.6%	46.7
	PWV-G-43E-T1	649.55	71.7	143.4%	
	PWV-G-43E-T2	439.6	48.5	97.1%	
ORLEC28	Crucible	58.91	6.5	13.0%	12.7
	PWV-G-93A-T1	22.99	2.5	5.1%	
	PWV-G-93A-T2	13.15	1.5	2.9%	

Table 6.1. Results from DM100 Melter Off-Gas Emission Samples.

		ORLEC26 11/17/2015 13:21 -14:21 12.6 % Moisture, 106% Isokinetic				ORLEC12 12/3/2015 12:27 - 13:27 12.2% Moisture, 103.9% Isokinetic			
		Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF	Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total[$]	187981	351	0.19	536	211050	1211	0.57	174
	Al	7406	2.19	0.03	3376	8403	3.63	0.04	2317
	B	4345	14.2	0.33	305	4929	69.1	1.40	71.3
	Ca	1951	0.68	0.04	2857	2214	1.44	0.06	1539
	Cl*	280	86.8	31.0	3.23	318	140	44.1	2.27
	Cr	420	3.19	0.76	131	630	12.4	1.97	50.8
	F*	112	11.9	10.6	9.40	127	27.2	21.4	4.67
	Fe	588	0.14	0.02	4165	1111	1.69	0.15	656
	K	581	12.4	2.14	46.7	7437	225	3.02	33.1
	Mg	844	< 0.10	< 0.01	> 8442	958	0.12	0.01	8094
	Na	24929	102	0.41	243	24288	210	0.86	116
	Ni	11.0	< 0.10	< 0.91	> 110	12.5	< 0.10	< 0.80	> 125
	P	73.4	< 0.10	< 0.14	> 734	83.2	0.34	0.40	247
	Pb	13.0	< 0.10	< 0.77	> 130	14.7	0.18	1.21	82.8
	Re	0.00	< 0.10	NC	NC	13.6	8.12	59.9	1.67
	S*	224	8.07	3.60	27.8	63.7	4.71	7.41	13.5
	Sn	2569	0.47	0.02	5521	2915	1.55	0.05	1884
	Si	25347	3.79	0.01	6690	26975	8.21	0.03	3287
	Ti	504	0.12	0.02	4331	952	0.54	0.06	1753
	Zn	3374	1.78	0.05	1893	3828	6.38	0.17	600
	Zr	6250	0.27	0.004	23018	7091	0.84	0.01	8451
Gas	B	4345	0.74	0.02	5904	4929	< 0.10	< 0.00	> 49293
	Cl	280	< 0.10	< 0.04	> 2800	318	< 0.10	< 0.03	> 3177
	F	112	1.61	1.43	69.8	127	2.45	1.93	51.9
	S	224	< 0.10	< 0.04	> 2244	63.7	< 0.10	< 0.16	> 637

[$] - From gravimetric analysis of filters and particulate nitric acid rinses.

[#] - Feed rate calculated from target composition and steady state production rate.

*- Calculated from water dissolution of filter particulate and direct analysis of rinse solutions.

Table 6.1. Results from DM100 Melter Off-Gas Emission Samples (continued).

		ORLEC27 12/8/2015 13:21 - 14:21 12.4 % Moisture, 92.4% Isokinetic				ORLEC28 12/15/2015 12:08 - 13:08 14.0% Moisture, 96.9% Isokinetic			
		Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF	Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total[$]	208560	1103	0.53	189	206286	1249	0.61	165
	Al	8297	3.61	0.04	2298	8226	11.9	0.14	690
	B	4867	62.9	1.29	77.4	4826	76.9	1.59	62.8
	Ca	2186	1.45	0.07	1509	2162	2.28	0.11	949
	Cl*	314	124	39.7	2.52	311	106	34.2	2.92
	Cr	470	9.81	2.09	47.9	468	9.52	2.03	49.2
	F*	125	24.0	19.1	5.23	124	34.5	27.7	3.60
	Fe	659	0.51	0.08	1285	652	1.44	0.22	452
	K	7347	226	3.08	32.5	4337	152	3.51	28.5
	Mg	946	0.19	0.02	5007	938	0.11	0.01	8186
	Na	23977	182	0.76	131	25509	270	1.06	94.6
	Ni	12.3	< 0.10	< 0.81	> 123	12.2	< 0.10	< 0.82	> 122
	P	82.2	0.46	0.56	179	81.5	0.51	0.62	160
	Pb	14.6	0.13	0.88	113	14.4	0.15	1.05	95.3
	Re	13.4	7.37	55.0	1.82	13.3	9.66	72.8	1.37
	S*	251	6.50	2.59	38.6	249	12.2	4.88	20.5
	Sn	2879	1.17	0.04	2468	2854	3.71	0.13	769
	Si	27104	7.98	0.03	3396	27441	15.1	0.05	1819
	Ti	565	0.33	0.06	1701	559	0.55	0.10	1024
	Zn	3780	5.92	0.16	638	3748	13.2	0.35	283
	Zr	7002	0.72	0.01	9676	6942	2.10	0.03	3312
Gas	B	4867	< 0.10	< 0.00	> 48672	4826	< 0.10	< 0.00	> 48259
	Cl	314	< 0.10	< 0.03	> 3137	311	< 0.10	< 0.03	> 3110
	F	125	2.61	2.08	48.1	124	2.86	2.30	43.5
	S	251	< 0.10	< 0.04	> 2514	249	< 0.10	< 0.04	> 2493

[$] - From gravimetric analysis of filters and particulate nitric acid rinses.

[#] - Feed rate calculated from target composition and steady state production rate.

*- Calculated from water dissolution of filter particulate and direct analysis of rinse solutions.

Table 6.2. Particulate Removed from Cyclones after DM100 Tests (wt%).

	ORLEC26		**ORLEC12**		**ORLEC27**		**ORLEC28**	
Amounts removed	66 g		102 g		265 g		107 g	
Mineral phases detected	Halite, Quartz, Zircon		Halite, Quartz, Sylvine, Rutile, Zircon		Halite, Quartz, Sylvine, Rutile, Zircon		Halite, Quartz, Sylvine, Rutile, Zircon	
	Target Glass	OWV-O-110A	Target Glass	OWV-O-150A	Target Glass	PWV-O-52A	Target Glass	PWV-O-96A
Al_2O_3	10.00	4.30	10.00	3.35	10.00	2.84	10.00	4.90
$B_2O_3^{\#}$	10.00	14.25	10.00	19.99	10.00	18.75	10.00	18.17
CaO	1.95	1.98	1.95	1.31	1.95	1.14	1.95	1.76
Cl	0.20	14.26	0.20	7.18	0.20	7.26	0.20	4.20
Cr_2O_3	0.44	0.81	0.58	1.64	0.44	1.52	0.44	1.08
F	0.08	NM	0.08	NM	0.08	NM	0.08	NM
Fe_2O_3	0.60	0.32	1.00	0.97	0.60	0.72	0.60	0.67
K_2O	0.50	1.91	5.64	14.90	5.64	18.56	3.36	9.87
$Li_2O^{\#}$	&	0.03	&	0.02	&	0.02	&	0.02
MgO	1.00	0.09	1.00	0.04	1.00	0.04	1.00	0.06
MnO	&	0.02	&	< 0.01	&	< 0.01	&	0.02
Na_2O	24.00	33.67	20.61	29.24	20.61	28.54	22.11	29.72
NiO	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.02
P_2O_5	0.12	0.04	0.12	0.21	0.12	0.22	0.12	0.20
PbO	0.01	< 0.01	0.01	0.01	0.01	0.01	0.01	0.02
$ReO_2^{\$}$	&	0.057	0.01	0.299	0.01	0.380	0.01	0.272
RuO_2	&	0.11	&	0.06	&	0.03	&	0.07
SO_3	0.40	1.40	0.10	1.04	0.40	1.84	0.40	1.42
SiO_2	38.73	18.89	36.33	10.87	36.97	9.30	37.75	15.60
SnO_2	2.33	1.72	2.33	1.33	2.33	1.61	2.33	2.06
SrO	&	0.02	&	< 0.01	&	< 0.01	&	< 0.01
TiO_2	0.60	0.10	1.00	0.52	0.60	0.39	0.60	0.40
ZnO	3.00	2.85	3.00	3.63	3.00	3.52	3.00	4.57
ZrO_2	6.03	3.16	6.03	3.36	6.03	3.29	6.03	4.90
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

$^{\$}$ - Value from ICP-MS analysis of dissolved sample.
NM – Not measured.
& - Not a target constituent.

Table 6.3. Mass Balances for Rhenium, Sulfur, and Chlorine during DM100 Tests (% of Feed).

	Target Glass Concentrations*	Element	Glass	Particle Emissions	Gaseous Emissions	Total
LAWE3 (AP-101) [38]	0.1 wt.% ReO_2 0.35 wt.% SO_3 4.98 wt% K_2O 18.19 wt% Na_2O	Rhenium	20	63.7	< 0.1	83.7
		Sulfur	94.3	7.2	0.1	101.6
		Chlorine	75	52.0	0.5	127.5
LAWE4H (AN-105) [38]	0.1 wt.% ReO_2 0.41 wt.% SO_3 0.54 wt% K_2O 21.25 wt% Na_2O	Rhenium	35	60.0	< 0.1	95
		Sulfur	87.8	8.6	0.1	96.5
		Chlorine	65	46.5	0.1	111.5
ORLEC26 (AN-105)	0 wt.% ReO_2 0.4 wt.% SO_3 0.54 wt% K_2O 18.19 wt% Na_2O	Rhenium	NA	NA	NA	NA
		Sulfur	88	3.60	< 0.1	92
		Chlorine	70	31.0	< 0.1	101
ORLEC12 (AP-101)	0.01 wt.% ReO_2 0.1 wt.% SO_3 5.64 wt% K_2O 20.61 wt% Na_2O	Rhenium	30	59.9	< 0.1	90
		Sulfur	150	7.41	< 0.1	157
		Chlorine	70	44.1	< 0.1	114
ORLEC27 (AP-101)	0.01 wt.% ReO_2 0.4 wt.% SO_3 5.64 wt% K_2O 20.61 wt% Na_2O	Rhenium	30	55.0	< 0.1	85
		Sulfur	88	2.6	< 0.1	91
		Chlorine	75	39.7	< 0.1	115
ORLEC28 (51.66% AP-101 + 48.34% AN-105)	0.01 wt.% ReO_2 0.4 wt.% SO_3 3.36 wt% K_2O 22.11 wt% Na_2O	Rhenium	30	72.8	< 0.1	103
		Sulfur	88	4.9	< 0.1	93
		Chlorine	50	34.2	< 0.1	84

*- all glasses targeted at 0.2 wt% Cl and 0.08 wt% F
NA- Not Applicable

Table 6.4. Concentrations [ppmv] of Selected Species in Off-Gas Measured by FTIR Spectroscopy during DM100 Tests.

	ORLEC26		ORLEC12		ORLEC27		ORLEC28	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
H_2O (%)	6.5	< 1.0 - 16.4	6.4	1.3 - 10.5	5.8	< 1.0 - 12.1	7.1	1.6 - 18.4
CO	56.3	< 1.0 - 362	63.0	< 1.0 - 137	47.7	< 1.0 - 180	54.3	< 1.0 - 294
CO_2	3785	379 - 31394	4893	465 - 15902	4534	444 - 16984	4402	266 - 25737
HCN	< 0.1	< 1.0 - 1.9	< 0.1	NA	< 0.1	NA	< 0.1	< 1.0 - 1.4
HF	< 0.1	< 1.0 - 2.5	< 0.1	< 1.0 - 2.2	< 0.1	< 1.0 - 1.5	< 0.1	< 1.0 - 1.6
HCl	< 0.1	< 1.0 - 1.2	< 0.1	NA	< 0.1	NA	< 0.1	NA
NH_3	98.3	< 1.0 - 892	81.1	1.3 - 263	78.5	1.3 - 354	85.4	< 1.0 - 909
HNO_3	< 0.1	< 1.0 - 4.1	< 0.1	< 1.0 - 1.4	< 0.1	< 1.0 - 1.0	< 0.1	< 1.0 - 2.0
NO	1532	3.5 - 6117	2074	3.0 - 4192	1801	2.8 - 3707	1781	< 1.0 - 5316
NO_2	130	2.9 - 915	184	< 1.0 - 771	160	< 1.0 - 642	136	< 1.0 - 851
HNO_2	1.2	< 1.0 - 9.2	1.1	< 1.0 - 4.2	< 0.1	< 1.0 - 2.6	< 0.1	< 1.0 - 4.4
N_2O	209	< 1.0 - 1079	239	< 1.0 - 569	205	< 1.0 - 629	220	< 1.0 - 970

NA: Not applicable.

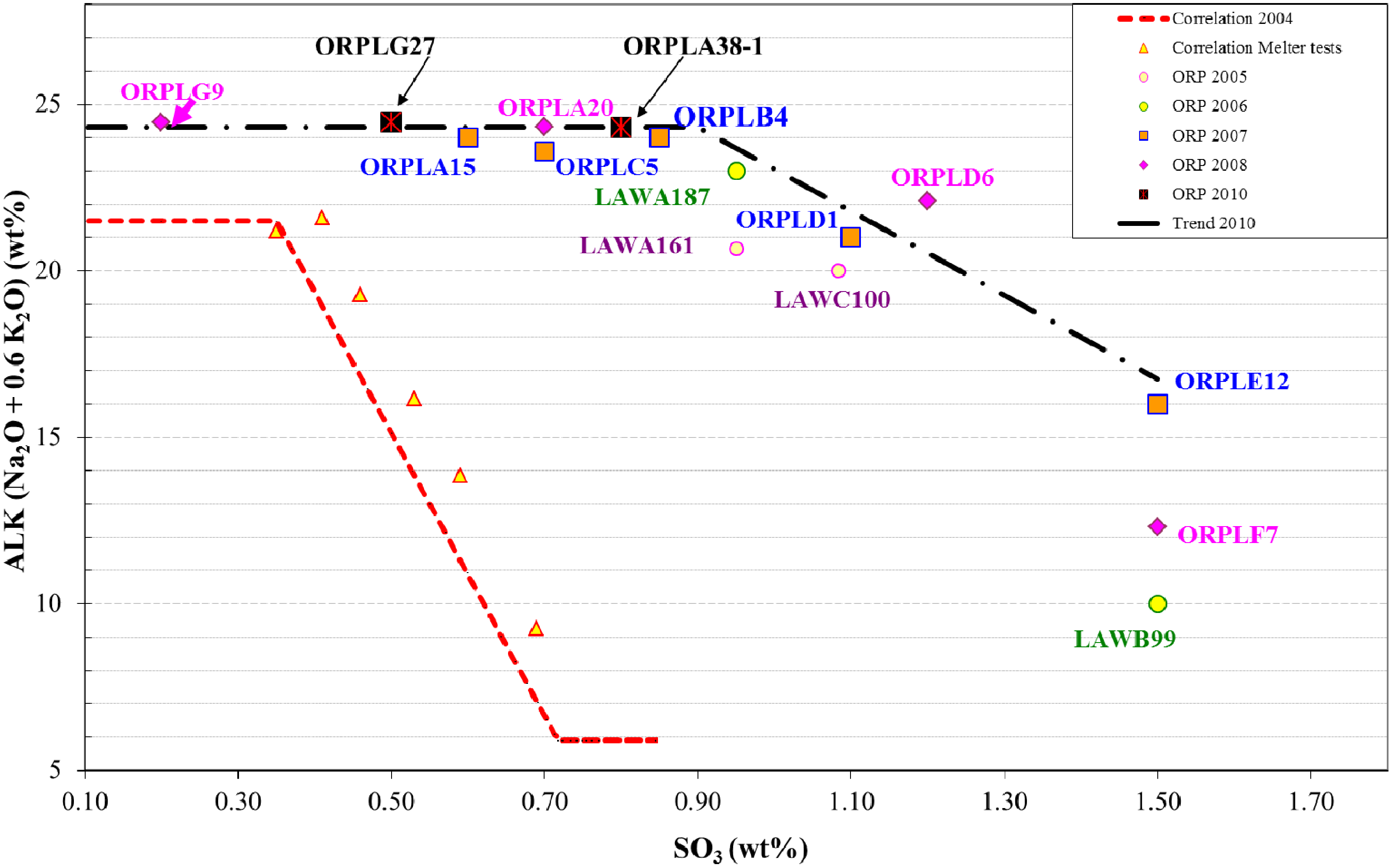


Figure 1.1. Overview of alkali oxides (Na_2O and K_2O) and SO_3 loadings for WTP baseline (red line) and ORP high waste loading LAW glasses (black line).

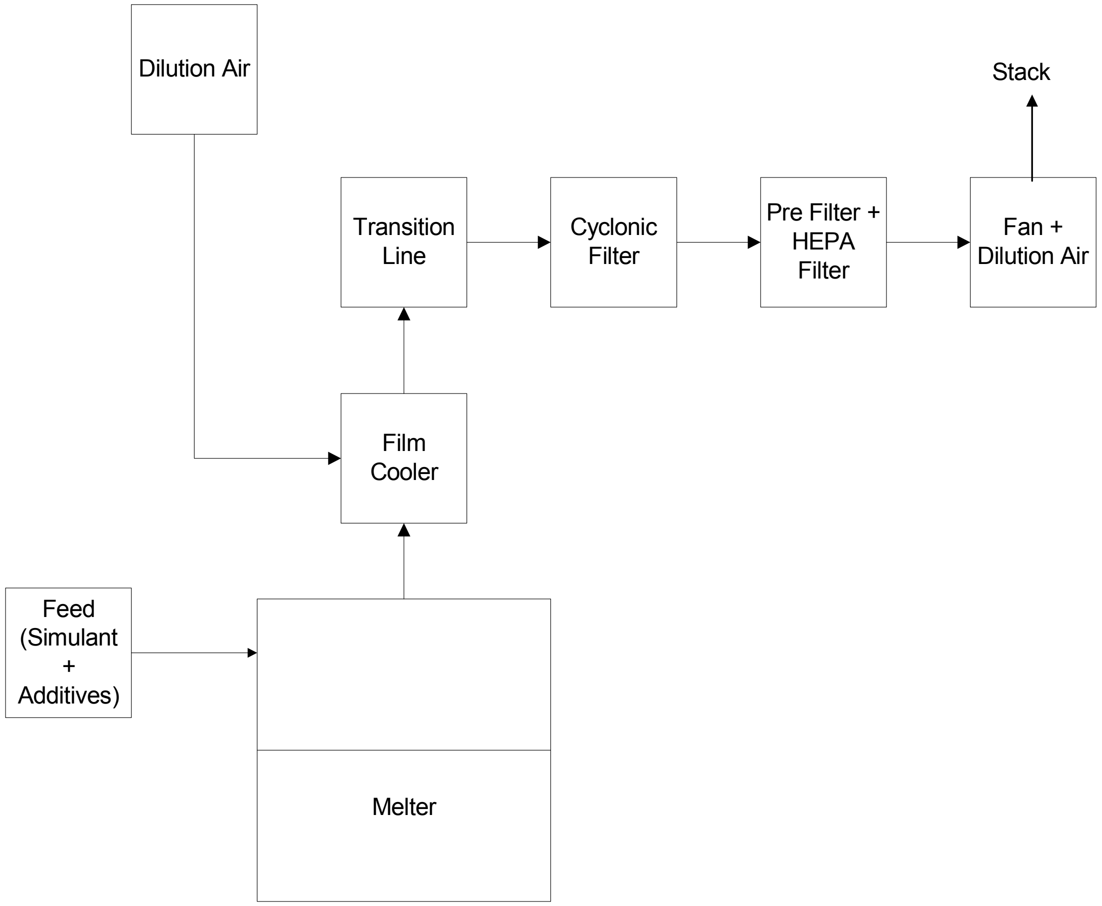


Figure 1.2. Schematic diagram of DuraMelter 100-WV vitrification system.

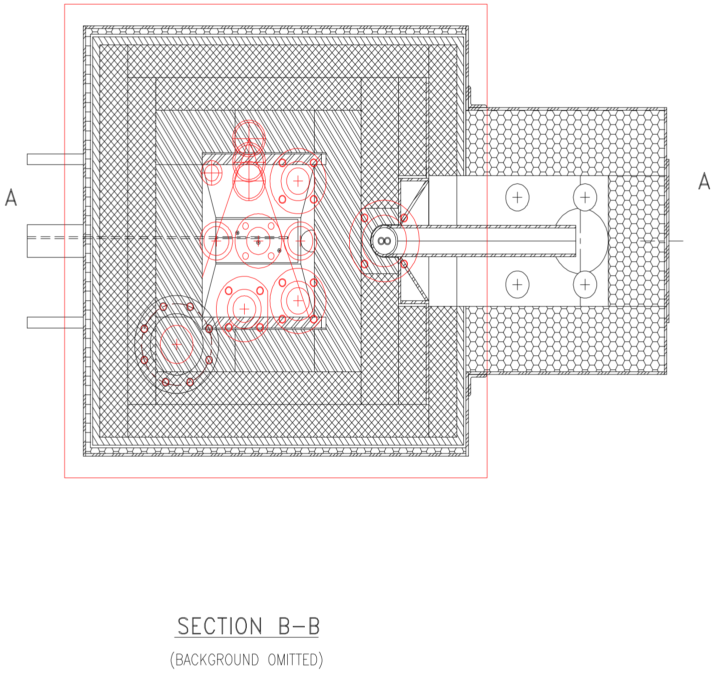


Figure 1.3.a. Cross-section through the DM100-WV melter – Plan View.

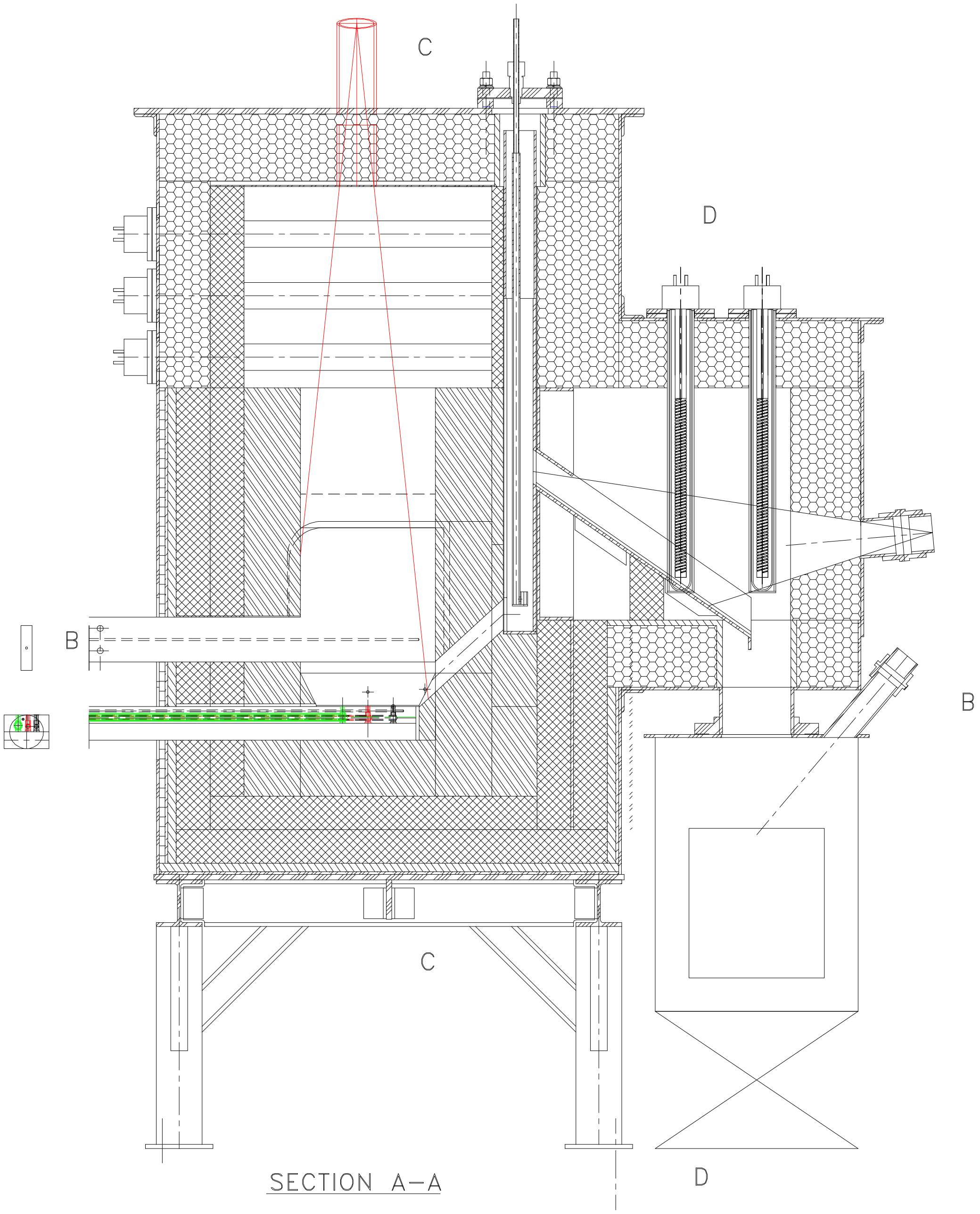


Figure 1.3.b. Cross-section through the DM100-WV melter – Section AA.

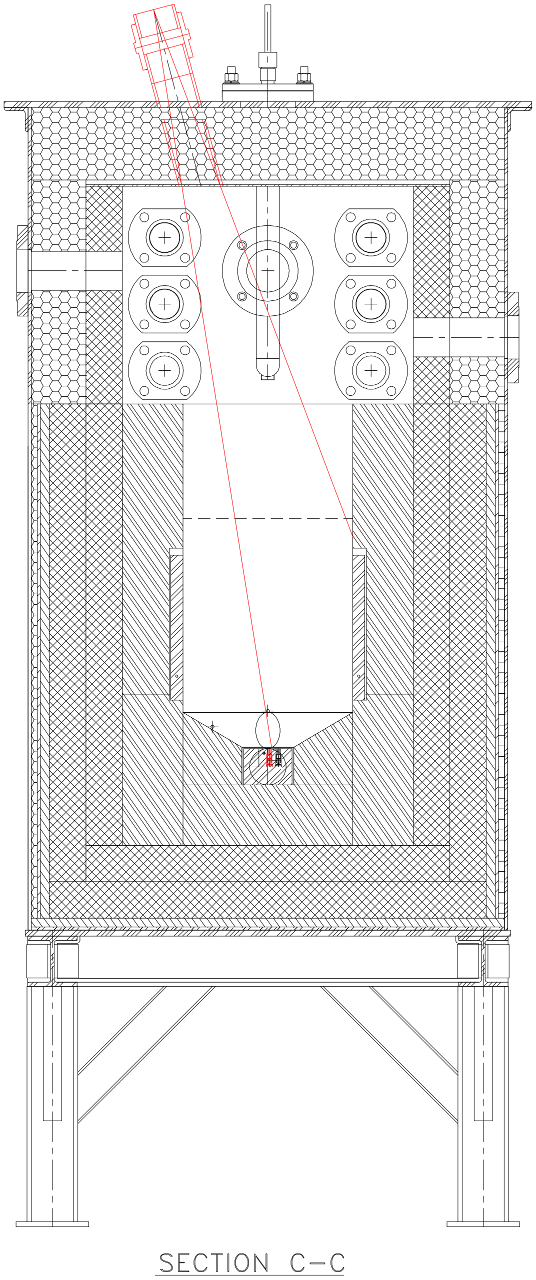


Figure 1.3.c. Cross-section through the DM100-WV melter—Section CC.

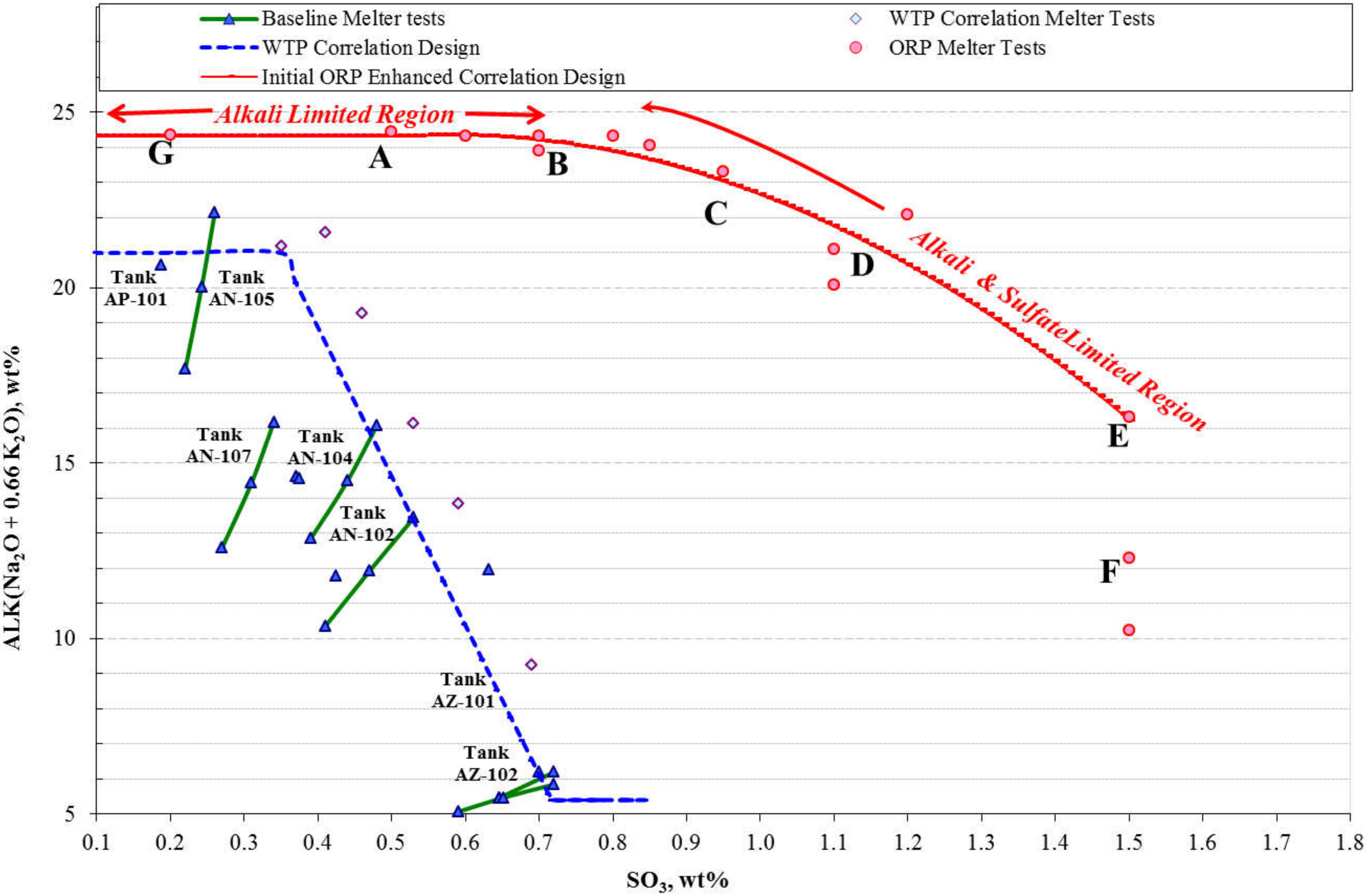
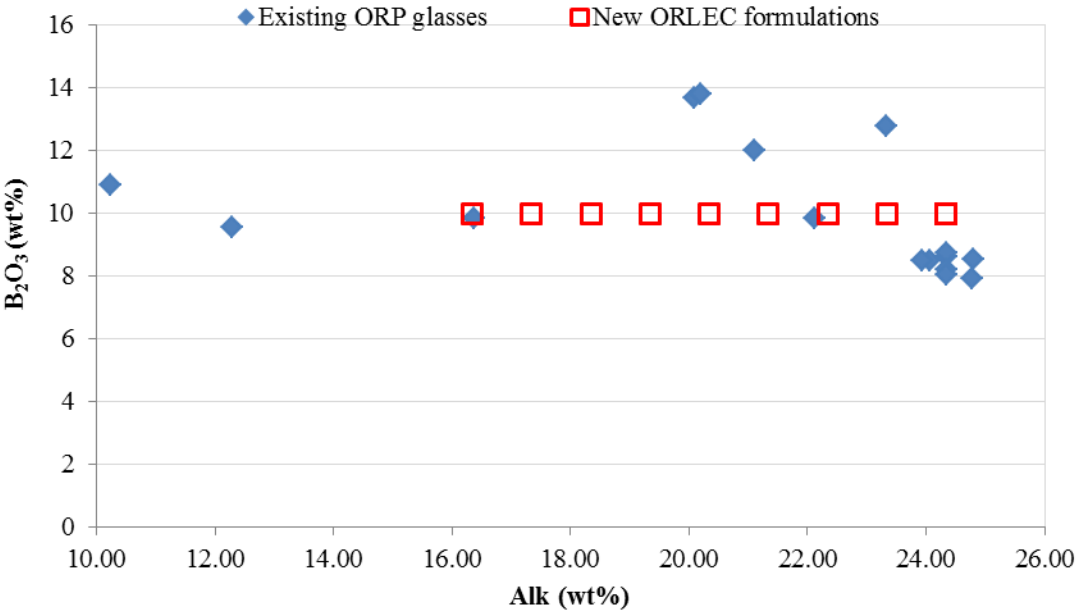


Figure 2.1. Display of the seven waste regions and the higher waste loading glasses that were used to underpin the Enhanced LAW Glass Correlation.



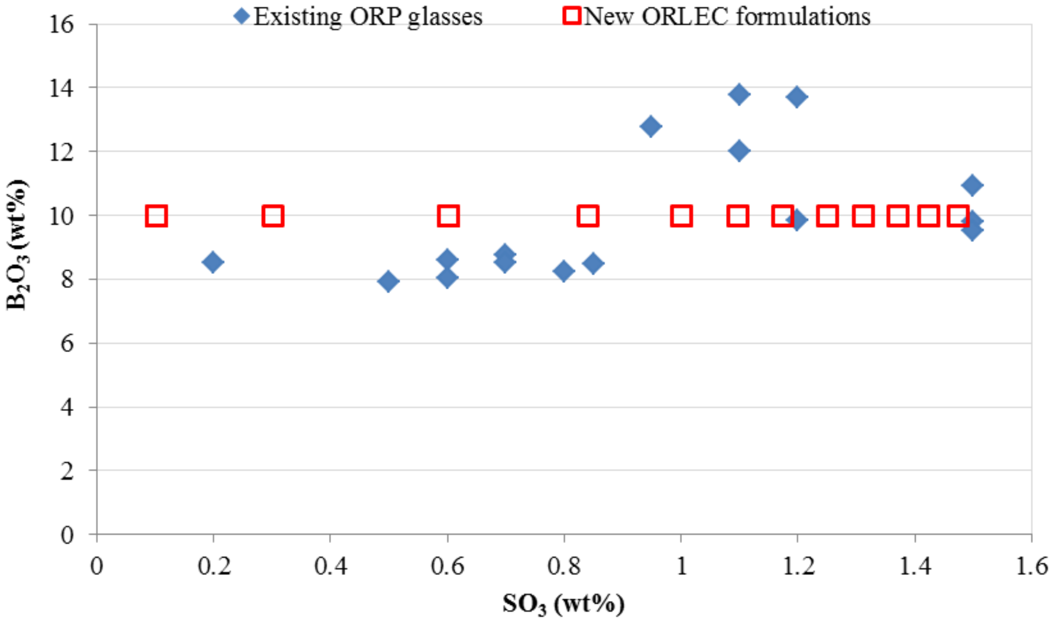
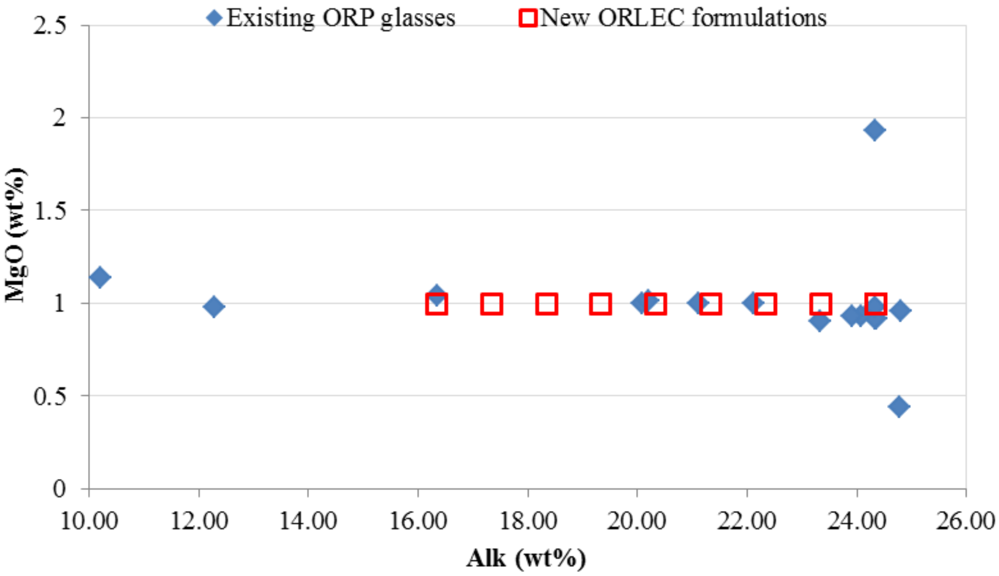


Figure 2.2. B_2O_3 concentrations used in the initial Enhanced LAW Glass Correlation.



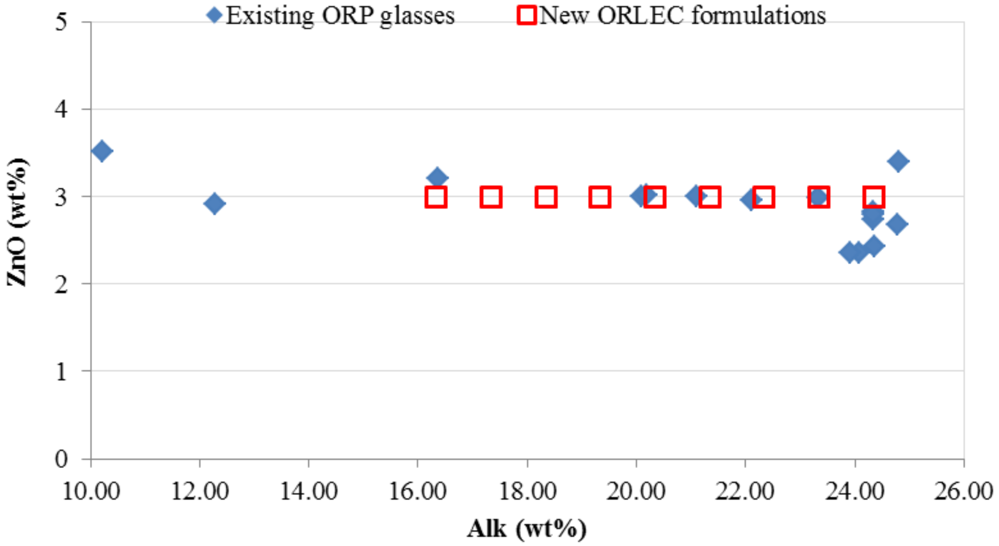


Figure 2.3. MgO and ZnO concentrations used in the initial Enhanced LAW Glass Correlation.

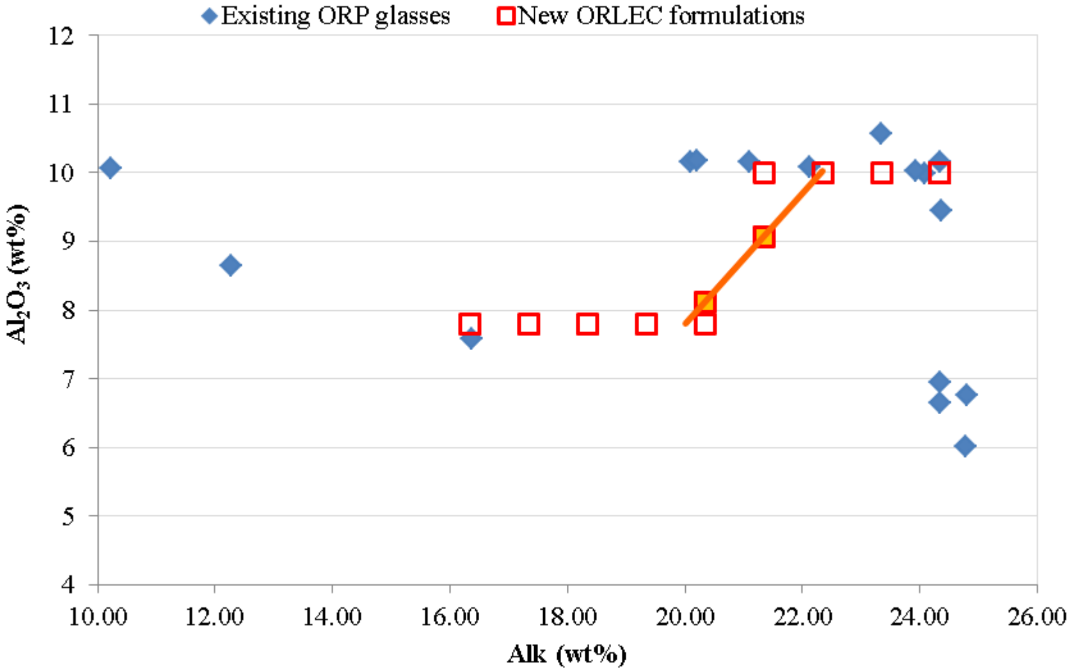
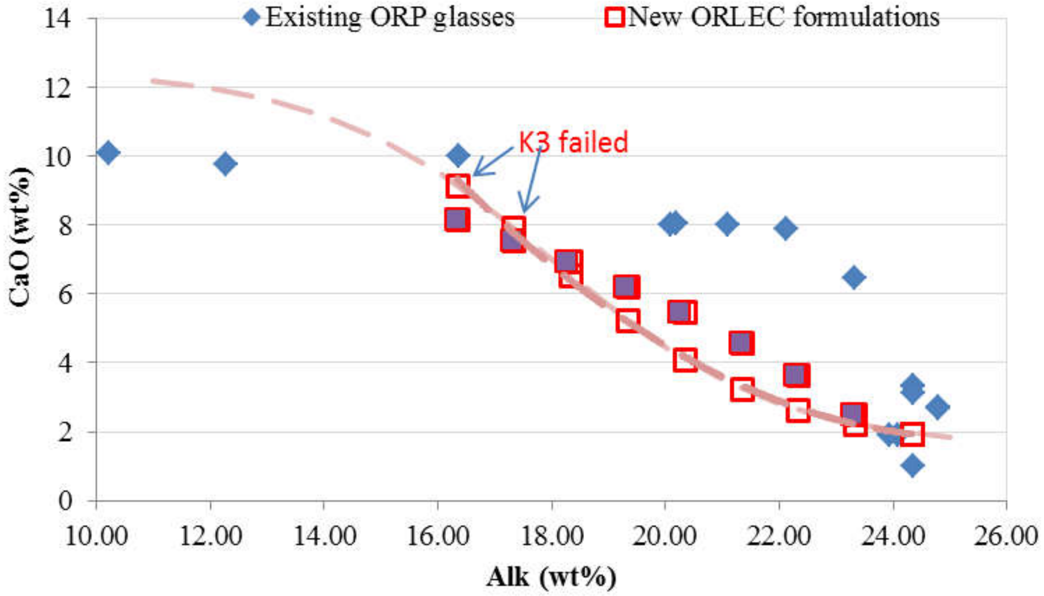


Figure 2.4. Al_2O_3 concentrations used in the initial Enhanced LAW Glass Correlation.



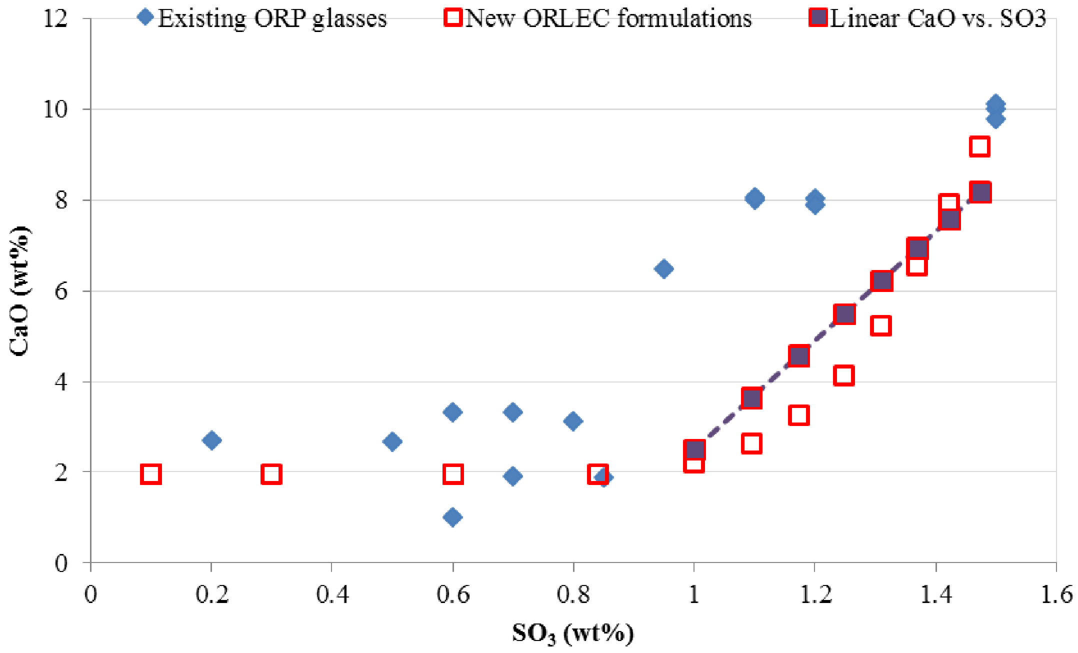


Figure 2.5. CaO concentrations used in the initial Enhanced LAW Glass Correlation.

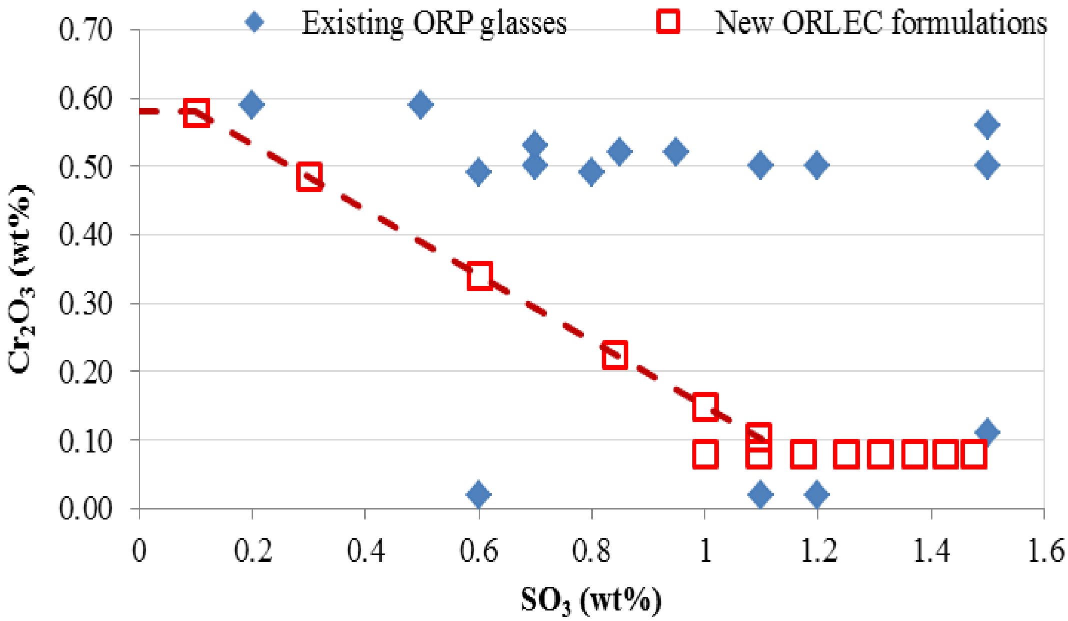


Figure 2.6. Cr_2O_3 concentrations used in the initial Enhanced LAW Glass Correlation.

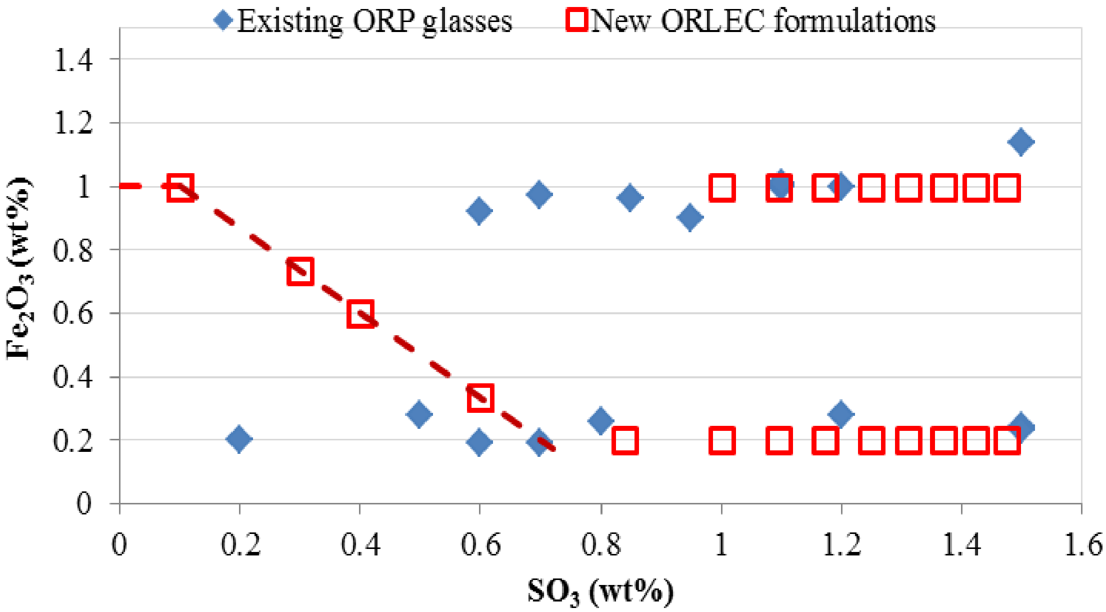


Figure 2.7. Fe_2O_3 concentrations used in the initial Enhanced LAW Glass Correlation.

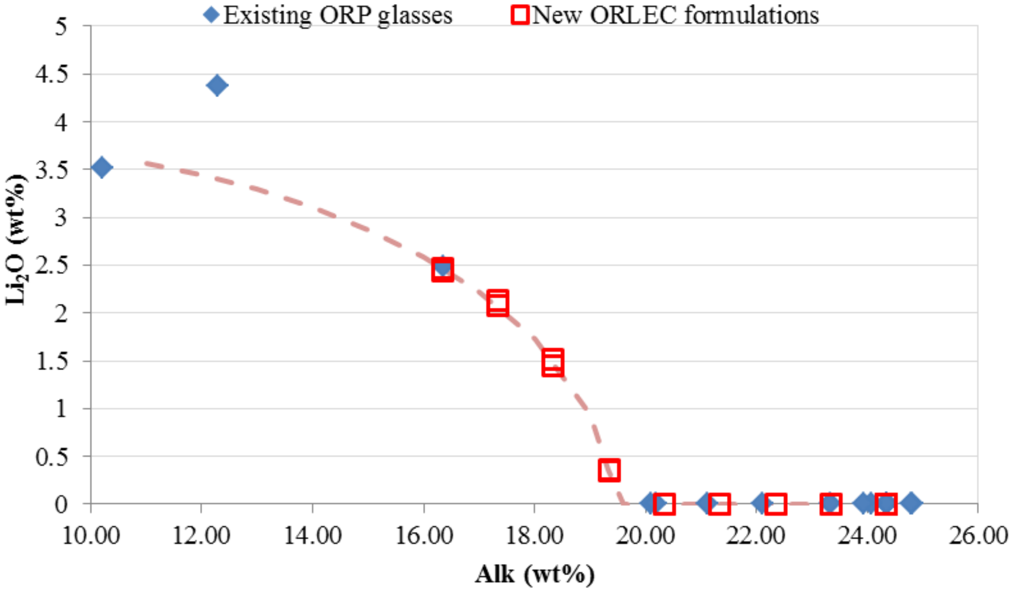


Figure 2.8. Li_2O concentrations used in the initial Enhanced LAW Glass Correlation.

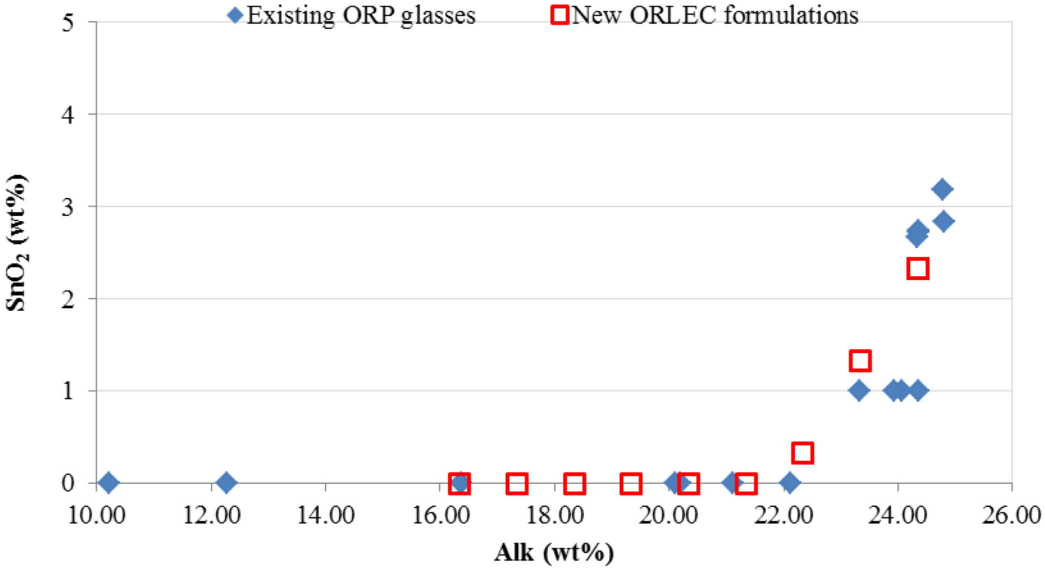


Figure 2.9. SnO_2 concentrations used in the initial Enhanced LAW Glass Correlation.

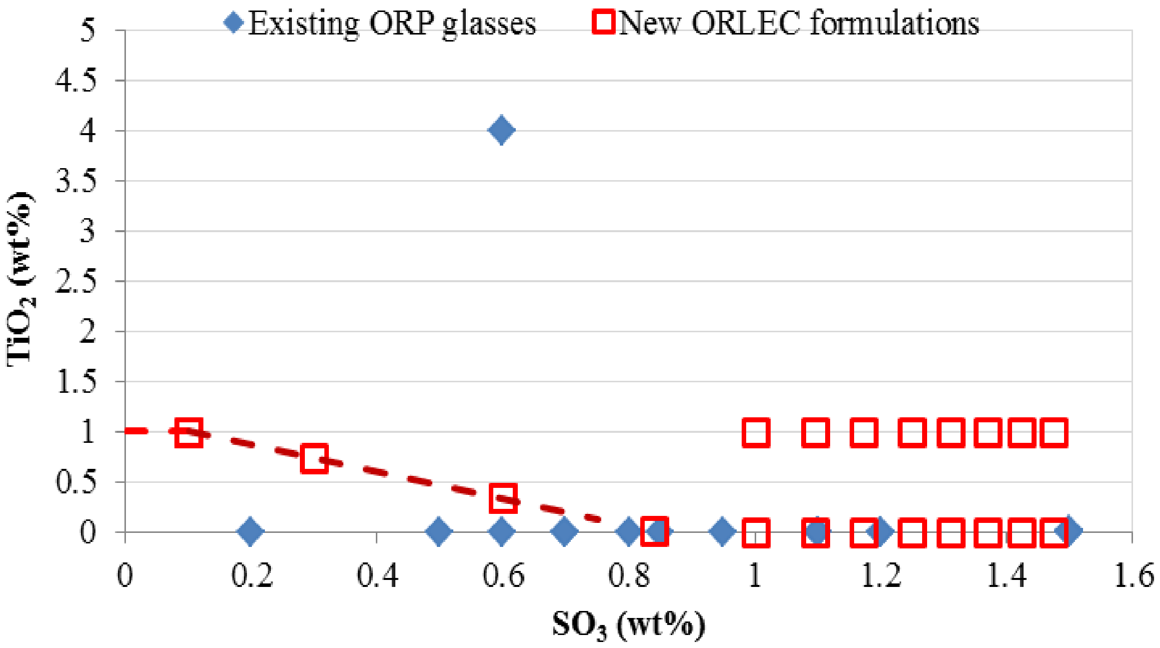


Figure 2.10. TiO_2 concentrations used in the initial Enhanced LAW Glass Correlation.

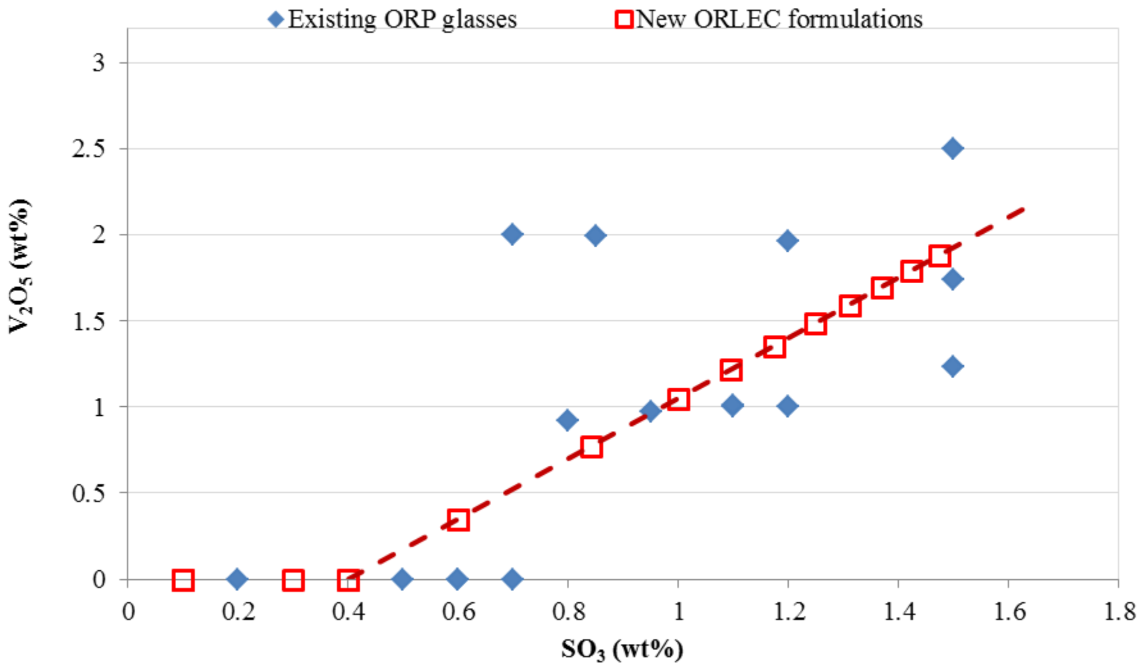


Figure 2.11. V_2O_5 concentrations used in the initial Enhanced LAW Glass Correlation.

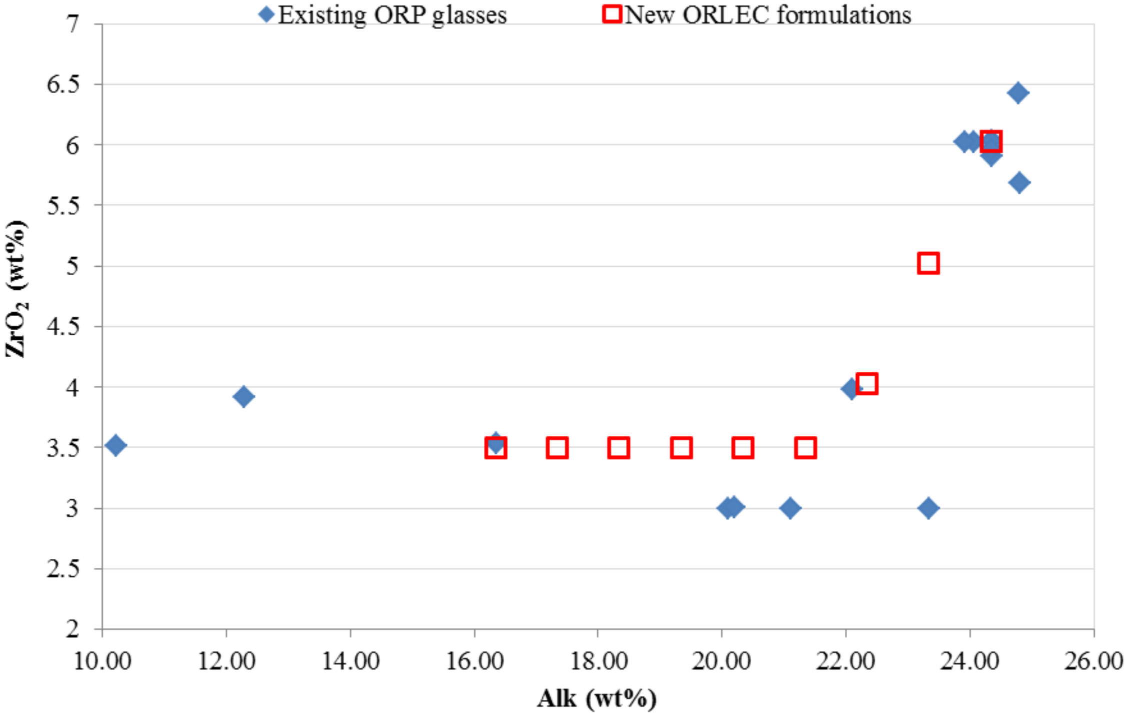


Figure 2.12. ZrO_2 concentrations used in the initial Enhanced LAW Glass Correlation.

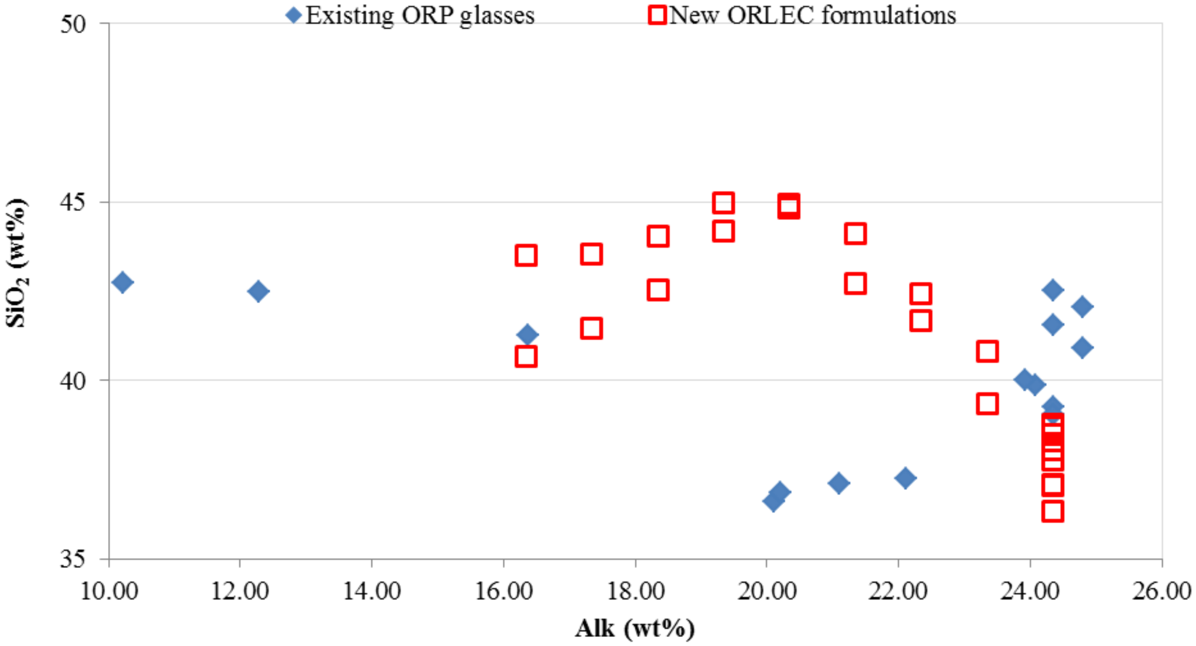


Figure 2.13. SiO_2 concentrations used in the initial Enhanced LAW Glass Correlation.

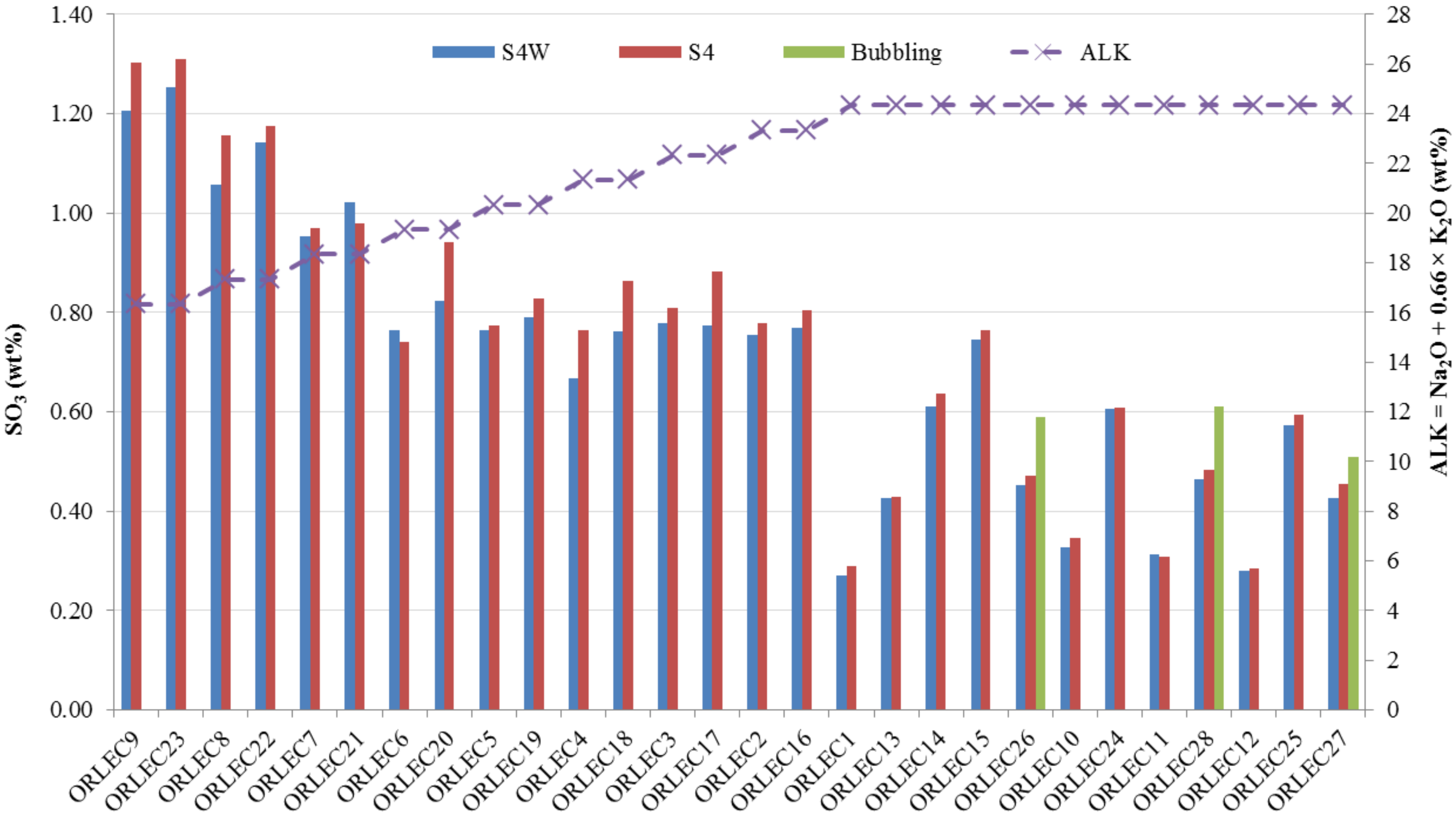


Figure 3.1. Sulfate solubility determined by batch over-saturation and by bubbling tests for twenty eight ORLEC crucible glasses.

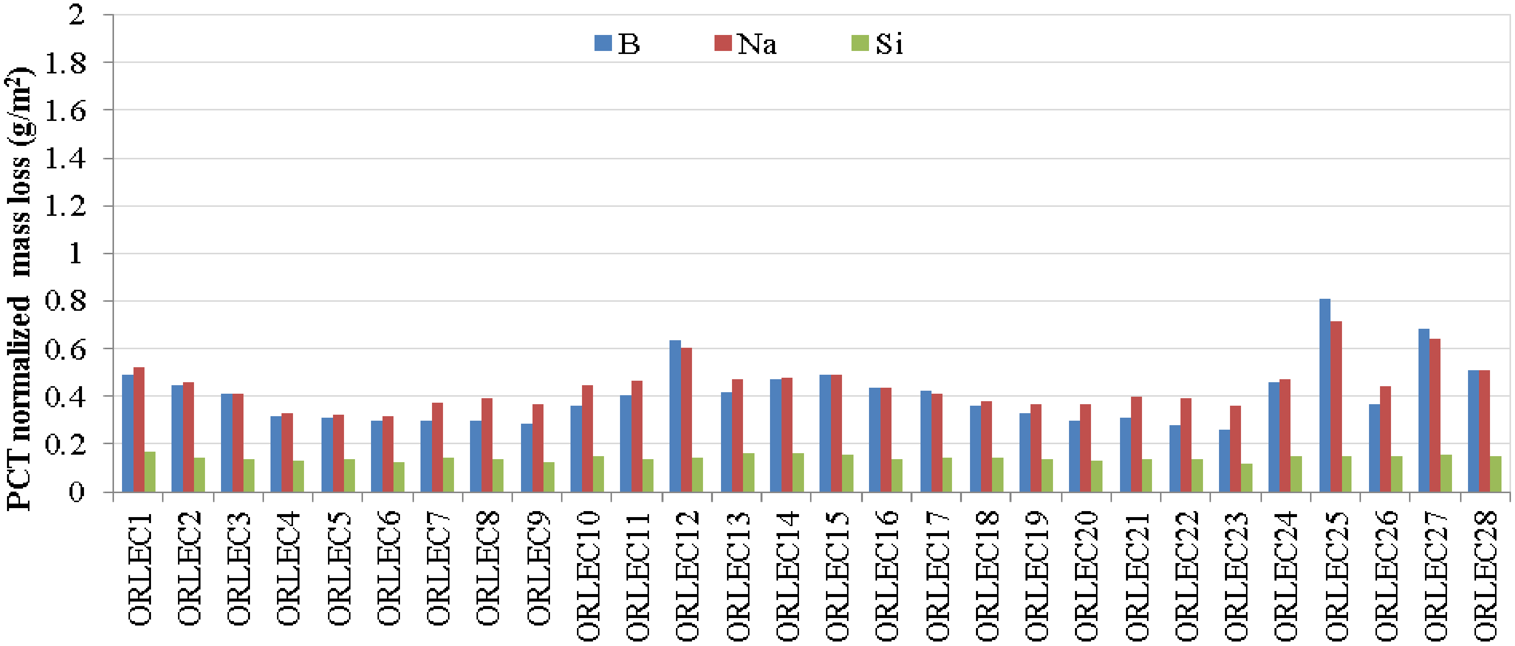


Figure 3.2. Normalized PCT releases for twenty eight ORLEC crucible glasses.

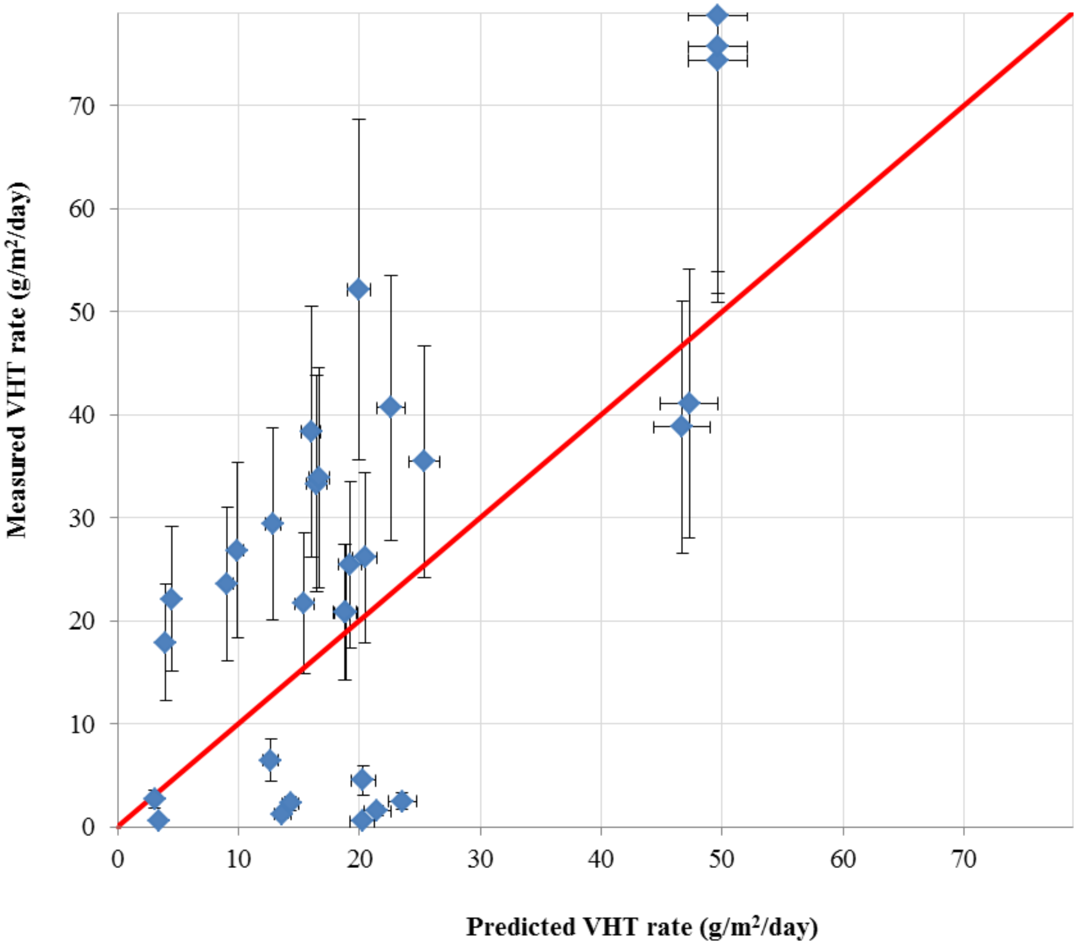


Figure 3.3. Comparison of predicted and measured VHT alteration rates for twenty eight ORPLEC crucible glasses. (Percent relative standard deviation (%RSD) of VHT measurement is estimated to be 31% [50]).

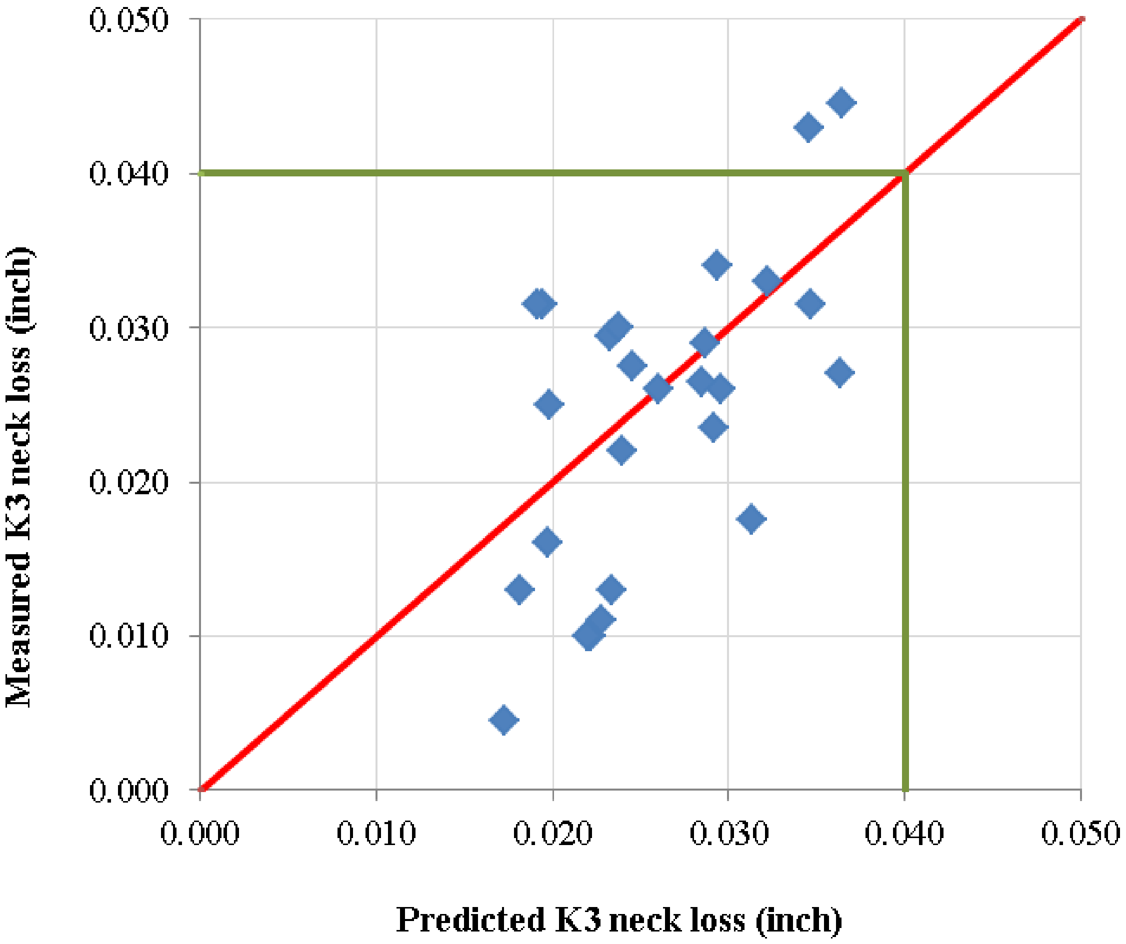


Figure 3.4. Comparison of predicted and measured K-3 neck corrosion loss for twenty six ORLEC glasses.

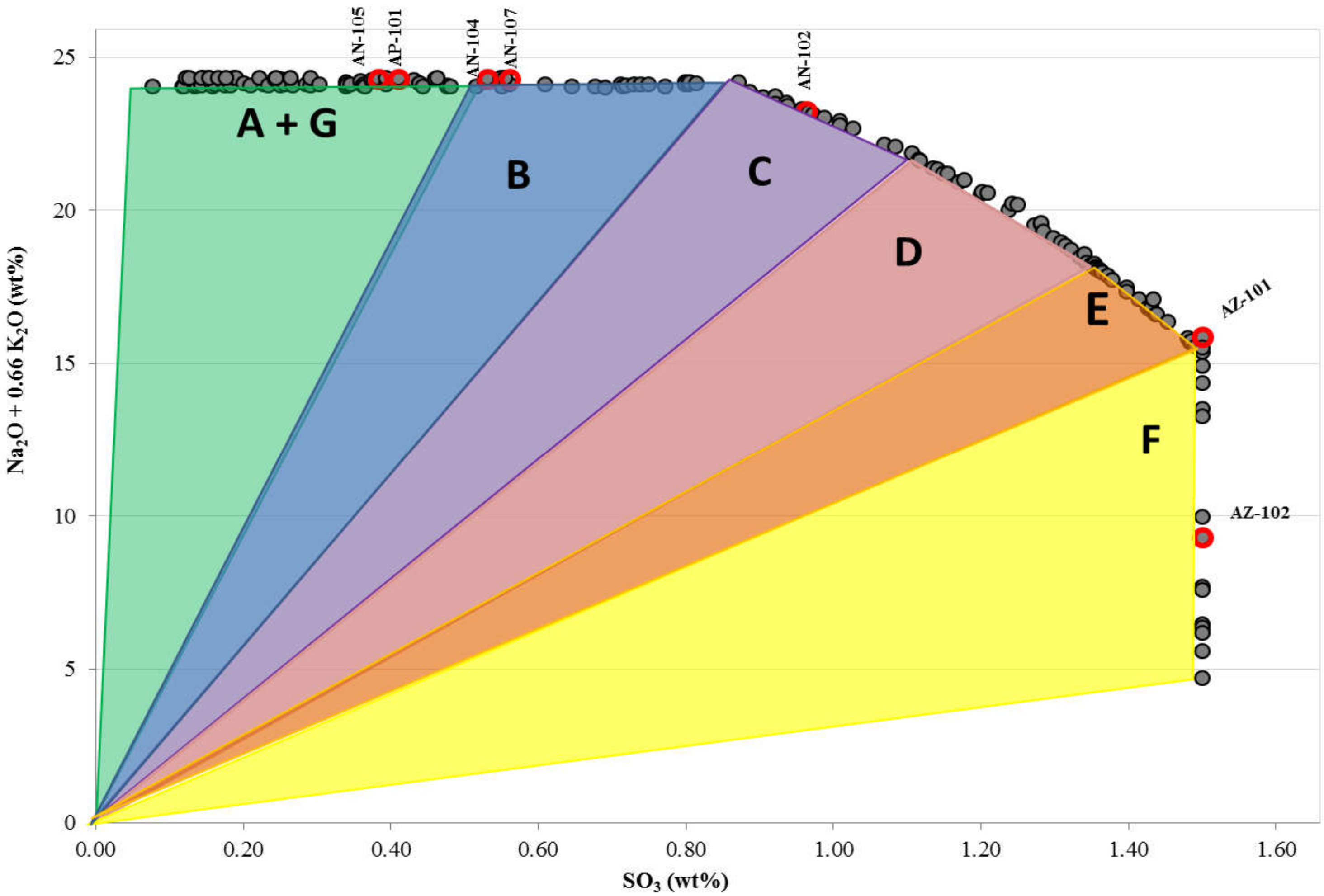


Figure 3.5. Illustration of potential application of the initial Enhanced LAW Glass Correlation to the 177 tank waste compositions (black circles) in the SO_3 versus ALK space. The seven red markers identify tank wastes used in correlation development.

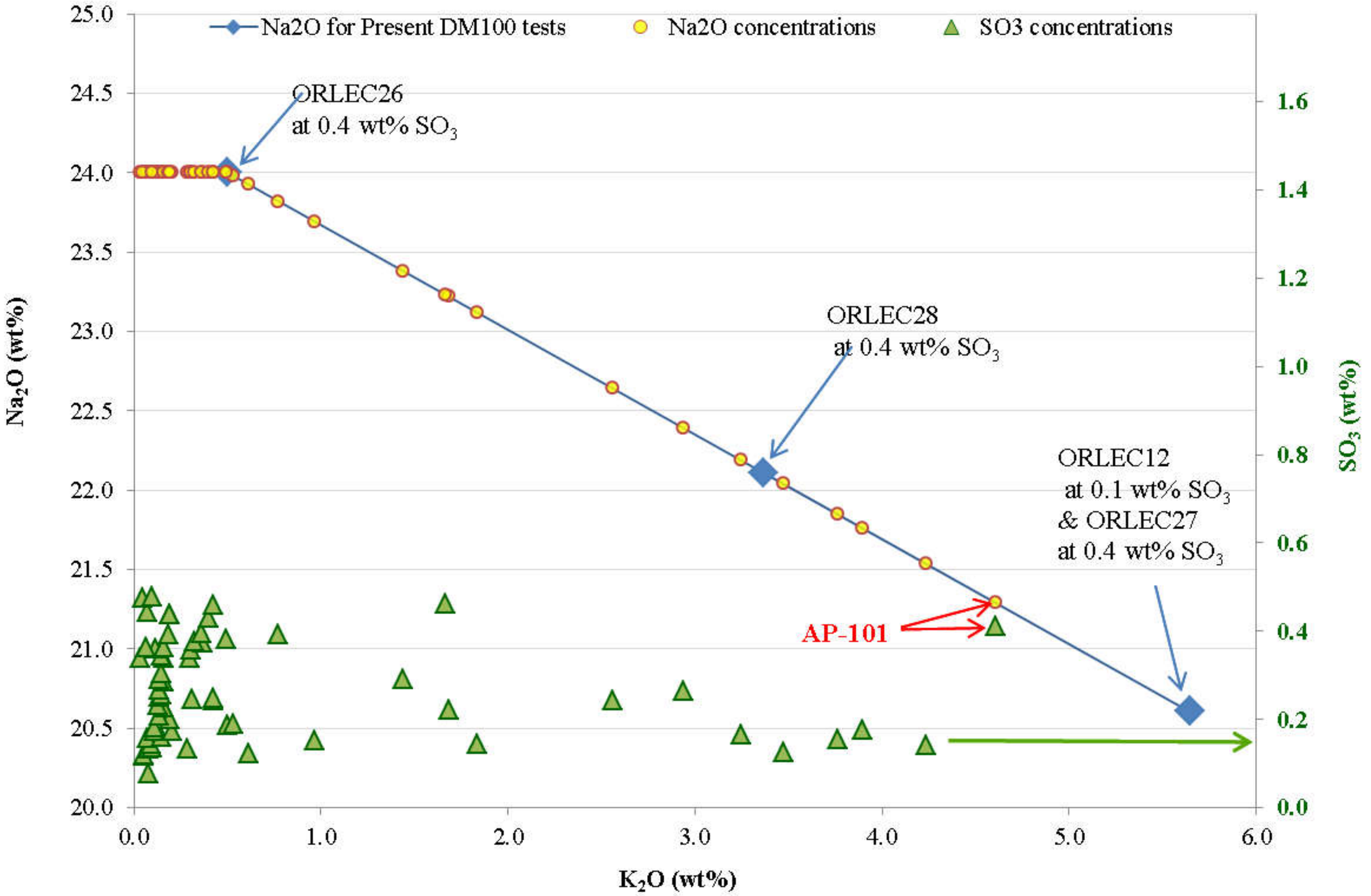


Figure 3.6. Illustration of the Na_2O, K_2O, and SO_3 concentrations of the four glasses selected for DM100 melter tests and the corresponding compositions of the high-alkali Hanford LAW compositions described in TFCOUP [62] (Na_2O values on the left y-axis and SO_3 values on the right y-axis).

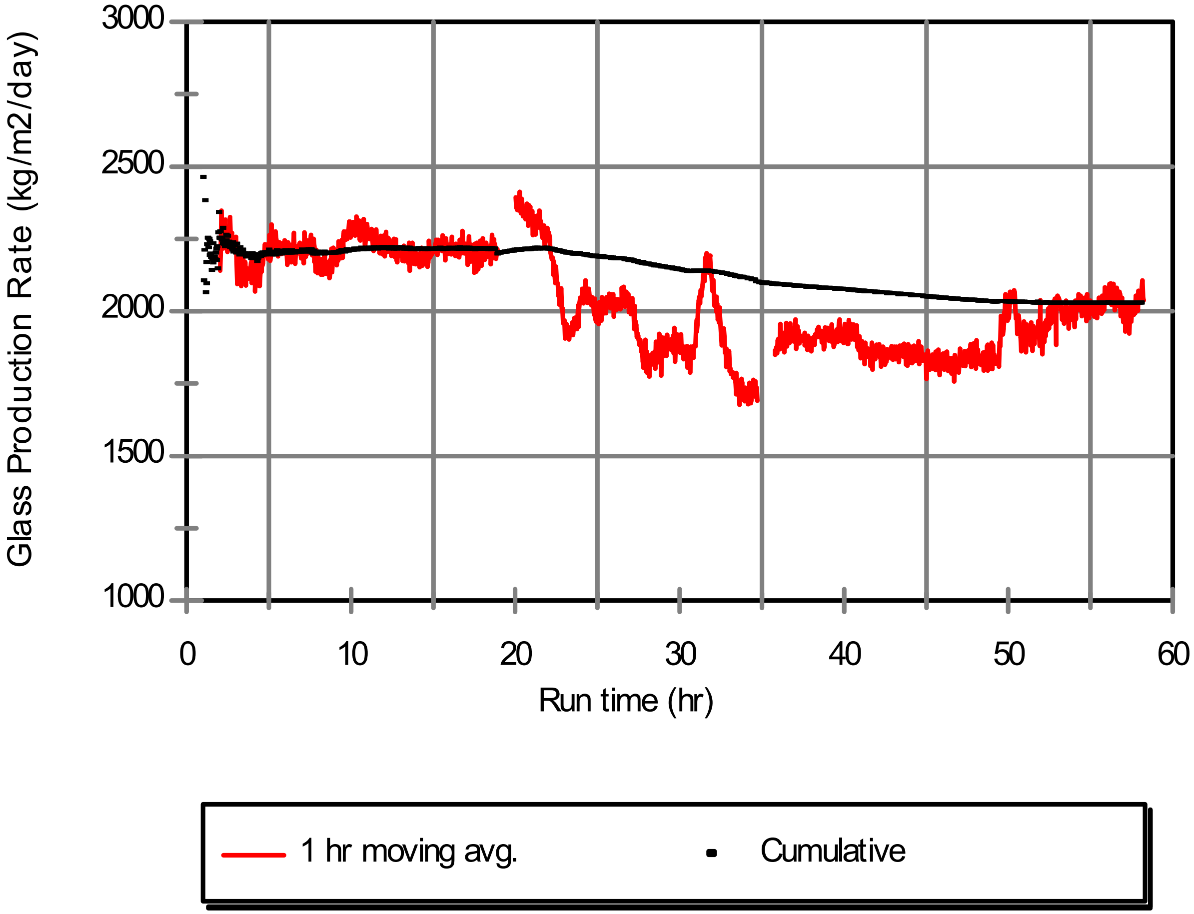


Figure 4.1.a. Glass production rates during DM100 test with ORLEC26.

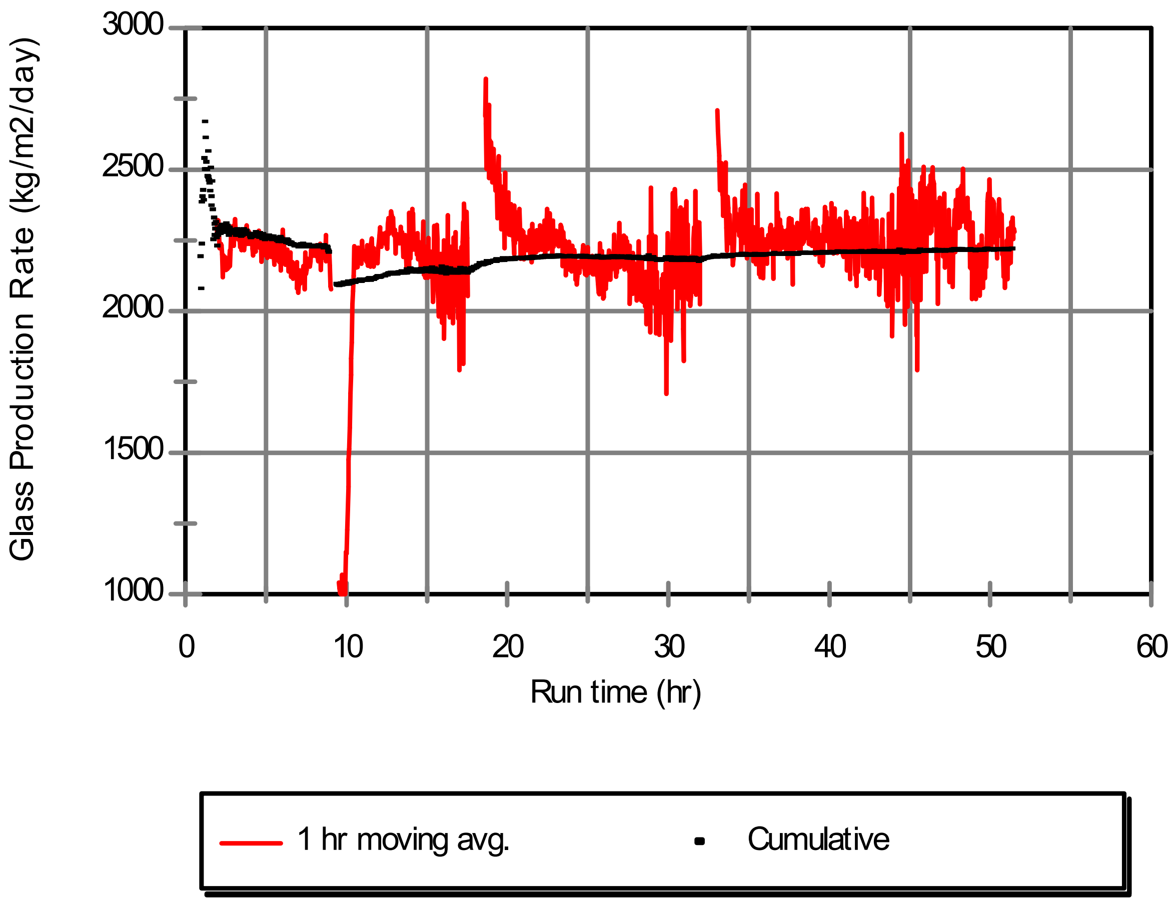


Figure 4.1.b. Glass production rates during DM100 test with ORLEC12.

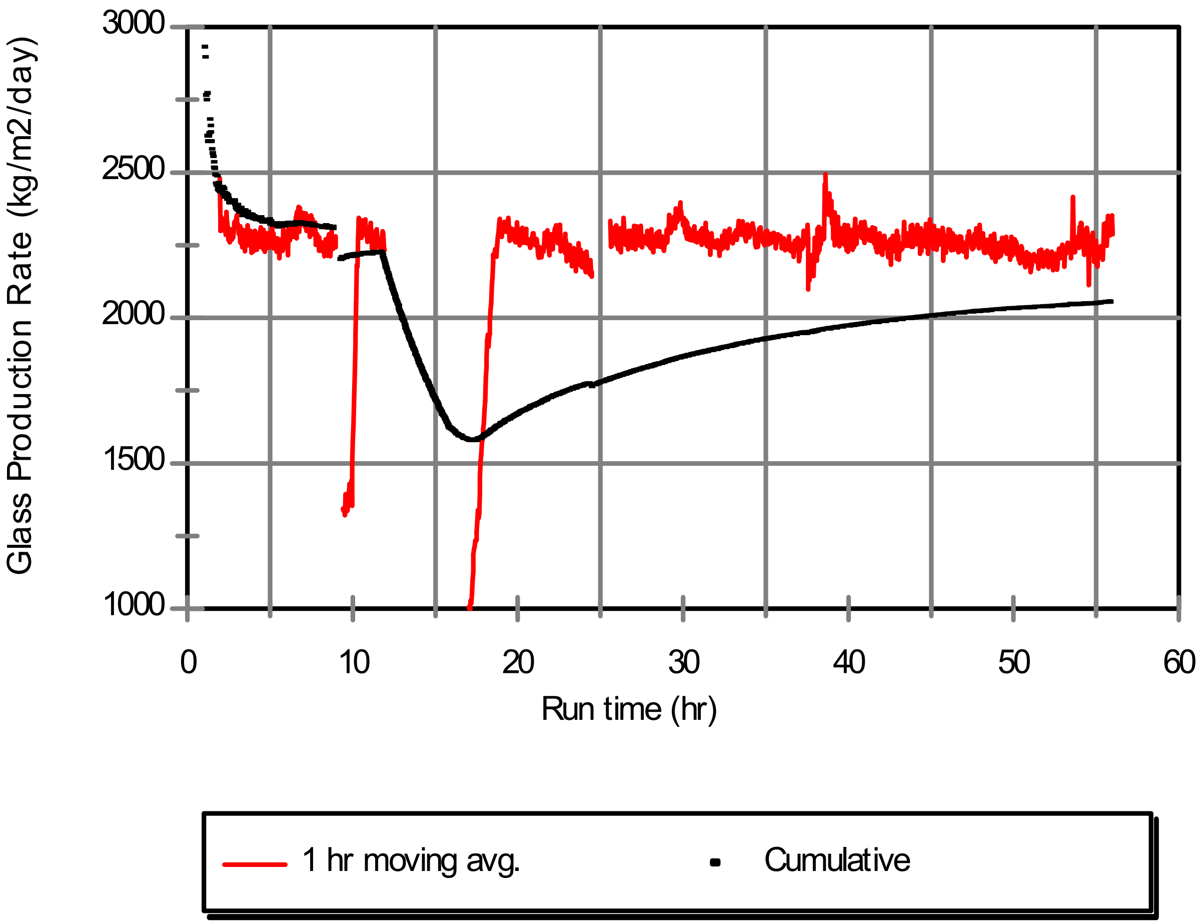


Figure 4.1.c. Glass production rates during DM100 test with ORLEC27.

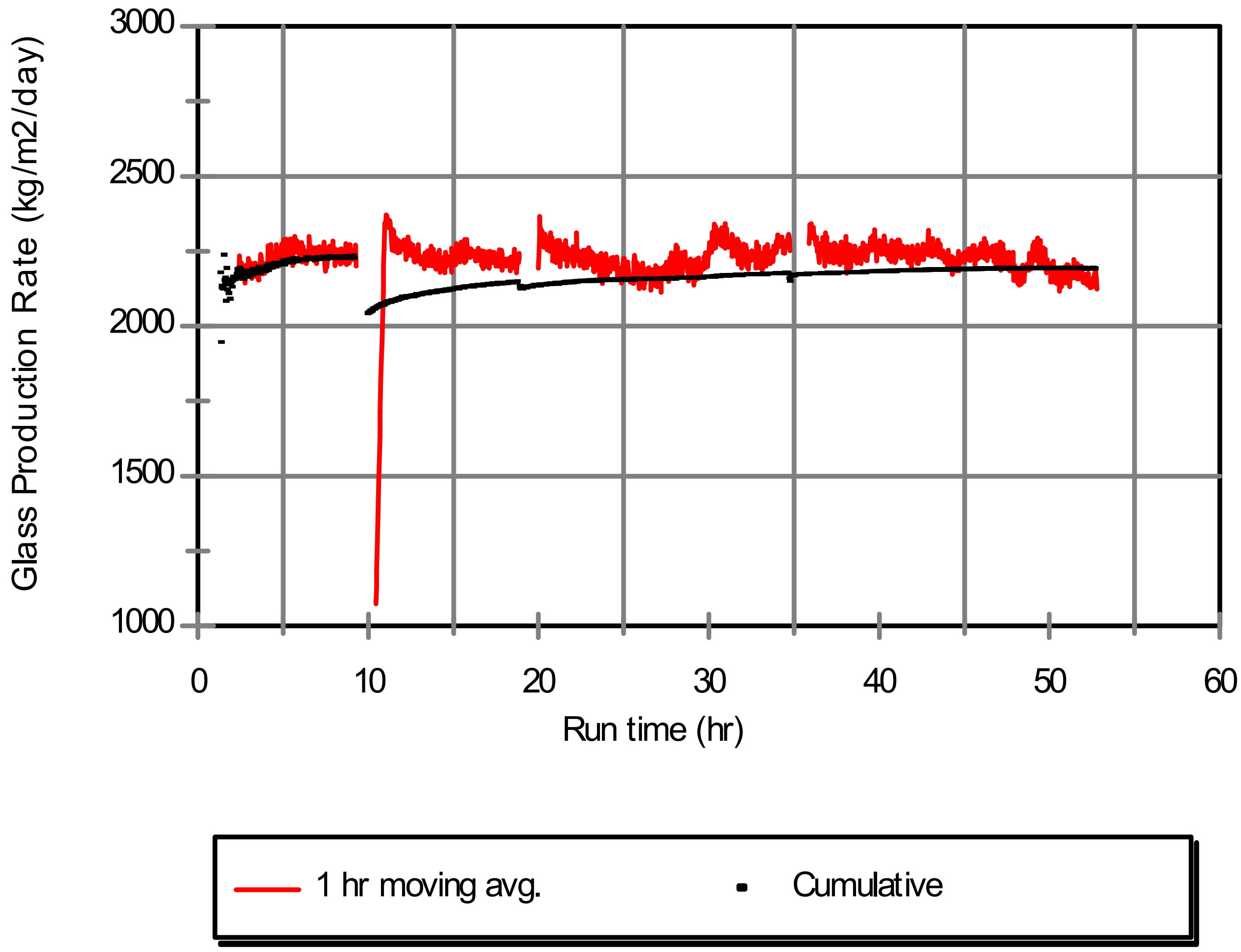


Figure 4.1.d. Glass production rates during DM100 test with ORLEC28.

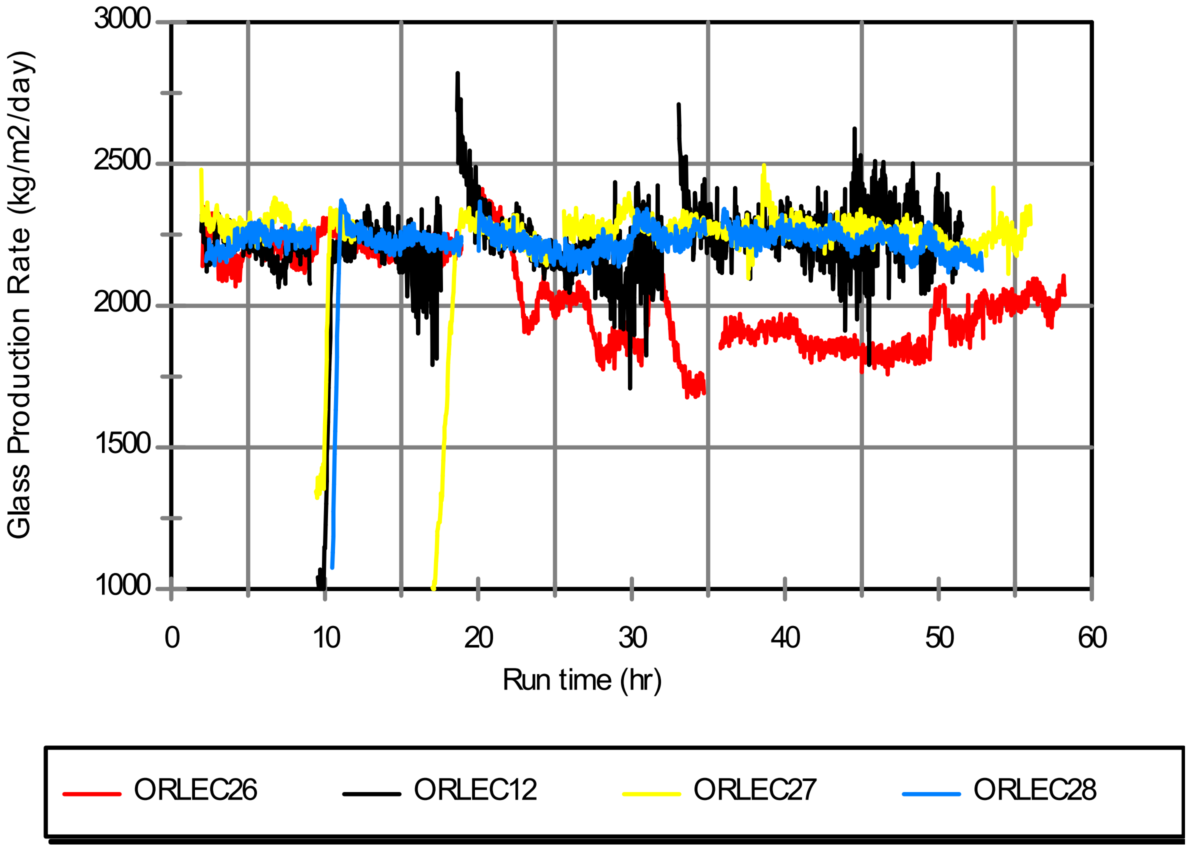


Figure 4.1.e. Instantaneous glass production rates during DM100 tests.

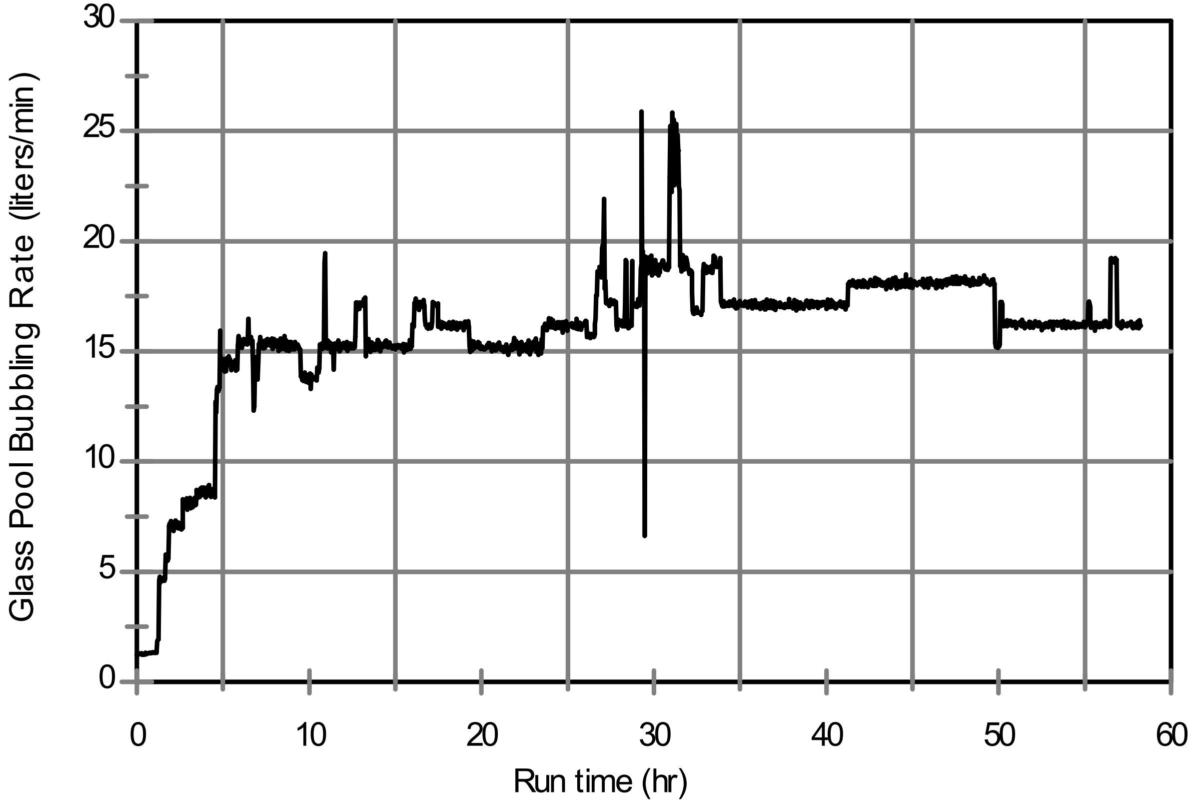


Figure 4.2.a. Glass pool bubbling during DM100 test with ORLEC26.

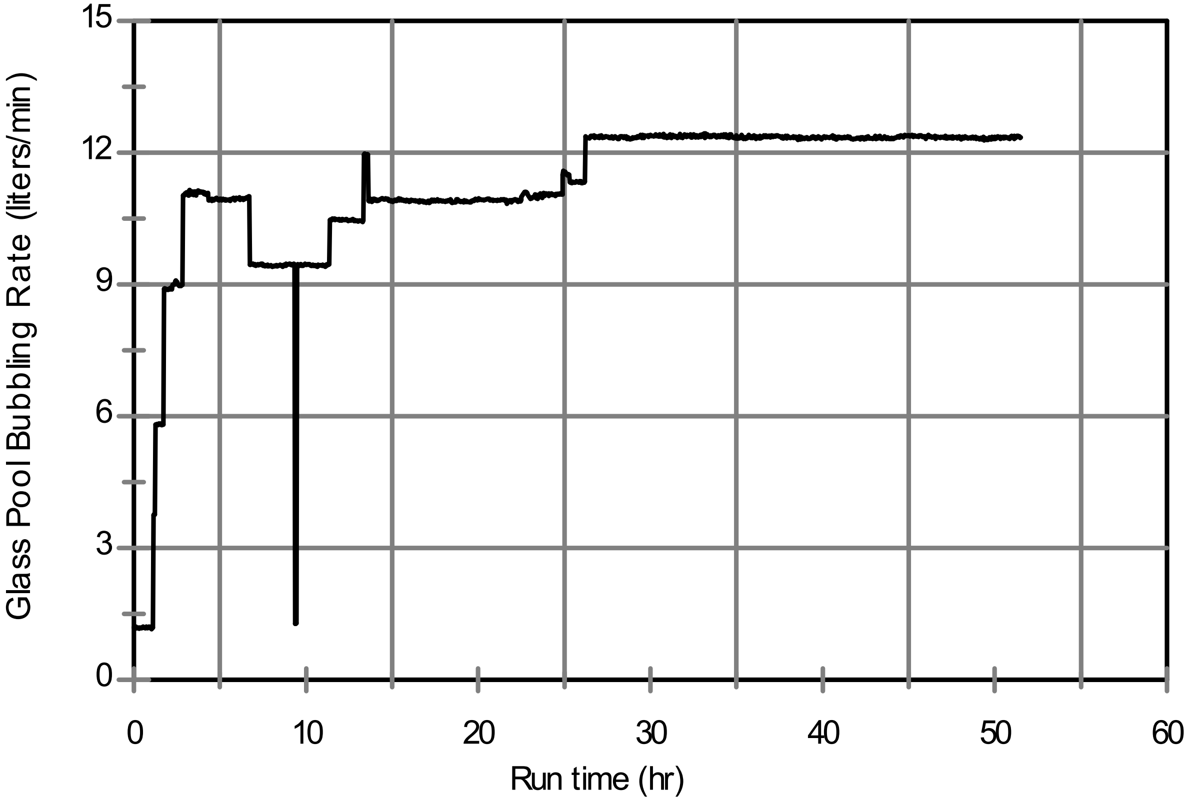


Figure 4.2.b. Glass pool bubbling during DM100 test with ORLEC12.

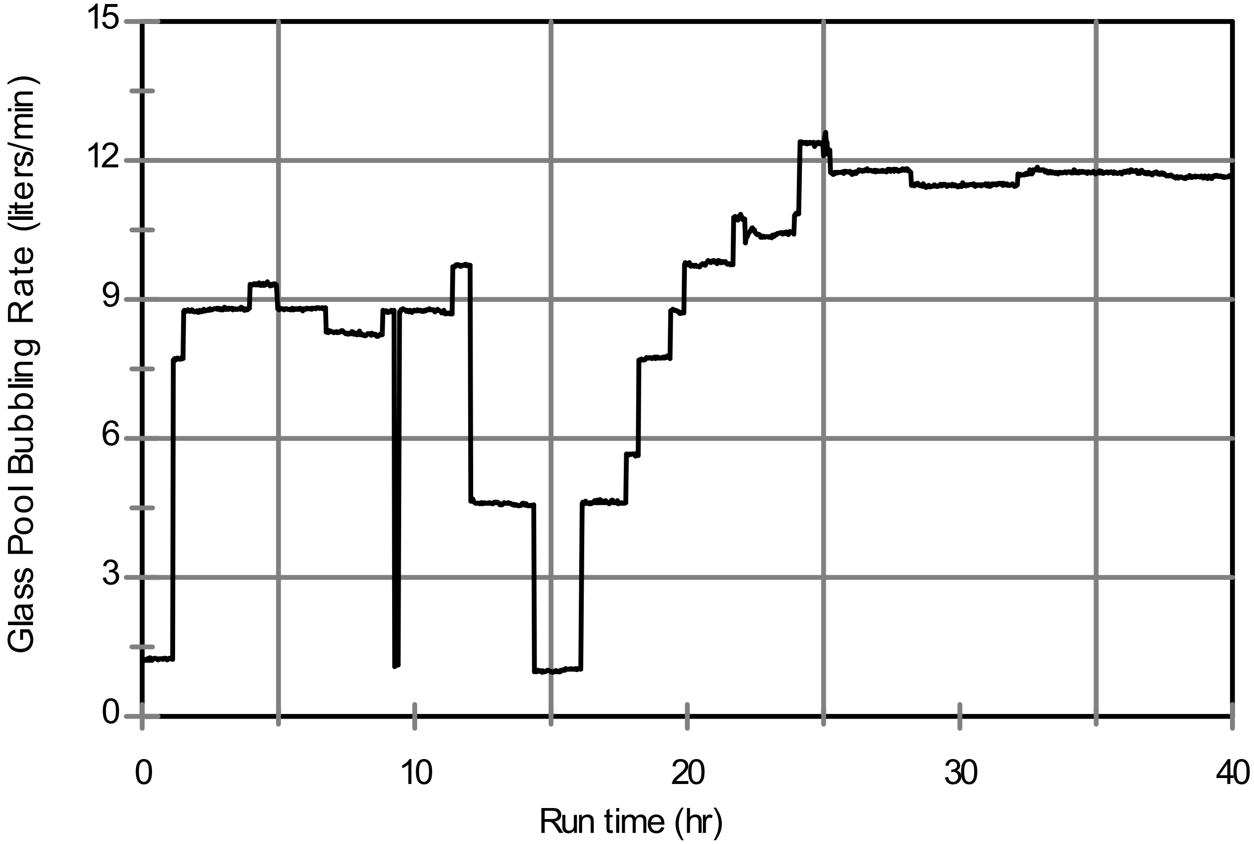


Figure 4.2.c. Glass pool bubbling during DM100 test with ORLEC27.

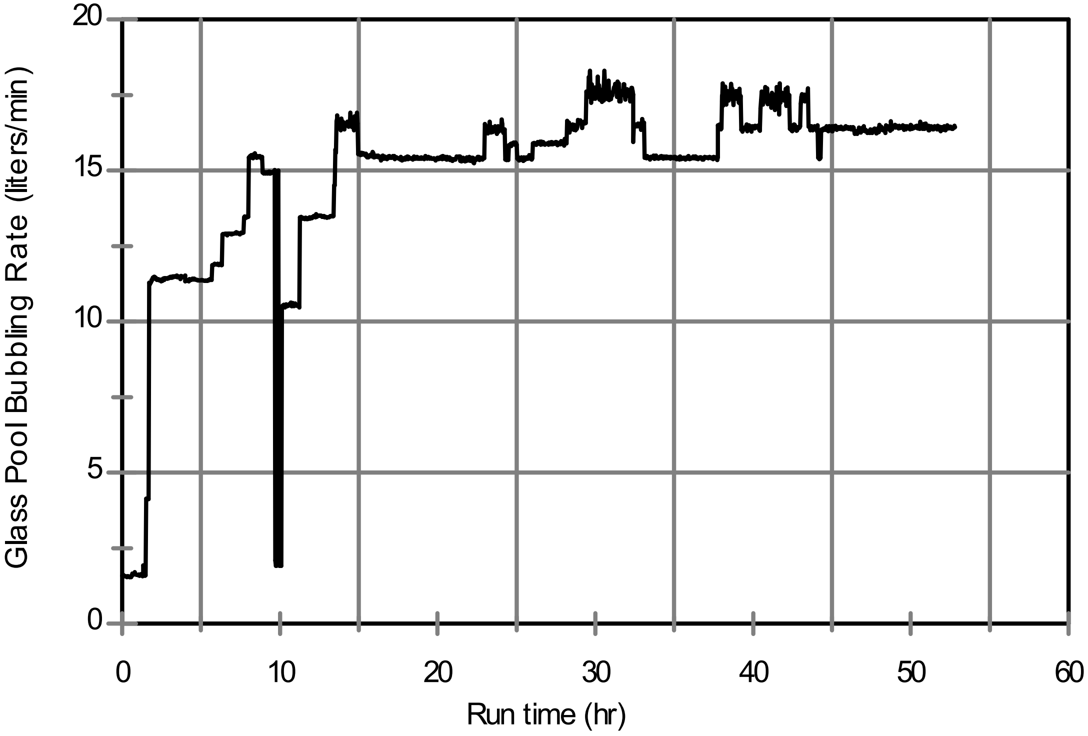


Figure 4.2.d. Glass pool bubbling during DM100 test with ORLEC28.

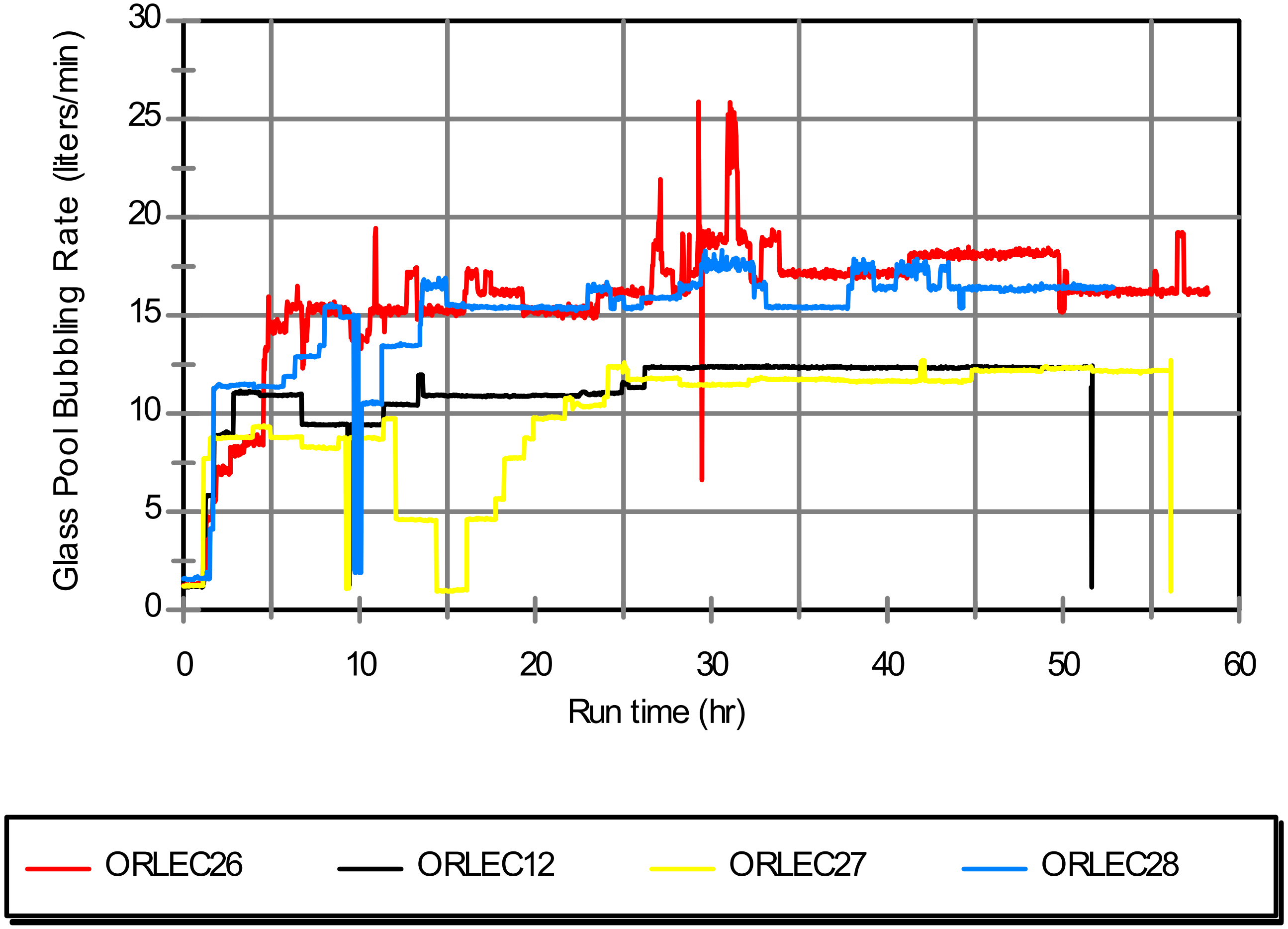


Figure 4.2.e. Glass pool bubbling during DM100 tests.

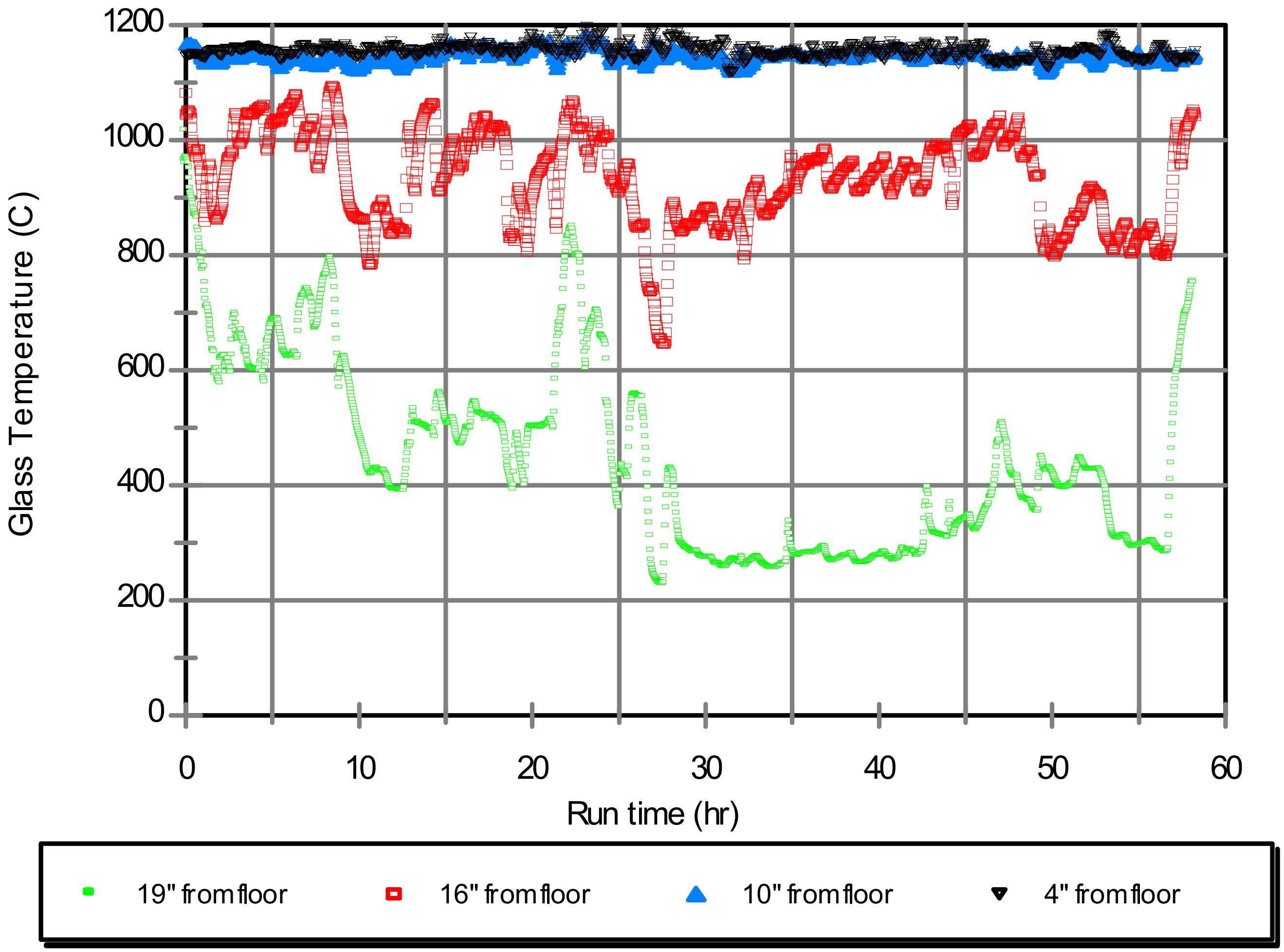


Figure 4.3.a. Glass temperatures during DM100 test with ORLEC26.

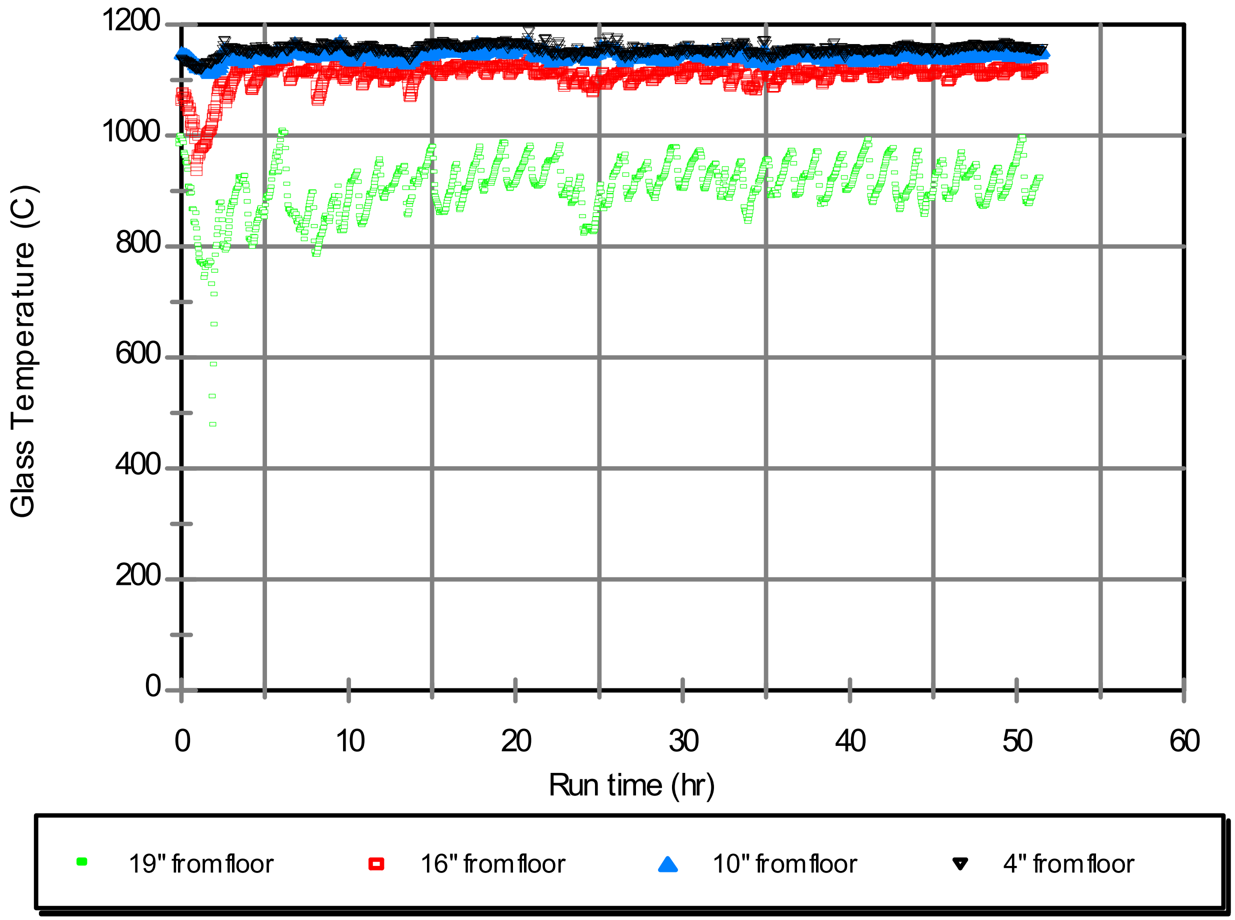


Figure 4.3.b. Glass temperatures during DM100 test with ORLEC12.

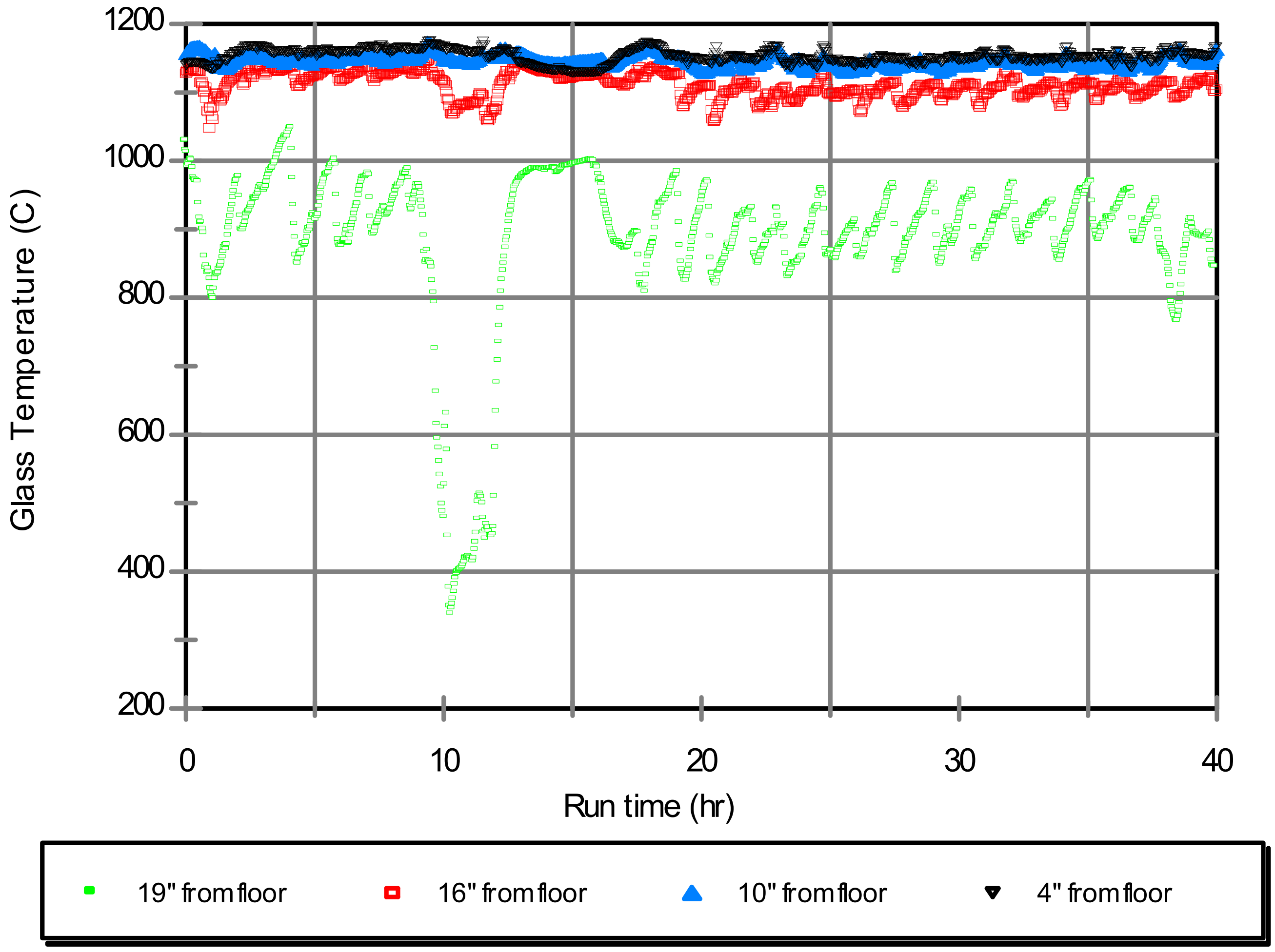


Figure 4.3.c. Glass temperatures during DM100 test with ORLEC27.

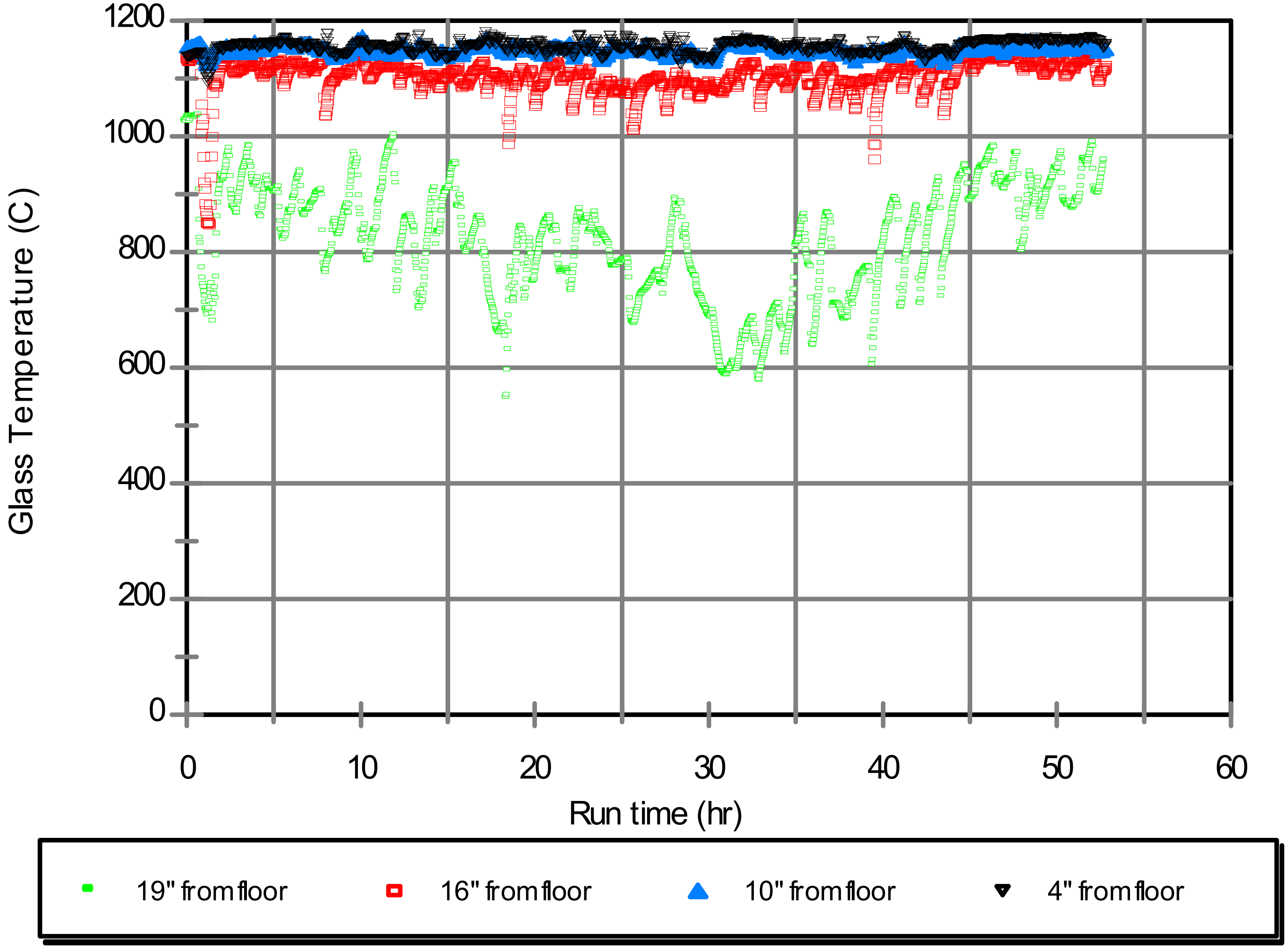


Figure 4.3.d. Glass temperatures during DM100 test with ORLEC28.

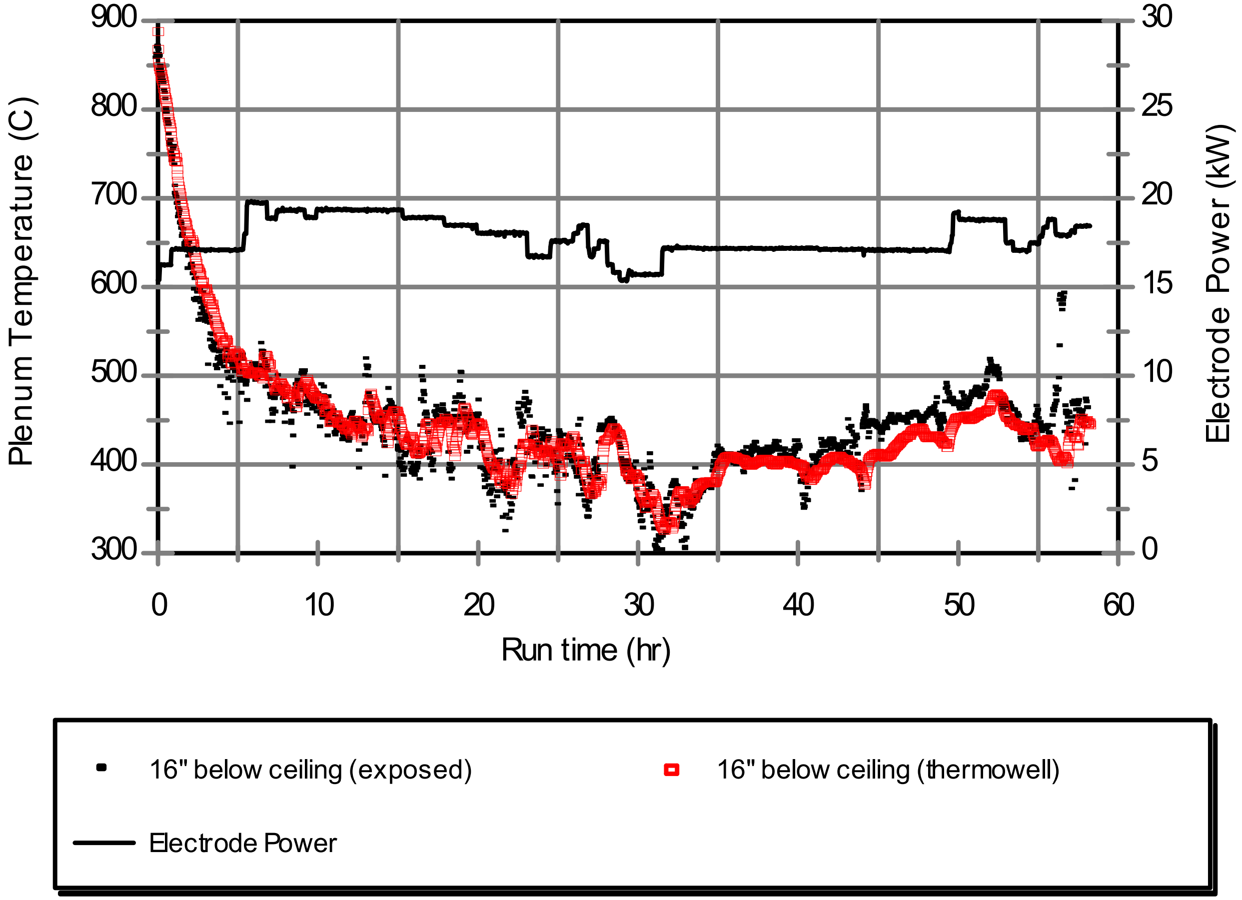


Figure 4.4.a. Plenum temperatures and electrode power during DM100 test with ORLEC26.

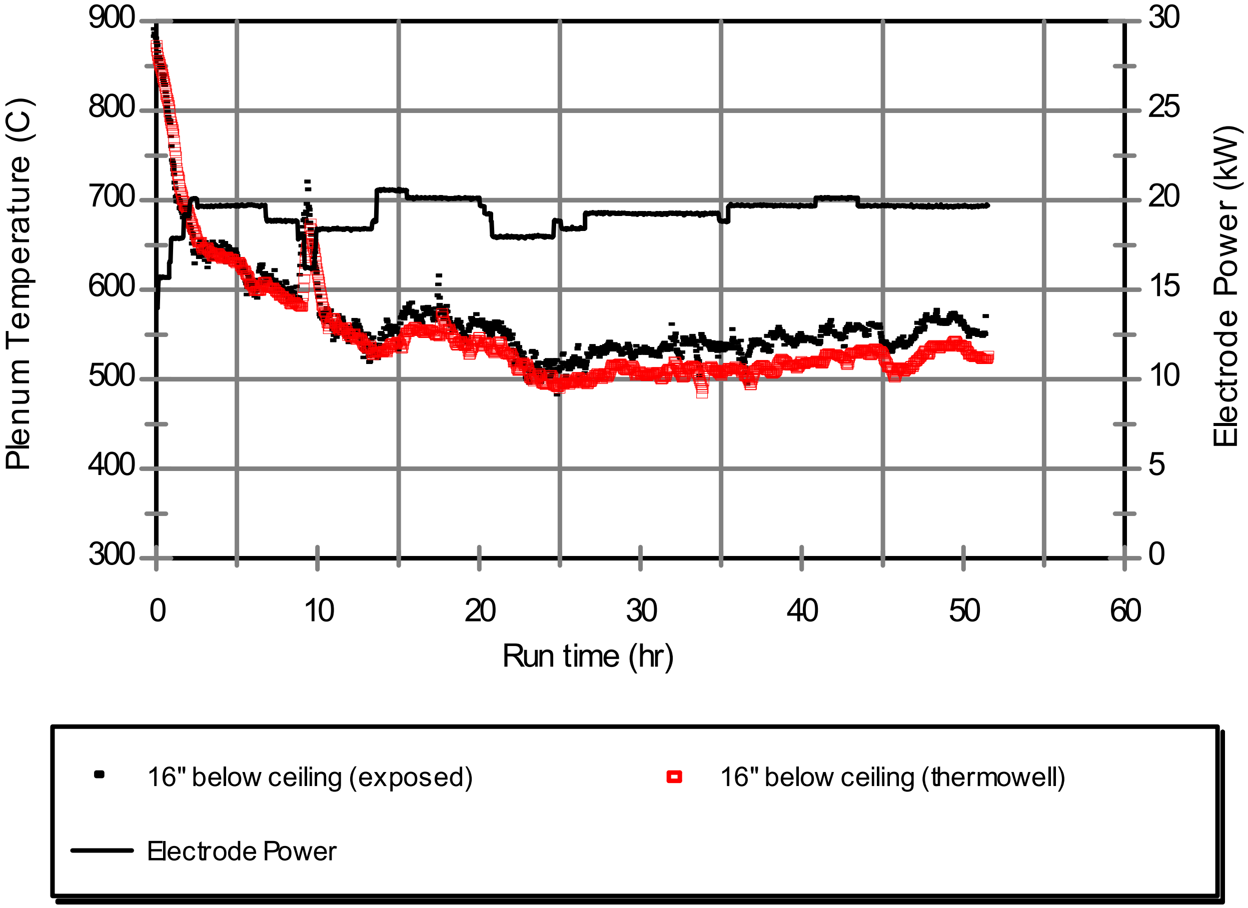


Figure 4.4.b. Plenum temperatures and electrode power during DM100 test with ORLEC12.

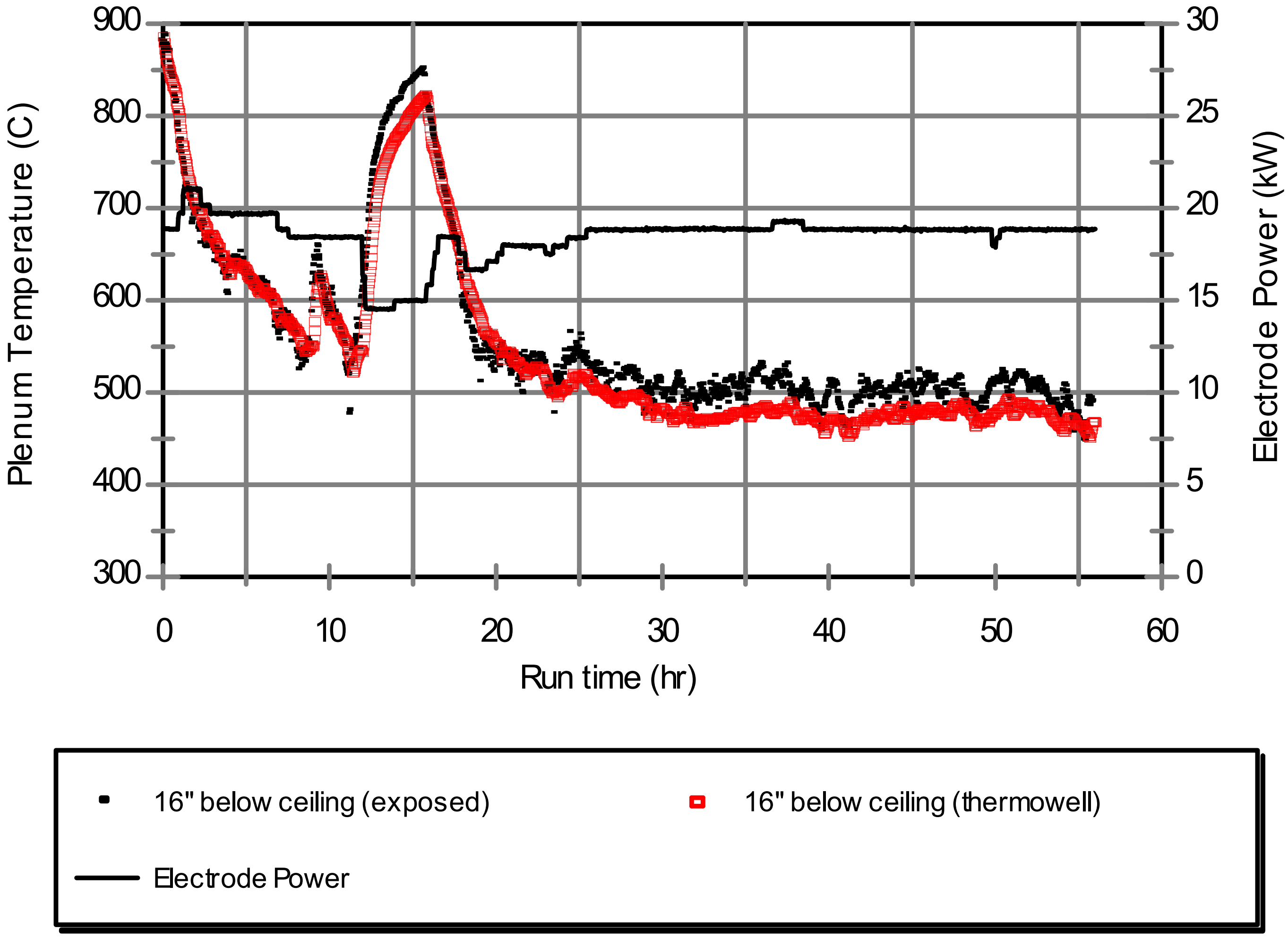


Figure 4.4.c. Plenum temperatures and electrode power during DM100 test with ORLEC27.

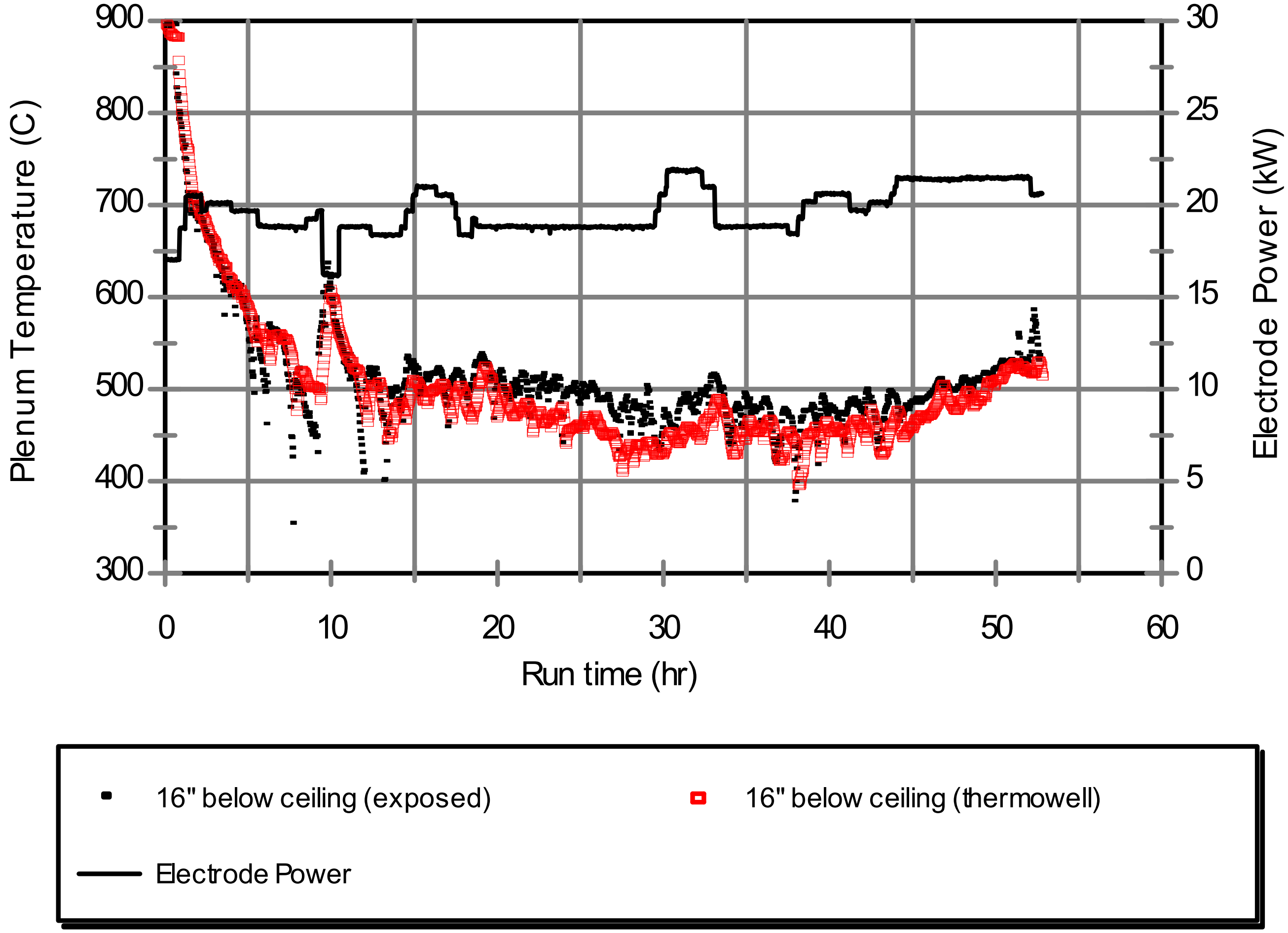


Figure 4.4.d. Plenum temperatures and electrode power during DM100 test with ORLEC28.

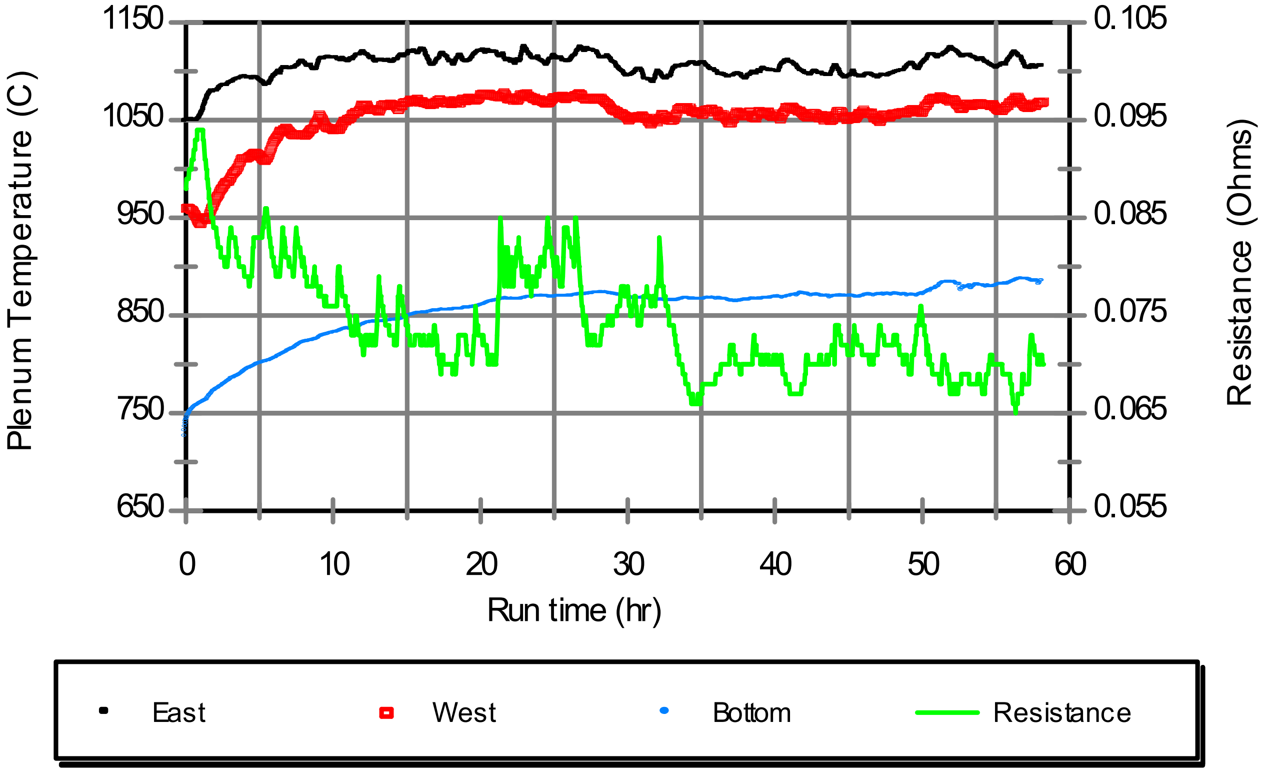


Figure 4.5.a. Electrode temperatures and melt pool resistance during DM100 test with ORLEC26.

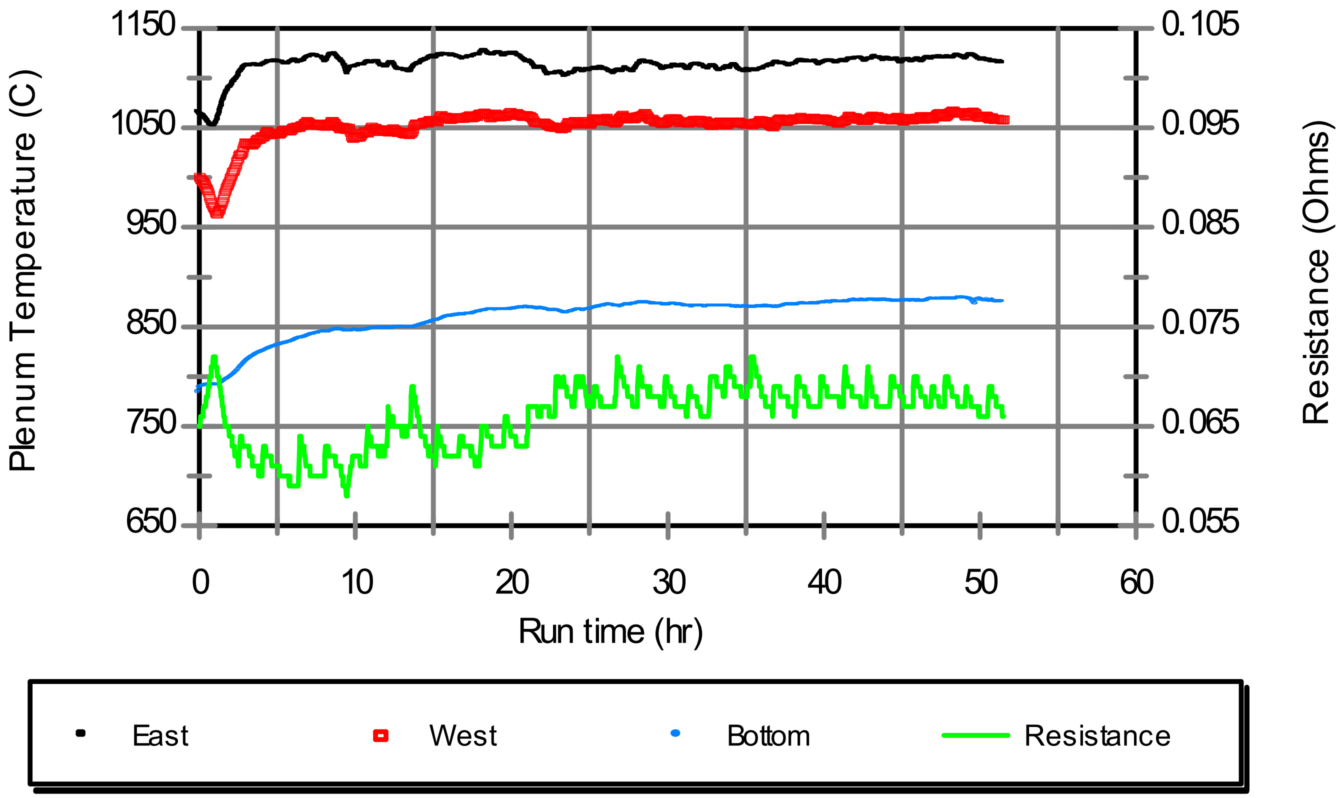


Figure 4.5.b. Electrode temperatures and melt pool resistance during DM100 test with ORLEC12.

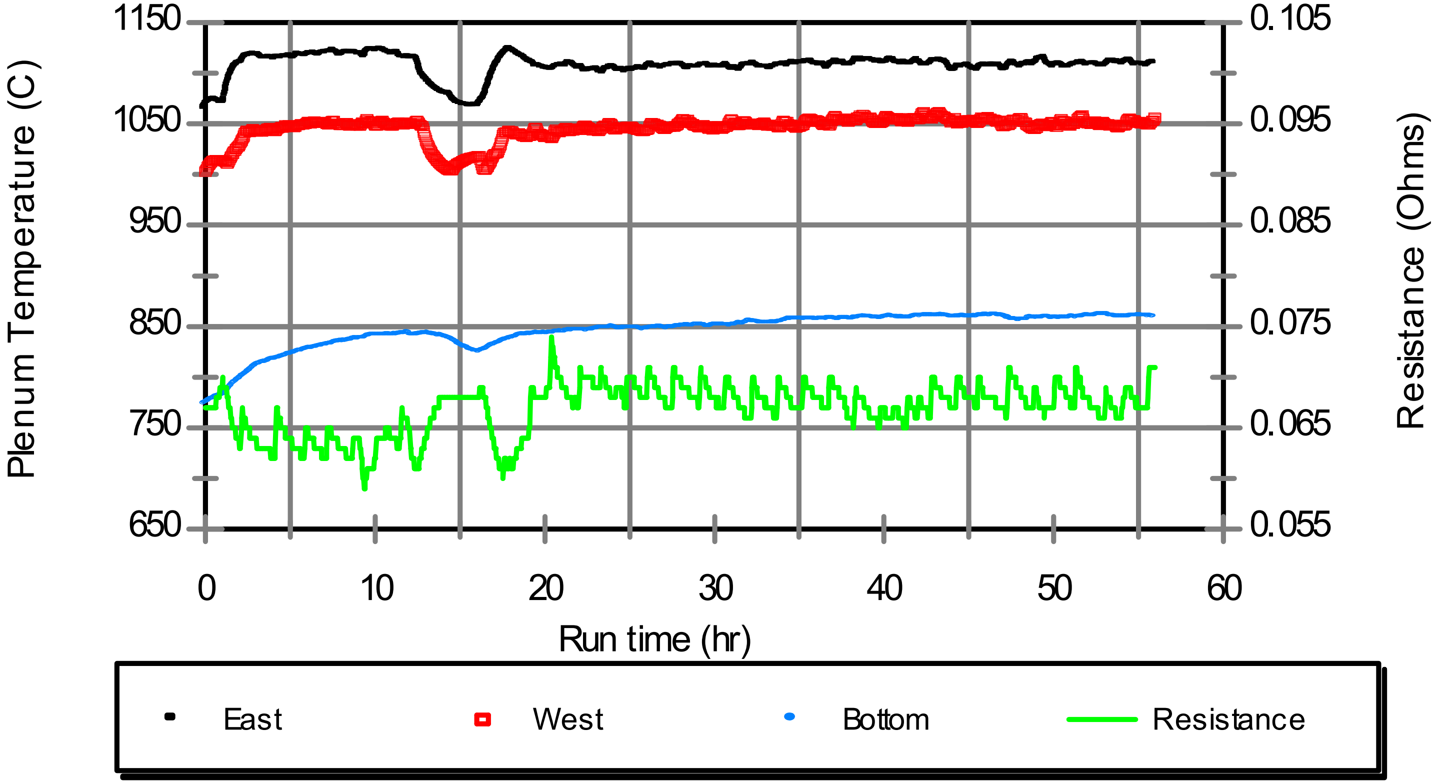


Figure 4.5.c. Electrode temperatures and melt pool resistance during DM100 test with ORLEC27.

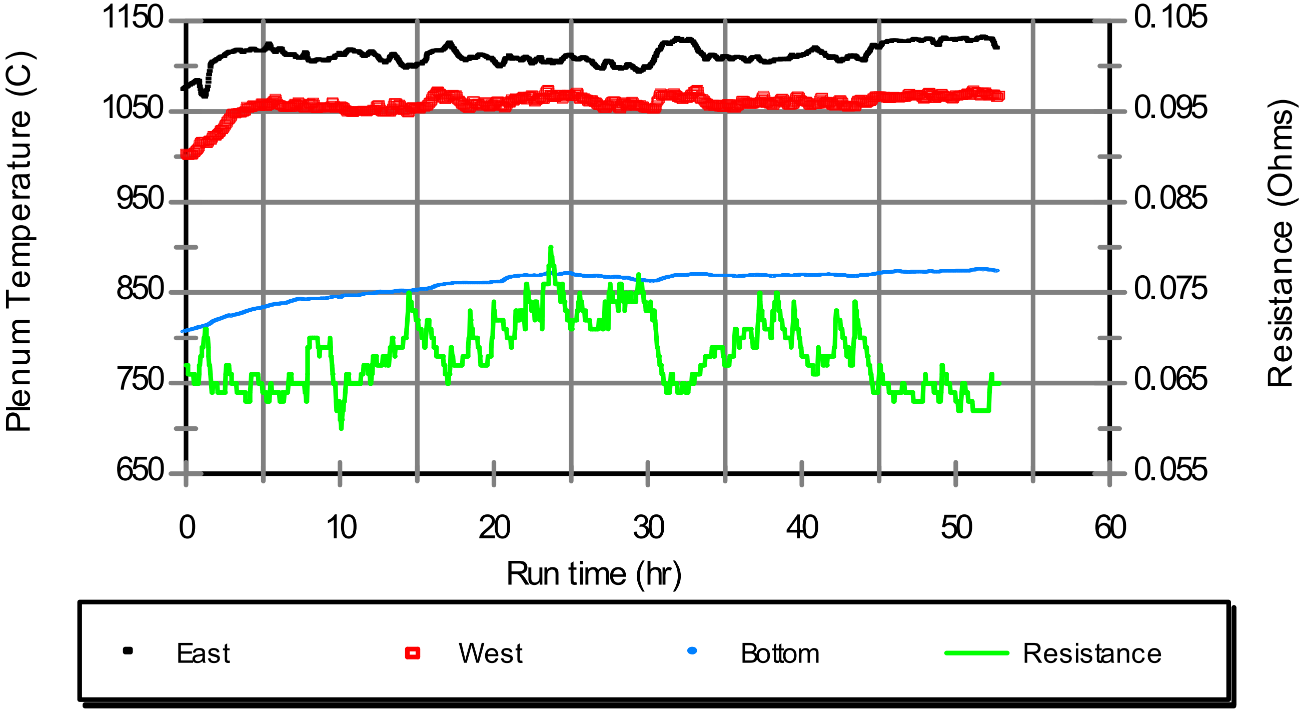


Figure 4.5.d. Electrode temperatures and melt pool resistance during DM100 test with ORLEC28.

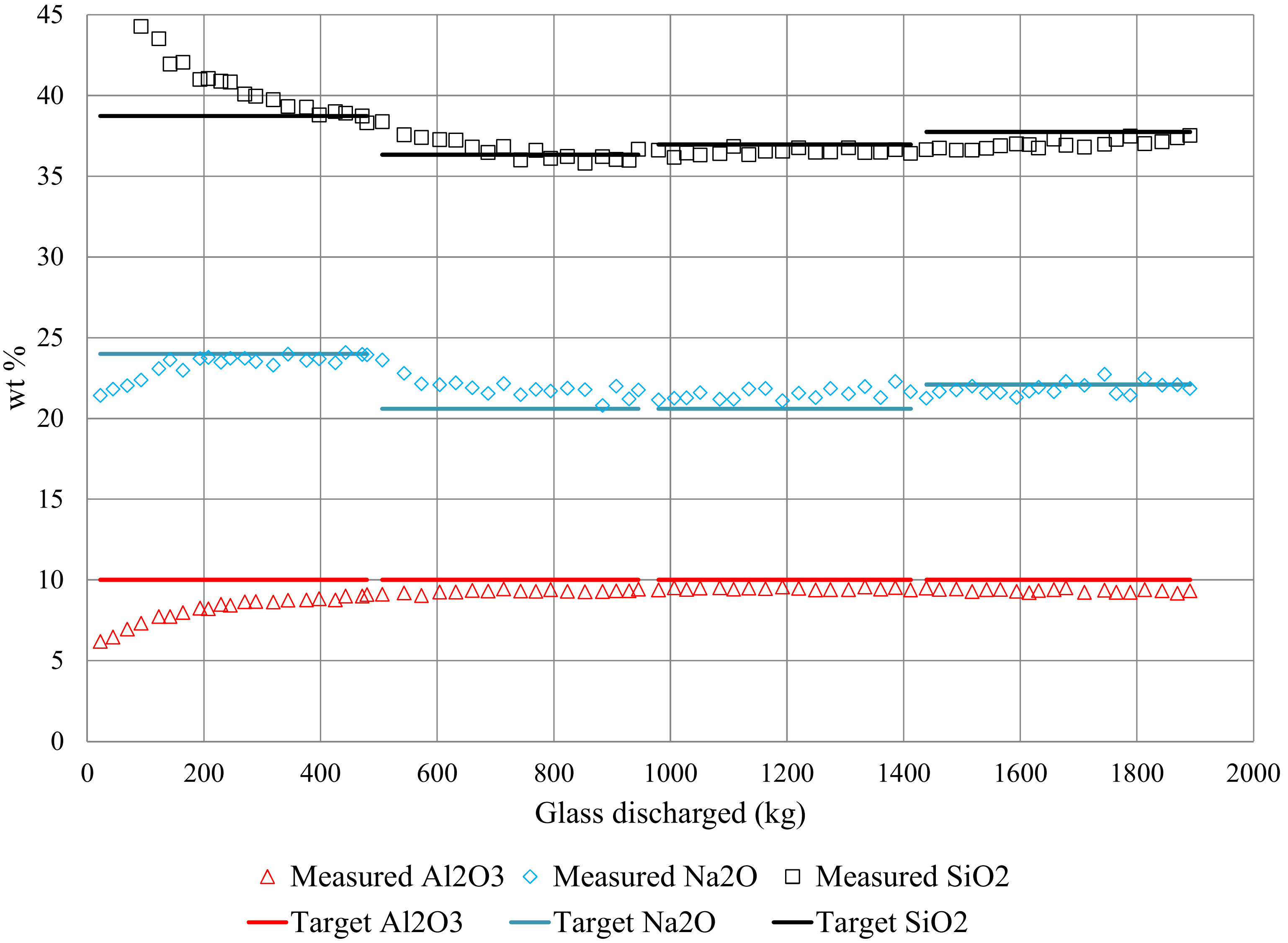


Figure 5.1. XRF analysis of silicon, sodium, and aluminum oxides in DM100 product glasses.

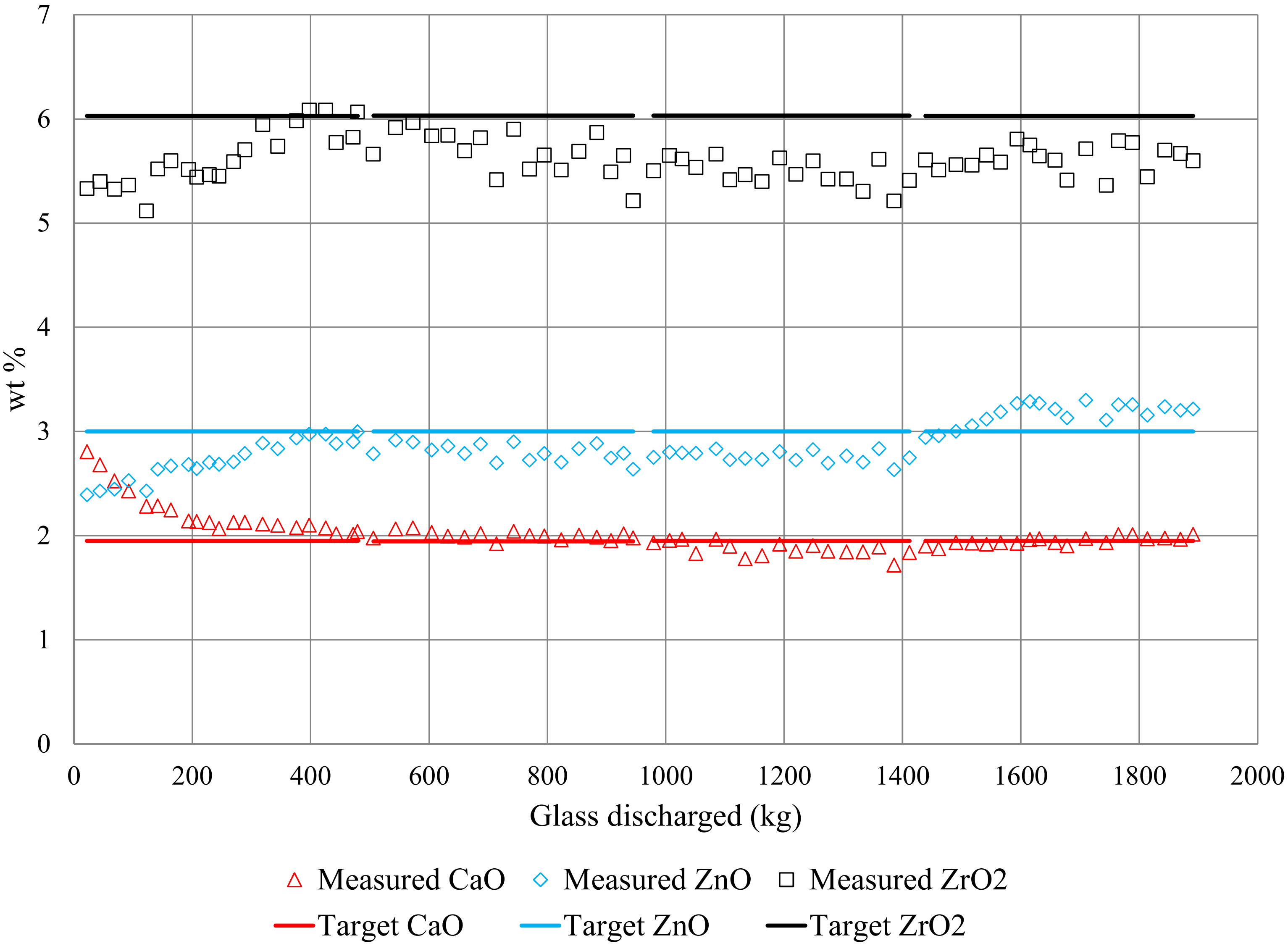


Figure 5.2. XRF analysis of calcium, zinc, and zirconium oxides in DM100 product glasses.

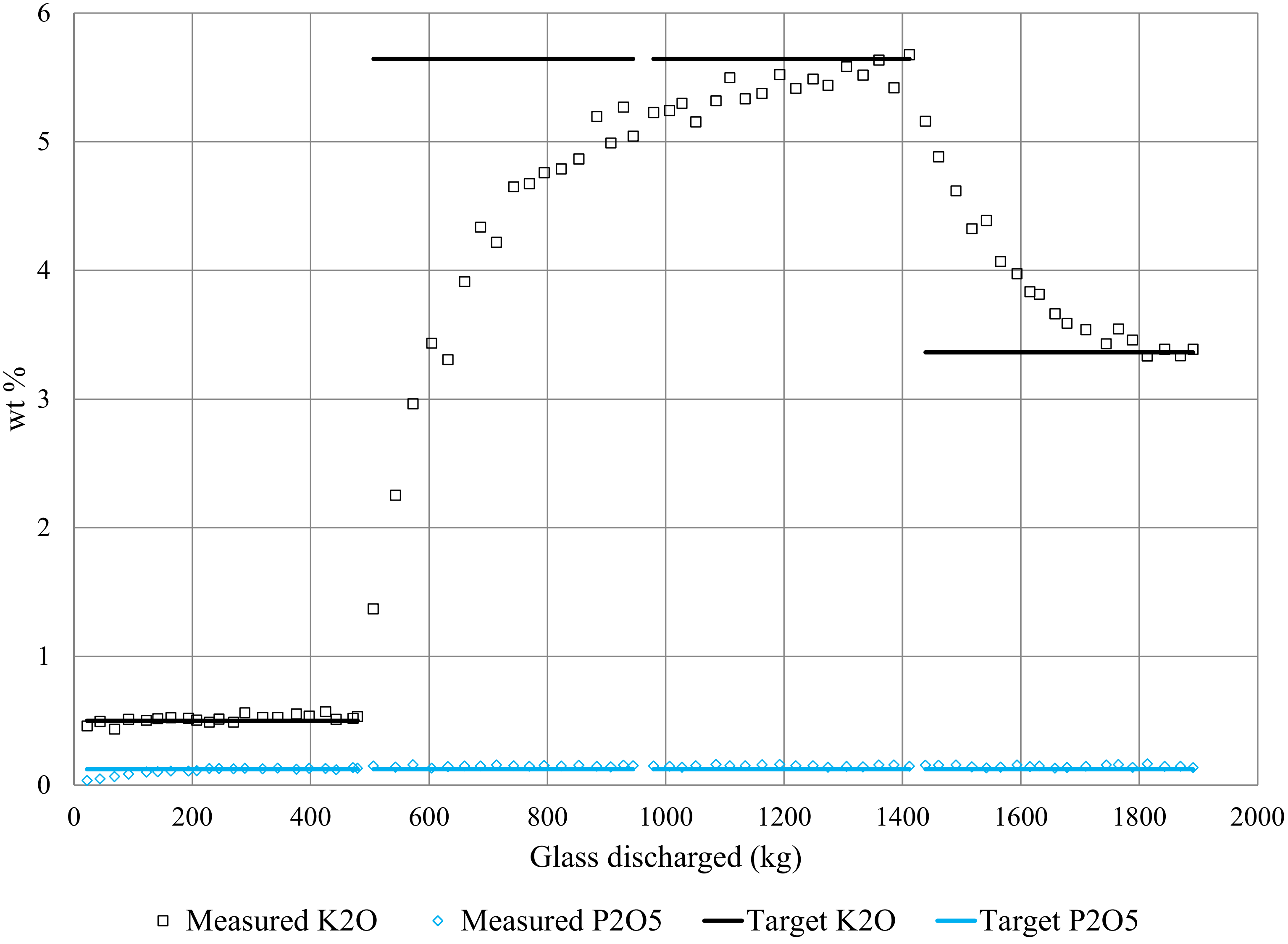


Figure 5.3. XRF analysis of potassium and phosphorus oxides in DM100 product glasses.

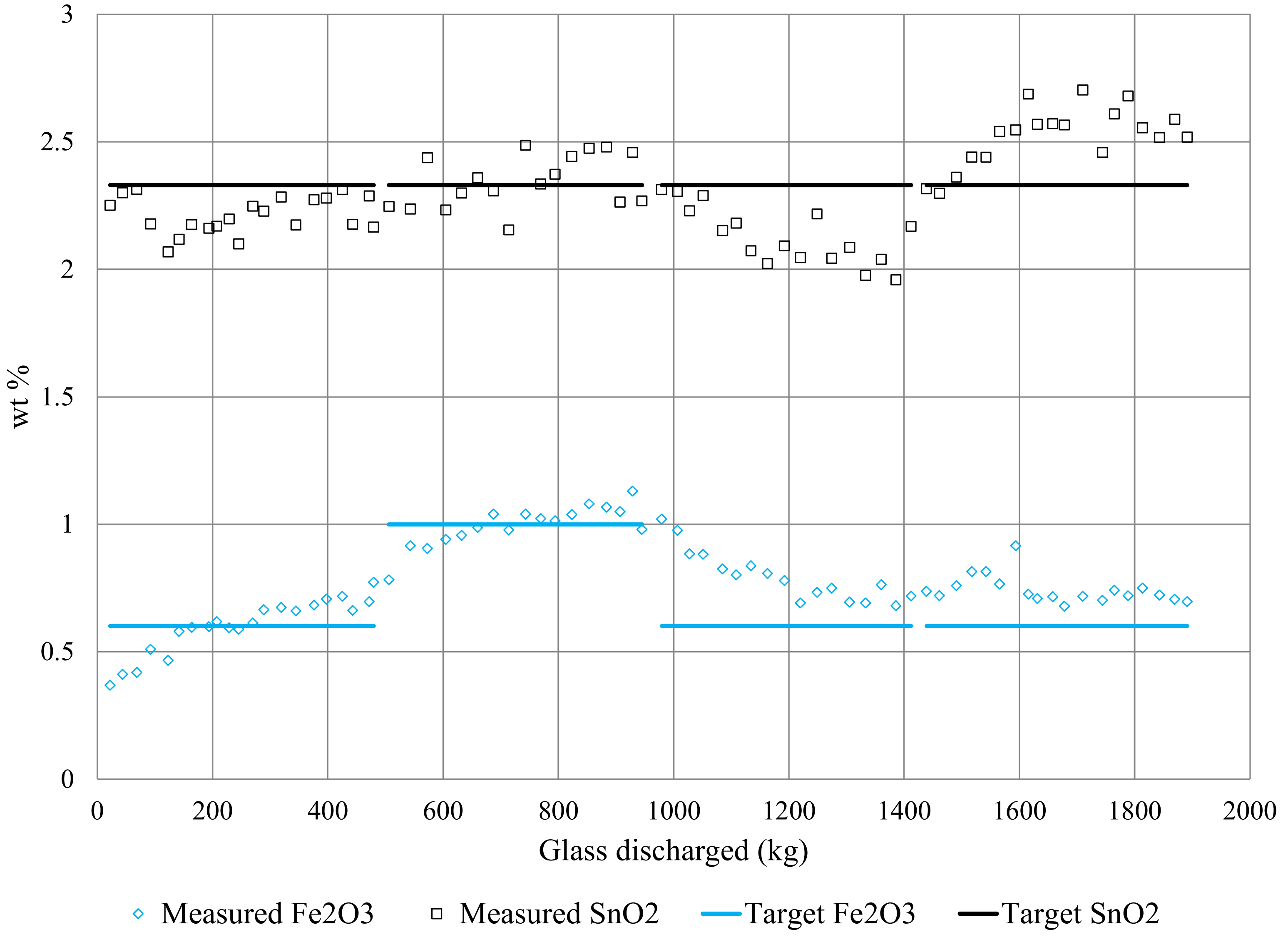


Figure 5.4. XRF analysis of iron and tin oxides in DM100 product glasses.

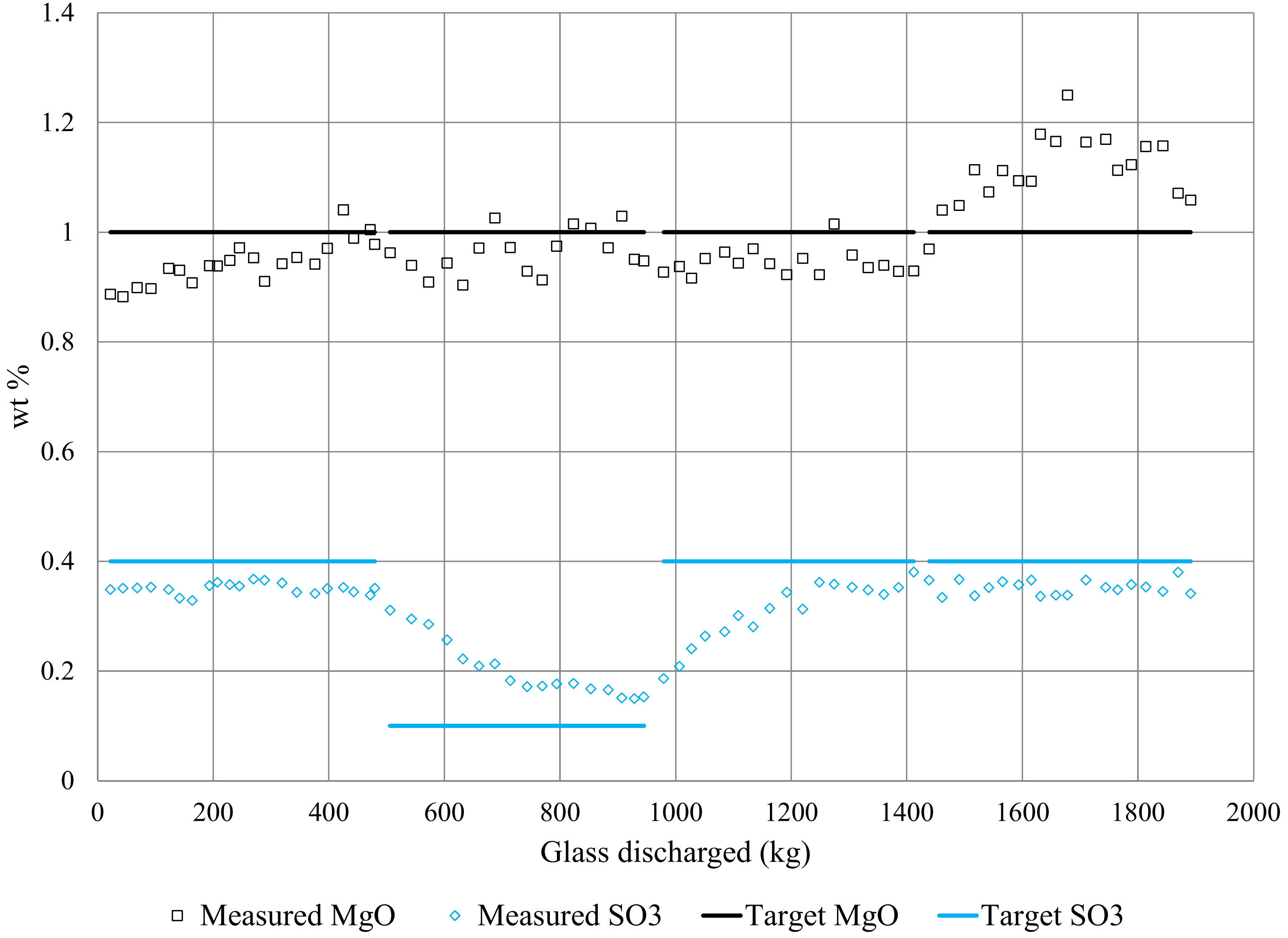


Figure 5.5. XRF analysis of magnesium and sulfur oxides in DM100 product glasses.

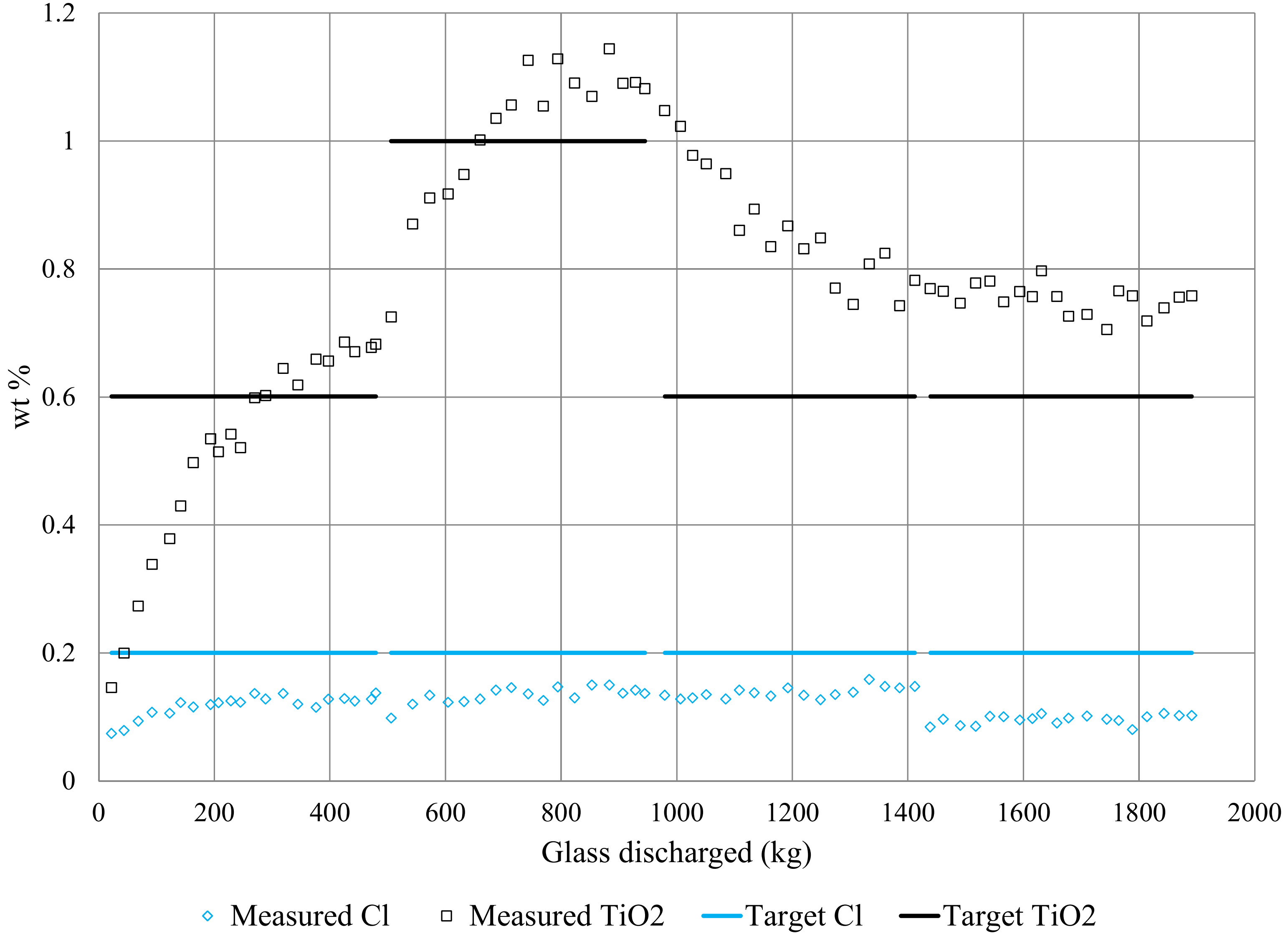


Figure 5.6. XRF analysis of titanium oxide and chlorine in DM100 product glasses.

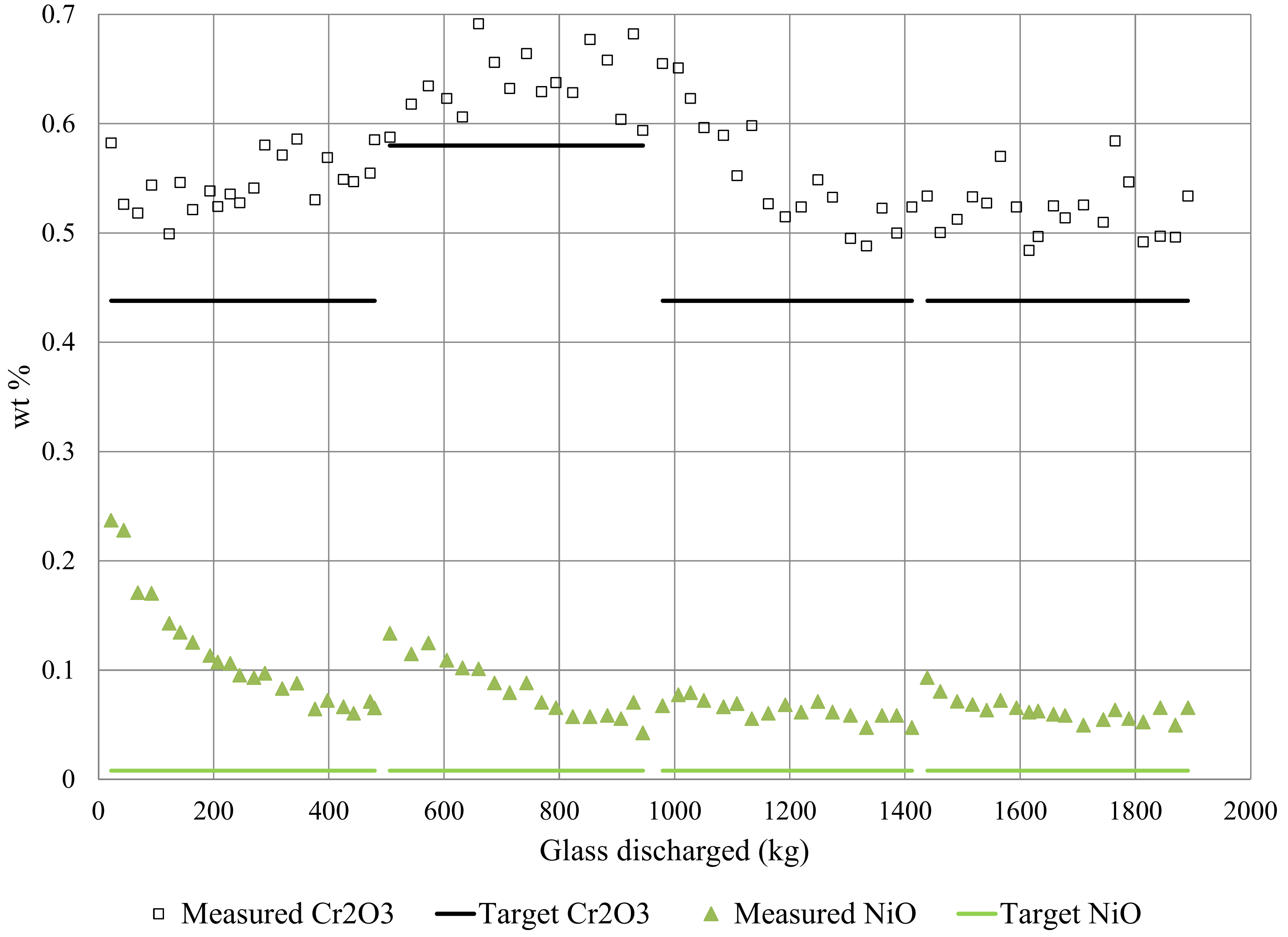


Figure 5.7. XRF analysis of chromium and nickel oxides in DM100 product glasses.

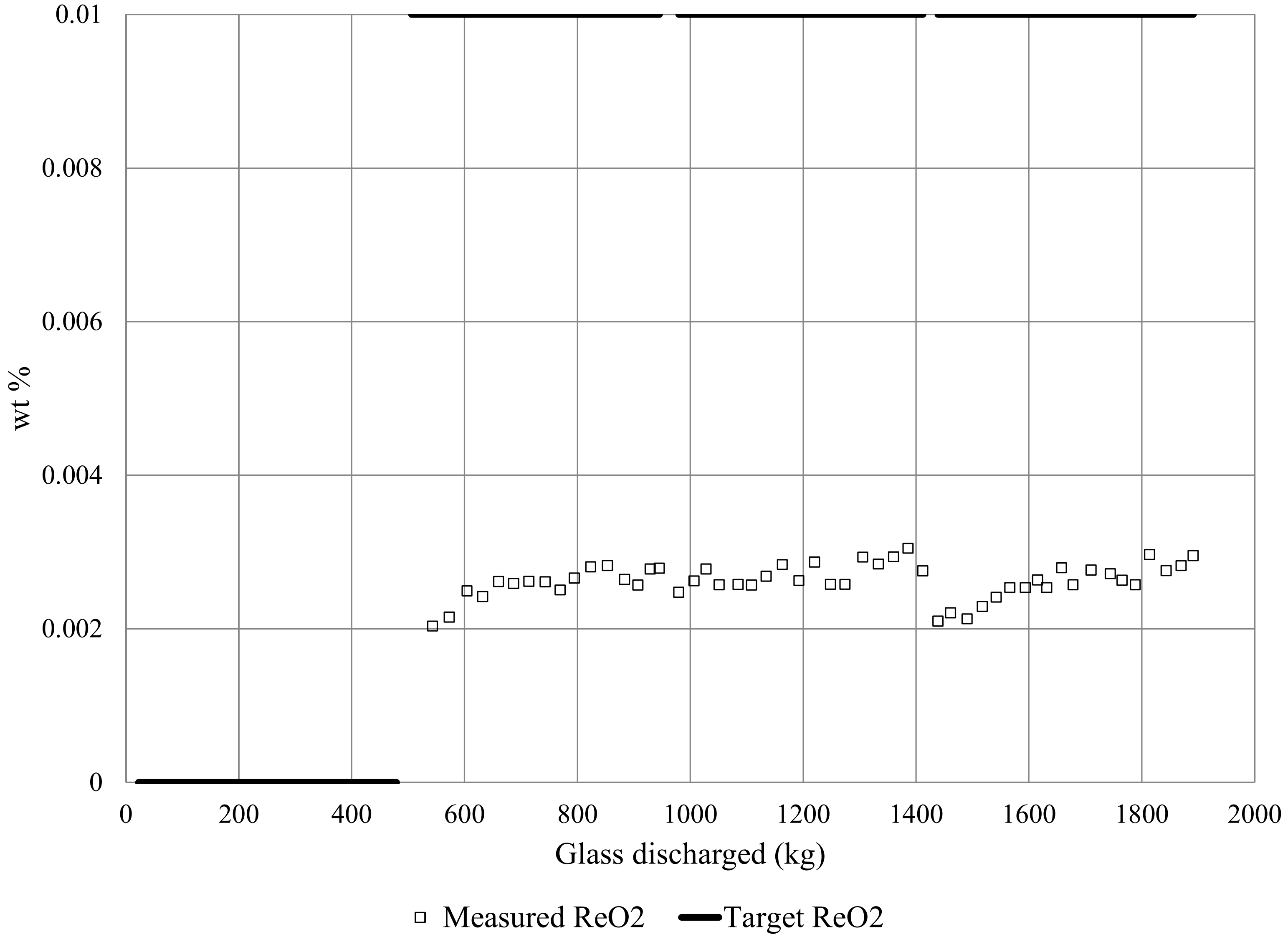


Figure 5.8. XRF analysis of rhenium oxide in DM100 product glasses.

Figure 5.9. Dip samples taken immediately after processing the ORLEC27 glass composition; no secondary phase observed.

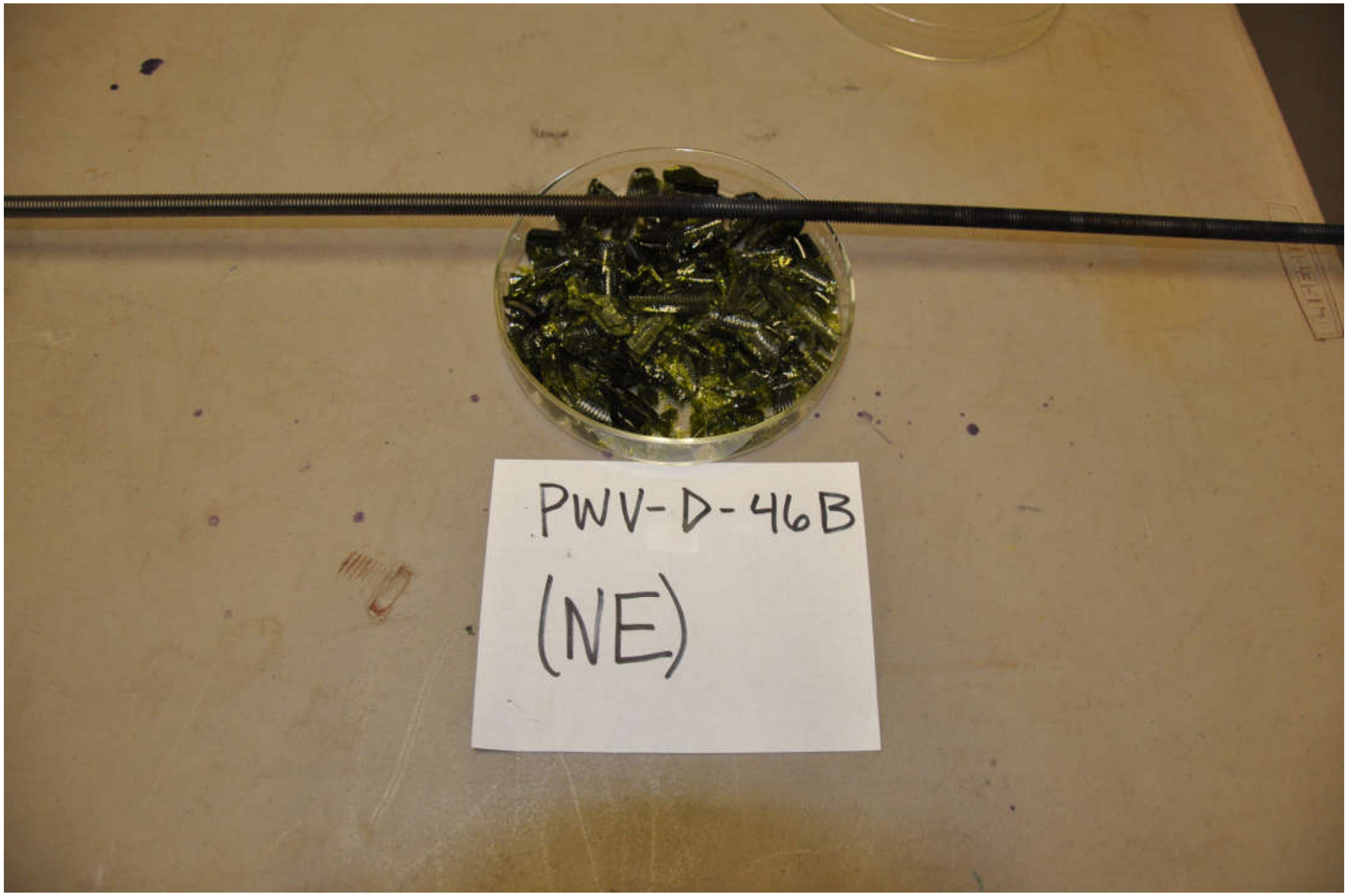


Figure 5.10. Dip sample taken immediately after processing the ORLEC27 glass composition; no secondary phase observed.

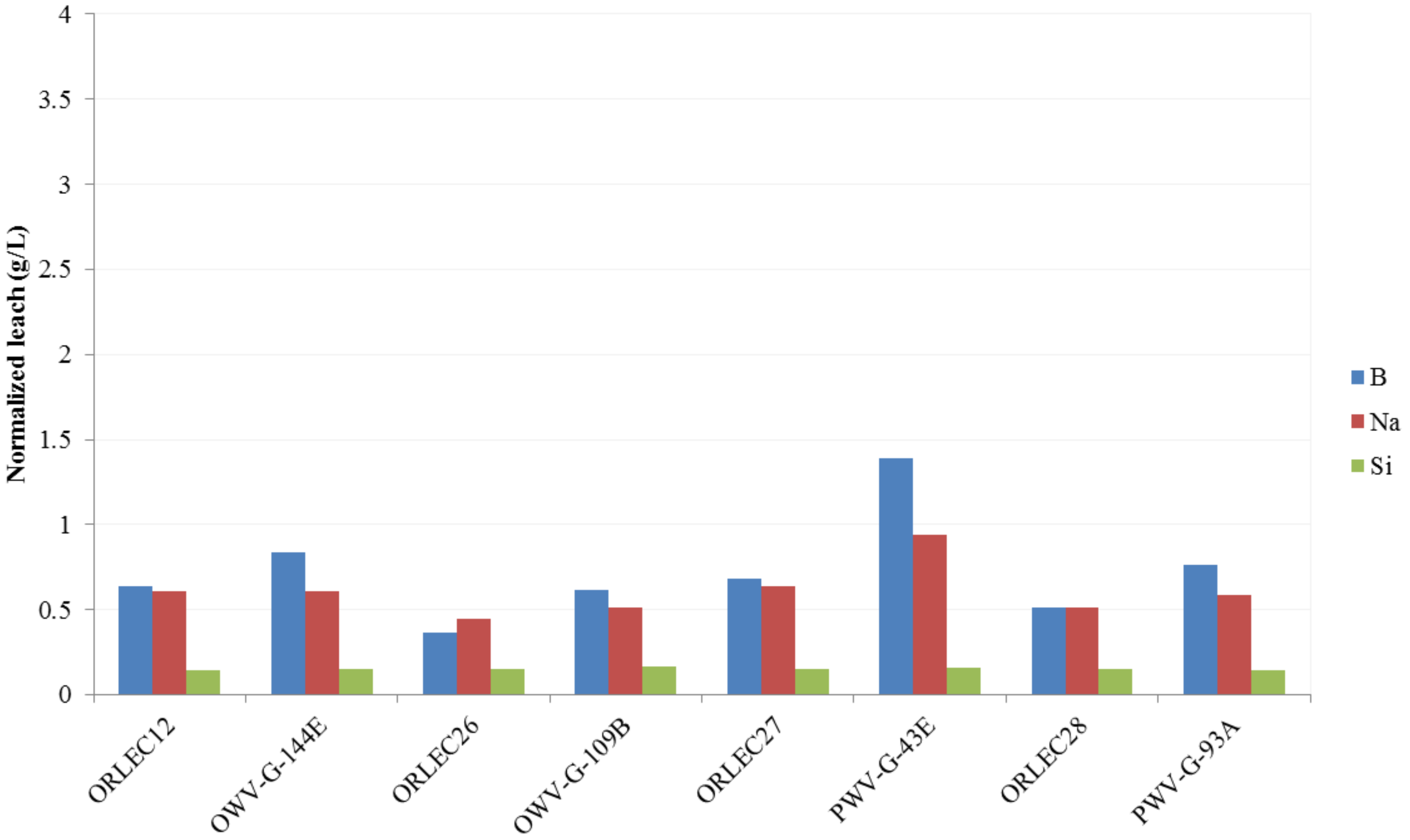


Figure 5.11. Comparison of PCT releases of crucible and melter glass samples.

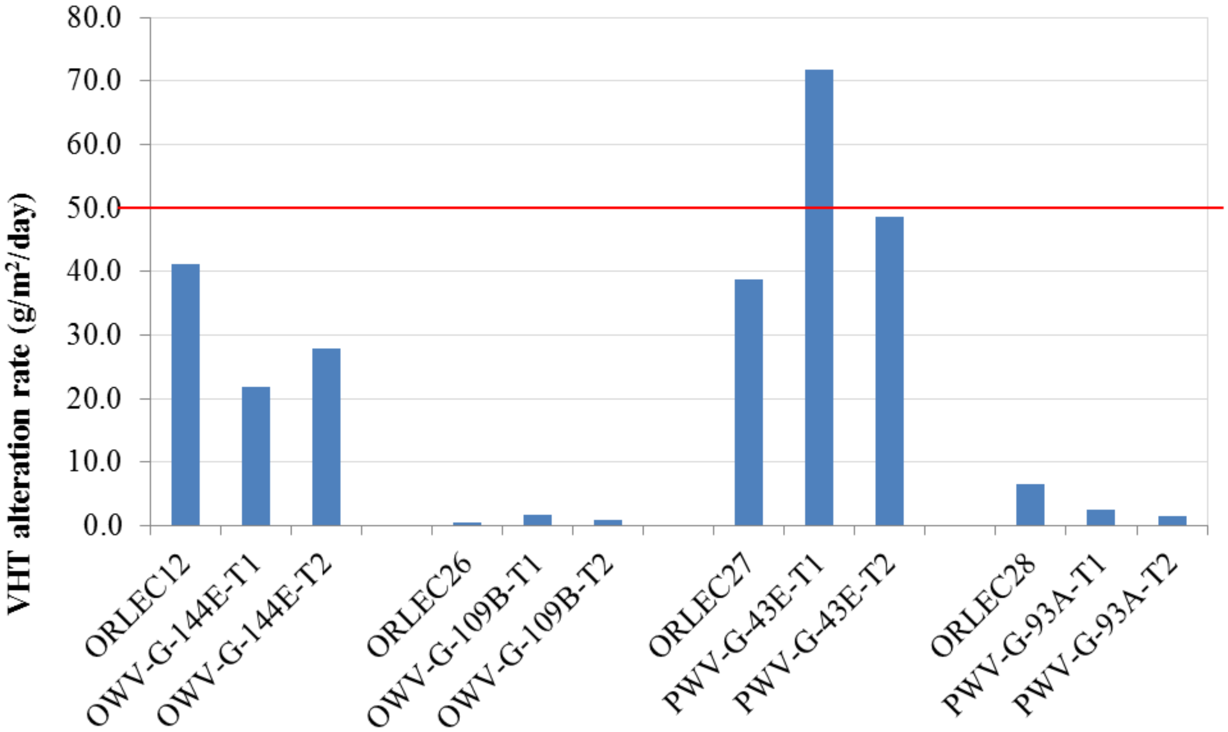
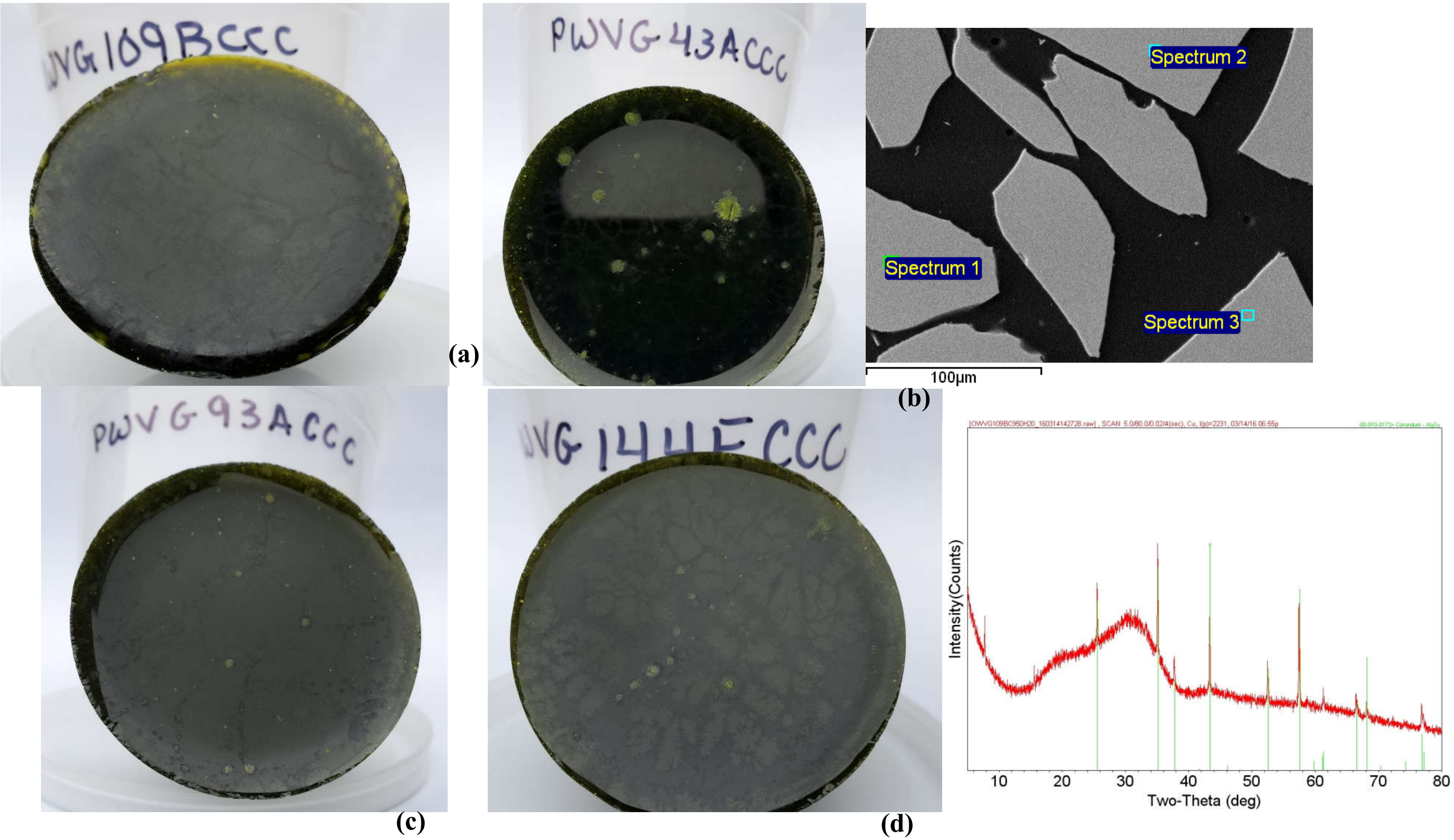


Figure 5.12. Comparison of VHT alteration rates of crucible and melter glass samples.



OWVG109BC950H20

Figure 5.13. Results of heat treatment of melter glasses: (a-d) photos of glasses collected after CCC heat-treatment; SEM micrograph of glass after isothermal heat-treatment at 950°C for 20 hours (no crystal in all four samples); Quantitative XRD (with Al_2O_3 standard) showing no evidence of crystalline phases (all four similar).

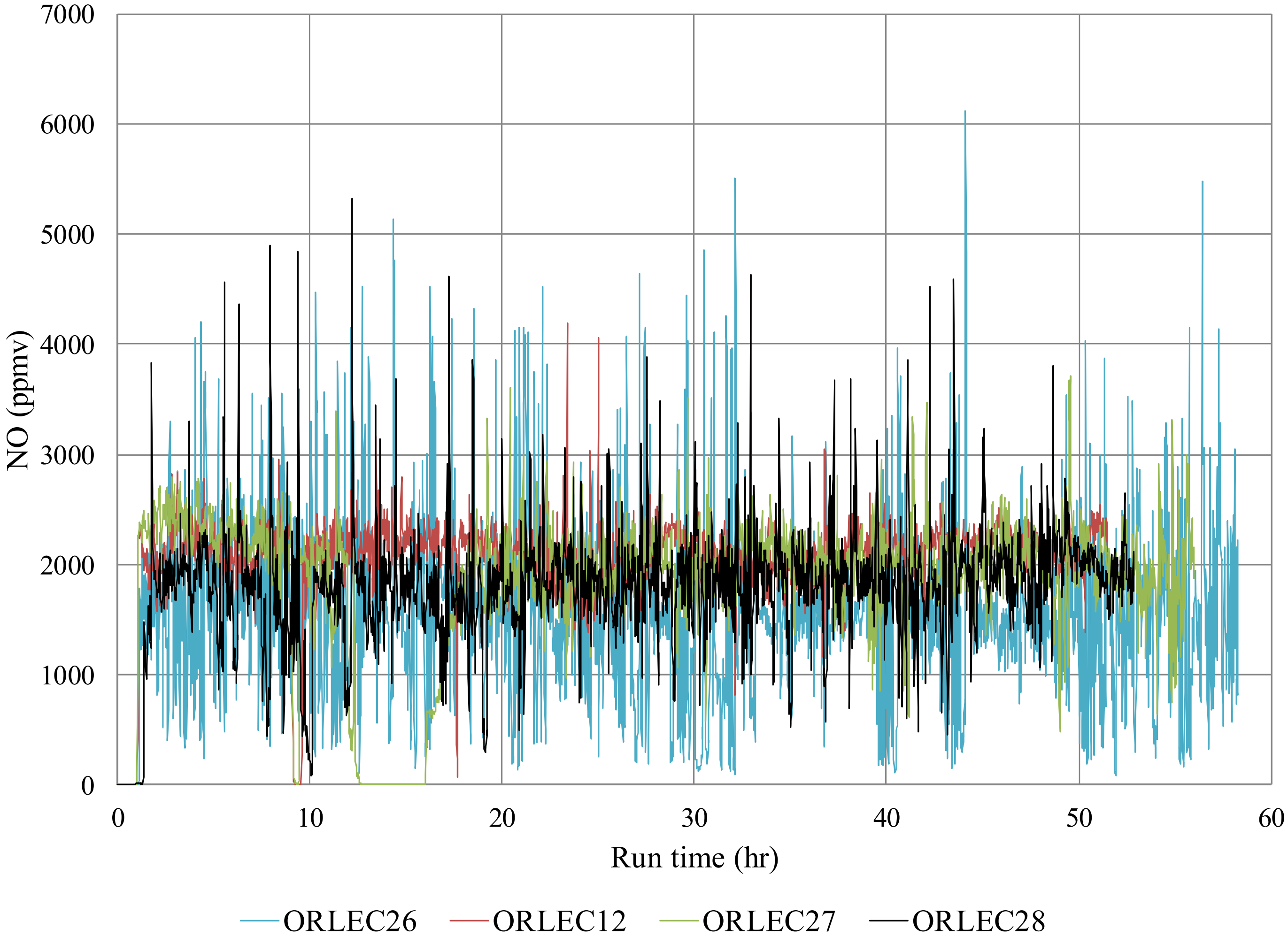


Figure 6.1. Nitrogen monoxide concentrations in off-gas from FTIR during DM100 tests.

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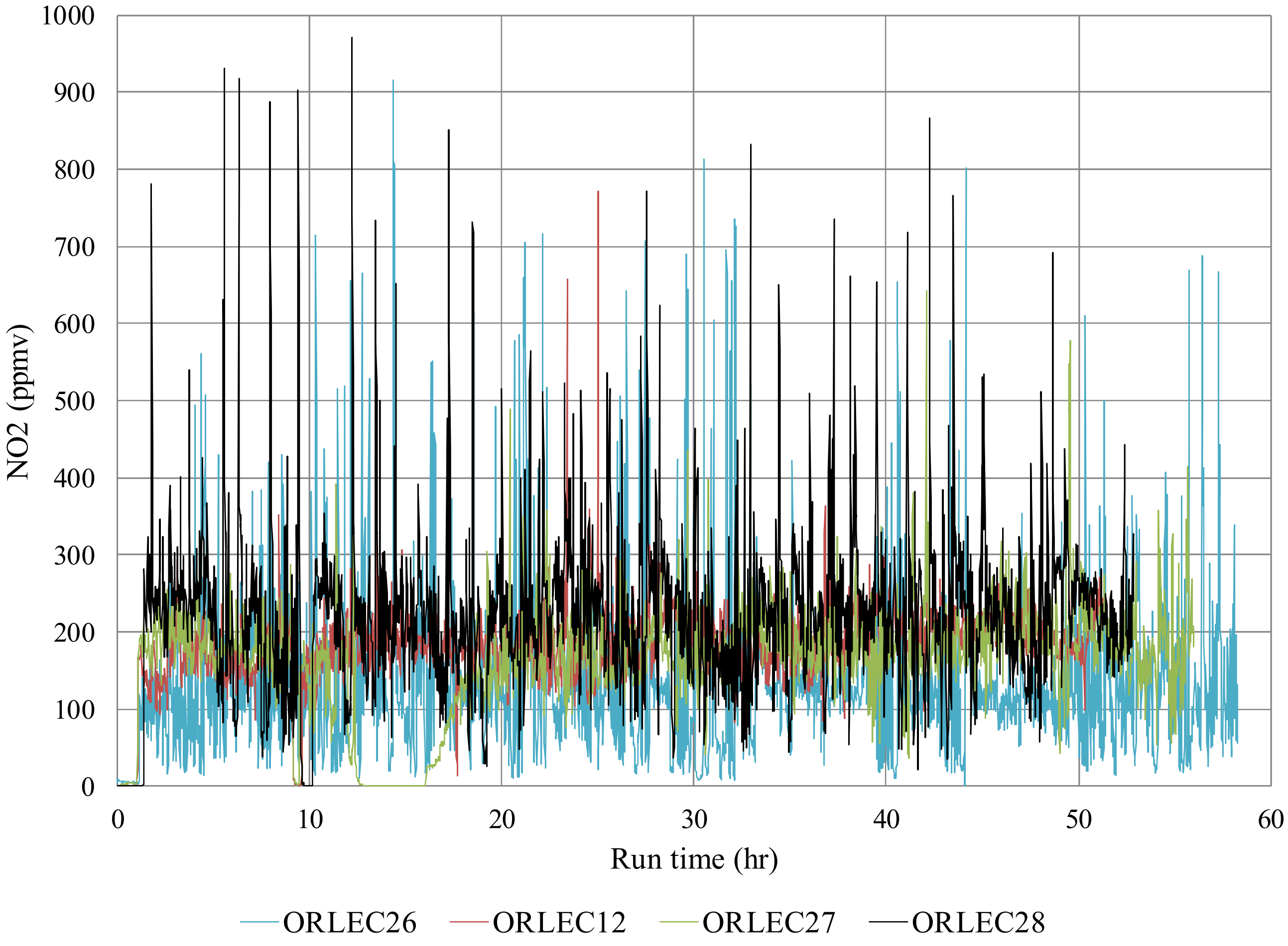

Figure 6.2. Nitrogen dioxide concentrations in off-gas from FTIR during DM100 tests.

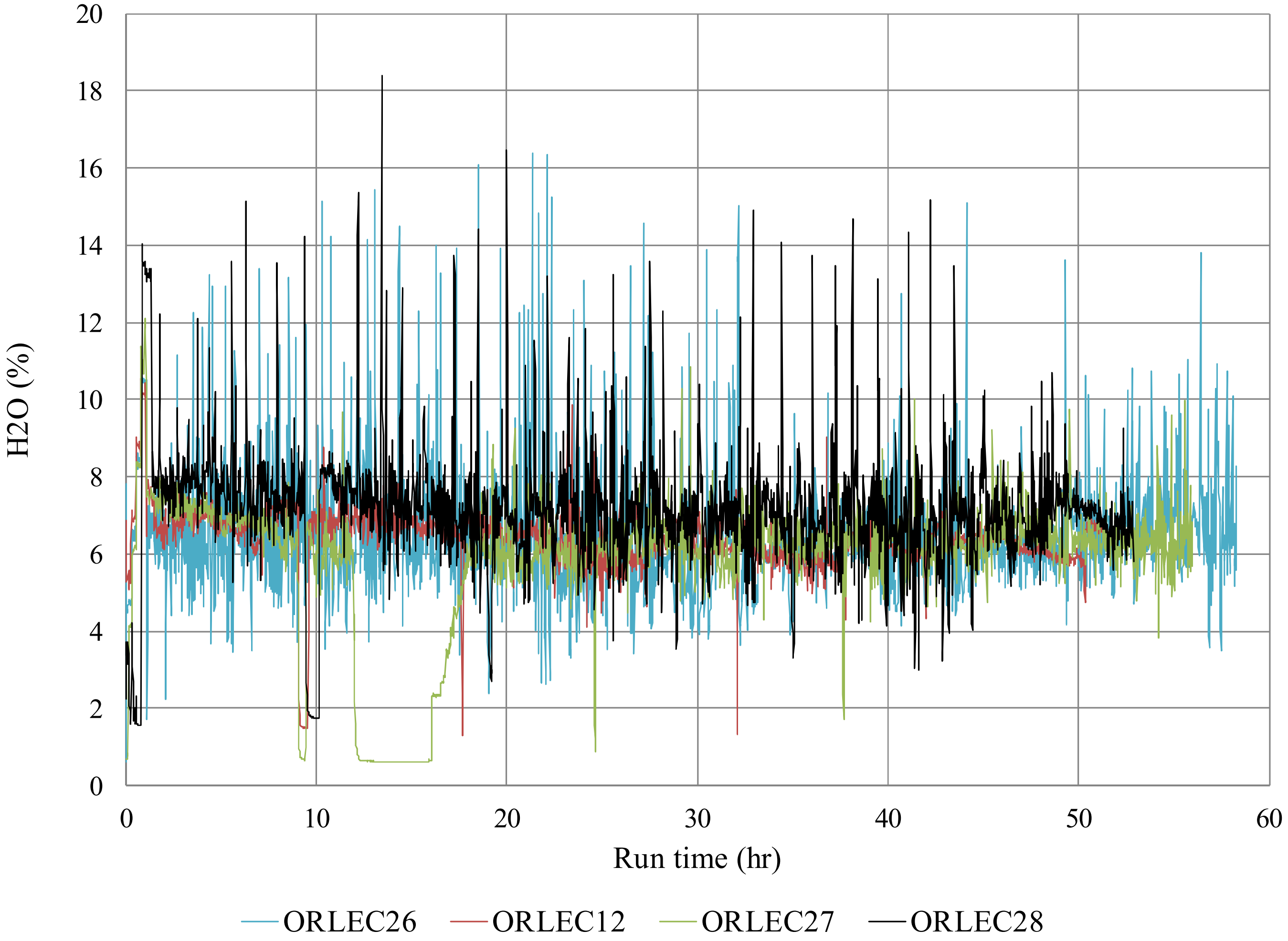

Figure 6.3. Water concentration in off-gas from FTIR during DM100 tests.

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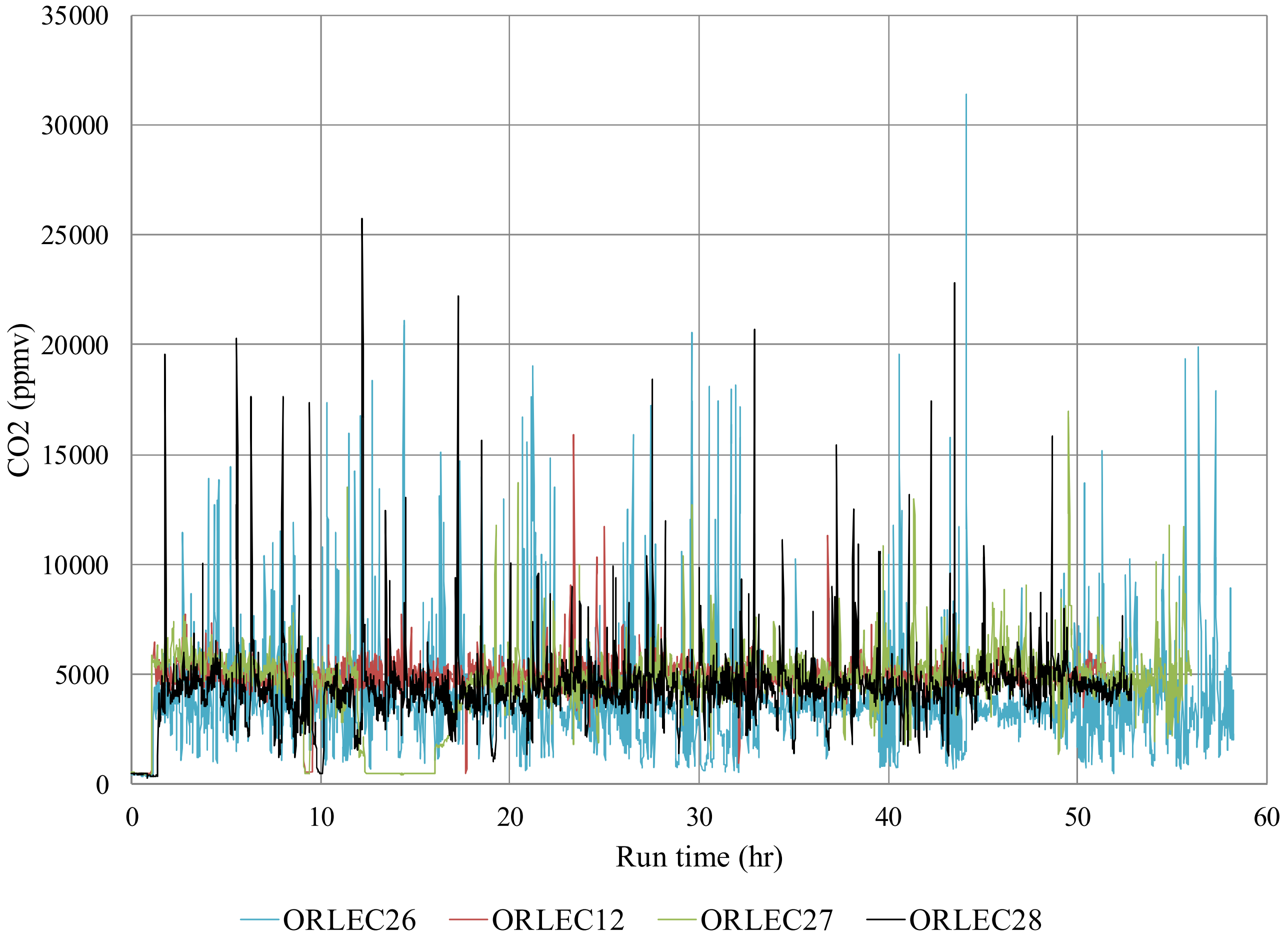

Figure 6.4. Carbon dioxide concentration in off-gas from FTIR during DM100 tests.

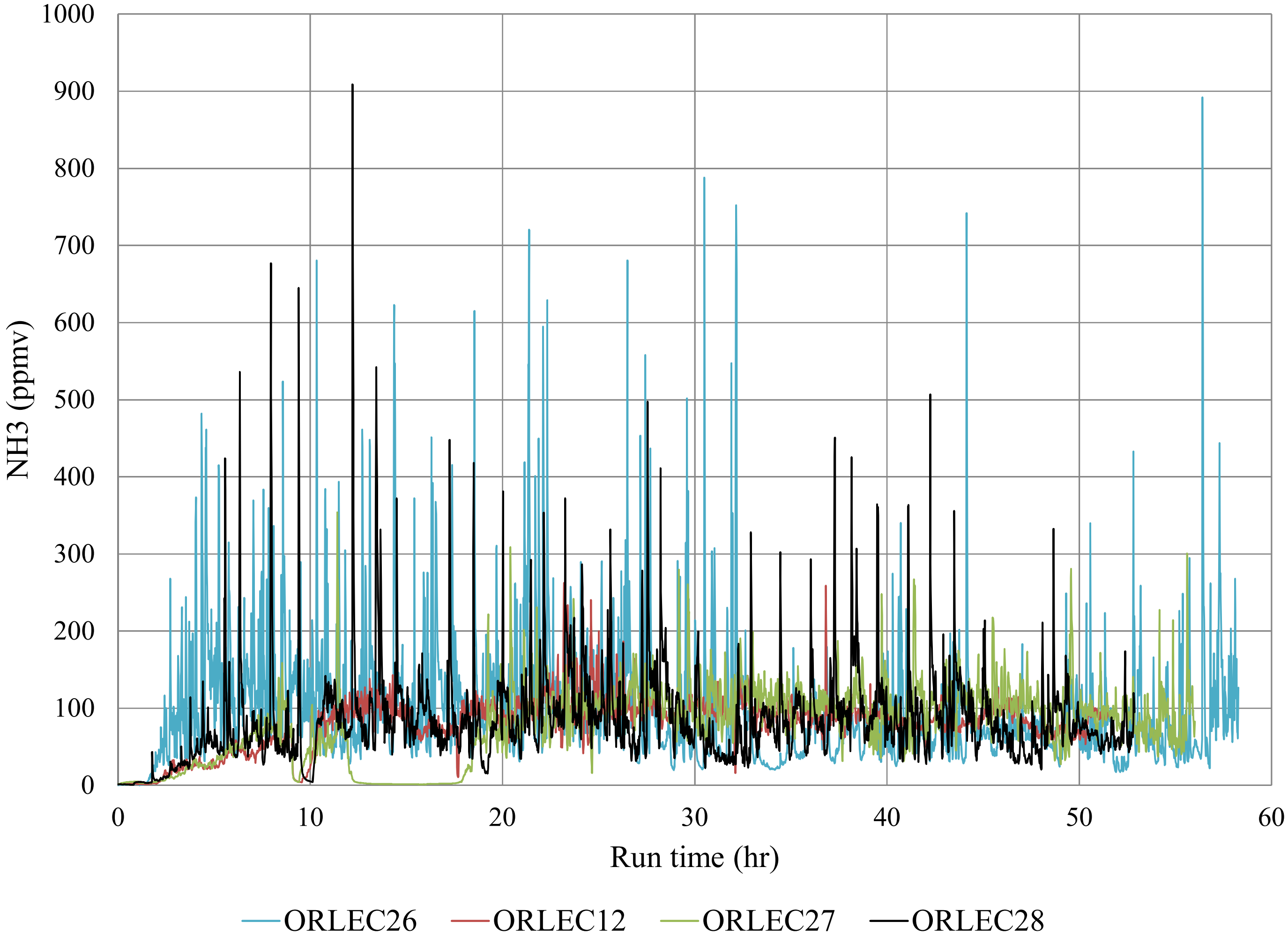

Figure 6.5. Ammonia concentration in off-gas from FTIR during DM100 tests.

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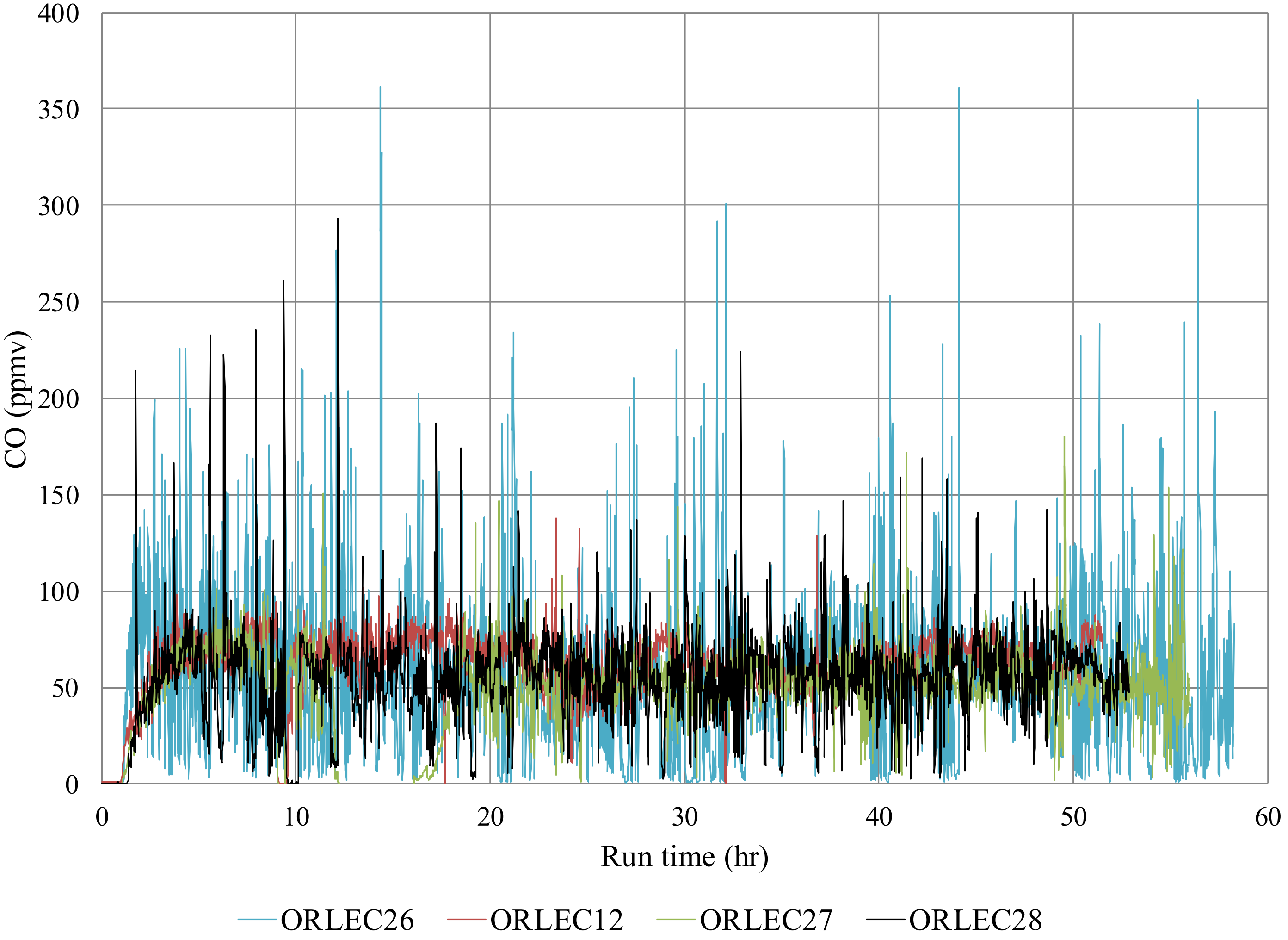

Figure 6.6. Carbon monoxide concentration in off-gas from FTIR during DM100 tests.