# Vitrification of Hanford Tank 241-AP-105 Waste at 7 M Na and Equivalent Simulant

September 2023

DR Dixon
JB Lang
MA Hall
RK Brown
DA Cutforth
WC Eaton
J Marcial
SA Luksic
AM Westesen
RA Peterson

**U.S. DEPARTMENT OF ENERGY**

**DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes **any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights**. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

# Vitrification of Hanford Tank 241-AP-105 Waste at 7 M Na and Equivalent Simulant

September 2023

DR Dixon
JB Lang
MA Hall
RK Brown
DA Cutforth
WC Eaton
J Marcial
SA Luksic
AM Westesen
RA Peterson

Pacific Northwest National Laboratory
Richland, Washington 99354

Revision History

| Revision Number | Effective Date | Description of Change |
|---|---|---|
| 0 | September 2023 | Initial issue. |

# Summary

Hanford Site nuclear waste is to be vitrified at the Waste Treatment and Immobilization Plant (WTP), which is a part of the safe and efficient retrieval, treatment, and disposal mission of the U.S. Department of Energy Office of River Protection. Hanford tank 241-AP-105 (referred to herein as AP-105) is one of the initial Hanford radioactive tank wastes planned to be processed and vitrified. A portion of AP-105 waste was retrieved by Washington River Protection Solutions, LLC (WRPS) and transferred to Pacific Northwest National Laboratory (PNNL). The waste went through dilution in the laboratory by blending with Columbia River water to reach a target sodium (Na) concentration of 7 M, solids filtration, and cesium removal by ion exchange. A glass composition and glass forming chemical (GFC) additions were calculated from the Kim et al. glass models[1] to satisfy the WTP baseline requirements based on analysis of the AP-105 sample received by PNNL (prior to dilution) and the target dilution to 7 M Na. Based on the AP-105 composition and GFC additions, a simulant version of this melter feed was calculated and batched.

As preparation for the processing of the 7 M Na AP-105 waste melter feed, the simulant version of the melter feed was processed in a non-radioactive, continuous laboratory-scale melter (CLSM) system to understand production expectations. The 7 M Na AP-105 simulant melter feed was charged into the CLSM for 7.50 h of processing, which produced 6.13 kg of glass, for an average glass production rate of 1735 kg $m^2$ $d^{-1}$ without any issues pumping the slurry or visual anomalous behavior during vitrification.

Since there were no processing issues with the 7 M Na AP-105 simulant melter feed, the actual 7 M Na AP-105 waste melter feed was then processed in a CLSM system built into a contamination area in a radioactive environment. The melting behavior characteristics appeared similar for both the simulant and waste melter feeds. The 7 M Na AP-105 waste melter feed was charged into the CLSM for 6.71 h of processing, which produced 6.58 kg of glass, for an average glass production rate of 2079 kg $m^2$ $d^{-1}$.

Samples of the 7 M Na AP-105 simulant and melter feeds as well as selected glass and offgas liquid samples were analyzed to determine the concentration of certain chemical constituents. Based on this analysis, most of the primary components in the glass produced from the conversion of the 7 M Na AP-105 melter feeds were within 10 % of their target values, as has routinely been the case with glasses produced through vitrification in both the radioactive and non-radioactive CLSM systems. However, the $ZrO_2$ content in the 7 M Na AP-105 simulant CLSM run was less than its target, due to an under batching of zircon in the melter feed.

A constituent of interest present in low quantities in the 7 M Na AP-105 waste is ^{99}Tc or its non-radioactive surrogate, Re, added to the 7 M Na AP-105 simulant. Analysis for the quantities of ^{99}Tc and Re in the 7 M NA AP-105 glass product resulted in an average single-pass retention from the melter feed during relative chemical steady state of 49 ± 2 % for ^{99}Tc and 38 ± 1 % for Re. Compared to the processing of other melter feeds, the retention of ^{99}Tc in the 7 M Na AP-105 glass was greater than in lower Na molarity AP-105 glasses, while the retention of Re in the 7 M Na AP-105 was equivalent to lower Na molarity AP-105 glass. Both the 7 M Na AP-105 waste and 7 M Na AP-105 simulant were processed at greater average glass production rates than their lower Na molarity AP-105 counterparts that

---

[1] Kim DS, JD Vienna, and AA Kruger. 2012. *Preliminary ILAW Formulation Algorithm Description, 24590 LAW RPT-RT-04-0003, Rev. 1*. ORP-56321, Revision 0. U. S. Department of Energy Office of River Protection, Richland, Washington.

were previously processed in the CLSM and reported elsewhere[2,3]. The 7 M Na AP-105 waste processed faster than the 7 M Na AP-105 simulant likely due to the lower concentration than expected of primary components in the waste compared to the values used to calculate the simulant.

A spike of iodine was added into the 7 M Na AP-105 simulant melter feed that could be detected above the analysis detection limits and was measured in all subsequent glass pours after melter feed charging had begun. Iodine appeared in greater quantities in the glass pours immediately preceding or following the burn off of the cold cap. It is recommended to continue to perform future tests with I spikes at this level to determine how melter feed composition may affect I retention or if the primary influence is the cold-cap coverage. Iodine was also recovered in the CLSM offgas system primarily in the liquid samples, with low quantities partitioning to the filters, signaling that iodine may be recycled from offgas streams to the melter feed in high quantities.

Offgas liquid samples were analyzed for acetonitrile, which was detectable in the condensate and demister liquids collected from the CLSM system. A greater amount of acetonitrile was produced per sucrose in the melter feed during the 7 M Na AP-105 simulant run than the waste run, likely due to a higher plenum temperature in the waste run or the lower concentration than expected of nitrates/nitrites in the waste.

---

[2] Dixon DR, CM Stewart, JJ Venarsky, JA Peterson, GB Hall, TG Levitskaia, JR Allred, WC Eaton, JB Lang, MA Hall, DA Cutforth, AM Rovira, and RA Peterson. 2018. *Vitrification of Hanford Tank Waste 241-AP-105 in a Continuous Laboratory-Scale Melter*. PNNL-27775 (RPT-DFTP-010, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

[3] Dixon DR, AM Westesen, MA Hall, CM Stewart, JB Lang, DA Cutforth, WC Eaton, and RA Peterson. 2022. *Vitrification of Hanford Tank Wastes for Condensate Recycle and Feed Composition Changeover Testing*. PNNL-32344, Rev. 1 (RPT-DFTP-033, Rev. 1). Pacific Northwest National Laboratory, Richland, Washington.

# Acknowledgements

# Acronyms and Abbreviations

| | |
|---|---|
| APEL | Applied Process Engineering Laboratory |
| ARL | analytical reporting limit |
| CA | contamination area |
| CLSM | continuous laboratory-scale melter |
| DF | decontamination factor |
| DFLAW | direct-feed low-activity waste |
| DM10 | DuraMelter10 |
| DOE-ORP | U.S. Department of Energy Office of River Protection |
| EMF | Effluent Management Facility |
| ETF | Effluent Treatment Facility |
| GFC(s) | glass-forming chemical(s) |
| HCA | high contamination area |
| HEPA | high-efficiency particulate air (filters) |
| HLW | high-level waste |
| IC | ion chromatography |
| ICP-AES | inductively coupled plasma atomic emission spectroscopy |
| ICP-MS | inductively coupled plasma mass spectrometry |
| LAW | low-activity waste |
| LSL2 | Life Sciences Laboratory 2 |
| PNNL | Pacific Northwest National Laboratory |
| psia | pounds per square inch absolute |
| QA | quality assurance |
| $R$ | retention |
| R&D | research and development |
| Rec | recovery |
| RPL | Radiochemical Processing Laboratory |
| RWTP | Radioactive Waste Test Platform |
| SBS | submerged-bed scrubber |
| sccm | standard cubic centimeters per minute |
| SwRI | Southwest Research Institute |
| TC | thermocouple |
| TOC | total organic carbon |
| TSCR | Tank Side Cesium Removal |
| WRPS | Washington River Protection Solutions, LLC |
| WTP | Waste Treatment and Immobilization Plant |
| WWFTP | WRPS Waste Form Testing Program |

# Contents

# Figures

# Tables

# 1.0  Introduction

It is the responsibility of the U.S. Department of Energy-Office of River Protection (DOE-ORP) to safely and efficiently retrieve, treat, and dispose of approximately 56 million gallons of radioactive waste located in underground tanks on the Hanford Site in Washington State. The Hanford waste tanks are currently operated and managed by Washington River Protection Solutions, LLC (WRPS). As part of tank farm operations, WRPS supports DOE-ORP's waste retrieval mission. An important element of the DOE-ORP mission is the construction and operation of the Waste Treatment and Immobilization Plant (WTP), which will process and stabilize tank waste. Currently, the first phase of the planned WTP startup and operation, called direct-feed low-activity waste (DFLAW), involves directly processing only the liquid supernatant portion of the waste by vitrification in electric melters in the WTP low-activity waste (LAW) facility without full pretreatment (Bernards et al. 2017). A second portion of the tank waste, called high-level waste (HLW), is set to contain most of the radioactivity inventory (Bernards et al. 2017).

To meet the acceptance criteria at the WTP LAW facility, WRPS designed a Tank Side Cesium Removal (TSCR) system to remove suspended solids and cesium (Cs/$^{137}$Cs) from the supernatant (Bernards et al. 2017). After these processes, the waste will be combined with glass-forming chemicals (GFCs) to form a mixed slurry, called melter feed, that can be charged into the melters. During vitrification, a stable glass is produced for disposal while water, volatile waste components, and a portion of semi-volatiles from the waste-to-glass conversion process escape to the offgas treatment system, where they are captured, primarily as condensate. This offgas condensate will then be concentrated by evaporation in the Effluent Management Facility (EMF) and recycled back to the LAW facility to be incorporated into the melter feed. Recycled radionuclides technetium-99 ($^{99}$Tc) and iodine-129 ($^{129}$I) are expected to accumulate in the offgas treatment waste stream. Under normal operations, the evaporator bottoms will be returned to the LAW melter facility but could also be returned to the tank farm without evaporation when the EMF evaporator is unavailable. The evaporator overhead condensate will be sent to the Effluent Treatment Facility (ETF).

A test program was established at Pacific Northwest National Laboratory (PNNL) to conduct scaled unit operation process steps with actual Hanford tank waste (Peterson et al. 2017). To facilitate this program, the Radioactive Waste Test Platform (RWTP) was established to allow for baseline and alternative flowsheets and unit operations to be tested in comparable tests where both the direct effect of changes and the downstream effects of changes could be evaluated. As a part of this platform, a continuous laboratory-scale melter (CLSM) system was designed and constructed in the Radiochemical Processing Laboratory (RPL) at PNNL for vitrifying treated tank waste samples. An identical, duplicate CLSM system (to process and study non-radioactive waste simulants) was also constructed at PNNL, and a study was performed to evaluate the system performance (Dixon et al. 2020a).

Since its commissioning in 2018, the radioactive CLSM system located in the RPL (hereafter referred to as the rad-CLSM) has processed many samples of Hanford tank wastes while simulant versions of these wastes have also been processed in the simulant CLSM system located in the Life Sciences Laboratory 2 (LSL2) (hereafter referred to as the sim-CLSM). A summary of each waste vitrification campaign is given in Table 1.1 along with the reports that describe each aspect of the campaign.

Table 1.1. Summary of Hanford Waste CLSM Vitrification Campaigns

| Glass Name | Waste | Condensate Recycle | Filtration Report | Cs Removal Report | Vitrification Report | Notes |
|---|---|---|---|---|---|---|
| AP-105 | 241-AP-105 | n/a | Geeting et al. 2018a | Fiskum et al. 2018 | Dixon et al. 2018 | Condensate post-processing[a] |
| AP-107 | 241-AP-107 | n/a | Geeting et al. 2018b | Westesen et al. 2021a | Dixon et al. 2019 | Simulant run separately[b] |
| AP-107-1R | 241-AP-107 | From AP-107 | Geeting et al. 2019 | Fiskum et al. 2019 | Dixon et al. 2020b | No simulant run |
| AP-107-2R & AP-105 | 241-AP-107 & 241-AP-105 | From AP-107-1R | Allred et al. 2021 & Allred et al. 2020 | Westesen et al. 2021b & Fiskum et al. 2021 | Dixon et al. 2022a | No simulant run |
| AP-101 | 241-AP-101 | n/a | Allred et al. 2022 | Westesen et al. 2022 | Dixon et al. 2022b | n/a |

[a] Cantrell et al. 2018
[b] Dixon et al. 2022c

The samples of waste received for vitrification as described in this report were from Hanford tank 241-AP-105. Upon receipt, the tank 241-AP-105 waste was diluted to a target sodium concentration of 7 M (hereafter called 7 M Na AP-105). The purpose of vitrifying the 7 M Na AP-105 waste was to evaluate its processing and compare it with the vitrification of previously tested AP-105 waste at lower Na levels. To prepare for the processing of the 7 M Na AP-105 waste, given that this composition had not been processed in the CLSM previously, a simulant of the 7 M Na AP-105 melter feed was designed and processed in the sim-CLSM. Results from the 7 M Na AP-105 waste and simulant processing help demonstrate the ability of the CLSM system to support future WTP programmatic needs by providing information about melter feed production and processability with obtainable volumes of tank waste. These results will add to the growing database of cold-cap behavior under different melter feed compositions and the distribution of semi-volatile components between glass and offgas products.

## 2.0  Quality Assurance

All research and development (R&D) work at PNNL is performed in accordance with PNNL's Laboratory-Level Quality Management Program, which is based on a graded application of NQA-1-2000, *Quality Assurance Requirements for Nuclear Facility Applications* (ASME 2000), to R&D activities. To ensure that all client quality assurance (QA) expectations were addressed, the QA controls of the PNNL's WRPS Waste Form Testing Program (WWFTP) QA program were also implemented for this work. The WWFTP QA program implements the requirements of NQA-1-2008, *Quality Assurance Requirements for Nuclear Facility Applications* (ASME 2008), and NQA-1a-2009, *Addenda to ASME NQA-1-2008* (ASME 2009). These are implemented through the *WWFTP Quality Assurance Plan* (QA-WWFTP-001) and associated QA-NSLW-numbered procedures that provide detailed instructions for implementing NQA-1 requirements for R&D work.

The work described in this report was assigned the technology level "Applied Research" and was planned, performed, documented, and reported in accordance with procedure QA-NSLW-1102, *Scientific Investigation for Applied Research*. All staff members contributing to the work received proper technical and QA training prior to performing quality-affecting work.

# 3.0 Experimental

This section describes the experimental process used to prepare the 7 M Na AP-105 simulant melter feed and the 7 M Na AP-105 waste melter feed from the actual Hanford tank 241-AP-105 waste. The sim-CLSM and rad-CLSM, which were used to vitrify the melter feeds, and the analyses of the resultant samples are also explained.

## 3.1 Melter Feed Preparation

The simulant version of the 7 M Na AP-105 waste was designed based on chemical analysis of the as-received AP-105 waste and supplemented with chemical data of a previous sample of AP-105 waste (Fiskum et al. 2021). This chemical data was calculated to a target dilution of 7 M Na to determine the composition of 7 M Na AP-105 simulant, the results of which are shown in Table 3.1. The chemical recipe to create 7 M Na AP-105 simulant from this composition is shown in Table 3.2. The composition of the 7 M Na AP-105 simulant was used as input into the Kim et al. (2012) model for WTP baseline glass formulation to calculate the mass of GFCs to form 7 M Na AP-105 melter feed. The amount of GFCs to be added per liter of 7 M NA AP-105 simulant are also shown in Table 3.2 and these GFCs were estimated to increase the volume of the resultant 7 M Na AP-105 simulant melter feed by 0.3884 L per liter of simulant. Ultimately, 10.0 L of 7 M Na AP-105 simulant melter feed was batched, which weighed 16.295 kg for a measured melter feed density of 1.63 kg L$^{-1}$ with a calculated glass yield of 740 g of glass per liter of melter feed. This melter feed was spiked with $Re_2O_7$, to a desired target of 8.1 ppm Re in the final glass if 100 % retained, and KI, to a desired target of 100 ppm I in the final glass if 100% retained, during batching.

Table 3.1. 7 M Na AP-105 Simulant and Waste Compositions

| Analyte | 7 M Na AP-105 Simulant Composition (mg L$^{-1}$) | 7 M Na AP-105 Waste Composition (mg L$^{-1}$) | % Difference (%) |
|---|---|---|---|
| Al | 16666 | 16440 | -1.4 |
| Cl | 4548[a] | 3508 | -29.6 |
| Cr | 398 | 391 | -1.7 |
| K | 4416 | 4568 | 3.3 |
| Na | 160930 | 155516 | -3.5 |
| P | 468 | 436 | -7.3 |
| S | 1416 | 1277 | -10.9 |
| NO2 | 74284[a] | 44811 | -65.8 |
| NO3 | 136441[a] | 116694 | -16.9 |
| TOC | 3031[a] | 2416 | -25.5 |
| | M | M | |
| Na | 7.00 | 6.76 | -- |

[a] Value calculated based on AP-105 composition in Fiskum et al. 2021

Table 3.2. 7 M Na AP-105 Simulant Chemical Recipe and Melter Feed GFCs Additions

| Chemicals | Amount (g L$^{-1}$) | |
|---|---|---|
| Re$_2$O$_7$ Solution (661 ppm-Re) | 10.82 | |
| KI | 0.20 | |
| Al(NO$_3$)$_3$ · 9H$_2$O | 231.72 | |
| NaOH | 184.12 | |
| KOH | 6.27 | |
| Na$_2$CrO$_4$ | 1.24 | |
| Na$_3$PO$_4$ · 12H$_2$O | 5.74 | |
| NaCl | 7.50 | |
| Na$_2$SO$_4$ | 6.27 | |
| NaC$_2$H$_3$O$_2$ (sodium acetate) | 2.59 | |
| NaHCO$_2$ (sodium formate) | 4.29 | |
| C$_2$H$_4$O$_3$ (glycolic acid) | 2.40 | |
| Na$_2$C$_2$O$_4$ (sodium oxalate) | 4.23 | |
| NaNO$_2$ | 111.40 | |
| NaNO$_3$ | 29.54 | |
| GFCs | | Assay |
| Al$_2$SiO$_5$ (Kyanite) | 51.28 | 98.1 |
| H$_3$BO$_3$ (Boric Acid) | 183.09 | 100.2 |
| Ca$_2$SiO$_4$ (Wollastonite) | 46.36 | 97.8 |
| Fe$_2$O$_3$ (Hematite) | 54.13 | 99.4 |
| Mg$_2$SiO$_4$ (Olivine) | 30.90 | 90.5 |
| SiO$_2$ (Silica) | 388.81 | 99.5 |
| TiO$_2$ (Rutile) | 14.32 | 95.4 |
| ZnO (Zinc Oxide) | 36.19 | 99.9 |
| ZrSiO$_4$ (Zircon) | 46.25 | 99.1 |
| C$_{12}$H$_{22}$O$_{11}$ (Sucrose) | 74.42 | 100.0 |
| Waste Loading (%) | 25.5% | |
| Target Glass Yield (g L feed$^{-1}$) | 739.7 | |

Actual supernatant from Hanford tank 241-AP-105 was collected by WRPS and received by PNNL. Upon receipt, PNNL diluted the AP-105 waste with Columbia River water to a target of 7 M Na and passed the liquid through a back-pulse dead-end filter system for solids removal (Allred et al. 2023). The analyzed sodium molarity of the diluted 7 M Na AP-105 waste was 6.76 M. The approximately 7.1 L of resulting liquid were processed through an ion exchange column system at 16 °C, which collected all but 2 % of the $^{137}$Cs activity from waste, while 94% or more of all desired analytes (see Table 3.1) remained in the waste (Westesen et al. 2023).

The composition of the 7 M Na AP-105 waste was measured after ion exchange (Westesen et al. 2023) and the primary analyte values are shown in Table 3.1. The difference between the 7 M Na AP-105 composition used to batch the simulant (and calculate the GFCs) compared to the actual 7 M Na AP-105 waste is also give in Table 3.1. Two batches of 7 M Na AP-105 waste melter feed were prepared, batch 1 used 6.511 kg of 7 M Na AP-105 waste and batch 2 used 2.755 kg of 7 M Na AP-105 waste. Given a composite density for the 7 M Na AP-105 waste of 1.3108 g mL$^{-1}$, the volume of waste in batch 1 was 4.97 L and batch 2 was 2.10 L. The GFCs added per liter to each batch were the same as those used for the 7 M Na AP-105 simulant as shown in Table 3.2. The final 7 M Na AP-105 waste melter feed in batch 1 weighed 11.110 kg with an estimated volume of 6.90 L and batch 2 weighed 4.701 kg with an estimated

volume of 2.92 L. Both batches of 7 M Na AP-105 waste melter feed had a resultant density of 1.61 kg $L^{-1}$ with a calculated glass yield of 740 g of glass per liter of melter feed.

The target glass compositions expected from the vitrification of the 7 M Na AP-105 melter feed (referred to as AP-105-7M), as calculated by the Kim et al. (2012) glass models, are shown in Table 3.3. Table 3.3 also displays the target glass compositions of the 5.5 M Na AP-105 waste that was previously vitrified in the rad-CLSM as well as a comparable composition for glass based on an AP-105 simulant processed in a scaled-melter from literature (Matlack et al. 2017).

Table 3.3. Target Glass Compositions for the 7 M Na AP-105 CLSM Runs
and Other AP-105 Based Glasses

| Component | AP-105-7M (wt%) | AP-105[a] (wt%) | WDFL1[b] (wt%) |
|---|---|---|---|
| $Al_2O_3$ | **6.13** | 6.13 | 6.10 |
| $B_2O_3$ | **9.95** | 9.95 | 10.00 |
| CaO | **2.07** | 2.64 | 2.08 |
| Cl | **0.24** | 0.22 | 0.45 |
| $Cr_2O_3$ | **0.06** | 0.06 | 0.05 |
| F | **0.00** | 0.00 | 0.01 |
| $Fe_2O_3$ | **5.52** | 5.52 | 5.50 |
| $K_2O$ | **0.51** | 0.49 | 0.41 |
| $Li_2O$ | **0.00** | 0.00 | --.-- |
| MgO | **1.49** | 1.49 | 1.48 |
| $Na_2O$ | **20.95** | 19.35 | 21.00 |
| NiO | **0.01** | 0.02 | 0.00 |
| $P_2O_5$ | **0.10** | 0.11 | 0.17 |
| $SO_3$ | **0.29** | 0.33 | 0.30 |
| $SiO_2$ | **44.73** | 45.76 | 44.54 |
| $TiO_2$ | **1.40** | 1.40 | 1.40 |
| ZnO | **3.51** | 3.51 | 3.50 |
| $ZrO_2$ | **3.02** | 3.02 | 3.00 |
| Total | **100.0** | 100.0 | 100.0 |

Information for the glasses associated with the testing described in this report is shown in **boldface** type.
[a] Dixon et al. (2018 and 2022a)
[b] Matlack et al. (2017)

## 3.2  CLSM System

This section describes the sim-CLSM, assembled under a fume canopy in the LSL2, and the rad-CLSM assembled in a high contamination area (HCA) fume hood in the RPL with supporting equipment located in an adjacent contamination area (CA) fume hood and the surrounding areas. The general operating conditions for the performance of both CLSM systems are also detailed.

### 3.2.1  System Design and Configuration

The CLSM system was designed to collect samples of glass, offgas particulate, and offgas condensate without upsetting continuous operation. The CLSM was not designed to be fully prototypic of the WTP LAW melters, but to reproduce the feed-to-glass conversion process performed in the melters. A simplified flow diagram of both the radioactive and simulant CLSM systems is shown in Figure 3.1.
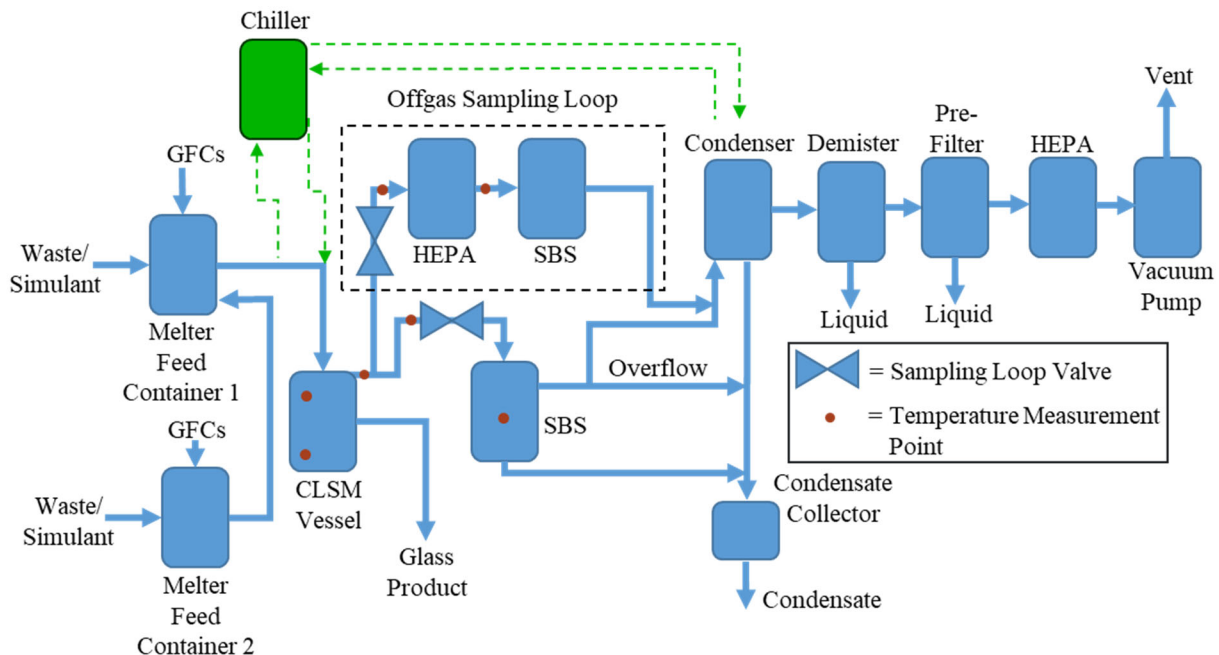
Figure 3.1. Simplified flow diagram of the CLSM systems.

The 7 M Na AP-105 simulant CLSM run used one container of melter feed, placed in the 'Melter Feed Container 1' position, while the 7 M Na AP-105 waste CLSM run used two containers of melter feed so that both the 'Melter Feed Container 1' and 'Melter Feed Container 2' positions were occupied. Each container was agitated by an overhead mixer and spindle for at least 24 hours prior to processing in the CLSM system and remained continuously agitated during testing. In the rad-CLSM, a peristaltic pump was used to move the melter feed from Container 2, in the CA fume hood, into Container 1, in the HCA hood, when desired. The melter feed was pumped from Container 1 to the CLSM vessel by a progressive cavity pump through quarter-inch, stainless-steel tubing, which could produce a continuous drip of melter feed at a steady rate. Between the previous runs in the CLSM systems with AP-101 waste and simulant (Dixon et al. 2022b) and the current series of runs with 7 M Na AP-105, the progressive cavity pumps were replaced with new pumps in both the sim-CLSM and rad-CLSM. The stainless-steel feed tubing that entered the CLSM vessel was water-cooled to prevent evaporation of the melter feed in the tubing that could result in feed line blockage.

The CLSM vessel was fabricated as an octagonal cross-sectional design using Inconel 690 plate and sized to an equivalent cylindrical diameter of approximately 12.0 cm (4.7 inches), resulting in a cross-section and glass surface area of 0.0113 $m^2$ with a plenum volume of 0.0018 $m^3$. A see-through, acrylic version of the CLSM vessel and the actual Inconel version are shown in Figure 3.2. The glass inventory in the CLSM vessel was approximately 2.0 kg, resulting in a glass melt pool depth of ~6.4 cm (2.5 inches).
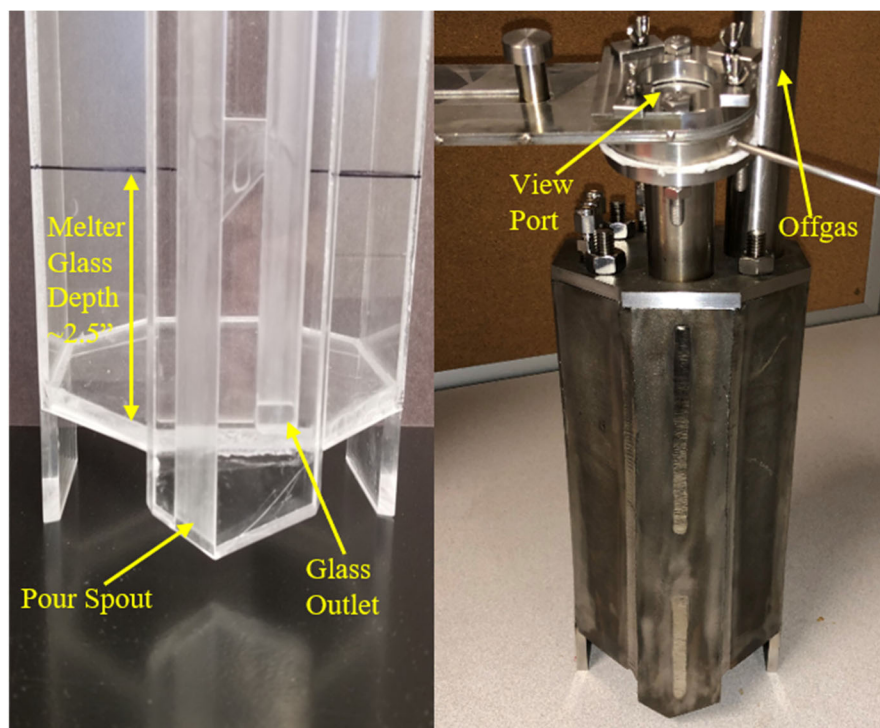
Figure 3.2. Acrylic CLSM vessel model (left) and actual CLSM vessel (right).

As seen in Figure 3.3, the lid of the CLSM vessel contained eight access ports: three for thermocouples ("TC" in the figure), one for an air bubbler, one for the feed tubing, one for a sight glass into the vessel ("Viewport" in the figure), one for the connection to the offgas system, and one for pressure relief ("Back-Up Offgas" in the figure). Heat was supplied externally to the CLSM vessel by a surrounding furnace. The hot zone of the furnace was located below and around the glass melt pool while the offgas head space, called the plenum, of the CLSM vessel was surrounded by insulation. The CLSM achieved continuous operation by periodically pouring glass out of the melt pool to a glass discharge box located below the CLSM vessel. Pouring was achieved by lowering the vacuum maintained on the CLSM vessel by the offgas system, which allowed glass to pour by rising through a discharge riser and passing over an overflow weir.
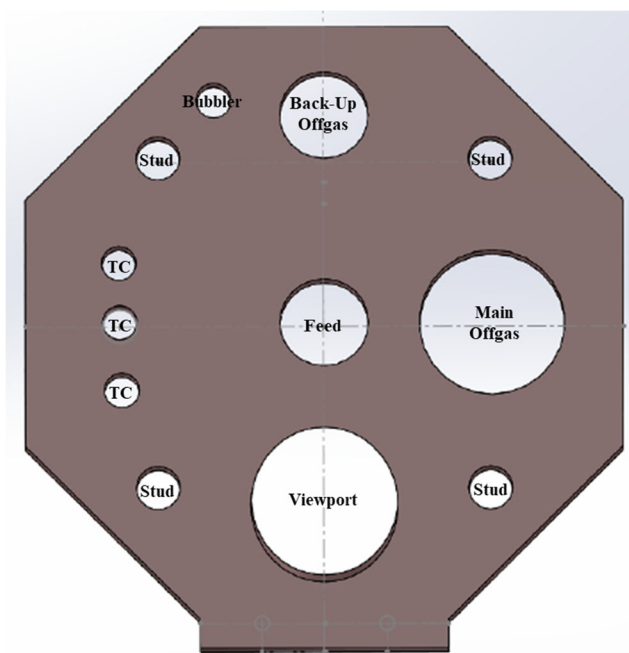
Figure 3.3. CLSM vessel lid and identified ports. The designation 'TC' stands for a thermocouple port.

The offgas produced by the conversion of melter feed to molten glass was drawn off from a port in the CLSM vessel lid into the offgas system with a vacuum pump. The offgas system was constructed of stainless-steel piping and the units described subsequently. Except when the offgas stream was sampled, the offgas would flow through the primary pathway in the offgas system, which consisted of a submerged-bed scrubber (SBS; referred to as the primary SBS), a condenser, a demister, a polypropylene pre-filter, and a high-efficiency particulate air (HEPA) filter (referred to as the primary HEPA filter). The primary SBS and the condenser worked together to both cool the offgas, causing condensation of steam, and perform scrubbing to remove other soluble gases and aerosols as much as possible. The cool liquid from the condenser along with the liquid overflow from the primary SBS drained into a collector where this condensate liquid could be drained periodically. Offgas from the condenser passed through a demister, that allowed any remaining liquid to accumulate before the pre-filter and primary HEPA filter captured any remaining difficult-to-remove particulates. After HEPA filtration, the offgas flowed through the vacuum pump and was released into the HCA fume hood ventilation system for the radioactive CLSM system or the top of the fume canopy for the simulant CLSM system. If needed, the pre-filter and primary HEPA filter could be bypassed and the offgas could flow directly from the demister to the vacuum pump.

The total offgas stream could be sampled by closing the sampling valve in the primary offgas pathway to divert the full offgas flow through a sampling loop containing heated HEPA filters (referred to as the sampling HEPA filters) followed by an SBS (referred to as the sampling SBS). This sampling train consisted of three parallel housings, each with a sampling HEPA filter. Each housing was available for a discrete sampling evolution. The sampled offgas stream was then released back into the primary offgas pathway before the condenser unit. Sampling of the total offgas stream avoided the inherent issues with offgas piping geometry and design that are encountered with slip-stream sampling and ensured that the sample was representative. Offgas sampling durations were typically 10-30 minutes or until the sampling HEPA filters became impassable.

The CLSM system consisted of commercially available as well as custom-built parts. In addition to the CLSM system described above (shown in Figure 3.1), supporting equipment included a controller for the

furnace; a water chiller pumping system to cool all of the necessary locations in the CLSM system, such as the condenser and the primary SBS, with a separate liquid pump plumbed into the chiller line to transport cooling water to the feed nozzle at a controlled rate; a water flush pump for washing out the melter feed pumping system; a controller for the heat trace around the sampling and primary HEPA filters; and a computer for controlling the CLSM system while continuously recording process data. An image of the sim-CLSM layout under the fume canopy in LSL2 is shown in Figure 3.4 and an image of the rad-CLSM layout in the fume hoods in RPL is shown in Figure 3.5.
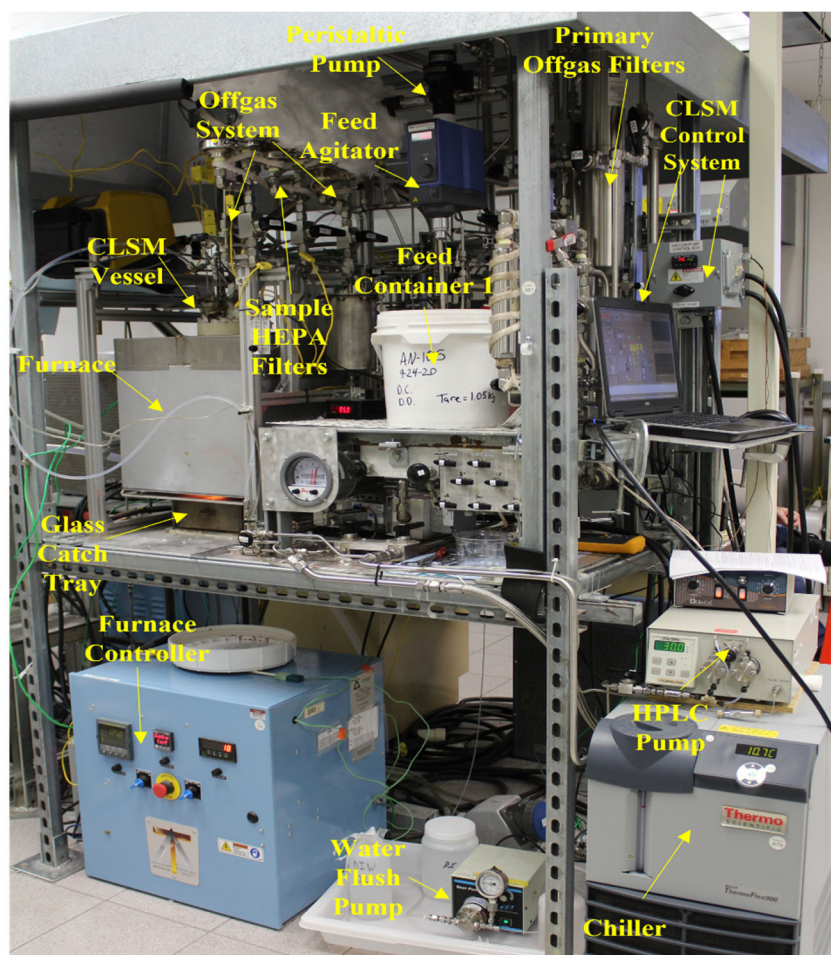


Figure 3.4. The sim-CLSM layout under the fume canopy in the LSL2.
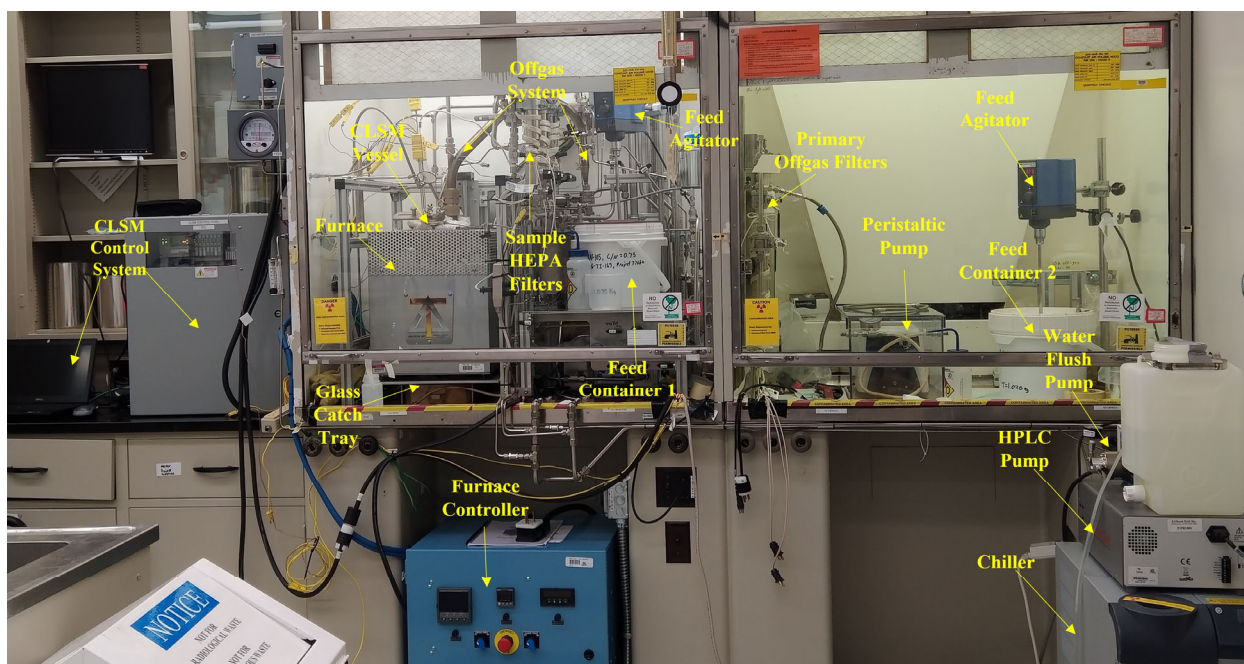
Figure 3.5. The rad-CLSM layout in the RPL HCA (left) and CA (right) fume hoods.

## 3.2.2 Test Conditions

The CLSM system was operated to maintain a glass melt pool temperature of 1150 °C (± 30 °C) by manually adjusting the control temperature of the surrounding furnace as necessary. During feeding operations, the melter feed was charged onto the glass melt surface in the CLSM vessel, forming a batch blanket, called a cold cap, where the feed was heated and converted to glass (Dixon et al. 2015). The feeding rate (governed by the progressive cavity pump with an operational range from 0-36 revolutions per minute) and air bubbling rate (governed by a mass flow controller that could deliver air at 50-3000 standard cubic centimeters per minute [sccm] through a high-temperature 600 nickel alloy tube that was submerged in the glass melt pool) were varied to maintain a target cold-cap coverage over the glass melt surface of 75-95%. The cold-cap coverage was determined to be in the appropriate range when the temperature in the plenum fell into the 500-700 °C range and this could be confirmed through visual observation (by visually estimating the cold-cap coverage) in the viewport of the CLSM vessel lid. The CLSM briefly did produce glass melt pool and plenum temperatures above and below the target ranges.

Typical of slurry-fed melters, the plenum temperature and cold-cap coverage were influenced by many factors, including feed composition and component concentrations, which may vary between different melter feeds (Matlack et al. 2011). The target production rate range for both 7 M Na AP-105 melter feeds processed in the CLSM were derived from the previous processing of LAW melter feeds in the CLSM (Dixon et al. 2020a, 2020b, 2022a, and 2022b), and are listed in Table 3.4. However, similar DFLAW melter feed recipes specifically designed after the 7 M Na AP-105 waste have not been studied in literature, so there were no additional production rate ranges to be used for comparison. The general production range values did align with the designed operation rates at the WTP of 15 metric tons of glass per day [MTG d$^{-1}$] of immobilized LAW (Bernards et al. 2017).

Table 3.4. Target CLSM Operating Conditions

| Parameter | CLSM Target Range |
|---|---|
| Target glass production rate, kg m$^{-2}$ d$^{-1}$ | 1500 – 2000 |
| Melt surface area, m$^2$ | 0.0113 |
| Target feeding rate, kg-feed h$^{-1}$ | 1.59 – 2.12 |
| Target feeding rate, L-feed h$^{-1}$ | 1.01 – 1.35 |
| Bubbling rate, sccm | 50 – 2000 |
| Target glass melt temperature, °C | 1150 ± 30 |
| Plenum temperature range, °C | 500 – 700 |
| Plenum vacuum normal operation, in-H$_2$O | 2 – 4 |
| Offgas piping temperature range, °C | < 500 |
| Primary SBS temperature, °C | 15 – 35 |

The condenser in the offgas system was operated with chilled water and the condensate drained periodically from a collector vessel. The liquid level in the primary SBS was maintained by overflow so that the pressure-drop across the primary SBS remained relatively constant; the temperature was maintained by circulating chilled water through cooling coils in the primary SBS. In the offgas sampling loop, the sampling HEPA filters were wrapped with heat trace and covered with insulation to maintain an elevated temperature (>100 °C) and prevent/reduce condensation prior to the sampling SBS. The offgas system vacuum pump was operated such that it pulled a vacuum on the CLSM vessel during feeding operation. The nominal operating vacuum was 2–4 in-H$_2$O. As described in Section 3.2.1, the CLSM vessel vacuum was reduced periodically to pour glass. At the end of the run, the bubbler air and viewport purge air were adjusted to increase the pressure in the melter, pouring controlled volumes of glass from the CLSM vessel until the remainder of the glass inventory had exited the vessel.

## 3.3   Sample Analysis Methods

The mass of the container with the 7 M Na AP-105 simulant melter feed was measured upon completion of batching, then before and after processing to determine the initial and final mass of melter feed. For the 7 M Na AP-105 waste melter feed, the masses of the 7 M Na AP-105 waste and each individual GFCs added to the two batches of 7 M Na AP-105 waste melter feed were measured and totaled to calculate the initial mass in each container before processing. The masses of the containers with the 7 M Na AP-105 waste melter feed were measured after processing for the final mass of melter feed.

The masses of all product streams were weighed after the run; these included the glass from each pour, the total condensate, the final sump contents from both the sampling SBS and primary SBS (the SBS sumps contained only the liquid from the final capacity of each SBS since, during operation, the SBS liquid would overflow into the condensate collector), the liquid in the demister, the liquid that had accumulated in the pre-filter housing, the pre-filter, the primary HEPA filters, and the sampling HEPA filters. Approximately 10-mL or 10-g samples (for liquid or solid streams, respectively) were taken of the melter feed and from selected product streams. Appropriate product streams were selected by the operational team to gain insight about the operational behavior of each CLSM run. These selected samples, and whole primary/sampling HEPA filters, were sent to the Southwest Research Institute (SwRI) for cation and anion chemical analysis. The analysis methods employed by SwRI and each component measured using each method are given in Table 3.5.

Table 3.5. Sample Chemical Analysis Methods and Components Scanned

| Methods | Component |
|---|---|
| ICP-AES (inductively coupled plasma-atomic emission spectroscopy) | Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, K, La, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Pd, S, Sb, Se, Si, Sn, Sr, Th, Ti, Tl, U, V, W, Y, Zn, and Zr |
| ICP-MS (inductively coupled plasma mass spectrometry) | Total Cs, Total I, Re, and $^{99}$Tc |
| IC (ion chromatography) or Ion-Specific Electrode | Bromide/Bromine, Chloride/Chlorine, Fluoride/Fluorine, Nitrate, Nitrite, Phosphate, and Sulfate |
| Alpha Spectroscopy | $^{241}$Am, $^{242}$Cm, $^{243/244}$Cm, $^{237}$Np, $^{238}$Pu, $^{239/240}$Pu, and $^{244}$Pu |
| TOC Analyzer | Total Organic Carbon (TOC) |
| SW-846 Method 8260D | Acetonitrile ($CH_3CN$) |

# 4.0   CLSM Run Results

This section describes the operation of the CLSM for the 7 M Na AP-105 simulant run in the LSL2 on March 20th, 2023, and the 7 M Na AP-105 waste run in the RPL on April 12th, 2023. The production and chemical analysis results are also detailed.

## 4.1   Operational Description

For the 7 M Na AP-105 simulant run, during set-up of the sim-CLSM, a mixture of approximately 2.0 kg of AP-105 and AN-105 glass pieces, produced previously (Dixon et al. 2018 and 2020a), were loaded into the CLSM vessel as the initial glass inventory. An amount of Re had been retained in this glass mixture during the previous runs. The furnace surrounding the CLSM vessel was heated from room temperature to 1250 °C at 5 °C min$^{-1}$. The CLSM run then began by charging the 7 M Na AP-105 simulant melter feed into the CLSM vessel at 12:00 PM, when the glass temperature had reached its desired range. The time (using the start of feeding as 0.00 h), mass of each individual glass pour (including the mass loaded into the vessel as well as the initial and final pours before or after the runtime, respectively), and cumulative mass of glass poured during the run are given in Table 4.1. Following the termination of feeding, the cold cap burned off (all remaining melter feed in the cold cap and plenum walls was converted into glass) and the glass inventory was poured out of the CLSM vessel, corresponding with the final glass pour reported for the run. Given the total mass of glass poured and the inventory of glass loaded into the CLSM vessel, the mass of glass produced during the 7 M Na AP-105 simulant run was 6.13 kg, corresponding to over 3 turnovers of the 2.0 kg glass inventory.

It was also noted that during the run for two, brief periods (at 0.51 h and 2.96 h) the progressive cavity pump stopped charging melter feed into the CLSM vessel and required a flush with water to clean the pumping chamber and return to normal operation. During these time periods, the cold cap decreased in size, but was not eliminated, although the glass production rate was 0 since melter feed was not being charged. Also, at 6.39 h the CLSM vacuum began to lose capacity due to particulate blockage on the lid of the CLSM vessel, so melter feed charging was stopped to raise the temperature in the plenum and allow the particulate to melt. After approximately 0.40 h, the vacuum returned to full capacity and melter feed charging began again.

For the 7 M Na AP-105 waste run, during set-up of the CLSM system, approximately 2.0 kg of 7 M Na AP-105 glass pieces, from the final pour of 7 M Na AP-105 simulant run, were loaded into the CLSM vessel as the initial glass inventory. The furnace surrounding the CLSM vessel was heated from room temperature to 1250 °C at 10 °C min$^{-1}$. At this time, the software controlling the rad-CLSM disconnected from system. To restore the connection, the system had to be cooled and restarted. As a result, a portion of the glass capacity in the CLSM vessel was poured out (designated as the 'Shutdown Pour' in Table 4.1). Connection between the software and rad-CLSM system was restored, and the 7 M Na AP-105 run was then continued.

Additional glass pieces from the 7 M Na AP-105 simulant run (designated as the 'Re-Load' in Table 4.1) were loaded into the CLSM vessel to make up for the capacity lost during the shutdown pour. The furnace surrounding the CLSM vessel was heated from room temperature to 1250 °C at 10 °C min$^{-1}$. The CLSM run then began by charging the 7 M Na AP-105 waste melter feed into the CLSM vessel at 10:04 AM, when the glass reached its desired temperature range. The time (using the start of feeding as 0.00 h), mass of each individual glass pour and the cumulative mass of glass poured during the run are given in Table 4.1. Following the termination of feeding, the cold cap burned off (all remaining melter feed in the cold cap and plenum walls was converted into glass) and the glass inventory was poured out of the CLSM

vessel, corresponding with the final glass pour reported for the run. Given the total mass of glass poured and the inventory of glass loaded into the CLSM vessel, the mass of glass produced during the CLSM run was 6.58 kg, corresponding to over 3 turnovers of the 2.0 kg glass inventory.

It was also noted during the run that the transfer of 7 M Na AP-105 waste melter feed from 'Melter Feed Container 2' into 'Melter Feed Container 1', see Figure 3.1 for positioning, began at 2.21 h and ended when as much feed as possible had been transferred. At 6.39 h the objectives of the 7 M Na AP-105 waste run had been accomplished and the CLSM vacuum began to lose capacity due to particulate blockage on the lid of the CLSM vessel. The CLSM operations team decided to stop melter feed charging to raise the temperature in the plenum and allow the particulate to melt. After approximately 0.35 h the vacuum returned to full capacity and melter feed charging began again to vitrify the remaining 7 M Na AP-105 waste melter feed.

The cold-cap behavior for the 7 M Na AP-105 waste melter feed was similar to the 7 M Na AP-105 simulant melter feed and adhered closest to previous AP-107 runs (Dixon et al. 2019, 2020b, and 2022a) rather than the previous lower Na molarity AP-105 runs (Dixon et al. 2018 and 2022a). The 7 M Na AP-105 runs had a smooth cold cap that was quick to respond to operator input. The cold cap remained at a steady size and coverage requiring infrequent changes in operating conditions.

Table 4.1. Timing and Mass of Glass Pours During the
7 M Na AP-105 Simulant and Waste CLSM Runs

| Simulant Pour Time (h) | Simulant Glass Mass Poured (g) | Simulant Cumulative Glass Mass Poured (kg) | Waste Pour Time (h) | Waste Glass Mass Poured (g) | Waste Cumulative Glass Mass Poured (kg) |
|---|---|---|---|---|---|
| Load | 1977.56 | -- | Load | 1921.55 | -- |
| Initial | 48.38 | 0.05 | Shutdown Pour | 1203.29 | -- |
| 0.67 | 218.83 | 0.27 | Re-Load | 1535.49 | -- |
| 1.17 | 304.56 | 0.57 | Initial | 78.44 | 0.08 |
| 1.67 | 347.72 | 0.92 | 0.58 | 599.92 | 0.68 |
| 2.14 | 469.12 | 1.39 | 1.14 | 470.07 | 1.15 |
| 2.67 | 551.21 | 1.94 | 1.68 | 552.42 | 1.70 |
| 3.17 | 418.07 | 2.36 | 2.01 | 328.53 | 2.03 |
| 3.67 | 381.17 | 2.74 | 2.43 | 406.36 | 2.44 |
| 4.29 | 596.06 | 3.34 | 2.76 | 561.70 | 3.00 |
| 4.80 | 319.93 | 3.66 | 3.38 | 401.29 | 3.40 |
| 5.09 | 392.40 | 4.05 | 3.93 | 267.59 | 3.67 |
| 5.59 | 686.98 | 4.73 | 4.43 | 420.07 | 4.09 |
| 6.34 | 993.03 | 5.73 | 4.93 | 443.32 | 4.53 |
| 7.67 | 153.91 | 5.88 | 5.54 | 299.91 | 4.83 |
| 8.19 | 185.43 | 6.07 | 6.01 | 403.71 | 5.23 |
| Final | 2040.78 | 8.11 | 6.59 | 777.28 | 6.01 |
| Total Produced | -- | 6.13 | 6.96 | 750.01 | 6.76 |
| | | | Final | 2069.06 | 8.83 |
| | | | Total Produced | -- | 6.58 |

## 4.2 Production Results

The production results from the 7 M Na AP-105 simulant and waste CLSM runs are given in Table 4.2. The production results include the total values of the feeding time (and low flow duration within the feeding time), operational downtime, measured mass of glass produced, calculated mass of melter feed

consumed, and average values for the glass production rate, feeding rate, glass temperature, and plenum temperature. The processing values recorded during the simulant CLSM run are displayed in Figure 4.1a and those recorded during the waste CLSM run are displayed in Figure 4.1b. These results include the glass and plenum temperatures, the average glass production rate during the portion of the run with each melter feed, the bubbling flux rate, and the melter vessel vacuum measurements. Three offgas samples were collected during the simulant CLSM run, though while the second was collected, the pump stopped charging melter feed. As a result, the second offgas sample during the simulant CLSM run was not analyzed for semi-volatile retention. Two offgas samples were collected during the waste CLSM run. The occurrence of each offgas sample in the timeline for each of the runs are shown in relation to the processing values in Figure 4.1.

Table 4.2. CLSM Production Results During Both 7 M NA AP-105 CLSM Runs

| Parameter | 7 M Na AP-105 Simulant CLSM Run | 7 M Na AP-105 Waste CLSM Run |
|---|---|---|
| Test Date | 3/20/2023 | 4/12/2023 |
| Feeding Duration, h | 7.50 | 6.71 |
| Low Flow Duration, h | 0 | 0 |
| Downtime, h | 0.72 | 0 |
| Glass Produced, kg | 6.13 | 6.58 |
| Melter Feed Consumed, kg | 14.37 | 13.99 |
| Average Glass Production Rate, kg m$^{-2}$ d$^{-1}$ | 1735 | 2079 |
| Average Feeding Rate, kg h$^{-1}$ | 1.92 | 2.08 |
| Average Bubbling Flux Rate, L m$^{-2}$ min$^{-1}$ | 118 | 106 |
| Average Glass Temperature, °C | 1141 | 1153 |
| Average Plenum Temperature, °C | 609 | 660 |
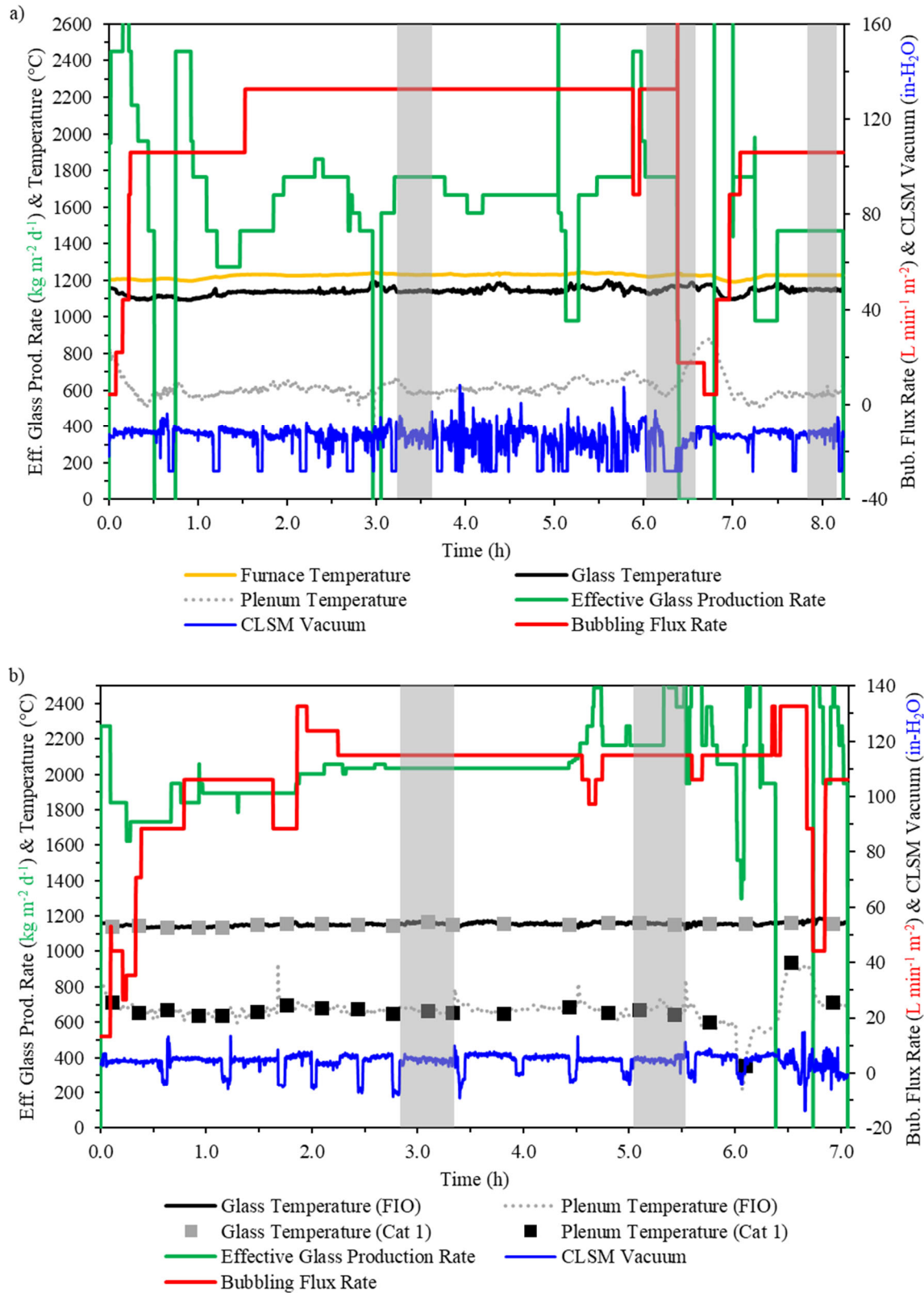
Figure 4.1. Processing values (glass and plenum temperatures, effective glass production rate, bubbling flux rate, and CLSM vacuum measurements) and offgas sample timing recorded during a) the 7 M Na AP-105 simulant CLSM run and b) the 7 M Na AP-105 waste CLSM run.

## 4.3   Sample Chemical Analysis

The samples selected for chemical analysis from the 7 M Na AP-105 simulant CLSM run are listed in Table A.1 in Appendix A along with the total mass of each sample stream and the concentration of each analyzed component listed in Table 3.5. Similarly, the samples selected for chemical analysis from the 7 M Na AP-105 waste CLSM run are listed in Table A.2 in Appendix A along with the total mass of each sample stream and the concentration of each analyzed component. The melter feed samples sent for analysis were pumped from their respective containers into sample vials. Each batch of the 7 M Na AP-105 melter feed was sent separately for analysis. In addition, samples of each batch of 7 M Na AP-105 melter feed were collected on the initial day the run was attempted (before the software disconnected from the system) and the day of the run. All melter feed samples were sent for analysis. Glass pours were selected for analysis over the range of each CLSM run. The occurrence of each glass pour in the timeline for each of the runs is listed in the sample name. For the collection of each offgas sample, the complete sampling HEPA filters were digested and analyzed independently while the same process was performed for the used primary HEPA filter. Due to their size, the pre-filters had to be split into four portions for shipment, but all four portions were digested and combined for analysis.

The samples of condensate collected throughout the run were all combined into a single portion and subsampled. Similarly, the liquid that accumulated in the demister was combined into a single portion and subsampled. Liquid accumulated in the pre-filter housing during the run was drained from the housing and collected. The sump from the primary SBS was drained after the run and collected. For the 7 M Na AP-105 simulant run, the offgas piping was washed with water into two portions: 1) from the CLSM vessel lid to the offgas switch (Denoted in Table A.1 as Primary Offgas Wash); and 2) the sampling loop piping (Denoted in Table A.1 as Sampling Offgas Wash). Due to radioactive contamination restrictions, the offgas piping was not able to be disassembled and washed after the 7 M Na AP-105 waste run. Aliquots of all the liquid portions described were sent for chemical analysis.

# 5.0   Discussion

This section discusses the insights gained from the CLSM runs with both the 7 M Na AP-105 simulant and 7 M Na AP-105 waste melter feeds and compares data to previous CLSM runs (Dixon et al. 2018, 2019, 2020a, 2020b, 2022a, and 2022b).

## 5.1   Glass Composition

Table 5.1 compares the compositions of the glass produced during the CLSM runs with their respective target compositions. Since the initial glass loaded into the CLSM vessels at the beginning of each CLSM run was slightly different than the target compositions (detailed in Section 4.1 ), both the average composition of glass produced during the runs and the composition of the last glass poured during each run are compared to the AP-105-7M target composition in Table 5.1. The average glass composition produced during each run was calculated by converting the analyzed component concentrations in each glass sample, listed in Table A.1 and Table A.2 of Appendix A, to their associated oxides and averaging based on the mass of each glass poured with each composition. For each primary glass component (present in >1.00 wt% amounts), the percent differences between the measured composition and the target composition are reported in Table 5.1.

Compositional trends for each composition component measured in the glass product from the 7 M Na AP-105 simulant and waste CLSM runs are displayed in Figure 5.1 and Figure 5.2. Since the 7 M Na AP-105 waste CLSM run began with the glass from the final pour of the 7 M Na AP-105 simulant CLSM run, the glass composition trends from both runs are given in cumulative succession on the same graph with respect to the amount of glass discharged. The glasses from the 7 M Na AP-105 simulant CLSM run are associated with the glass pours from 0.00 to 6.13 kg discharged. The glasses from the 7 M Na AP-105 waste CLSM run are associated with the glass pours from 5.41 to 12.71 kg discharged. Since glass was poured during the 7 M Na AP-105 waste run prior to charging (due to the software disconnection detailed in Section 4.1), the glass discharge mass associated with this prior discharge sample was 5.41 kg and each subsequent waste glass pour discharge mass was associated with the cumulative mass poured as listed in Table 4.1. Each graph shows the measured component content in the glass as black squares (■), the anticipated component content in the glass based on the target glass composition as a black, solid line (▬), and the expected component content in the glass based on the analyzed melter feed samples as a red, solid line (▬).

Most of the primary components measured in the AP-105-7M glass compositions produced from the 7 M Na AP-105 simulant and waste CLSM runs were within ±10 % of their target values as has previously been shown for a variety of glass compositions produced in the CLSM (Dixon et al. 2020a and 2020b). Three components differed by greater than ±10 % from their target glass compositions during individual glass pours in the CLSM runs, shown in Figure 5.1 , while their averages and final pours were within ±10 %, shown in Table 5.1: CaO, $SO_3$, and MgO. The initial glass loaded into the CLSM vessel for the 7 M Na AP-105 simulant run was a mixture of AP-105 (composition given in Table 3.3) and AN-105 glass (composition given in Dixon et al. 2020a).

Table 5.1. Comparison of 7 M Na AP-105 Simulant and Waste CLSM
Run Glass Products with Target Compositions

| Component | Target AP-105-7M | Measured Average Simulant AP-105-7M | % Diff. Target to Average Simulant AP-105-7M | Measured Final Simulant AP-105-7M | % Diff. Target to Final Simulant AP-105-7M | Measured Average Waste AP-105-7M | % Diff. Target to Average Waste AP-105-7M | Measured Final Waste AP-105-7M | % Diff. Target to Final Waste AP-105-7M |
|---|---|---|---|---|---|---|---|---|---|
| | wt% | wt% | % | wt% | % | wt% | % | wt% | % |
| $Al_2O_3$ | 6.13 | 6.09 | -0.6 | 6.11 | -0.3 | 5.99 | -2.2 | 6.02 | -1.7 |
| $B_2O_3$ | 9.95 | 10.16 | 2.1 | 10.05 | 1.0 | 10.35 | 4.0 | 10.36 | 4.1 |
| CaO | 2.07 | 2.03 | -2.3 | 2.02 | -2.4 | 2.08 | 0.3 | 2.10 | 1.1 |
| Cl | 0.24 | 0.38 | -- | 0.43 | -- | 0.31 | -- | 0.28 | -- |
| $Cr_2O_3$ | 0.06 | 0.13 | -- | 0.11 | -- | 0.16 | -- | 0.14 | -- |
| $Fe_2O_3$ | 5.52 | 5.44 | -1.6 | 5.45 | -1.4 | 5.66 | 2.4 | 5.63 | 1.9 |
| $K_2O$ | 0.51 | 0.48 | -- | 0.48 | -- | 0.49 | -- | 0.50 | -- |
| MgO | 1.49 | 1.39 | -6.9 | 1.39 | -6.3 | 1.43 | -3.7 | 1.43 | -3.6 |
| $Na_2O$ | 20.95 | 21.21 | 1.2 | 21.28 | 1.6 | 19.87 | -5.1 | 19.92 | -4.9 |
| NiO | 0.01 | 0.05 | -- | 0.04 | -- | 0.02 | -- | 0.03 | -- |
| $P_2O_5$ | 0.10 | 0.11 | -- | 0.13 | -- | 0.04 | -- | 0.03 | -- |
| $SO_3$ | 0.29 | 0.37 | -- | 0.37 | -- | 0.27 | -- | 0.25 | -- |
| $SiO_2$ | 44.73 | 45.33 | 1.3 | 45.31 | 1.3 | 45.48 | 1.7 | 45.46 | 1.6 |
| $TiO_2$ | 1.40 | 1.37 | -2.7 | 1.37 | -2.8 | 1.41 | 0.2 | 1.41 | 0.5 |
| ZnO | 3.51 | 3.41 | -2.8 | 3.50 | -0.4 | 3.52 | 0.2 | 3.54 | 0.8 |
| $ZrO_2$ | 3.02 | 2.04 | -32.5 | 1.94 | -35.7 | 2.90 | -4.0 | 2.90 | -3.9 |
| Total | 100.0 | 100.0 | | 100.0 | | 100.0 | | 100.0 | |

The target of CaO in the AP-105 (2.64 wt%) and AN-105 glass composition (2.46 wt%) differed from that in AP-105-7M (2.07 wt%). As a result, the CaO composition moved from ~2.7 wt% in the initial glass poured during the 7 M Na AP-105 simulant CLSM run to the desired AP-105-7M target by one turnover (2.0 kg of glass poured) of the CLSM vessel inventory. Likewise, the target of $SO_3$ was greater in the AP-105 and AN-105 glasses than the AP-105-7M, but the analyzed composition in the glass produced during the 7 M Na AP-105 simulant run reached the desired target by one turnover of the CLSM vessel inventory. While the target of MgO in AP-105 and AN-105 glass were virtually identical to that in the AP-105-7M glass, it was discovered in the analysis of the AN-105 glass (Dixon et al. 2020a) that the actual amount of MgO in the glass was less than the desired target because the chemical used to batch was less pure than the chemical source used to calculate the melter feed composition. Nevertheless, the MgO composition moved from ~1.1 wt% in the initial glass poured during the 7 M Na AP-105 simulant CLSM run to the desired AP-105-7M target by two turnover of the CLSM vessel inventory.

One component, $ZrO_2$, differed by greater than ±10 % from its target glass composition in all the measured glass pours in the 7 M Na AP-105 simulant CLSM run, shown in Figure 5.1. It was discovered that an insufficient amount of the GFC zircon flour ($ZrSiO_4$) was added into the melter feed during batching, resulting in the $ZrO_2$ in the resultant glass being approximately 35 % less than its AP-105-7M glass target. In addition, based on the analysis of the 7 M Na AP-105 simulant melter feed, the expected amounts of $SiO_2$ and $ZrO_2$ in the glass were below their desired AP-105-7M target values, while all other major components (>1.00 wt%) were greater than their targets, as shown in the red lines in Figure 5.1 and Figure 5.2. While one reason for the differences between feed expectation and actual amount in the glass pours is the deficiency of zircon batched into the melter feed, this does not account for why the actual amounts of every component except for $ZrO_2$ in the glass pours were in the ranges expected based on the AP-105-7M glass targets. Thus, it is understood that the sample of melter feed used for analysis was not fully representative of the 7 M Na AP-105 simulant melter feed, but was lacking an amount of silica, a

heavy component that may settle if the melter feed is not fully agitated while transferring during sample preparation or analysis. The deficiency of silica in the analyzed melter feed sample, and the under-batching of zircon, will affect the amounts of components recovered during the 7 M Na AP-105 simulant run, calculated in Section 5.2.

The trends for $Cr_2O_3$ and NiO in Figure 5.2 revealed a spike in their content above the glass target and melter feed levels at the start of each run, followed by a decrease with each subsequent glass pour. These trends indicated that when the glass inventory was idling in the CLSM vessel, during heat-up of the system or idling periods as previously observed (Dixon et al. 2020a and 2020b), Cr and Ni from the walls of the CLSM vessel were incorporated into the glass melt due to corrosion of the vessel. The CLSM vessel is constructed from Inconel-690, an alloy with relatively high Ni (minimum of 58.0 %) and Cr (a range from 27.0 to 31.0 %), with the balance provided by several additional components (Fe range from 7.0 to 11.0 %, Si at 0.50 % maximum, Mn at 0.50 % maximum, S at 0.015 % maximum, and Cu at 0.50 % maximum). A similar phenomenon has been observed in the DM10 melter, which is lined with refractory with high Cr levels and heated by Inconel-690 electrodes, after idling periods (Matlack et al. 2010, 2011, and 2018).

Other minor glass components present in the target glass compositions ($K_2O$, $P_2O_5$, and Cl) varied by more than 10% from their glass target values in individual glass products due to reasons including, but not limited to, fluctuations in the melter feeds resulting in the actual target varying from the glass target, irregular volatility from the glass melt or in the cold cap, differences between the levels used in the waste simulant vs the actual amount in the waste, and analytical uncertainty due to the low concentrations compared to other glass composition components. The behavior of K and Cl (along with other semi-volatiles) in the CLSM offgas treatment system will be discussed further in Section 5.3.
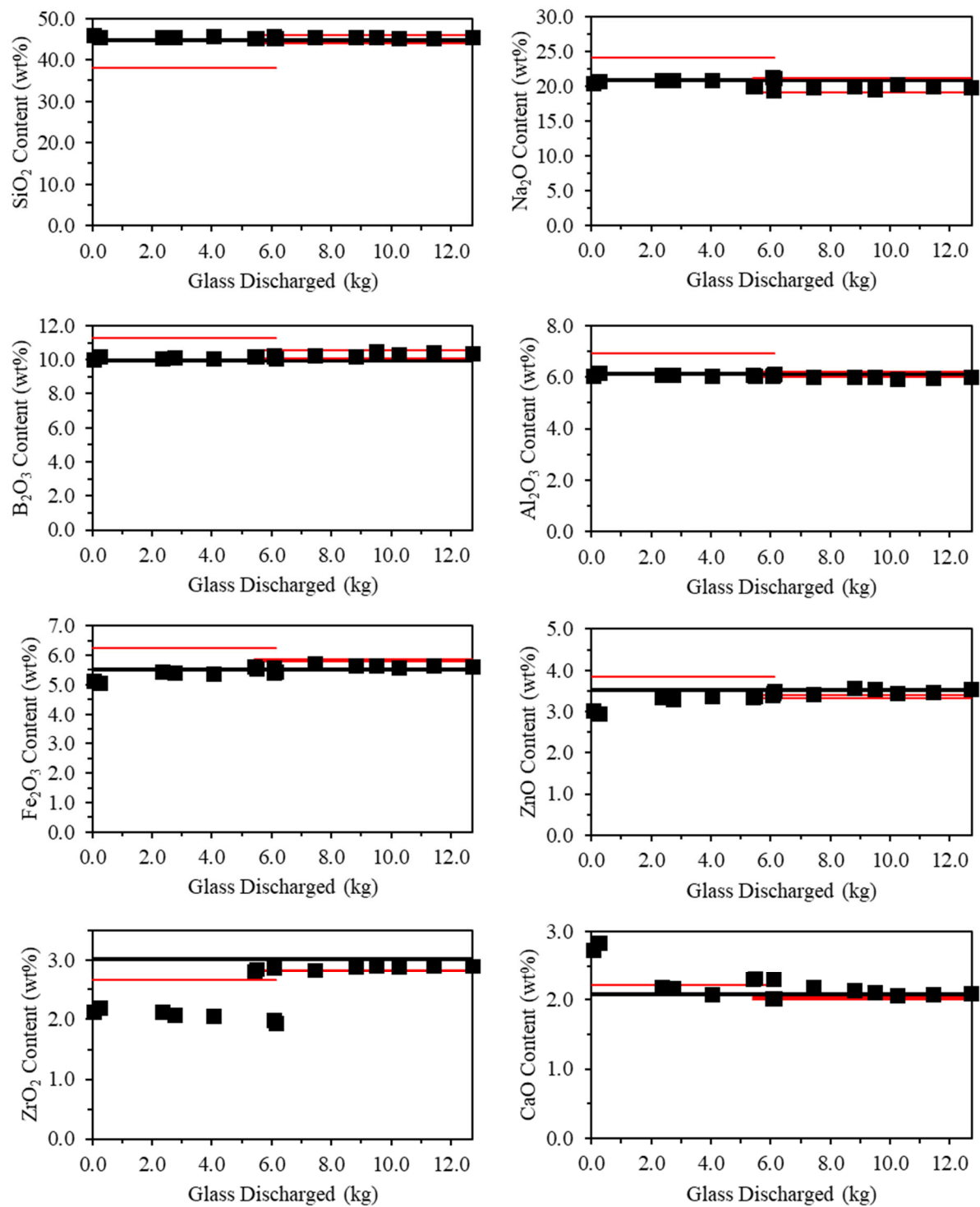
Figure 5.1. Content of a set of components ($SiO_2$, $Na_2O$, $B_2O_3$, $Al_2O_3$, $Fe_2O_3$, ZnO, $ZrO_2$, and CaO) in the glass produced during the CLSM runs with the 7 M Na AP-105 simulant and waste melter feeds. The values in the black squares were measured in the glass, the black lines were the targets in the glass, and the red lines were the expected values from analysis of the melter feeds (7 M Na AP-105 simulant from 0.00 – 6.13 kg and 7 M Na AP-105 waste from 5.41 – 12.71 kg).
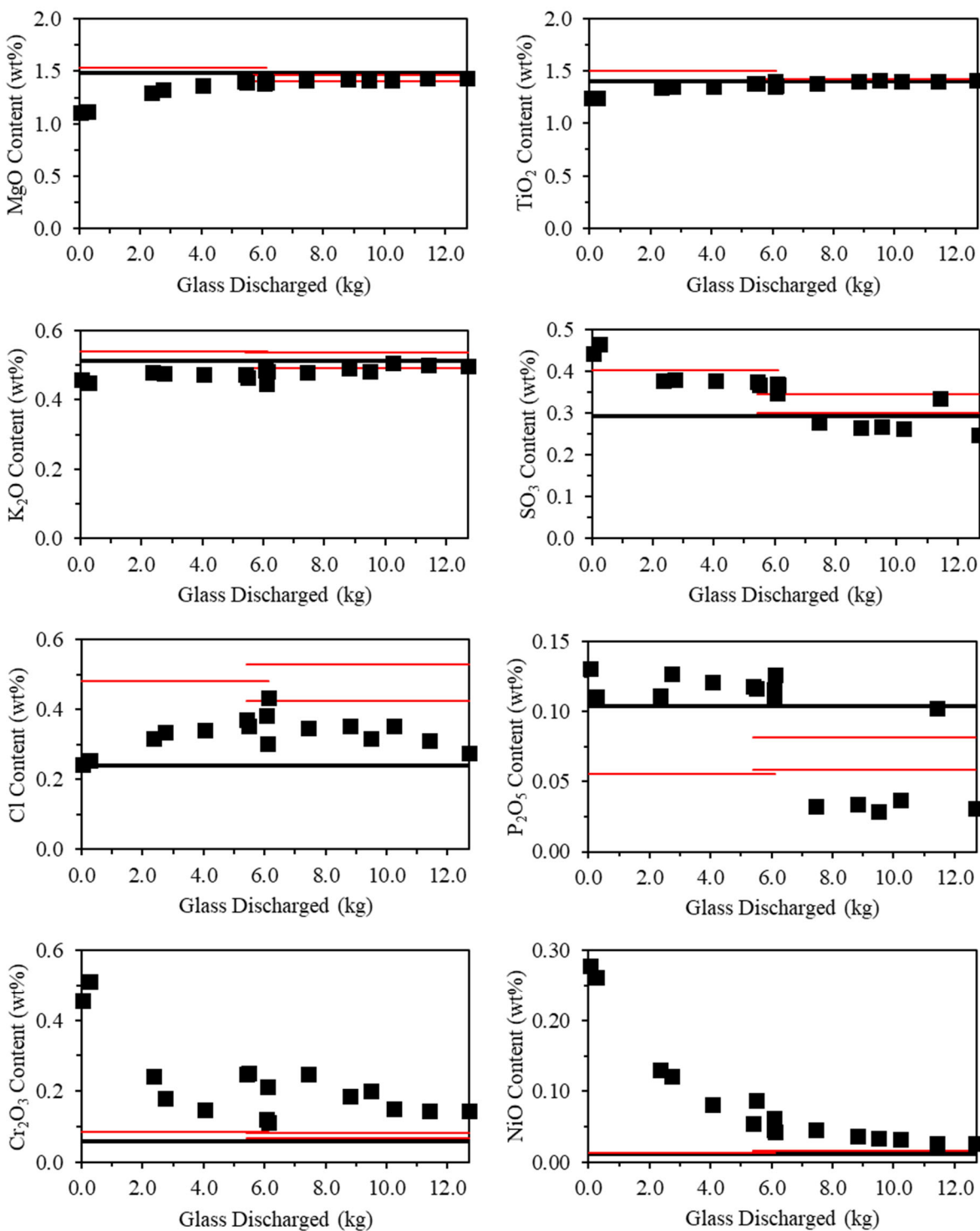
Figure 5.2. Content of a set of primary components (MgO, TiO₂, K₂O, SO₃, Cl, P₂O₅, Cr₂O₃, and NiO) in the glass produced during the CLSM run with the 7 M Na AP-105 simulant and waste melter feeds. The values in the black squares were measured in the glass, the black lines were the targets in the glass, and the red lines were the expected values from analysis of the melter feeds (7 M Na AP-105 simulant from 0.00 – 6.13 kg and 7 M Na AP-105 waste from 5.41 – 12.71 kg).

Several components were present as minor (2500 ppm or less) impurities in the melter feeds and glass product during the 7 M Na AP-105 simulant and waste CLSM runs. The compositional trends for each minor impurity are shown in Figure 5.3 and Figure 5.4 with respect to the amount of glass discharged. Each graph shows the measured component content in the glass as black squares (■) and the expected component content in the glass based on the analyzed melter feed samples (if above the analytical detection limit) as a red line (—). Squares that are red instead of black and red lines that are dashed instead of solid indicate that the measured values were below the analysis limit of detection, thus the value for the detection limit was used for the calculation.

The content of the impurity components in the 7 M Na AP-105 glass product followed two general trends. The first trend was a spike (or deficiency) of the component in the initial glass that decreased with each subsequent pour until the component reached its expected value based on the content in the 7 M Na AP-105 melter feeds. This trend applied to V, Sn, Li, Pb, La, Cu, Sr, and F shown in Figure 5.3 and Figure 5.4. Following this trend, all components had reached their expected values by 3 turnovers of the CLSM vessel contents (6 kg of glass discharged). Previously, impurity spikes reached their targets in 2 turnovers of the CLSM vessel (Dixon et al. 2020a and 2020b), indicating that the spikes were greater in the AP-105 and AN-105 glass pieces used to start the 7 M Na AP-105 simulant CLSM run.

The second impurity trend was a component level staying relatively constant in all glass pours. This trend applied to W, Mn, Mo, Y, Ba, Co, As, and Cd shown in Figure 5.3 and Figure 5.4. Within this trend, Y (~40 ppm) remained at a level greater than expected based on the 7 M Na AP-105 melter feeds, as has been previously analyzed in CLSM glass products (Dixon et al. 2020a, and 2020b). The source of Y at these levels in the glass products is likely leaching as an impurity from the material of the CLSM vessel, as described regarding the $Cr_2O_3$ and NiO content in the glass product.

The measured activity of each analyzed radionuclide in the glass products from the 7 M Na AP-105 waste CLSM run, with respect to the mass of glass discharged, is shown in Figure 5.5. There were no radionuclides present in the 7 M Na AP-105 simulant feed, so only the portion of glass discharged during the 7 M Na AP-105 waste CLSM run, from 5.41 to 12.71 kg discharged are displayed in Figure 5.5. Each graph shows the measured component content in the glass as black squares (■) and the expected component content in the glass based on the analyzed melter feed samples (if above the analytical detection limit) as a red line (—). Squares that are red instead of black and red lines that are dashed instead of solid indicate that the measured values were below the analysis limit of detection, thus the value for the detection limit was used for the calculation. The trend of the radionuclides in the glass product began around 0 in the initial glass and increased until they reached the expected values in the melter feed, which were reached by two turnovers of the CLSM glass contents.
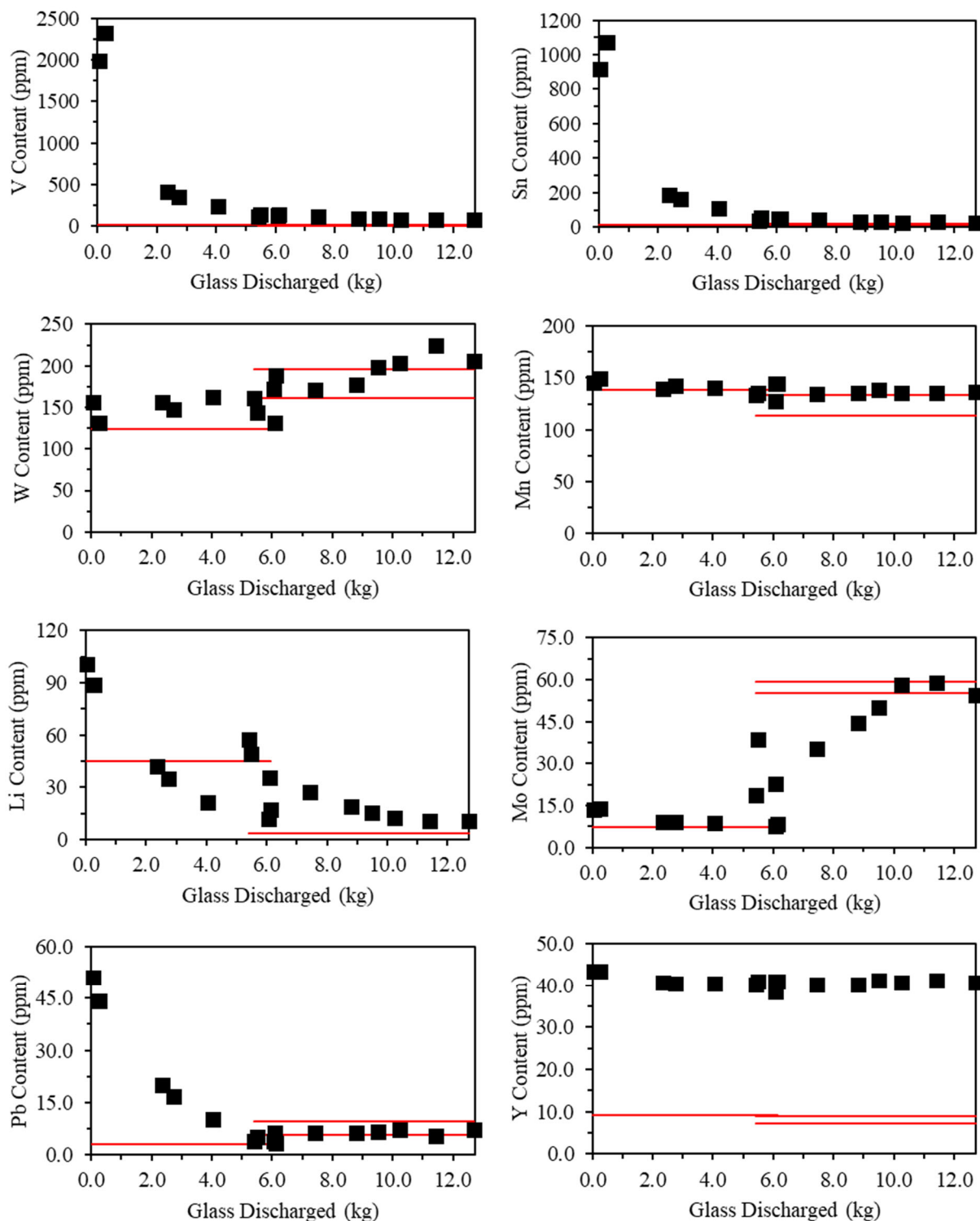
Figure 5.3. Content of a set of minor glass impurities (V, Sn, W, Mn, Li, Mo, Pb, and Y) in the glass produced during the CLSM run with the 7 M Na AP-105 simulant and waste melter feeds. The values in the black squares were measured in the glass and the red lines were the expected values from analysis of the melter feeds (7 M Na AP-105 simulant from 0.00 – 6.13 kg and 7 M Na AP-105 waste from 5.41 – 12.71 kg).
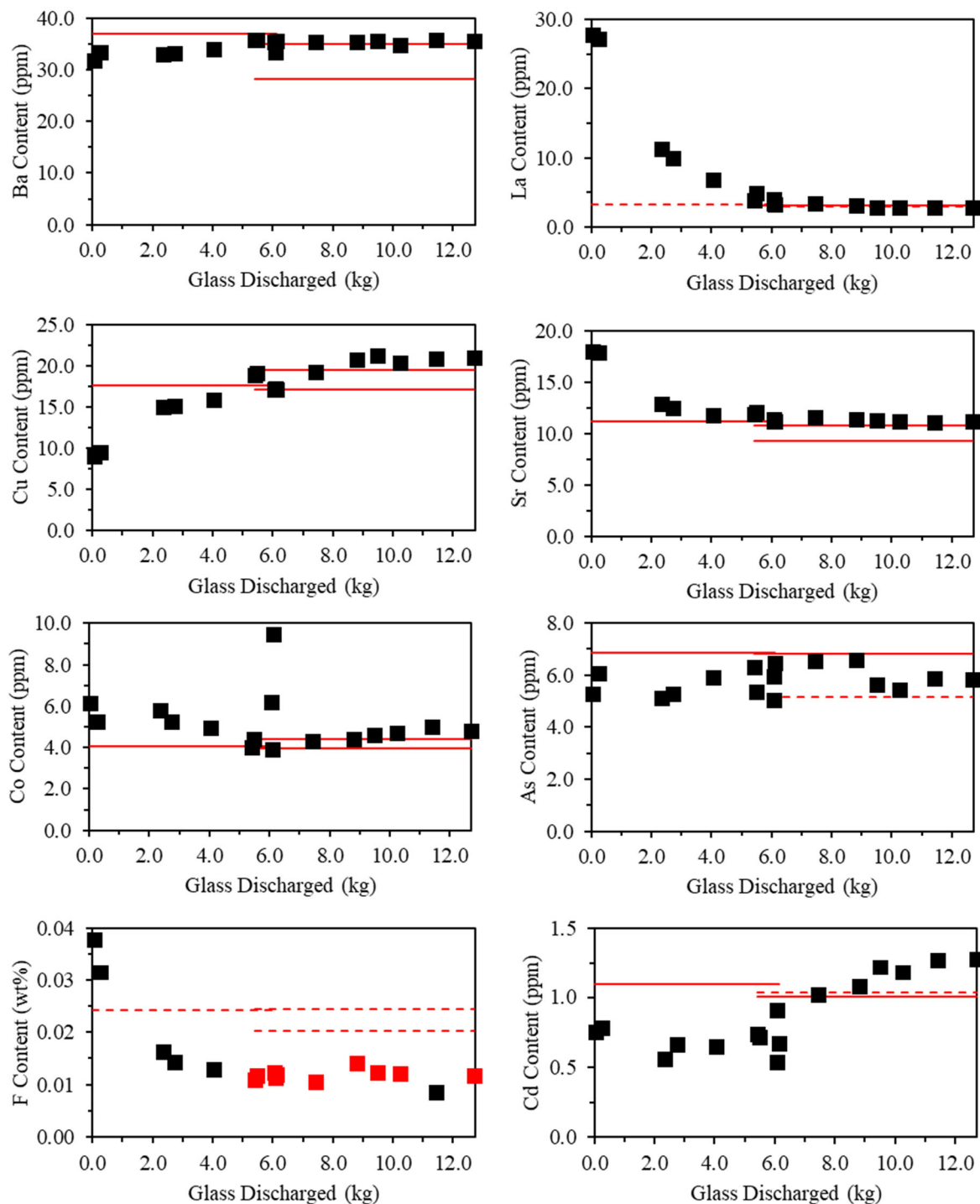
Figure 5.4. Content of a set of minor glass impurities (Ba, La, Cu, Sr, Co, As, F, and Cd) in the glass produced during the CLSM run with the 7 M Na AP-105 simulant and waste melter feeds. The values in the black squares were measured in the glass and the red lines were the expected values from analysis of the melter feeds (7 M Na AP-105 simulant from 0.00 – 6.13 kg and 7 M Na AP-105 waste from 5.41 – 12.71 kg). Squares that are red instead of black and red lines that are dashed instead of solid indicate that the measured values were below the analysis limit of detection, thus the value for the detection limit was used.
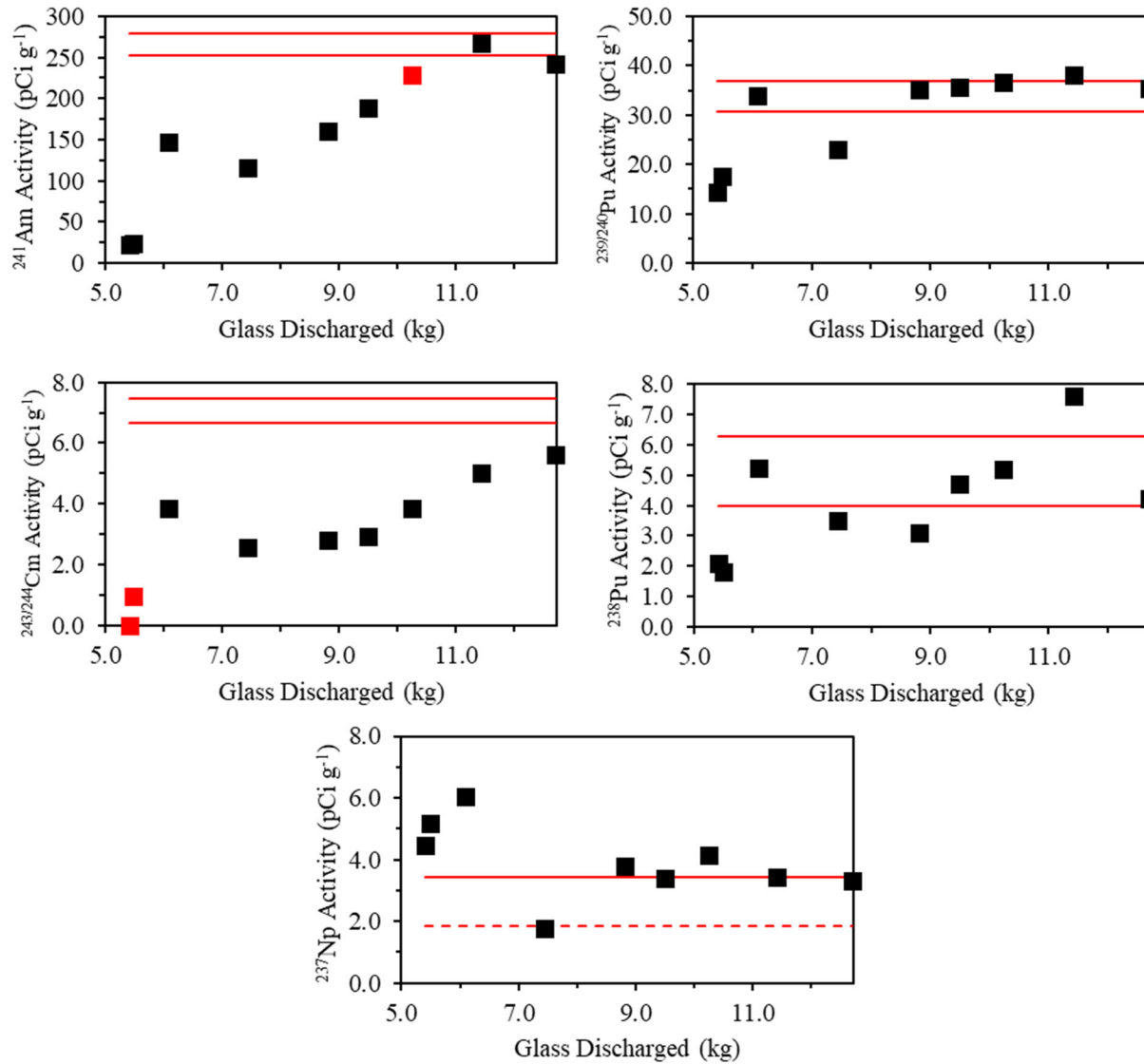
Figure 5.5. Activity of radionuclides ($^{241}$Am, $^{239/240}$Pu, $^{243/244}$Cm, $^{238}$Pu, and $^{237}$Np) in the glass produced during the CLSM run with the 7 M Na AP-105 waste melter feed. The values in the black squares were measured in the glass and the red lines were the expected values from analysis of the 7 M Na AP-105 waste melter feeds (from 5.41 – 12.71 kg). Squares that are red instead of black and red lines that are dashed instead of solid indicate that the measured values were below the analysis limit of detection, thus the value for the detection limit was used.

## 5.2   DF, R, and Rec Calculations

The decontamination factor (DF) of any component through any unit in a melter system is described as the mass flow rate of the component into the unit divided by the mass flow rate of the component out of the unit in the secondary product stream. In the CLSM system, there is one incoming mass flow stream, the melter feed, and there are two output mass flow streams, the glass (primary product stream) produced from the CLSM and the offgas (secondary product stream) exiting the CLSM. The CLSM offgas is comprised of gaseous mass exiting the system, vapor which is condensed by the offgas system as condensate, and solids that settle or are filtered. Thus, the DF of any component through the CLSM vessel

is defined as the mass flow rate of that component in the melter feed divided by the mass flow rate of that component in the offgas stream. Given a state of no component accumulation in the CLSM vessel, the DF for a component in the CLSM vessel can be given by Eq. (5.1):

$$\text{DF}_i = \frac{\dot{m}_{i,feed}}{\dot{m}_{i,offgas}} \tag{5.1}$$

where $\dot{m}_{i,feed}$ is the mass flow rate [mg min$^{-1}$] of a component ($i$) in the melter feed and $\dot{m}_{i,offgas}$ is the mass flow rate [mg min$^{-1}$] of the same component in the offgas as recovered by the units in the CLSM offgas system in the glass product.

The retention ($R$) of any component in the glass produced from the CLSM vessel is then defined as the mass flow rate of that component in the glass product divided by the mass flow rate of the same component in the melter feed and this value can be determined by Eq. (5.2):

$$R_i = \frac{\dot{m}_{i,glass}}{\dot{m}_{i,feed}} \tag{5.2}$$

where $\dot{m}_{i,glass}$ is the mass flow rate [mg min$^{-1}$] of a component ($i$) in the glass product, The $R_i$ value can be reported as a fraction or percentage (if Eq. (5.2) is multiplied by 100).

Finally, the recovery (Rec) of any component in the CLSM system is defined as the mass flow rate of the component out of the system in the summation of the glass and offgas divided by the mass flow rate of the same component into the system via the melter feed. The Rec$_i$ value can be reported as a fraction or percentage (if multiplied by 100) and is defined in Eq. (5.3):

$$\text{Rec}_i = \frac{\dot{m}_{i,glass} + \dot{m}_{i,offgas}}{\dot{m}_{i,feed}} \tag{5.3}$$

For Eq. (5.1), Eq. (5.2), and Eq. (5.3), if the values are calculated for a fixed amount of time (e.g., the offgas sampling times or the total runtime) mass flow rates become total mass values ($m_i$; [mg]).

The components of primary interest in the CLSM glass product, in addition to the components in the target glass compositions, are $^{99}$Tc (or Re in the simulant), Cs, and I. Given the demonstrated volatility behavior of meta-stable technetium, $^{99m}$Tc, from an idling glass melt (Matlack et al. 2010; Pegg 2015) and the potential unsteady incorporation of components into the glass melt while the cold cap varies from its target coverage and thickness, the $R_{99Tc}$, $R_{Re}$, and $R_I$ values were calculated during the total runtime, each individual glass pour, and during the offgas sampling timeframes (for $^{99}$Tc and Re only) when the cold-cap characteristics were believed to be steady.

The values for DF, $R$, and $Rec$ were calculated separately for the CLSM runs processing the 7 M Na AP-105 simulant melter feed and 7 M Na AP-105 waste melter feed. For each component of the AP-105-7M glass compositions captured in the CLSM glass product (Table 5.1), and the additional desired nuclides $^{99}$Tc, Re, Cs, and I where applicable, the following mass flow rates were calculated:

- Input into the CLSM vessel from the melter feed; $\dot{m}_{i,feed}$. Calculated during each run by dividing the total mass of each component (given the melter feed component concentrations listed in Table A.1 and Table A.2 and the total mass of each melter feed composition calculated to have been consumed during the run, shown in Table 4.2) by the total runtime of 7.50 h for the 7 M Na AP-105 simulant run and 6.71 for the 7 M Na AP-105 waste run.

Discussion <span style="float:right">5.10</span>

- Output from the CLSM vessel in the glass product; $\dot{m}_{i,glass}$. Calculated from the glass component concentrations and the total glass mass produced in the 7 M Na AP-105 simulant run of 6.13 kg and in the 7 M Na AP-105 waste run of 6.58 kg, with the amount of each component present in the initial glass subtracted from the total mass.

- Output from the CLSM vessel in the captured offgas; $\dot{m}_{i,offgas}$. Calculated from the summation from all the offgas units, primarily the collected condensate, demister liquid, primary SBS sump, and filters, with the amount of every component in the appropriate number of blank HEPA filters subtracted from the total mass. For the 7 M Na AP-105 simulant run, the condensate totaled 6.31 kg, demister liquid 0.17 kg, and primary SBS sump 1.20 kg and for the 7 M Na AP-105 waste run, the condensate totaled 3.27 kg, demister liquid 2.68 kg, and primary SBS sump 0.88 kg.

The mass flow rate data for the entire runtime of the 7 M Na AP-105 simulant CLSM run are given in Table 5.2 and the mass flow rate data for the entire runtime of the 7 M Na AP-105 waste CLSM run are given in Table 5.3. Note that the chemical analysis results for Cs in both the 7 M Na AP-105 simulant and waste melter feeds, and the results for I in the 7 M Na AP-105 waste melter feeds and most glass pour samples, were below the analytical limit of detection, thus the values for the detection limits, given in Table A.2 of Appendix A, were used for calculations where necessary and all related results should be treated as best estimates. From these mass flow rates, the $DF_i$, $R_i$, and $Rec_i$ values, the latter two reported as percentages, were calculated as shown in Equations (5.1), (5.2), and (5.3), respectively. The values were calculated for the entire runtime of both the 7 M Na AP-105 simulant and waste CLSM runs and are reported in Table 5.2 and Table 5.3, respectively.

For the 7 M Na AP-105 simulant and waste runs, most all component recoveries were within ±10 % of complete recovery. The $Rec_i$ values for Cs, Cr, and Ni were greater than 110 % most likely due to spikes of those components being present in the initial glass loaded into the CLSM vessel, as demonstrated in Figure 5.2 for $Cr_2O_3$ and NiO. The $Rec_i$ values for P were outside of the 90 – 110 % range most likely due to analytical uncertainty being near (or below) the detection limits in the glass and offgas samples. In the 7 M Na AP-105 simulant run, the $Rec_i$ value for I was greater than 110 % most likely due to the washing of the sim-CLSM offgas system clearing out accumulated I from previous runs and, as discussed in Section 5.1, the $Rec_i$ values for Si and Zr were outside of the 90 – 110 % range most likely due to the batching deficiency of zircon and analysis sample's lack of silica. In the 7 M Na AP-105 waste run, two components, F and Li, had $Rec_i$ values greater than 100 % most likely due to spikes of those components being present in the initial glass loaded into the CLSM vessel, as demonstrated in Figure 5.3 for Li and Figure 5.4 for F.

Table 5.2. Component Mass Flow Rates, DFs, Retentions, and
Recoveries During the7 M Na AP-105 Simulant CLSM Run

| Component | $\dot{m}_{i,feed}$ | $\dot{m}_{i,glass}$ | $\dot{m}_{i,offgas}$ | Melter DF | $R$ | Rec |
|---|---|---|---|---|---|---|
| Units | mg min$^{-1}$ | mg min$^{-1}$ | mg min$^{-1}$ | | % | % |
| Re | 0.12 | 0.04 | 0.05 | 2.5 | 36 | 76 |
| Total Cs | 0.00[a] | 0.00 | 0.00 | --[b] | --[b] | --[b] |
| Total I | 1.34 | 0.18 | 1.52 | 0.9 | 14 | 128 |
| Al | 476 | 432 | 1 | 842 | 91 | 91 |
| B | 454 | 423 | 3 | 158 | 93 | 94 |
| Ca | 204 | 194 | 0 | 919 | 95 | 95 |
| Cl | 62 | 51 | 6 | 10 | 81 | 92 |
| Cr | 8 | 12 | 0 | 33 | 159 | 162 |
| F | 3[a] | 1 | 0 | 6 | 40 | 56 |
| Fe | 565 | 510 | 1 | 584 | 90 | 90 |
| K | 58 | 54 | 1 | 64 | 92 | 94 |
| Li | 1 | 0 | 0 | 184 | 28 | 28 |
| Mg | 120 | 112 | 0 | 14683 | 94 | 94 |
| Na | 2329 | 2110 | 17 | 139 | 91 | 91 |
| Ni | 1 | 6 | 0 | 41 | 405 | 407 |
| P | 3 | 7 | 1 | 3 | 213 | 249 |
| S | 21 | 20 | 1 | 28 | 95 | 99 |
| Si | 2306 | 2841 | 1 | 3374 | 123 | 123 |
| Ti | 117 | 110 | 0 | 4478 | 94 | 94 |
| Zn | 399 | 368 | 1 | 472 | 92 | 92 |
| Zr | 256 | 202 | 0 | 8350 | 79 | 79 |
| Total | 7385 | 7453 | 35 | 213[c] | 101[c] | 101[c] |

[a] Component concentrations were below analytical reporting limits for a majority of samples in the given stream and values should be considered best estimates.

[b] Values were not calculated because the melter feed sample was below the analytical reporting limit.

[c] Values were calculated using the mass flow rate totals from previous columns.

Table 5.3. Component Mass Flow Rates, DFs, Retentions, and
Recoveries During the 7 M Na AP-105 Waste CLSM Run

| Component | $\dot{m}_{i,feed}$ | $\dot{m}_{i,glass}$ | $\dot{m}_{i,offgas}$ | Melter DF | $R$ | Rec |
|---|---|---|---|---|---|---|
| Units | mg min$^{-1}$ | mg min$^{-1}$ | mg min$^{-1}$ | | % | % |
| $^{99}$Tc | 0.12 | 0.06 | 0.04 | 3.1 | 51 | 84[e] |
| Total Cs | 0.00[a] | 0.00 | 0.00 | 0.8 | 109[c] | 238[c,e] |
| Total I | --[b] | 0.02[a] | 0.06 | -- | -- | -- |
| Al | 508 | 509 | 0 | 4057 | 100 | 100 |
| B | 513 | 516 | 2 | 259 | 101 | 101 |
| Ca | 230 | 239 | 0 | 3467 | 104 | 104 |
| Cl | 71 | 50 | 14 | 5 | 70 | 90[e] |
| Cr | 8 | 18 | 0 | 31 | 227 | 230 |
| F | 3[a] | 2[a] | 0 | 9[c] | 53[c] | 649[c,e] |
| Fe | 647 | 636 | 0 | 1490 | 98 | 98 |
| K | 66 | 66 | 1 | 66 | 100 | 102[e] |
| Li | 0 | 0 | 0 | 48 | 230 | 232 |
| Mg | 139 | 139 | 0 | 36714 | 100 | 100 |
| Na | 2301 | 2368 | 13 | 184 | 103 | 103 |
| Ni | 2 | 3 | 0 | 67 | 155 | 156 |
| P | 5 | 3 | 0 | 445 | 55 | 56 |
| S | 20 | 17 | 1 | 23 | 87 | 92[e] |
| Si | 3376 | 3416 | 0 | 18137 | 101 | 101 |
| Ti | 135 | 135 | 0 | 24063 | 100 | 100 |
| Zn | 427 | 454 | 0 | 1691 | 106 | 107 |
| Zr | 332 | 344 | 0 | -- | 104 | 104 |
| Total | 8782 | 8915 | 28 | 310[d] | 102[d] | 102[d] |

[a] Component concentrations were below analytical reporting limits for the given stream and values should be considered best estimates.

[b] The component was not analyzed in the melter feed.

[c] Values were calculated using best estimates for mass flow rates and should therefore be considered best estimates.

[d] Values were calculated using the mass flow rate totals from previous columns.

[e] Values include an adjusted amount of the component expected from an offgas piping wash as described in Section 5.3.

## 5.3 Offgas Analysis

The seven components detected in appreciable quantities in the samples collected from the various units in the CLSM offgas treatment system during prior runs (Dixon et al. 2020b, 2022a, and 2023) were $^{99}$Tc (or Re), Cs, I, S, K, Cl, and F. These components were likewise present in the samples collected from the offgas treatment system during the 7 M Na AP-105 simulant and waste CLSM runs. The total quantities of these components collected in the CLSM vessel output streams, the glass, and 4 collective units in the offgas treatment system (the sampling loop, primary SBS sump, accumulated condensate, and end filters) are shown in Table 5.4. The "Condensate" unit contains the summation of both the accumulated condensate liquid and the demister liquid from the entirety of each run. The "End Filters" unit described in Table 5.4 includes the liquids that accumulated in the pre-filter housing, as well as the pre-filter and primary HEPA filter, all totaled together.

Table 5.4. Quantities of Selected Components in CLSM Output Streams During the
7 M Na AP-105 Simulant and Waste CLSM Runs

| | Re (mg) | Cs (mg) | I (mg) | Cl (mg) | F (mg) | K (mg) | S (mg) |
|---|---|---|---|---|---|---|---|
| 7 M Na AP-105 Simulant CLSM Run | | | | | | | |
| Glass | 18.7 | 1.54 | 83.1 | 22805 | 568 | 24083 | 8953 |
| Wash + Sampling | 3.95 | 0.0938 | 0.473 | 1185 | 46.9 | 56.8 | 100 |
| SBS Sump | 3.25 | 0.0794 | 167 | 1125 | 19.9 | 67.0 | 42.9 |
| Condensate | 10.9 | 0.602 | 491 | 479 | 145 | 239 | 169 |
| End Filters | 2.87 | 0.149 | 26.7 | 118 | 6.28 | 43.7 | 28.9 |

| | $^{99}$Tc (mg) | Cs (mg) | I (mg) | Cl (mg) | F (mg) | K (mg) | S (mg) |
|---|---|---|---|---|---|---|---|
| 7 M Na AP-105 Waste CLSM Run | | | | | | | |
| Glass | 24.9 | 0.729 | 6.14[b] | 20026 | 713[b] | 26530 | 6928 |
| Wash + Sampling[a] | 3.01 (1.80) | 0.0877 (0.0280) | 0.0552 (0.0552) | 2378 (726) | 33.9 (2.48) | 56.3 (34.3) | 100 (28.7) |
| SBS Sump | 1.20 | 0.0654 | 1.08 | 409 | 9.9 | 29.3 | 18.6 |
| Condensate | 6.73 | 0.427 | 18.9 | 2804 | 107 | 181 | 152 |
| End Filters | 4.99 | 0.280 | 5.44 | 238 | 7.24 | 136 | 70.6 |

[a] Values outside of parentheses were calculated to consider the amount of each component expected to be present during an offgas piping wash; the values inside of parentheses were calculated only from the sampling HEPA filters.

[b] I and F concentrations in glass samples were below analytical reporting limits; the value should be considered a best estimate.

The measured sampling loop values for the 7 M Na AP-105 waste CLSM run are given in parentheses in the 'Wash + Sampling' row of Table 5.4. From previous offgas analysis in the simulant CLSM system (Dixon et al. 2020a and 2022b), when the offgas piping from the CLSM vessel to the sampling loop was washed upon the conclusion of each CLSM run, an amount of the inventory of each component (Re, S, K, Cl, and F) recovered in the offgas system was found in the offgas piping wash. Since the radioactive CLSM system in RPL cannot be disassembled and washed for analysis due to safety restrictions, the same recovery principle was applied as an assumption for all the components recovered in the offgas system during the 7 M Na AP-105 waste CLSM run. Thus, the estimated quantities of each component, factoring to the percentage recovered in the sim-CLSM offgas piping wash, are shown without parentheses in the 'Wash + Sampling' row of Table 5.4 for the 7 M Na AP-105 waste CLSM run.

The quantities of each component in the output streams from Table 5.4 were converted to percentages of the total quantities in the output streams via Eq. (5.4):

$$Output\%_{i,s} = \frac{m_{i,s}}{\sum_s m_{i,s}} \times 100 \qquad (5.4)$$

where $Output\%_{i,s}$ is the percentage (%) of the quantity of a component ($i$; $^{99}$Tc, Re, Cs, I, Cl, F, K, S) in each output stream ($s$; Glass, Wash + Sampling, SBS Sump, Condensate, End Filters) and $m_{i,s}$ is the mass of a component ($i$) in stream ($s$). The $Output\%_{i,s}$ for each of the streams in the offgas treatment system during the 7 M Na AP-105 simulant CLSM run is displayed in Figure 5.6a and during the 7 M Na AP-105 waste CLSM run is displayed in Figure 5.6b. The $Output\%_{I,Condensate}$ value in the 7 M Na AP-105 simulant CLSM run is 63.9 % and in the 7 M Na AP-105 waste CLSM run is 59.8 %.
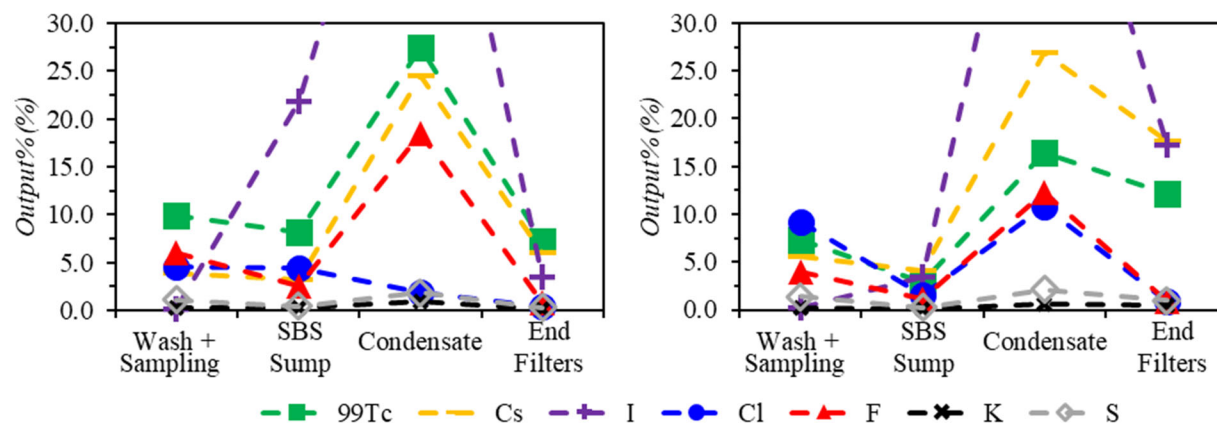
Figure 5.6. Percentage of the quantity of each component in the output stream (*Output%*) in the CLSM offgas treatment system during a) the 7 M Na AP-105 simulant run and, b) the 7 M Na AP-105 waste run.

The recovery of I in the various offgas units differed from the general behavior of the other semi-volatiles shown in Figure 5.6. Over 90 % of the I recovered in the offgas system under the conditions for both the 7 M Na AP-105 simulant and waste CLSM runs was located in the liquid samples (SBS sump, condensate, demister, and pre-filter fluid), with less than 10 % collected on the HEPA and pre-filter media. This indicates that a significant portion of the iodine could be recycled back to the feed along with other semi-volatile components.

## 5.4   $^{99}$Tc and Re Retention and Analysis

The measured content of $^{99}$Tc or Re in the glass product from the 7 M Na AP-105 simulant and waste runs marked as black squares (■), with respect to the mass of glass discharged, and their expected component content in the glass based on the analyzed melter feed samples if 100% retained are marked by the red inset line (—) in Figure 5.7. The $^{99}$Tc or Re retention values, $R_{99Tc}$ and $R_{Re}$, calculated for each glass pour are also displayed in Figure 5.7 with respect to the mass of glass discharged. The characteristic relationships between Re or $^{99}$Tc and Cs are shown in Table 5.5 for the 7 M Na AP-105 simulant CLSM run and in Table 5.6 for the 7 M Na AP-105 waste CLSM run. These tables include $R_{99Tc}$ (or $R_{Re}$) and $Rec_{99Tc}$ (or $Rec_{Re}$) values calculated exclusively during the sampling time periods, marked on Figure 4.1a for the 7 M Na AP-105 simulant CLSM run and on Figure 4.1b for the 7 M Na AP-105 waste CLSM run.
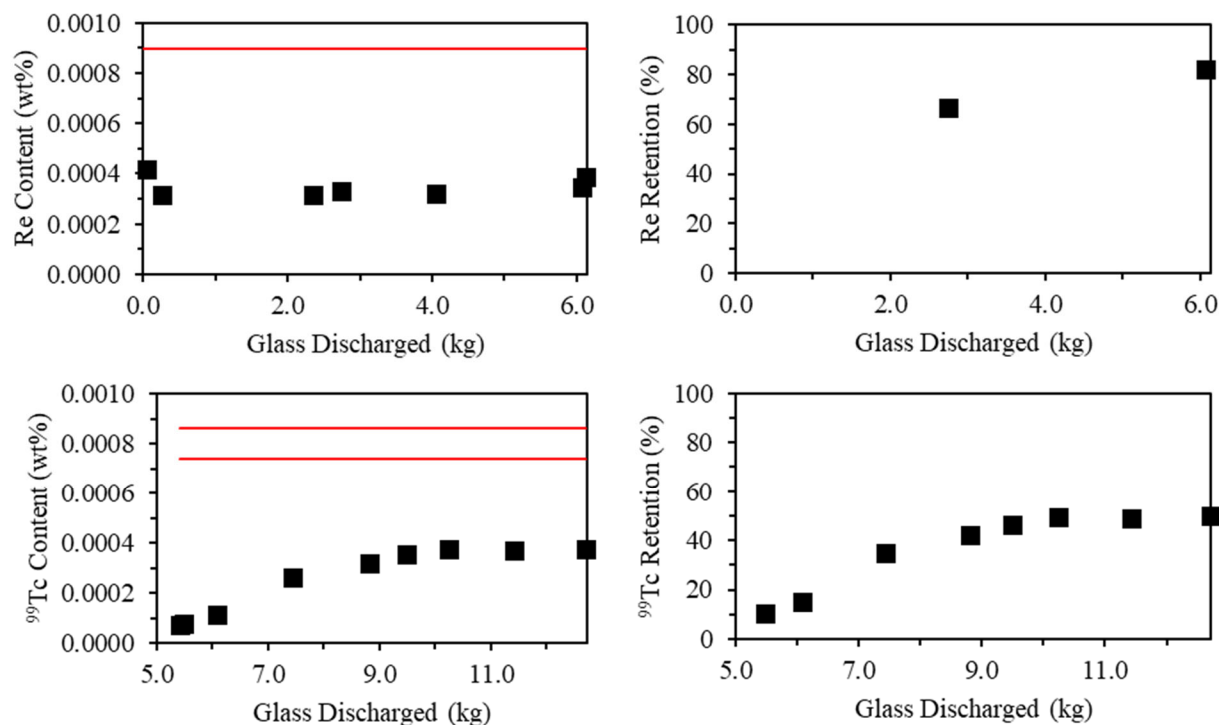
Figure 5.7. Measured Re content and retention in the glass product from the 7 M Na AP-105 simulant CLSM run (top; 0.00 – 6.13 kg discharged) and measured $^{99}$Tc content and retention in the glass product from the 7 M Na AP-105 waste CLSM run (bottom; 5.41 – 12.71 kg discharged).

Table 5.5. Re and Cs Relationships During the 7 M Na AP-105 Simulant CLSM Run

| Re Glass Target (ppm) | Cs Glass Target[a] (ppm) | Re/Cs Target Mass Ratio (mg mg$^{-1}$) | Glass Pour Time (h) | Glass Discharged (kg) | Re Glass Actual (ppm) | Cs Glass Actual (ppm) | Re Retention (%) | Re Sampling Retention (%) | Re Sampling Recovery (%) |
|---|---|---|---|---|---|---|---|---|---|
| 8.54 | 0.109 | 78.2 | Initial | 0.05 | 4.17 | 5.22 | 49 | | |
| 8.54 | 0.109 | 78.2 | 0.67 | 0.27 | 3.10 | 4.82 | 36 | | |
| 8.54 | 0.109 | 78.2 | 3.17 | 2.36 | 3.13 | 1.74 | 37 | | |
| 8.54 | 0.109 | 78.2 | 3.67 | 2.74 | 3.25 | 1.38 | 38 | 38 | 67 |
| 8.54 | 0.109 | 78.2 | 5.09 | 4.05 | 3.20 | 0.77 | 37 | | |
| 8.54 | 0.109 | 78.2 | 8.19 | 6.07 | 3.41 | 0.22 | 40 | 40 | 82 |
| 8.54 | 0.109 | 78.2 | Final | 6.13 | 3.79 | 0.42 | 44 | | |
| | | | | | | Total, $R_i$ | 36 | | |
| | | | | | | Total, $Rec_i$ | 76 | | |

[a] The Cs glass target was based on analysis of the melter feed, which was below the analysis limit of detection, thus the value for the detection limit is displayed.

Table 5.6. $^{99}$Tc and Cs Relationships During the 7 M Na AP-105 Waste CLSM Run

| $^{99}$Tc Glass Target (wt%) | Cs Glass Target[a] (wt%) | $^{99}$Tc/Cs Target Mass Ratio (mg mg$^{-1}$) | Glass Pour Time (h) | Glass Discharged (kg) | $^{99}$Tc Glass Actual (wt%) | Cs Glass Actual (wt%) | $^{99}$Tc Retention (%) | $^{99}$Tc Sampling Retention (%) | $^{99}$Tc Sampling Recovery (%) |
|---|---|---|---|---|---|---|---|---|---|
| 7.42 | 0.101 | 73.8 | Initial | 5.49 | 0.753 | 0.501 | 10 | | |
| 7.42 | 0.101 | 73.8 | 0.58 | 6.09 | 1.12 | 0.526 | 15 | | |
| 7.42 | 0.101 | 73.8 | 2.01 | 7.44 | 2.60 | 0.289 | 35 | | |
| 7.42 | 0.101 | 73.8 | 3.38 | 8.81 | 3.11 | 0.185 | 42 | 42 | 66 |
| 7.42 | 0.101 | 73.8 | 4.43 | 9.50 | 3.44 | 0.139 | 46 | | |
| 7.42 | 0.101 | 73.8 | 5.54 | 10.24 | 3.67 | 0.108 | 49 | 49 | 76 |
| 7.42 | 0.101 | 73.8 | 6.59 | 11.42 | 3.64 | 0.0857[b] | 49 | | |
| 7.42 | 0.101 | 73.8 | Final | 12.71 | 3.71 | 0.0901[b] | 50 | | |
| | | | | | | Total, $R_i$ | 51 | | |
| | | | | | | Total, $Rec_i$ | 84[c] | | |

[a] The Cs glass target was based on analysis of the melter feed, which was below the analysis limit of detection, thus the value for the detection limit is displayed.

[b] Cs concentrations in glass samples were below analytical reporting limits; the values should be considered a best estimate.

[c] Values reported include the estimate for mass recovered in offgas piping wash, described in Section 5.3.

The 2.0 kg of AP-105 and AN-105 glass pieces loaded into the CLSM vessel for the start of the 7 M Na AP-105 simulant run contained Re that had been retained during previous runs (Dixon et al. 2018 and 2020a), which account for the high $R_{Re}$ value during the initial glass pour. The retention of Re in the glass during the processing of the 7 M Na AP-105 simulant melter feed then reached a relative chemical steady state after two turnovers of the CLSM vessel glass inventory to arrive at a $R_{Re}$ value of 38 ± 1 %. Compared to the previous CLSM runs processing AP-105 simulant melter feed at 5.6 M Na (Dixon et al. 2018), the retention of Re when processing 7 M Na AP-105 was equivalent.

The glass loaded into the CLSM vessel for the start of the 7 M Na AP-105 waste run did not contain any $^{99}$Tc, yet the retention of $^{99}$Tc in the glass during the processing of the 7 M Na AP-105 waste melter feed reached a relative chemical steady state after two turnovers of the CLSM vessel glass inventory to arrive at a $R_{99Tc}$ value of 49 ± 2 %. This indicates that components of low quantity in the melter feed can reach their steady retention value after two turnovers regardless of if they are in excess, like the Re scenario, or deficient, like $^{99}$Tc, in the initial glass. Compared to previous CLSM runs processing AP-105 waste melter feed ($R_{99Tc}$ ranged from 24 to 45 % in different conditions; Dixon et al. 2018 and 2022a), the retention of $^{99}$Tc was greater while processing the 7 M Na AP-105 melter feed, indicating that a waste sample diluted by less water may be able to retain more low quantity components like $^{99}$Tc. As observed first when processing AP-101 simulant vs waste melter feed (Dixon et al. 2023), the 7 M Na AP-105 melter feed processed in the CLSM demonstrated $R_{99Tc} > R_{Re}$ when processing waste versus simulant.

## 5.5 Cs and I Retention and Analysis

The measured content of Cs and I in the glass product from the 7 M Na AP-105 simulant and waste runs is shown in Figure 5.8 with respect to the mass of glass discharged. Each graph shows the measured component content in the glass as black squares (■) and the expected component content in the glass based on the analyzed melter feed samples if 100 % retained, shown as the red inset line (—). Squares that are red instead of black and red lines that are dashed instead of solid indicate that the measured values were below the analysis limit of detection, thus the value for the detection limit was used for the calculations and should be considered best estimates.
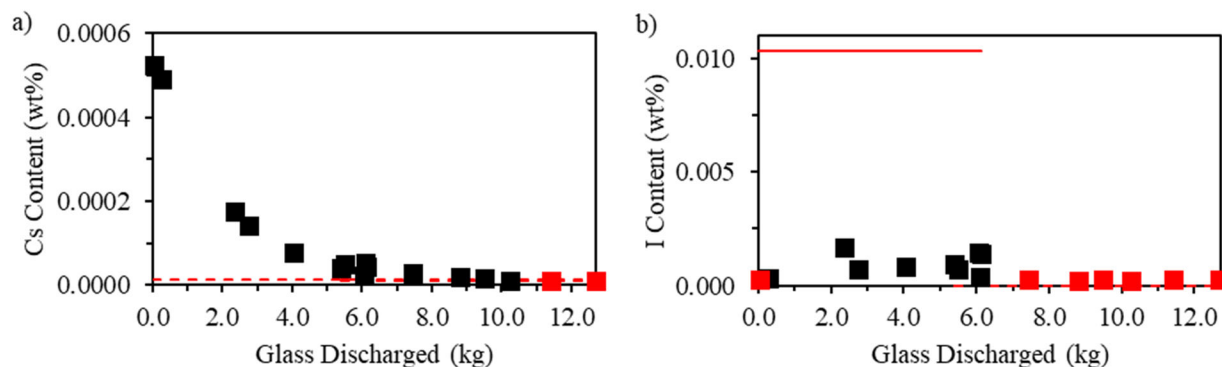
Figure 5.8. Measured a) Cs and b) I content in the glass produced during the CLSM run with the 7 M Na AP-105 simulant and waste melter feeds. The values in the black squares were measured in the glass and the red lines were the expected values from analysis of the melter feeds (7 M Na AP-105 simulant from 0.00 – 6.13 kg and 7 M Na AP-105 waste from 5.41 – 12.71 kg). Squares that are red instead of black and red lines that are dashed instead of solid indicate that the measured values were below the analysis limit of detection, thus the value for the detection limit was used.

The 2.0 kg of AP-105 and AN-105 glass pieces loaded into the CLSM vessel for the start of the 7 M Na AP-105 simulant run contained a spike of ~5 ppm of Cs that fell below 10 % of this initial spike value in the glass after three turnovers of the CLSM vessel glass inventory. Prior to the final pour at the end of the 7 M Na AP-105 waste CLSM run, the Cs content in the glass had fallen below analytical reporting limits.

During a majority of the previous CLSM runs, when samples had been analyzed for I content (Dixon et al. 2020b and 2022a), the I levels in the glasses and melter feeds were below the analysis detection limits, while the I levels in the liquid samples were above detection limits. In attempts to detect I at appreciable levels in the CLSM glass product, AP-101 simulant melter feed was spiked with KI which was detected at 23.4 ppm for a target I in the glass of 49 ppm if 100 % retained (Dixon et al. 2023). However, even with this spike, I was only detected above the analytical reporting limit in two glass pours, as described in (Dixon et al. 2023).

To further understand I volatility behavior, the 7 M Na AP-105 simulant melter feed was spiked with a greater amount of KI to a target of 98 ppm I in the glass if 100 % retained. At this level, I was detected above analytical limits in all analyzed glasses after the initial pour. The I retention values, $R_I$, calculated for each glass pour are shown in Table 5.7 for the 7 M Na AP-105 simulant CLSM run. The glass pours with the greatest amount of I retained were those immediately preceding or following a period of cold-cap burn off (pour times 3.17, 8.19, and Final), a behavior that had been observed previously in the AP-101 simulant CLSM run (Dixon et al. 2023). As such, defining a steady state, single-pass retention value for I in the 7 M Na AP-105 isn't clear from the data, though its volatility appears greater than anticipated based on the ~50 % retention factor used in the Kim et al. (2012) glass models and it is recommended that future testing spike to the same I target levels to determine if differences may exist in I retention for different melter feed compositions.

Table 5.7. I Retention During the 7 M Na AP-105 Simulant CLSM Run

| I Glass Target (ppm) | Glass Pour Time (h) | Glass Discharged (kg) | I Glass Actual (ppm) | I Retention (%) |
|---|---|---|---|---|
| 98.2 | Initial | 0.05 | 2.44[a] | 2 |
| 98.2 | 0.67 | 0.27 | 3.17 | 3 |
| 98.2 | 3.17 | 2.36 | 16.7 | 17 |
| 98.2 | 3.67 | 2.74 | 6.93 | 7 |
| 98.2 | 5.09 | 4.05 | 8.25 | 8 |
| 98.2 | 8.19 | 6.07 | 14.5 | 15 |
| 98.2 | Final | 6.13 | 13.9 | 14 |
| | | | Total, $R_i$ | 14 |
| | | | Total, $Rec_i$ | 128 |

[a] I concentration in glass sample was below analytical reporting limits; the value should be considered a best estimate.

## 5.6  Acetonitrile Analysis

The measured levels of acetonitrile in the condensate and demister liquids collected in the CLSM offgas system are listed for the 7 M Na AP-105 simulant and waste CLSM runs in Table A.1 and Table A.2 of Appendix A, respectively. As discussed in Dixon et al. (2023), the acetonitrile concentrations in the liquids collected in the CLSM offgas system are greater than the levels of acetonitrile in the liquids collected in other scaled melter systems (Matlack et al. 2011, 2017, and 2018).

Table 5.8 displays the amount of acetonitrile collected in each liquid, calculated from the acetonitrile concentration in the liquid, the liquid density, and the total mass of liquid collected. The 'Total Run Acetonitrile per Sucrose' column in Table 5.8 factored in CLSM system rule (determined in Dixon et al. 2023) that ~90 % of the total acetonitrile collected during the run was found in the combination of the condensate and demister liquids. For the 7 M Na AP-105 CLSM runs, the waste melter feed generated slightly less acetonitrile per sucrose than the simulant melter feed, likely because the waste melter feed had fewer nitrates/nitrites than expected for the amount of sucrose added (see Table 3.1). This acetonitrile result also adhered to the trend that a hotter average plenum temperature, as measured in the 7M Na waste CLSM run compared to the simulant (see Table 4.2), leads to less acetonitrile production (Matlack et al. 2017 and 2018).

Table 5.8. Acetonitrile in Liquids from the 7 M NA AP-105 Simulant and Waste CLSM Runs

| Liquid | | Acetonitrile Concentration (mg L$^{-1}$) | Total Acetonitrile (mg) | Acetonitrile per Sucrose (g kg$^{-1}$) | Total Run Acetonitrile per Sucrose (g kg$^{-1}$) |
|---|---|---|---|---|---|
| Condensate | Simulant | 270 | 1700 | 3.827 | 4.252 |
| Condensate | Waste | 270 | 881 | 1.848 | 3.752 |
| Demister | Waste | 310 | 728 | 1.529 | |

## 5.7  Production Comparison

Table 4.2 reported the production characteristics for both the 7 M Na AP-105 simulant and waste CLSM runs. Compared to previous processing of 5.6 M Na AP-105 simulant melter feed in the sim-CLSM (Dixon et al. 2018 and 2020a), the 7 M Na AP-105 simulant melter feed processed ~150 kg m$^{-2}$ d$^{-1}$ faster, with about a 30 °C hotter plenum temperature and a ~20 L min$^{-1}$ m$^{-2}$ higher bubbling flux rate. This result

indicates that a waste sample diluted by less water will be able to process faster. Observationally, the cold cap in both the 7 M Na AP-105 and AP-107 simulant CLSM runs behaved similarly.

The 7 M Na AP-105 waste melter feed processed ~350 kg m$^{-2}$ d$^{-1}$ faster than the 7 M Na AP-105 simulant melter feed with about a 50 °C hotter plenum temperature and a ~12 L min$^{-1}$ m$^{-2}$ lower bubbling flux rate. This is likely due to the 7 M Na AP-105 waste having lower concentrations for most every primary component (shown in Table 3.1) compared to the values used for the simulant.

The average glass production rate during the 7 M Na AP-105 waste CLSM run was much greater (500 – 700 kg m$^{-2}$ d$^{-1}$) than the rate achieved in the previous runs with lower Na molarity AP-105 waste melter feeds (Dixon et al. 2018 & 2022a). This gives a strong indication that the previous rad-CLSM runs were limited by a restriction in the pumping system and that the replacement pump with a larger capacity was able to optimize melter feed processing and cold-cap coverage.

# 6.0  Conclusions

A sample of AP-105 waste was procured by WRPS and given to PNNL for processing through the RWTP. A simulant version of the 7 M Na AP-105 waste was designed was designed based on analysis of the AP-105 tank waste sample as-received and an assumed target dilution of the waste from a sodium molarity of 9.17 M to the desired 7 M Na. A glass composition was calculated for this 7 M Na AP-105 simulant from the Kim et al. (2012) glass models, GFCs were added to the simulant, and the resultant melter feed was processed in the sim-CLSM over a 7.50-hour processing period with a new progressive cavity pump, producing 6.13 kg of glass for an average glass production rate of 1735 kg $m^2$ $d^{-1}$. The simulant processing demonstrated that 7 M Na AP-105 melter feed could vitrified without any aberrant behavior and defined the expected production ranges for waste processing.

The sample of AP-105 waste went through solids filtration and cesium removal by ion exchange, ending at an actual sodium concentration of 6.76 M. The same glass composition and GFCs additions calculations used for the 7 M Na AP-105 simulant were used for the formation of the 7 M Na AP-105 waste melter feed. Over 6.71 hours of processing, 6.71 kg of glass were produced for an average glass production rate of 2079 kg $m^2$ $d^{-1}$ for 7 M Na AP-105 waste melter feed in the CLSM system. It is believed that this value for average glass production rate when processing 7 M Na AP-105 waste melter feed was greater than the 7 M Na AP-105 simulant processing because the actual waste sample had lower concentrations of most all primary components. Other conclusions from the 7 M Na AP-105 simulant and waste CLSM runs include:

- The cold-cap behavior for the 7 M Na AP-105 waste melter feed was similar to the 7 M Na AP-105 simulant melter feed. Additionally, these runs mirrored previous AP-107 runs (Dixon et al. 2019, 2020b, and 2022a) with a smooth cold cap that was quick to respond to operator input. The cold cap remained at a steady size and coverage requiring infrequent changes in operating conditions.

- Both the 7 M Na AP-105 waste and simulant were processed at greater average glass production rates than their lower Na molarity AP-105 counterparts processed in the CLSM. The 7 M Na AP-105 waste processed faster than the 7 M Na AP-105 simulant likely due to the lower concentration than expected of primary components in the waste compared to the values used to calculate the simulant.

- Most of the primary components in the glass produced during the CLSM runs were within 10 % of their targets based on the AP-105-7M glass compositions. However, the $ZrO_2$ content in the 7 M Na AP-105 simulant CLSM run was only about two thirds of its target, likely due to an under batching of zircon in the melter feed.

- The recovery values for $SiO_2$ during the 7 M Na AP-105 simulant CLSM run was above the expected range of $100 \pm 10$ % due to the melter feed sample collected for analysis settling and being deficient in silica.

- Components recovered in the CLSM offgas system (Re, ^{99}Tc, Cs, I, S, K, Cl, and F) during the 7 M Na AP-105 simulant and waste runs were recovered in similar proportions and totals in each unit of the offgas system compared to previous CLSM runs.

- Iodine was recovered in the CLSM offgas system primarily in the liquid samples, with low quantities partitioning to the filters, leading to the indication that iodine has a high potential to be recycled with the liquids from the offgas system back to the melter feed.

- The relative chemical steady-state retention of Re when processing the 7 M Na AP-105 simulant melter feed was $38 \pm 1$ %, which was equivalent to the retention of Re when processing lower Na molarity AP-105 in the sim-CLSM.

- The relative chemical steady-state retention of ^{99}Tc when processing the 7 M Na AP-105 waste melter feed was $49 \pm 2$ %, which was greater than the ^{99}Tc retention when processing lower Na molarity AP-105 in the rad-CLSM.

- A spike of ~5 ppm Cs was present in the initial glass used for the 7 M Na AP-105 simulant CLSM run, and the Cs had decreased to ~0.5 ppm when the glass was used in the 7 M Na AP-105 waste CLSM run, before reaching a value below analytical reporting limits due to the low amount of Cs in the 7 M Na AP-105 waste.

- Iodine was added as a spike of ~42 ppm into the 7 M Na AP-105 simulant melter feed and I was retained above the analysis detection limit in all glass pours after charging began. Greater amounts of I were retained in the glass poured immediately before or after the cold cap had burned off, a similar behavior to what had been previously observed in the sim-CLSM. It is recommended to continue spiking melter feeds with I at such levels to determine how composition and cold-cap coverage play factors in retention.

- Acetonitrile was detectable in the condensate and demister liquids collected from the CLSM system with a greater amount in the 7 M Na AP-105 simulant run than the waste run, likely due to the lower concentration than expected of nitrates/nitrites in the waste, but also backing the trend that a hotter plenum temperature leads to less acetonitrile production.

# 7.0   References

Allred JR, JGH Geeting, AM Westesen, EC Buck, and RA Peterson. 2020. *Fiscal Year 2020 Filtration of Hanford Tank Waste 241-AP-105*. PNNL-30485, Rev. 0 (RPT-DFTP-021, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Allred JR, JGH Geeting, AM Westesen, EC Buck, and RA Peterson. 2021. *Fiscal Year 2021 Filtration of Hanford Tank Waste 241-AP-107 Supernatant Samples Obtained at Prototypic Tank Level and Filtered at 16 °C*. PNNL-31557, Rev. 0 (RPT-DFTP-028, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Allred JR, EC Buck, CA Burns, RC Daniel, JGH Geeting, ZB Webb, AM Westesen, and RA Peterson. 2022. *Fiscal Year 2022 Filtration of Hanford Tank Waste 241- AP-101 Supernatant at 16 °C*. PNNL-32851, Rev. 0 (RPT-DFTP-032, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Allred JR, C Alvarez, EC Buck, CA Burns, RC Daniel, JGH Geeting, AM Westesen, and RA Peterson. 2023. *Fiscal Year 2023 Filtration of Hanford Tank Waste 241- AP-105 Supernatant at 16 °C*. PNNL-34265, Rev. 0 (RPT-DFTP-036, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

ASME. 2000. NQA-1-2000, *Quality Assurance Requirements for Nuclear Facility Applications*. The American Society of Mechanical Engineers, New York, New York.

ASME. 2008. NQA-1-2008, *Quality Assurance Requirements for Nuclear Facility Applications*. The American Society of Mechanical Engineers, New York, New York.

ASME 2009. NQA-1a-2009, *Addenda to ASME NQA-1-2008*. The American Society of Mechanical Engineers, New York, New York.

Bernards JK, TM Hohl, RT Jasper, SL Orcutt, SD Reaksecker, CS Smalley, AJ Schubick, TL Waldo II, EB West, LM Bergmann, RO Lokken, AN Praga, SN Tilanus, and MN Wells. 2017. *River Protection Project System Plan*. ORP-11242, Rev. 8. U.S. Department of Energy Office of River Protection, Richland, Washington.

Cantrell KJ, II Leavy, MM Snyder, SR Baum, SD Shen, BD Williams, SA Saslow, and EJ Krogstad. 2018. *Off-Gas Condensate and Cast Stone Analysis Results*. PNNL-27765, Rev. 0 (RPT-DFTP-012, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Dixon DR, MJ Schweiger, BJ Riley, R Pokorny, and P Hrma. 2015. *Temperature Distribution within a Cold Cap during Nuclear Waste Vitrification*. *Environmental Science and Technology* 49:8856-8863.

Dixon DR, CM Stewart, JJ Venarsky, JA Peterson, GB Hall, TG Levitskaia, JR Allred, WC Eaton, JB Lang, MA Hall, DA Cutforth, AM Rovira, and RA Peterson. 2018. *Vitrification of Hanford Tank Waste 241-AP-105 in a Continuous Laboratory-Scale Melter*. PNNL-27775 (RPT-DFTP-010, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Dixon DR, CM Stewart, JJ Venarsky, JA Peterson, GB Hall, TG Levitskaia, JR Allred, WC Eaton, JB Lang, MA Hall, DA Cutforth, AM Rovira, and RA Peterson. 2019. *Vitrification of Hanford Tank Waste 241-AP-107 in a Continuous Laboratory-Scale Melter*. PNNL-28361, Rev. 0 (RPT-DFTP-014, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Dixon DR, MA Hall, JB Lang, DA Cutforth, CM Stewart, and WC Eaton. 2020a. *Continuous Laboratory-Scale Melter Runs for System Evaluation*. PNNL-30073, Rev. 0 (EWG-RPT-024, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Dixon DR, AM Westesen, MA Hall, CM Stewart, JB Lang, DA Cutforth, WC Eaton, and RA Peterson. 2020b. *Vitrification of Hanford Tank 241-AP-107 with Recycled Condensate*. PNNL-30189, Rev. 0 (RPT-DFTP-024, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Dixon DR, AM Westesen, MA Hall, CM Stewart, JB Lang, DA Cutforth, WC Eaton, and RA Peterson. 2022a. *Vitrification of Hanford Tank Wastes for Condensate Recycle and Feed Composition Changeover Testing*. PNNL-32344, Rev. 1 (RPT-DFTP-033, Rev. 1). Pacific Northwest National Laboratory, Richland, Washington.

Dixon DR, JB Lang, MA Hall, CM Stewart, DA Cutforth, WC Eaton, J Marcial, AM Westesen, and RA Peterson. 2022b. *Vitrification of Hanford Tank 241-AP-101 Waste and Simulant*. PNNL-33600, Rev. 0 (RPT-DFTP-035, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Dixon DR, MA Hall, JB Lang, DA Cutforth, CM Stewart, and WC Eaton. 2022b. *Retention analysis from vitrified low-activity waste and simulants in a laboratory-scale melter*. Ceramics International, 48: 5955-5964, DOI: 10.1016/j.ceramint.2021.08.102.

Fiskum SK, JR Allred, HA Colburn, AM Rovira, MR Smoot, and RA Peterson. 2018. *Multi-Cycle Cesium Ion Exchange Testing Using Spherical Resorcinol-Formaldehyde Resin with Diluted Hanford Tank Waste 241-AP-105*. PNNL-27432 (RPT-DFTP-006, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Fiskum SK, AM Rovira, HA Colburn, AM Carney, and RA Peterson. 2019. *Cesium Ion Exchange Testing Using a Three-Column System with Crystalline Silicotitanate and Hanford Tank Waste 241-AP-107*. PNNL-28958, Rev. 0 (RPT-DFTP-013, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Fiskum SK, AM Westesen, AM Carney, TT Trang-Le and RA Peterson. 2021. *Ion Exchange Processing of AP-105 Hanford Tank Waste through Crystalline Silicotitanate in a Staged 2- then 3-Column System*. PNNL-30712, Rev. 0 (RPT-DFTP-025, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Geeting JGH, JR Allred, AM Rovira, RW Shimskey, CA Burns, and RA Peterson. 2018a. *Crossflow Filtration of Hanford Tank AP-105 Supernatant*. PNNL-27085 (RPT-DFTP-005, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Geeting JGH, AM Rovira, JR Allred, RW Shimskey, CA Burns, and RA Peterson. 2018b. *Filtration of Hanford Tank AP-107 Supernatant*. PNNL-27638 (RPT-DFTP-009, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Geeting JGH, JR Allred, AM Rovira, and RA Peterson. 2019. *Fiscal Year 2019 Filtration of Hanford Tank AP-107 Supernatant*. PNNL-28780, Rev. 0 (RPT-DFTP-015, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Kim DS, JD Vienna, and AA Kruger. 2012. *Preliminary ILAW Formulation Algorithm Description, 24590 LAW RPT-RT-04-0003, Rev. 1*. ORP-56321, Revision 0. U. S. Department of Energy Office of River Protection, Richland, Washington.

Matlack KS, IS Muller, I Joseph, and IL Pegg. 2010. *Improving Technetium Retention in Hanford LAW Glass – Phase 1,* VSL-10R1920-1, Rev. 0, Vitreous State Laboratory, The Catholic University of America, Washington, DC and Energy*Solutions* Federal EPC, Inc., Calverton, Maryland.

Matlack KS, IS Muller, RA Callow, N D'Angelo, T Bardakci, I Joseph, and IL Pegg. 2011. *Improving Technetium Retention in Hanford LAW Glass – Phase 2*. VSL-11R2260-1, Rev. 0, Vitreous State Laboratory, The Catholic University of America, Washington, DC and Energy*Solutions* Federal EPC, Inc., Calverton, Maryland.

Matlack KS, H Abramowitz, IS Muller, I Joseph, and IL Pegg. 2017. *DFLAW Glass and Feed Qualifications to Support WTP Start-Up and Flow-Sheet Development*. VSL-17R4330-1, Rev. 0. Vitreous State Laboratory, The Catholic University of America, Washington, DC and Atkins Energy Federal EPC, Inc., Calverton, Maryland.

Matlack KS, H Abramowitz, IS Muller, I Joseph, and IL Pegg. 2018. *DFLAW Glass and Feed Qualifications for AP-107 to Support WTP Start-Up and Flow-Sheet Development*, VSL-18R4500-1, Rev. 0, Vitreous State Laboratory, The Catholic University of America, Washington, DC and Atkins Energy Federal EPC, Inc., Columbia, Maryland.

Pegg IL. 2015. *Behavior of technetium in nuclear waste vitrification processes*. Journal of Radioanalytical Nuclear Chemistry, 305: 287-292. DOI 10.1007/s10967-014-3900-9.

Peterson RA, SK Fiskum, WC Eaton, and J Geeting. 2017. *Functions and Requirements of the Radioactive Waste Test Platform.* PNNL-26322 (RPT-DFTP-002, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Westesen AM, SK Fiskum, HA Colburn, JR Allred, MR Smoot, and RA Peterson. 2021a. *Cesium Ion Exchange Testing Using Crystalline Silicotitanate with Hanford Tank Waste 241-AP-107*. PNNL-27706, Rev. 1 (RPT-DFTP-011, Rev. 1). Pacific Northwest National Laboratory, Richland, Washington.

Westesen AM, SK Fiskum, AM Carney, EL Campbell, TT Trang-Le, and RA Peterson. 2021b. *Reduced Temperature Cesium Removal from AP-107 Using Crystalline Silicotitanate*. PNNL-31868, Rev. 0 (RPT-DFTP-027, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Westesen AM, EL Campbell, AN Williams, AM Carney, TT Trang-Le, and RA Peterson. 2022. *Reduced Temperature Cesium Removal from AP-101 Using Crystalline Silicotitanate*. PNNL-32911, Rev. 0 (RPT-DFTP-034, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

Westesen AM, EL Campbell, C Alvarez, AM Carney, TT Trang-Le, and RA Peterson. 2023. *Cesium Removal from 5.5 and 7.0 M Na AP-105 Using Crystalline Silicotitanate*. PNNL-34395, Rev. 0 (RPT-DFTP-037, Rev. 0). Pacific Northwest National Laboratory, Richland, Washington.

# Appendix A – Chemical Analysis of Samples Collected from the 7 M NA AP-105 Simulant and Waste CLSM Runs

The table in this section displays the complete chemical analytical results for all samples from the 7 M NA AP-105 simulant and waste CLSM run that were sent to SwRI for analysis. Values colored red indicate the associated sample results were less than the analytical reporting limit (ARL) and thus the reporting limits are listed in the tables. Values marked with "--" denote that the analysis was not performed for a specific sample.

Table A.1. Chemical Analysis of Samples Produced During the 7 M Na AP-105 Simulant CLSM Run

| Sample Name | Sample Mass (kg) | Component Concentration (mg kg$^{-1}$) | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Re | Total Cs | Total I | Ag | Al | As | B | Ba | Be | Bi | Ca |
| 7 M Na AP-105 Simulant Melter Feed | 14.37 | 3.65 | 0.0466 | 41.9 | 0.931 | 14900 | 2.93 | 14200 | 15.8 | 4.66 | 37.3 | 6400 |
| Glass Pour (Initial) | 0.05 | 4.17 | 5.22 | 2.44 | 0.974 | 31800 | 5.27 | 30900 | 31.8 | 4.87 | 39.0 | 19400 |
| Glass Pour (0.67 h) | 0.22 | 3.10 | 4.82 | 3.17 | 0.983 | 32000 | 6.07 | 31100 | 33.4 | 4.91 | 39.3 | 19900 |
| Glass Pour (3.17 h) | 2.09 | 3.13 | 1.74 | 16.7 | 0.988 | 31800 | 5.14 | 30800 | 33.0 | 4.94 | 39.5 | 15400 |
| Glass Pour (3.67 h) | 0.38 | 3.25 | 1.38 | 6.93 | 0.980 | 31700 | 5.27 | 31000 | 33.2 | 4.90 | 39.2 | 15200 |
| Glass Pour (5.09 h) | 1.31 | 3.20 | 0.767 | 8.25 | 0.999 | 31800 | 5.92 | 31000 | 33.9 | 5.00 | 40.0 | 14700 |
| Glass Pour (8.19 h) | 2.02 | 3.41 | 0.221 | 14.5 | 0.983 | 31500 | 5.03 | 31300 | 35.3 | 4.92 | 39.3 | 14200 |
| Glass Pour (Final) | 2.04 | 3.79 | 0.421 | 13.9 | 9.91 | 31750 | 6.47 | 30650 | 35.6 | 4.96 | 39.7 | 14200 |
| Primary HEPA A | 0.02 | 69.5 | 4.79 | 3.16 | 0.959 | 11000 | 2.40 | 10400 | 15600 | 0.479 | 3.83 | 4550 |
| Primary HEPA B | 0.02 | 1.32 | 0.111 | 0.898 | 0.917 | 11750 | 2.54 | 10850 | 16650 | 0.459 | 3.67 | 4750 |
| Sampling HEPA 1 | 0.02 | 46.0 | 2.24 | 1.02 | 0.976 | 11300 | 3.24 | 10700 | 16000 | 0.488 | 3.90 | 4730 |
| Sampling HEPA 3 | 0.02 | 50.0 | 0.403 | 2.13 | 0.904 | 11500 | 2.57 | 10600 | 16300 | 0.452 | 3.62 | 4540 |
| Pre-filter | 0.26 | 5.03 | 0.1855 | 2.48 | 0.528 | 5.28 | 1.32 | 35.0 | 0.266 | 0.264 | 2.11 | 3.88 |
| Condensate | 6.31 | 1.66 | 0.0921 | 73.7 | 0.493 | 27.2 | 1.23 | 148 | 0.247 | 0.247 | 1.97 | 7.94 |
| Primary SBS | 1.20 | 2.70 | 0.0659 | 139 | 0.495 | 37.8 | 1.24 | 200 | 0.427 | 0.248 | 1.98 | 11.8 |
| Demister | 0.17 | 2.27 | 0.118 | 150 | 0.456 | 27.1 | 1.14 | 136 | 0.228 | 0.228 | 1.82 | 10.6 |
| Pre-filter housing | 0.01 | 4.10 | 0.152 | 177 | 0.369 | 6.11 | 2.59 | 139 | 0.387 | 0.184 | 1.48 | 9.79 |
| Sampling Line Wash | 0.06 | 2.32 | 0.0506 | 1.12 | 0.501 | 25.4 | 1.25 | 80.5 | 0.250 | 0.250 | 2.00 | 7.78 |
| Primary Line Wash | 0.23 | 9.86 | 0.212 | 1.60 | 0.496 | 112 | 1.24 | 235 | 0.248 | 0.248 | 1.98 | 104 |

Table A.1. Chemical Analysis of Samples Produced During the 7 M Na AP-105 Simulant CLSM Run (cont.)

| Sample Name | Component Concentration (mg kg$^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cd | Co | Cr | Cu | Fe | K | La | Li | Mg | Mn | Mo | Na |
| 7 M Na AP-105 Simulant Melter Feed | 0.466 | 1.73 | 240 | 7.51 | 17700 | 1820 | 1.40 | 19.3 | 3750 | 59.0 | 3.11 | 72900 |
| Glass Pour (Initial) | 0.749 | 6.12 | 3090 | 9.02 | 35600 | 3780 | 27.8 | 101 | 6640 | 145 | 13.7 | 151000 |
| Glass Pour (0.67 h) | 0.780 | 5.24 | 3430 | 9.48 | 34700 | 3670 | 27.1 | 88.8 | 6630 | 149 | 13.9 | 151000 |
| Glass Pour (3.17 h) | 0.557 | 5.78 | 1640 | 15.0 | 37600 | 3920 | 11.3 | 42.0 | 7720 | 139 | 9.21 | 153000 |
| Glass Pour (3.67 h) | 0.665 | 5.23 | 1220 | 15.1 | 37300 | 3900 | 9.91 | 34.7 | 7880 | 142 | 9.06 | 153000 |
| Glass Pour (5.09 h) | 0.651 | 4.93 | 1000 | 15.9 | 37400 | 3900 | 6.84 | 21.5 | 8150 | 140 | 8.68 | 154000 |
| Glass Pour (8.19 h) | 0.538 | 6.18 | 816 | 17.1 | 37300 | 3980 | 3.39 | 11.5 | 8210 | 144 | 7.80 | 156000 |
| Glass Pour (Final) | 0.672 | 9.49 | 743 | 17.1 | 37400 | 3935 | 3.20 | 16.9 | 8260 | 145 | 8.23 | 155000 |
| Primary HEPA A | 0.479 | 24.0 | 607 | 2.27 | 263 | 8690 | 1.44 | 6.96 | 704 | 6.68 | 18.3 | 33300 |
| Primary HEPA B | 0.459 | 22.9 | 46.6 | 0.785 | 170 | 8615 | 1.38 | 3.33 | 758 | 5.49 | 13.9 | 24450 |
| Sampling HEPA 1 | 0.488 | 24.4 | 128 | 1.26 | 299 | 8990 | 1.46 | 3.63 | 754 | 6.59 | 13.7 | 32400 |
| Sampling HEPA 3 | 0.452 | 22.6 | 60.3 | 1.59 | 312 | 8860 | 1.36 | 3.25 | 719 | 6.03 | 13.7 | 32600 |
| Pre-filter | 0.264 | 0.264 | 19.9 | 0.344 | 66.1 | 90.1 | 0.793 | 0.793 | 2.64 | 0.596 | 1.36 | 1065 |
| Condensate | 0.247 | 0.247 | 9.31 | 0.247 | 36.5 | 36.7 | 0.740 | 0.740 | 2.47 | 0.247 | 0.493 | 718 |
| Primary SBS | 0.248 | 0.248 | 6.68 | 0.248 | 48.3 | 55.6 | 0.743 | 0.743 | 2.48 | 0.248 | 0.495 | 1010 |
| Demister | 0.228 | 0.258 | 35.6 | 0.602 | 161 | 45.5 | 0.684 | 0.684 | 2.28 | 1.89 | 2.94 | 743 |
| Pre-filter housing | 0.184 | 34.6 | 2130 | 54.8 | 8970 | 56.4 | 0.553 | 0.957 | 1.93 | 183 | 246 | 786 |
| Sampling Line Wash | 0.250 | 0.251 | 11.4 | 0.433 | 92.0 | 43.8 | 0.751 | 0.751 | 2.50 | 2.03 | 0.501 | 820 |
| Primary Line Wash | 0.248 | 0.248 | 31.0 | 0.402 | 270 | 145 | 0.744 | 6.43 | 14.6 | 1.23 | 1.94 | 3400 |

Table A.1. Chemical Analysis of Samples Produced During the 7 M Na AP-105 Simulant CLSM Run (cont.)

| Sample Name | Component Concentration (mg kg⁻¹) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ni | P | Pb | Pd | S | Sb | Se | Si | Sn | Sr | Th | Ti |
| 7 M Na AP-105 Simulant Melter Feed | 43.4 | 98.3 | 1.28 | 23.3 | 653 | 23.3 | 23.3 | 72200 | 5.16 | 4.76 | 23.3 | 3650 |
| Glass Pour (Initial) | 2170 | 568 | 51.2 | 24.4 | 1760 | 24.4 | 24.4 | 214000 | 916 | 18.0 | 24.4 | 7380 |
| Glass Pour (0.67 h) | 2020 | 473 | 44.1 | 24.6 | 1830 | 24.6 | 24.6 | 209000 | 1070 | 17.9 | 24.6 | 7330 |
| Glass Pour (3.17 h) | 1010 | 479 | 20.0 | 24.7 | 1490 | 24.7 | 24.7 | 210000 | 187 | 12.9 | 24.7 | 7950 |
| Glass Pour (3.67 h) | 933 | 547 | 16.7 | 24.5 | 1500 | 24.5 | 24.5 | 210000 | 165 | 12.5 | 24.5 | 7950 |
| Glass Pour (5.09 h) | 628 | 524 | 10.2 | 25.0 | 1500 | 25.0 | 25.0 | 212000 | 109 | 11.8 | 25.0 | 8050 |
| Glass Pour (8.19 h) | 357 | 500 | 3.83 | 24.6 | 1460 | 24.6 | 24.6 | 209000 | 49.3 | 11.2 | 24.6 | 8010 |
| Glass Pour (Final) | 327 | 540 | 3.40 | 24.8 | 1445 | 24.8 | 24.8 | 208000 | 48.4 | 11.2 | 24.8 | 8035 |
| Primary HEPA A | 27.5 | 120 | 4.46 | 2.40 | 927 | 2.40 | 2.40 | 370000 | 2.18 | 224 | 2.40 | 18.0 |
| Primary HEPA B | 4.63 | 115 | 2.45 | 2.29 | 213 | 2.29 | 2.29 | 393500 | 2.09 | 241 | 2.29 | 19.4 |
| Sampling HEPA 1 | 7.56 | 122 | 2.77 | 2.44 | 592 | 2.44 | 2.44 | 374000 | 1.95 | 231 | 2.44 | 21.0 |
| Sampling HEPA 3 | 10.6 | 113 | 3.06 | 2.26 | 527 | 2.26 | 2.26 | 390000 | 3.49 | 228 | 2.26 | 20.5 |
| Pre-filter | 7.32 | 6.60 | 0.396 | 1.32 | 39.0 | 1.32 | 1.32 | 6.60 | 1.06 | 0.264 | 1.32 | 0.264 |
| Condensate | 0.430 | 51.5 | 0.370 | 1.23 | 25.9 | 1.23 | 1.23 | 31.0 | 0.987 | 0.247 | 1.23 | 0.962 |
| Primary SBS | 0.653 | 108 | 0.372 | 1.24 | 35.6 | 1.24 | 1.24 | 44.5 | 0.991 | 0.248 | 1.24 | 1.76 |
| Demister | 19.3 | 125 | 0.342 | 1.14 | 30.8 | 1.14 | 1.14 | 24.4 | 0.912 | 0.228 | 1.14 | 1.75 |
| Pre-filter housing | 1320 | 94.0 | 0.277 | 9.22 | 240 | 9.22 | 0.922 | 4.61 | 2.10 | 0.184 | 0.922 | 0.800 |
| Sampling Line Wash | 17.9 | 9.63 | 0.376 | 1.25 | 47.0 | 1.25 | 1.25 | 23.1 | 1.00 | 0.25 | 1.25 | 2.54 |
| Primary Line Wash | 6.84 | 8.53 | 0.372 | 1.24 | 362 | 1.24 | 1.24 | 205 | 0.992 | 0.248 | 1.24 | 11.2 |

Table A.1. Chemical Analysis of Samples Produced During the 7 M Na AP-105 Simulant CLSM Run (cont.)

| Sample Name | Component Concentration (mg kg$^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tl | U | V | W | Y | Zn | Zr | Br | Cl | F | N as NO$_3$ | N as NO$_2$ |
| 7 M Na AP-105 Simulant Melter Feed | 140 | 23.3 | 5.11 | 53.1 | 3.90 | 12500 | 8010 | 97.8 | 1950 | 97.8 | 13900 | 10300 |
| Glass Pour (Initial) | 146 | 24.4 | 1990 | 156 | 43.3 | 24100 | 15600 | 123 | 2420 | 377 | -- | -- |
| Glass Pour (0.67 h) | 147 | 24.6 | 2320 | 131 | 43.4 | 23200 | 16000 | 117 | 2510 | 310 | -- | -- |
| Glass Pour (3.17 h) | 148 | 24.7 | 411 | 156 | 40.7 | 26500 | 15500 | 115 | 3120 | 161 | -- | -- |
| Glass Pour (3.67 h) | 147 | 24.5 | 353 | 147 | 40.5 | 26100 | 15100 | 117 | 3300 | 140 | -- | -- |
| Glass Pour (5.09 h) | 150 | 25.0 | 236 | 162 | 40.5 | 26900 | 15100 | 117 | 3390 | 127 | -- | -- |
| Glass Pour (8.19 h) | 147 | 24.6 | 130 | 172 | 40.9 | 27000 | 14500 | 122 | 3780 | 122 | -- | -- |
| Glass Pour (Final) | 149 | 24.8 | 139 | 188 | 41.1 | 27600 | 14100 | 117 | 4265 | 117 | -- | -- |
| Primary HEPA A | 14.4 | 24.0 | 1.14 | 82.6 | 2.15 | 10400 | 90.7 | 3.60 | 190 | 17.8 | 8550 | 3.60 |
| Primary HEPA B | 13.8 | 22.9 | 0.459 | 89.6 | 2.28 | 10650 | 95.9 | 0.995 | 43.3 | 2.70 | 254 | 0.995 |
| Sampling HEPA 1 | 14.6 | 24.4 | 0.543 | 85.2 | 2.21 | 10900 | 95.3 | 9.77 | 16300 | 296 | 559 | 48.8 |
| Sampling HEPA 3 | 13.6 | 22.6 | 1.04 | 88.2 | 2.20 | 10600 | 94.9 | 19.1 | 14900 | 65.8 | 757 | 95.5 |
| Pre-filter | 3.96 | 13.2 | 0.264 | 1.37 | 0.264 | 4.38 | 0.793 | 1.06 | 4.23 | 4.23 | 3490 | 4.23 |
| Condensate | 7.40 | 12.3 | 1.17 | 1.23 | 0.247 | 41.5 | 1.37 | 9.97 | 58 | 22.2 | 3960 | 9.97 |
| Primary SBS | 7.43 | 12.4 | 0.862 | 1.24 | 0.248 | 57.7 | 1.46 | 9.86 | 934 | 16.5 | 3250 | 9.86 |
| Demister | 6.84 | 11.4 | 1.79 | 1.14 | 0.228 | 36.6 | 1.85 | 9.10 | 652 | 27.9 | 39400 | 17.9 |
| Pre-filter housing | 5.53 | 9.22 | 14.2 | 6.76 | 0.184 | 2.18 | 0.553 | 14.6 | 68.7 | 21.5 | 118000 | 7.30 |
| Sampling Line Wash | 7.51 | 12.5 | 2.26 | 1.25 | 0.25 | 37.1 | 1.07 | 9.93 | 564 | 47.0 | 315 | 27.5 |
| Primary Line Wash | 7.44 | 12.4 | 14.5 | 1.24 | 0.248 | 150 | 10.8 | 9.84 | 2820 | 167 | 375 | 49.9 |

Table A.1. Chemical Analysis of Samples Produced During the 7 M Na AP-105 Simulant CLSM Run (cont.)

| Sample Name | P as $PO_4$ | Total S (Solids) or $SO_4$ (All Others) | TOC | Acetonitrile | Loss on Ignition (%) | Ash (%) |
|---|---|---|---|---|---|---|
| | | Component Concentration (mg kg$^{-1}$) | | Component Concentration (µg L$^{-1}$) | | |
| 7 M Na AP-105 Simulant Melter Feed | 97.8 | 1880 | 24300 | -- | 56.63 | 43.37 |
| Glass Pour (Initial) | -- | 1650 | -- | -- | 2.69 | 97.31 |
| Glass Pour (0.67 h) | -- | 1690 | -- | -- | 2.69 | 97.31 |
| Glass Pour (3.17 h) | -- | 1280 | -- | -- | 2.96 | 97.04 |
| Glass Pour (3.67 h) | -- | 1330 | -- | -- | 2.38 | 97.62 |
| Glass Pour (5.09 h) | -- | 1290 | -- | -- | 2.29 | 97.71 |
| Glass Pour (8.19 h) | -- | 1360 | -- | -- | 2.67 | 97.33 |
| Glass Pour (Final) | -- | 1300 | -- | -- | 3.15 | 96.85 |
| Primary HEPA A | 45 | 2640 | -- | -- | 4.57 | 95.43 |
| Primary HEPA B | 0.995 | 36.2 | -- | -- | 1.16 | 98.84 |
| Sampling HEPA 1 | 4.88 | 1370 | -- | -- | 3.45 | 96.55 |
| Sampling HEPA 3 | 9.55 | 896 | -- | -- | 3.21 | 96.79 |
| Pre-filter | 4.23 | 257 | -- | -- | -- | -- |
| Condensate | 9.97 | 190 | 262 | 270000 | -- | -- |
| Primary SBS | 9.86 | 213 | 311 | -- | -- | -- |
| Demister | 9.1 | 272 | 638 | -- | -- | -- |
| Pre-filter housing | 73 | 2340 | 2090 | -- | -- | -- |
| Sampling Line Wash | 9.93 | 171 | 20.1 | -- | -- | -- |
| Primary Line Wash | 9.84 | 1130 | 35.9 | -- | -- | -- |

Table A.2. Chemical Analysis of Samples Produced During the 7 M Na AP-105 Waste CLSM Run

| Sample Name | Sample Mass (kg) | Component Concentration (mg kg$^{-1}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $^{99}$Tc | Total Cs | Total I | Ag | Al | As | B | Ba | Be | Bi | Ca |
| 7 M Na AP-105 Waste Melter Feed, Batch 2, Sample 1 | 3.62 | 3.91 | 0.0432 | -- | 0.863 | 14750 | 2.30 | 14800 | 15.2 | 4.32 | 34.5 | 6460 |
| 7 M Na AP-105 Waste Melter Feed, Batch 1, Sample 1 | 10.37 | 3.71 | 0.0459 | -- | 0.918 | 15200 | 3.19 | 16200 | 17.6 | 4.59 | 36.7 | 6880 |
| 7 M Na AP-105 Waste Melter Feed, Batch 1, Sample 2 | -- | 3.49 | 0.0473 | -- | 0.947 | 15100 | 3.20 | 15500 | 16.4 | 4.73 | 37.9 | 6900 |
| 7 M Na AP-105 Waste Melter Feed, Batch 2, Sample 2 | -- | 3.49 | 0.0487 | -- | 0.973 | 13300 | 2.43 | 12700 | 13.3 | 4.87 | 38.9 | 5810 |
| Glass Pour Shutdown | 1.20 | 0.731 | 0.398 | 9.50 | 0.944 | 31700 | 6.31 | 31200 | 35.8 | 4.72 | 37.7 | 16200 |
| Glass Pour (Initial) | 0.08 | 0.753 | 0.501 | 7.13 | 0.941 | 31400 | 5.35 | 31100 | 35.8 | 4.71 | 37.7 | 16300 |
| Glass Pour (0.58 h) | 0.60 | 1.12 | 0.526 | 3.90 | 0.996 | 31500 | 5.97 | 30900 | 33.4 | 4.98 | 3.98 | 16100 |
| Glass Pour (2.01 h) | 1.35 | 2.60 | 0.289 | 2.36 | 0.960 | 31400 | 6.53 | 31400 | 35.4 | 4.80 | 38.4 | 15400 |
| Glass Pour (3.38 h) | 1.37 | 3.11 | 0.185 | 2.23 | 0.963 | 31300 | 6.57 | 31200 | 35.4 | 4.82 | 38.5 | 15000 |
| Glass Pour (4.43 h) | 0.69 | 3.44 | 0.139 | 2.34 | 0.990 | 31100 | 5.65 | 31800 | 35.6 | 4.95 | 39.6 | 14700 |
| Glass Pour (5.54 h) | 0.74 | 3.67 | 0.108 | 2.15 | 0.980 | 30900 | 5.44 | 31400 | 34.8 | 4.90 | 39.2 | 14500 |
| Glass Pour (6.59 h) | 1.18 | 3.64 | 0.0857 | 2.35 | 0.987 | 31100 | 5.86 | 31800 | 35.7 | 4.94 | 39.5 | 14600 |
| Glass Pour (Final) | 2.82 | 3.71 | 0.0901 | 2.39 | 0.947 | 31500 | 5.83 | 31800 | 35.5 | 4.74 | 37.9 | 14800 |
| Primary HEPA A | 0.02 | 2.00 | 0.188 | 0.694 | 0.953 | 11500 | 2.38 | 10900 | 16200 | 0.476 | 3.81 | 4600 |
| Sampling HEPA 1 | 0.02 | 50.5 | 1.13 | 1.91 | 0.908 | 11300 | 2.87 | 10600 | 16000 | 0.454 | 3.63 | 4490 |
| Sampling HEPA 2 | 0.02 | 61.1 | 0.613 | 1.52 | 0.970 | 11100 | 3.02 | 11300 | 15500 | 0.485 | 3.88 | 4420 |
| Pre-filter | 0.35 | 10.6 | 0.383 | 6.38 | 0.397 | 4.63 | 0.993 | 171 | 0.199 | 0.199 | 1.59 | 6.68 |
| Primary SBS | 0.88 | 1.36 | 0.0743 | 1.23 | 0.500 | 5.00 | 1.25 | 93.2 | 0.250 | 0.250 | 2.00 | 4.34 |
| Demister | 2.68 | 0.914 | 0.0754 | 2.54 | 0.543 | 8.12 | 1.25 | 88.6 | 0.250 | 0.250 | 2.00 | 3.80 |
| Condensate | 3.27 | 1.31 | 0.06875 | 3.70 | 0.500 | 6.15 | 1.25 | 110 | 0.250 | 0.250 | 2.00 | 2.50 |
| Pre-filter Housing | 0.22 | 5.93 | 0.667 | 14.9 | 0.473 | 12.1 | 1.18 | 210 | 0.237 | 0.237 | 1.89 | 5.91 |

Table A.2. Chemical Analysis of Samples Produced During the 7 M Na AP-105 Waste CLSM Run (cont.)

| Sample Name | Component Concentration (mg kg⁻¹) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cd | Co | Cr | Cu | Fe | K | La | Li | Mg | Mn | Mo | Na |
| 7 M Na AP-105 Waste Melter Feed, Batch 2, Sample 1 | 0.512 | 2.04 | 249 | 9.17 | 17500 | 2105 | 1.30 | 2.04 | 3805 | 61.0 | 30.5 | 73400 |
| 7 M Na AP-105 Waste Melter Feed, Batch 1, Sample 1 | 0.490 | 1.99 | 239 | 9.54 | 18600 | 1990 | 1.38 | 1.86 | 3970 | 64.1 | 28.7 | 69100 |
| 7 M Na AP-105 Waste Melter Feed, Batch 1, Sample 2 | 0.473 | 2.06 | 222 | 9.16 | 19400 | 1930 | 1.42 | 1.64 | 4200 | 62.6 | 27.9 | 67100 |
| 7 M Na AP-105 Waste Melter Feed, Batch 2, Sample 2 | 0.487 | 1.85 | 229 | 8.04 | 16400 | 1800 | 1.46 | 1.51 | 3430 | 53.4 | 25.9 | 63800 |
| Glass Pour Shutdown | 0.735 | 4.00 | 1670 | 18.8 | 38800 | 3880 | 3.85 | 57.6 | 8360 | 133 | 18.6 | 147000 |
| Glass Pour (Initial) | 0.712 | 4.42 | 1680 | 19.1 | 38100 | 3790 | 4.89 | 49.3 | 8270 | 135 | 38.6 | 146000 |
| Glass Pour (0.58 h) | 0.908 | 3.93 | 1430 | 17.2 | 38100 | 3630 | 4.00 | 35.7 | 8420 | 128 | 22.9 | 141000 |
| Glass Pour (2.01 h) | 1.02 | 4.28 | 1670 | 19.2 | 39500 | 3920 | 3.41 | 27.4 | 8440 | 134 | 35.3 | 146000 |
| Glass Pour (3.38 h) | 1.08 | 4.42 | 1260 | 20.7 | 38900 | 4010 | 3.13 | 18.9 | 8480 | 135 | 44.5 | 146000 |
| Glass Pour (4.43 h) | 1.22 | 4.60 | 1350 | 21.2 | 38600 | 3910 | 2.84 | 15.1 | 8330 | 138 | 49.9 | 142000 |
| Glass Pour (5.54 h) | 1.18 | 4.71 | 1020 | 20.3 | 38400 | 4130 | 2.75 | 12.4 | 8400 | 135 | 58.3 | 148000 |
| Glass Pour (6.59 h) | 1.27 | 5.00 | 979 | 20.9 | 38800 | 4090 | 2.88 | 10.4 | 8490 | 135 | 58.7 | 146000 |
| Glass Pour (Final) | 1.28 | 4.80 | 979 | 21.0 | 38900 | 4080 | 2.83 | 10.4 | 8550 | 136 | 54.3 | 146000 |
| Primary HEPA A | 0.476 | 23.8 | 48.0 | 0.825 | 170 | 8200 | 1.43 | 3.18 | 733 | 5.57 | 14.5 | 23600 |
| Sampling HEPA 1 | 0.454 | 22.7 | 104 | 1.66 | 216 | 9240 | 1.36 | 4.29 | 723 | 6.04 | 24.5 | 37600 |
| Sampling HEPA 2 | 0.485 | 24.2 | 102 | 1.61 | 202 | 9430 | 1.45 | 4.33 | 704 | 5.66 | 27.6 | 38800 |
| Pre-filter | 0.199 | 0.199 | 26.9 | 0.588 | 63.2 | 284 | 0.596 | 0.596 | 2.92 | 0.323 | 2.57 | 3130 |
| Primary SBS | 0.250 | 0.250 | 3.02 | 0.250 | 8.18 | 33.3 | 0.750 | 0.750 | 2.50 | 0.250 | 0.500 | 450 |
| Demister | 0.250 | 0.250 | 13.0 | 0.250 | 21.4 | 26.3 | 0.750 | 0.750 | 2.50 | 0.250 | 0.500 | 391 |
| Condensate | 0.250 | 0.250 | 11.0 | 0.250 | 15.2 | 33.8 | 0.751 | 0.751 | 2.50 | 0.250 | 0.500 | 491 |
| Pre-filter Housing | 0.237 | 0.272 | 71.6 | 1.09 | 171 | 178 | 0.710 | 1.20 | 2.37 | 1.79 | 6.10 | 2090 |

Table A.2. Chemical Analysis of Samples Produced During the 7 M Na AP-105 Waste CLSM Run (cont.)

| Sample Name | Component Concentration (mg kg$^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ni | P | Pb | Pd | S | Sb | Se | Si | Sn | Sr | Th | Ti |
| 7 M Na AP-105 Waste Melter Feed, Batch 2, Sample 1 | 60.7 | 164 | 5.44 | 21.6 | 615 | 21.6 | 21.6 | 77100 | 7.47 | 4.86 | 21.6 | 3735 |
| 7 M Na AP-105 Waste Melter Feed, Batch 1, Sample 1 | 61.5 | 119 | 2.72 | 23.0 | 592 | 23.0 | 23.0 | 104000 | 7.31 | 5.31 | 23.0 | 4000 |
| 7 M Na AP-105 Waste Melter Feed, Batch 1, Sample 2 | 60.8 | 168 | 2.64 | 23.7 | 570 | 23.7 | 23.7 | 102000 | 8.01 | 5.06 | 23.7 | 4040 |
| 7 M Na AP-105 Waste Melter Feed, Batch 2, Sample 2 | 52.6 | 103 | 4.5 | 24.3 | 559 | 24.3 | 24.3 | 83400 | 5.59 | 4.34 | 24.3 | 3440 |
| Glass Pour Shutdown | 421 | 507 | 3.96 | 23.6 | 1480 | 23.6 | 23.6 | 208000 | 39.7 | 11.9 | 23.6 | 8140 |
| Glass Pour (Initial) | 670 | 501 | 5.05 | 23.5 | 1450 | 23.5 | 23.5 | 208000 | 56.0 | 12.1 | 23.5 | 8140 |
| Glass Pour (0.58 h) | 478 | 475 | 6.22 | 2.49 | 1360 | 2.49 | 24.9 | 209000 | 49.7 | 11.4 | 24.9 | 8200 |
| Glass Pour (2.01 h) | 355 | 141 | 6.22 | 24.0 | 1100 | 24.0 | 24.0 | 210000 | 40.7 | 11.6 | 24.0 | 8200 |
| Glass Pour (3.38 h) | 280 | 146 | 6.27 | 24.1 | 1050 | 24.1 | 24.1 | 209000 | 33.2 | 11.4 | 24.1 | 8270 |
| Glass Pour (4.43 h) | 254 | 121 | 6.59 | 24.8 | 1050 | 24.8 | 24.8 | 208000 | 32.1 | 11.3 | 24.8 | 8240 |
| Glass Pour (5.54 h) | 253 | 159 | 7.04 | 24.5 | 1030 | 24.5 | 24.5 | 208000 | 28.2 | 11.2 | 24.5 | 8230 |
| Glass Pour (6.59 h) | 206 | 440 | 5.46 | 24.7 | 1320 | 24.7 | 24.7 | 208000 | 29.2 | 11.1 | 24.7 | 8280 |
| Glass Pour (Final) | 201 | 134 | 7.04 | 23.7 | 981 | 23.7 | 23.7 | 210000 | 27.1 | 11.2 | 23.7 | 8360 |
| Primary HEPA A | 4.62 | 119 | 2.46 | 2.38 | 225 | 2.38 | 2.38 | 389000 | 2.41 | 232 | 2.38 | 18.4 |
| Sampling HEPA 1 | 7.92 | 114 | 2.58 | 2.27 | 1060 | 2.27 | 2.65 | 380000 | 1.82 | 227 | 2.27 | 19.2 |
| Sampling HEPA 2 | 5.85 | 121 | 2.92 | 2.42 | 1040 | 2.42 | 4.25 | 370000 | 2.45 | 224 | 2.42 | 18.9 |
| Pre-filter | 0.569 | 4.97 | 0.298 | 0.993 | 129 | 0.993 | 0.993 | 4.97 | 0.795 | 0.199 | 0.993 | 0.199 |
| Primary SBS | 0.368 | 6.25 | 0.375 | 1.25 | 21.1 | 1.25 | 1.25 | 6.63 | 1.00 | 0.250 | 1.25 | 0.250 |
| Demister | 1.21 | 6.25 | 0.375 | 1.25 | 23.4 | 1.25 | 1.25 | 14.1 | 1.00 | 0.250 | 1.25 | 0.367 |
| Condensate | 0.747 | 6.255 | 0.375 | 1.25 | 27.5 | 1.25 | 1.25 | 7.78 | 1.00 | 0.250 | 1.25 | 0.250 |
| Pre-filter Housing | 27.6 | 14.0 | 0.355 | 1.18 | 115 | 1.18 | 1.18 | 19.5 | 0.947 | 0.237 | 1.18 | 0.576 |

Table A.2. Chemical Analysis of Samples Produced During the 7 M Na AP-105 Waste CLSM Run (cont.)

| Sample Name | Component Concentration (mg kg$^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tl | U | V | W | Y | Zn | Zr | Br | Cl | F | N as NO$_3$ | N as NO$_2$ |
| 7 M Na AP-105 Waste Melter Feed, Batch 2, Sample 1 | 130 | 21.6 | 5.29 | 96.2 | 3.82 | 12850 | 8450 | 95.5 | 2275 | 95.5 | 15800 | 10900 |
| 7 M Na AP-105 Waste Melter Feed, Batch 1, Sample 1 | 138 | 23.0 | 5.18 | 93.9 | 4.11 | 13400 | 10200 | 97.0 | 2070 | 97.0 | 13800 | 9930 |
| 7 M Na AP-105 Waste Melter Feed, Batch 1, Sample 2 | 142 | 23.7 | 5.69 | 92.4 | 4.24 | 12700 | 9900 | 96.3 | 2020 | 96.3 | 13300 | 9590 |
| 7 M Na AP-105 Waste Melter Feed, Batch 2, Sample 2 | 146 | 24.3 | 4.64 | 75.9 | 3.44 | 11100 | 8530 | 99.0 | 2140 | 99.0 | 14500 | 10000 |
| Glass Pour Shutdown | 142 | 23.6 | 112 | 161 | 40.3 | 26600 | 20600 | 107 | 3660 | 107 | -- | -- |
| Glass Pour (Initial) | 141 | 23.5 | 139 | 144 | 41.0 | 26700 | 20800 | 115 | 3470 | 115 | -- | -- |
| Glass Pour (0.58 h) | 74.7 | 24.9 | 128 | 132 | 38.5 | 27100 | 20800 | 110 | 2960 | 110 | -- | -- |
| Glass Pour (2.01 h) | 144 | 24.0 | 111 | 171 | 40.2 | 27100 | 20800 | 104 | 3430 | 104 | -- | -- |
| Glass Pour (3.38 h) | 144 | 24.1 | 93.8 | 177 | 40.2 | 28200 | 21000 | 122 | 3490 | 138 | -- | -- |
| Glass Pour (4.43 h) | 149 | 24.8 | 87.1 | 198 | 41.2 | 27900 | 21000 | 120 | 3100 | 120 | -- | -- |
| Glass Pour (5.54 h) | 147 | 24.5 | 81.4 | 203 | 40.7 | 27300 | 21000 | 119 | 3480 | 119 | -- | -- |
| Glass Pour (6.59 h) | 148 | 24.7 | 77.0 | 224 | 41.1 | 27400 | 21100 | 80.9 | 3060 | 84.2 | -- | -- |
| Glass Pour (Final) | 142 | 23.7 | 77.3 | 206 | 40.8 | 28100 | 21200 | 116 | 2720 | 116 | -- | -- |
| Primary HEPA A | 14.3 | 23.8 | 0.476 | 84.4 | 2.26 | 10900 | 94.1 | 0.912 | 17.8 | 7.40 | 553 | 0.912 |
| Sampling HEPA 1 | 13.6 | 22.7 | 0.454 | 90.0 | 2.20 | 10900 | 92.7 | 154 | 21800 | 83.5 | 161 | 94.2 |
| Sampling HEPA 2 | 14.5 | 24.2 | 0.485 | 83.9 | 2.16 | 10800 | 91.4 | 117 | 23300 | 70.7 | 261 | 114 |
| Pre-filter | 2.98 | 9.93 | 0.199 | 0.993 | 0.199 | 13.0 | 0.596 | 1.59 | 50.0 | 7.95 | 11200 | 7.95 |
| Primary SBS | 7.50 | 12.5 | 0.250 | 1.25 | 0.250 | 8.54 | 0.750 | 9.97 | 464 | 11.2 | 94.8 | 1810 |
| Demister | 7.50 | 12.5 | 0.250 | 1.25 | 0.250 | 14.6 | 0.750 | 10.0 | 412 | 19.9 | 1030 | 10.0 |
| Condensate | 7.51 | 12.5 | 0.250 | 1.25 | 0.250 | 13.9 | 0.751 | 9.94 | 521 | 16.4 | 134 | 1665 |
| Pre-filter Housing | 7.10 | 11.8 | 0.237 | 1.18 | 0.237 | 24.1 | 0.710 | 9.35 | 1020 | 20.2 | 23200 | 9.35 |

Table A.2. Chemical Analysis of Samples Produced During the 7 M Na AP-105 Waste CLSM Run (cont.)

| Sample Name | Component Concentration (mg kg$^{-1}$) | | | Component Concentration (µg L$^{-1}$) | Component Concentration (pCi g$^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | P as PO$_4$ | Total S (Solids) or SO$_4$ (All Others) | TOC | Acetonitrile | $^{241}$Am | $^{242}$Cm | $^{243/244}$Cm | $^{237}$Np | $^{238}$Pu | $^{239/240}$Pu | $^{244}$Pu |
| 7 M Na AP-105 Waste Melter Feed, Batch 2, Sample 1 | 53.1 | 1620 | 22800 | -- | 1.40E+02 | 2.01E-01 | 2.19E+00 | 2.39E+00 | 2.74E+00 | 2.02E+01 | 2.95E-01 |
| 7 M Na AP-105 Waste Melter Feed, Batch 1, Sample 1 | 51.4 | 1440 | 24500 | -- | 1.19E+02 | 6.18E-01 | 2.85E+00 | 2.69E+00 | 1.25E+00 | 1.59E+01 | 6.23E-01 |
| 7 M Na AP-105 Waste Melter Feed, Batch 1, Sample 2 | 53.3 | 1410 | 24050 | -- | 1.19E+02 | 4.69E-01 | 3.51E+00 | 8.73E-01 | 1.87E+00 | 1.44E+01 | 4.15E-01 |
| 7 M Na AP-105 Waste Melter Feed, Batch 2, Sample 2 | 94.2 | 1540 | 24400 | -- | 1.31E+02 | 7.96E-01 | 3.14E+00 | 1.61E+00 | 2.96E+00 | 1.73E+01 | 2.11E-01 |
| Glass Pour Shutdown | -- | 1220 | -- | -- | 2.24E+01 | 2.35E-01 | 0.00E+00 | 4.44E+00 | 2.09E+00 | 1.44E+01 | 7.84E-01 |
| Glass Pour (Initial) | -- | 1270 | -- | -- | 2.42E+01 | 0.00E+00 | 9.40E-01 | 5.16E+00 | 1.81E+00 | 1.75E+01 | 2.12E-01 |
| Glass Pour (0.58 h) | -- | 1040 | -- | -- | 1.47E+02 | 0.00E+00 | 3.86E+00 | 6.06E+00 | 5.22E+00 | 3.38E+01 | 0.00E+00 |
| Glass Pour (2.01 h) | -- | 1120 | -- | -- | 1.16E+02 | 2.32E-01 | 2.57E+00 | 1.76E+00 | 3.51E+00 | 2.30E+01 | 7.92E-01 |
| Glass Pour (3.38 h) | -- | 1070 | -- | -- | 1.60E+02 | 2.29E-01 | 2.82E+00 | 3.78E+00 | 3.09E+00 | 3.52E+01 | 4.11E-01 |
| Glass Pour (4.43 h) | -- | 907 | -- | -- | 1.89E+02 | 0.00E+00 | 2.93E+00 | 3.40E+00 | 4.69E+00 | 3.57E+01 | 0.00E+00 |
| Glass Pour (5.54 h) | -- | 1070 | -- | -- | 2.28E+02 | 9.78E-01 | 3.85E+00 | 4.13E+00 | 5.19E+00 | 3.66E+01 | 3.38E-01 |
| Glass Pour (6.59 h) | -- | 880 | -- | -- | 2.68E+02 | 5.29E-01 | 5.01E+00 | 3.41E+00 | 7.59E+00 | 3.82E+01 | 2.01E+00 |
| Glass Pour (Final) | -- | 729 | -- | -- | 2.42E+02 | 1.40E+00 | 5.62E+00 | 3.30E+00 | 4.24E+00 | 3.54E+01 | 8.46E-01 |
| Primary HEPA A | 0.912 | 74.7 | -- | -- | 5.51E-01 | 2.39E-01 | 1.39E-01 | 2.50E-03 | 1.19E-01 | 8.32E-01 | 3.35E-01 |
| Sampling HEPA 1 | 4.71 | 2320 | -- | -- | 1.04E+00 | 1.13E-01 | -1.73E-01 | -1.85E-01 | 0.00E+00 | 2.93E-01 | 1.95E-01 |
| Sampling HEPA 2 | 4.92 | 2290 | -- | -- | 6.50E-01 | 2.42E-01 | -1.85E-01 | -2.89E-01 | 2.17E-01 | 3.26E-01 | 2.17E-01 |
| Pre-filter | 7.95 | 721 | -- | -- | 6.29E-02 | 2.05E-02 | -7.82E-03 | -7.81E-03 | -2.15E-02 | 3.23E-02 | 1.08E-01 |
| Primary SBS | 9.97 | 63.7 | 400 | -- | 4.84E-02 | 0.00E+00 | 0.00E+00 | 8.42E-02 | -2.83E-02 | 1.70E-01 | 1.70E-01 |
| Demister | 10.0 | 103 | 405 | 310000 | 9.36E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | -3.30E-02 | -3.29E-02 | 1.65E-01 |
| Condensate | 9.94 | 80.6 | 418 | 270000 | 1.90E-01 | -3.14E-02 | -2.36E-02 | 9.65E-02 | -1.53E-02 | 8.48E-02 | 9.15E-02 |
| Pre-filter Housing | 18.7 | 738 | 676 | -- | 3.90E-01 | 0.00E+00 | 0.00E+00 | -5.01E-02 | 0.00E+00 | 1.05E-01 | 7.88E-02 |

Table A.2. Chemical Analysis of Samples Produced During the 7 M Na AP-105 Waste CLSM Run (cont.)

| Sample Name | Loss on Ignition (%) | Ash (%) |
|---|---|---|
| 7 M Na AP-105 Waste Melter Feed, Batch 2, Sample 1 | 54.81 | 45.19 |
| 7 M Na AP-105 Waste Melter Feed, Batch 1, Sample 1 | 52.72 | 47.28 |
| 7 M Na AP-105 Waste Melter Feed, Batch 1, Sample 2 | 54.50 | 45.50 |
| 7 M Na AP-105 Waste Melter Feed, Batch 2, Sample 2 | 60.24 | 39.76 |
| Glass Pour Shutdown | 2.49 | 97.51 |
| Glass Pour (Initial) | 2.20 | 97.80 |
| Glass Pour (0.58 h) | 2.19 | 97.81 |
| Glass Pour (2.01 h) | 2.71 | 97.29 |
| Glass Pour (3.38 h) | 2.62 | 97.38 |
| Glass Pour (4.43 h) | 2.87 | 97.13 |
| Glass Pour (5.54 h) | 2.50 | 97.50 |
| Glass Pour (6.59 h) | 2.77 | 97.23 |
| Glass Pour (Final) | 2.63 | 97.37 |
| Primary HEPA A | 1.47 | 98.53 |
| Sampling HEPA 1 | 3.42 | 96.58 |
| Sampling HEPA 2 | 3.71 | 96.29 |
| Pre-filter | -- | -- |
| Primary SBS | -- | -- |
| Demister | -- | -- |
| Condensate | -- | -- |
| Pre-filter Housing | -- | -- |

## Pacific Northwest
## National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354
1-888-375-PNNL (7665)

*www.pnnl.gov*