

Vitrification of Hanford Tank 241-AP-101 Waste and Simulant

November 2022

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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-101 (referred to herein as AP-101) is the second Hanford radioactive tank waste planned to be processed and vitrified. A portion of AP-101 waste was retrieved by Washington River Protection Solutions, LLC (WRPS) and transferred to Pacific Northwest National Laboratory (PNNL). The waste went through solids filtration and cesium removal by ion exchange before a glass composition was calculated from the Kim et al. glass models¹ to satisfy the WTP baseline requirements and then glass forming chemicals (GFCs) were added to the waste to form a liquid/solids mixture called melter feed.

To prepare for the processing of the AP-101 waste melter feed and learn about the production expectations, a simulant version of AP 101 waste was formulated from the best-basis inventory (BBI) for the Hanford Tank 241-AP-101 liquid² with an assumed target dilution of the waste from the BBI sodium molarity of 8.61 M to the desired 5.5 M Na. The same process was applied to the AP-101 simulant using glass models to determine GFCs additions to form a simulant melter feed, which was then processed in a non-radioactive, continuous laboratory-scale melter (CLSM) system. The AP-101 simulant melter feed was charged into the CLSM for 6.11 h of processing, which produced 6.55 kg of glass, for an average glass production rate of 2275 kg m² d⁻¹.

Since there were no processing issues with the AP-101 simulant melter feed, the actual AP-101 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 AP-101 waste melter feed was charged into the CLSM for 12.14 h of processing, which produced 8.75 kg of glass, for an average glass production rate of 1530 kg m² d⁻¹. During the AP-101 waste melter feed charging, the pump used to move the feed reached a maximum and it is believed that if the pump had a greater capacity, a greater average glass production rate could have been achieved.

Samples of the AP-101 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, the primary components in the glass produced from the conversion of the AP-101 melter feeds were within 10 % of their target values, as has routinely been the case with glasses produced through vitrification in the CLSM system. However, the recovery of several components during the AP-101 waste CLSM run fell below the expected range of 100 ± 10 % and indicated that the measurement for the amount of melter feed consumed may need to be revised to achieve a more accurate number under the given radioactive restrictions.

A constituent of interest present in low quantities in the AP-101 waste is ⁹⁹Tc or its non-radioactive surrogate, Re, added to the AP-101 simulant. Analysis for the quantities of ⁹⁹Tc and Re in the AP-101 glass product resulted in an average single-pass retention from the melter feed during relative chemical steady state of 55 ± 2 % for ⁹⁹Tc and 45 ± 2 % for Re. Compared to the processing of other melter feeds, the retention of ⁹⁹Tc in the AP-101 glass was greater than in both AP-107 and AP-105 glass, while the retention of Re in the AP-101 was less than in the AP-107 glass, but greater than in the AP-105 glass.

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.

² Detrich EJ. 2015. *Derivation of Best-Basis Inventory for Tank 241-AP-101 as of July 1, 2015*. RPP-RPT-50313, Rev. 02. Washington River Protection Solutions LLC, Richland, Washington.

A spike of I was added into the AP-101 melter feed that could be detected above the analysis detection limits. However, the iodine was only detectable above the ~6 ppm limit in one glass pour: the pour immediately following the burn off of the cold cap, where the I level reached ~30 ppm. This event was significant because the glass was poured immediately after burn off and thus it is presumed that the iodine had yet to volatilize from the glass melt while idling. It is recommended to perform future tests with I spikes at greater levels so that it can be detected in additional glass pours to determine if the expected 50 % retention of I used in the Kim et al. glass models can be confirmed.

Offgas liquid samples were analyzed for acetonitrile, which was present at greater concentrations in CLSM liquids than in other scaled melter systems. This result was expected based on unique conditions with the CLSM system including a small plenum space leading to low residence time for offgas and the rapidity of offgas cooling upon exiting the CLSM vessel due to the location and environment. About 90 % of the total acetonitrile captured during both the AP-101 simulant and waste CLSM runs was found in the offgas condensate and demister liquids, thus it is recommended that only those liquids be sent for analysis if future testing to study the presence of acetonitrile in offgas products is desired.

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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
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
SBS	submerged-bed scrubber
scm	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

Summary	iv
Acknowledgements.....	vi
Acronyms and Abbreviations	vii
Contents	viii
1.0 Introduction.....	1.1
2.0 Quality Assurance.....	2.1
3.0 Experimental.....	3.1
3.1 Melter Feed Preparation.....	3.1
3.2 CLSM System.....	3.4
3.2.1 System Design and Configuration.....	3.4
3.2.2 Test Conditions.....	3.9
3.3 Sample Analysis Methods	3.10
4.0 CLSM Run Results	4.1
4.1 AP-101 Simulant Run.....	4.1
4.1.1 Operational Description.....	4.1
4.1.2 Production Results.....	4.2
4.1.3 Sample Chemical Analysis.....	4.2
4.2 AP-101 Waste Run	4.4
4.2.1 Operational Description.....	4.4
4.2.2 Production Results.....	4.5
4.2.3 Sample Chemical Analysis.....	4.6
5.0 Discussion.....	5.1
5.1 Glass Composition.....	5.1
5.1.1 Primary Glass Components	5.1
5.1.2 Minor Glass Components	5.5
5.1.3 Minor Impurity and Radioactive Components	5.7
5.2 DF, R, and Rec Calculations.....	5.10
5.3 Offgas Analysis.....	5.14
5.4 ⁹⁹ Tc and Re Retention and Analysis	5.17
5.5 Cs and I Retention and Analysis.....	5.19
5.6 Acetonitrile Analysis	5.21
5.7 Production Comparison	5.22
6.0 Conclusions.....	6.1
7.0 References.....	7.1
Appendix A – Chemical Analysis of Samples Collected from the AP-101 Simulant and Waste CLSM Runs	A.1

Figures

Figure 3.1. Simplified flow diagram of the CLSM systems.	3.5
Figure 3.2. Acrylic CLSM vessel model (left) and actual CLSM vessel (right).....	3.6
Figure 3.3. CLSM vessel lid and identified ports. The designation ‘TC’ stands for a thermocouple port.....	3.7
Figure 3.4. The simulant CLSM system layout under the fume canopy in the APEL.....	3.8
Figure 3.5. The radioactive CLSM system layout in the RPL HCA (left) and CA (right) fume hoods.....	3.9
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 AP-101 simulant CLSM run and b) the AP-101 waste CLSM run.....	4.3
Figure 5.1. Content of a set of primary components (SiO ₂ , Na ₂ O, B ₂ O ₃ , Al ₂ O ₃ , Fe ₂ O ₃ , ZnO, and ZrO ₂) in the glass produced during the CLSM run with the AP-101 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 (AP-101 simulant from 0.00 – 6.56 kg and AP-101 waste from 6.61 – 15.30 kg).	5.3
Figure 5.2. Content of a set of primary components (CaO, Li ₂ O, TiO ₂ , and MgO) in the glass produced during the CLSM run with the AP-101 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 (AP-101 simulant from 0.00 – 6.56 kg and AP-101 waste from 6.61 – 15.30 kg).	5.4
Figure 5.3. Content of a set of minor components (K ₂ O, SO ₃ , Cl, F, Cr ₂ O ₃ , NiO, and P ₂ O ₅) in the glass produced during the CLSM run with the AP-101 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 (AP-101 simulant from 0.00 – 6.56 kg and AP-101 waste from 6.61 – 15.30 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.....	5.6
Figure 5.4. Content of a set of minor glass impurities (La, Mo, W, Ba, Sr, Mn, V, and As) in the glass produced during the CLSM run with the AP-101 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 (AP-101 simulant from 0.00 – 6.56 kg and AP-101 waste from 6.61 – 15.30 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.....	5.8
Figure 5.5. Content of a set of minor glass impurities (Sn, Y, Pb, Cu, Cd, and Co) in the glass produced during the CLSM run with the AP-101 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 (AP-101 simulant from 0.00 – 6.56 kg and AP-101 waste from 6.61 – 15.30 kg). 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..... 5.9

Figure 5.6. Activity of radionuclides (^{241}Am , $^{239/240}\text{Pu}$, ^{237}Np , ^{238}Pu , and $^{243/244}\text{Cm}$) in the glass produced during the CLSM run with the AP-101 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 AP-101 waste melter feeds (from 6.61 – 15.30 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..... 5.10

Figure 5.7. Percentage of the quantity of each component in the output stream (*Output%*) in the CLSM offgas treatment system during a) the AP-101 simulant run and, b) the AP-101 waste run..... 5.16

Figure 5.8. Percentage of the quantity of each component in the output stream (*Output%*) in the CLSM offgas treatment system during the AP-101 waste run with demister collection added to the ‘Condensate’ instead of the ‘End Filters’..... 5.17

Figure 5.9. Measured Re content and retention in the glass product from the AP-101 simulant CLSM run (top; 0.00 – 6.56 kg discharged) and measured ^{99}Tc content and retention in the glass product from the AP-101 waste CLSM run (bottom; 6.61 – 15.30 kg discharged)..... 5.18

Figure 5.10. Measured a) Cs and b) I content in the glass produced during the CLSM run with the AP-101 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 (AP-101 simulant from 0.00 – 6.56 kg and AP-101 waste from 6.61 – 15.30 kg)..... 5.20

Tables

Table 3.1. AP-101 Simulant and Waste Compositions.....	3.1
Table 3.2. AP-101 Simulant Chemical Recipe	3.2
Table 3.3. AP-101 Simulant and Waste Melter Feed GFCs Additions.....	3.2
Table 3.4. Target Glass Compositions for the AP-101 CLSM Runs and Previous CLSM Run Glasses	3.4
Table 3.5. Target CLSM Operating Conditions.....	3.10
Table 3.6. Sample Chemical Analysis Methods and Components Scanned.....	3.11
Table 4.1. Timing and Mass of Glass Pours During the AP-101 Simulant CLSM Run.....	4.1
Table 4.2. CLSM Production Results During Both AP-101 CLSM Runs.....	4.2
Table 4.3. Timing and Mass of Glass Pours During the AP-101 Waste CLSM Run	4.5
Table 5.1. Comparison of AP-101 Simulant and Waste CLSM Run Glass Products with Target Compositions	5.2
Table 5.2. Comparison of AP-101-S and AP-101-W Target Glass Compositions with the Compositions of the Analyzed Melter Feeds.....	5.5
Table 5.3. Component Mass Flow Rates, DFs, Retentions, and Recoveries During the AP-101 Simulant CLSM Run	5.13
Table 5.4. Component Mass Flow Rates, DFs, Retentions, and Recoveries During the AP-101 Waste CLSM Run.....	5.14
Table 5.5. Quantities of Selected Components in CLSM Output Streams During the AP-101 Simulant and Waste CLSM Runs	5.15
Table 5.6. Re and Cs Relationships During the AP-101 Simulant CLSM Run.....	5.18
Table 5.7. ⁹⁹ Tc and Cs Relationships During the AP-101 Waste CLSM Run	5.19
Table 5.8. Acetonitrile in Liquids from the AP-101 Simulant and Waste CLSM Runs	5.21
Table A.1. Chemical Analysis of Samples Produced During the AP-101 Simulant CLSM Run	A.1
Table A.2. Chemical Analysis of Samples Produced During the AP-101 Waste CLSM Run	A.6

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 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 melter 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 is designing a Tank Side Cesium Removal (TSCR) system to remove suspended solids and cesium ($\text{Cs}/^{137}\text{Cs}$) from the supernatant (Bernards et al. 2017). After these processes, the waste will be combined with glass-forming chemicals (GFCs) to form a mixed aqueous and solid slurry, called melter feed, that can be charged into the melter. 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 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 in the Applied Process Engineering Laboratory (APEL) at PNNL, and a study was performed to evaluate the system performance (Dixon et al. 2020a).

The first portion of waste received for vitrification was from tank 241-AP-105 (hereafter called AP-105). The AP-105 waste was filtered to remove solids (Geeting et al. 2018a), it underwent ion exchange to remove cesium (Fiskum et al. 2018), had GFCs added based on the WDFL1 composition designed by Matlack et al. (2017), and was vitrified in the CLSM (Dixon et al. 2018). The condensate produced from vitrification was concentrated and converted to a non-glass waste form based on the Cast Stone waste form formulation (Cantrell et al. 2018). To determine the expected production characteristics for AP-105 waste vitrification, a simulant version of the AP-105 waste was processed in the CLSM in APEL (Dixon et al. 2018).

The next portion of waste received was the supernatant from Hanford tank 241-AP-107 (hereafter called AP-107). This AP-107 waste went through solids removal by filtration (Geeting et al. 2018b) and cesium removal by ion exchange (Westesen et al. 2021a). After these activities, the Kim et al. (2012) model for WTP baseline glass formulation was used to calculate the mass of GFCs to be added to the AP-107 waste to form the AP-107 melter feed, which was vitrified in the CLSM (Dixon et al. 2019). In a subsequent study, the offgas condensate produced from the AP-107 vitrification was concentrated in an evaporator and added to a new portion of AP-107 waste, after the waste went through solids removal by filtration (Geeting et al. 2019) and cesium removal by ion exchange (Fiskum et al. 2019), to mimic the recycle action of the EMF and LAW facility (Dixon et al. 2020b). This combined AP-107 recycle composition was entered into the Kim et al. (2012) model to determine the appropriate GFCs and a new glass formulation (termed AP-107-R1), which was vitrified in the CLSM (Dixon et al. 2020b).

A two-cycle recycle action was mimicked by collecting the condensate liquids generated from vitrification of the AP-107 recycle composition in the CLSM (Dixon et al. 2020b) and concentrating the ~7.5 L of solution to ~512 mL while retaining over 95% of all desired analytes (Dixon et al. 2022a). This AP-107 concentrate was combined in a 7.0 vol% ratio with post-filtration (Allred et al. 2021) and post-ion exchange (Westesen et al. 2021b) AP-107 waste, the estimated composition of which was used in the Kim et al. (2012) model to determine the appropriate GFCs additions to form the two-time recycle AP-107 melter feed and a new glass formulation (termed AP-107-R2). The two-time recycle AP-107 melter feed was processed in the CLSM system after which an AP-105 melter feed, as calculated by the Kim et al. (2012) model from a sample of AP-105 waste that went through solids removal by filtration (Allred et al. 2020) and cesium removal by ion exchange (Fiskum et al. 2021), was processed without shutting the system down (Dixon et al. 2022a).

The purpose of the test described in this report was to evaluate the processing of the waste samples from Hanford tank 241-AP-101 (hereafter called AP-101), the second composition planned for processing in the DFLAW flowsheet. To prepare for the processing of the AP-101 waste given that this composition had not been processed in the CLSM previously, a simulant of AP-101 melter feed was designed and processed in the simulant CLSM system in the APEL. Results from the AP-101 processing were compared with previous AP-107 and AP-105 runs to help demonstrate the ability of the CLSM system to support future WTP programmatic needs regarding 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 AP-101 simulant melter feed and the AP-101 melter feed from the actual Hanford tank AP-101 waste. The CLSM systems in the APEL and the RPL, 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 AP-101 waste was designed from the best-basis inventory (BBI) for the Hanford Tank 241-AP-101 liquid (Detrich 2015) and an assumed target dilution of the waste from the BBI sodium molarity of 8.61 M to the desired 5.5 M Na. Based on these assumptions, the estimated AP-101 simulant composition used for input into the Kim et al. (2012) glass models is shown in Table 3.1 and the chemical recipe for the AP-101 waste simulant created from this composition is shown in Table 3.2. The amount of GFCs to be added per liter of AP-101 waste simulant, as determined by the Kim et al. (2012) glass models to calculate a glass composition to satisfy the WTP baseline requirements, are shown in Table 3.3 and these GFCs were estimated to increase the volume of the resultant AP-101 simulant melter feed by 0.4185 L per liter of waste simulant. Ultimately, 10.54 L of AP-101 simulant melter feed was batched, which weighed 16.795 kg for a measured melter feed density of 1.59 kg L⁻¹ with a calculated glass yield of 726 g of glass per liter of melter feed. This melter feed was spiked with Re₂O₇, 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. AP-101 Simulant and Waste Compositions

Analyte	AP-101 Simulant Composition (mg L ⁻¹)	AP-101 Waste Composition (mg L ⁻¹)
Al	9004	10267
Cr	600	542
K	3263	3778
Na	126445	131484
S	1890	1657
Cl	3097	3066
F	119	--
P	535	450
NO ₂	50450	49839
NO ₃	150712	138351
Tc-99	6.12	9.27
Total Organic Carbon (TOC)	1820	1834 ^(a)

^(a) Value estimated based on BBI

Table 3.2. AP-101 Simulant Chemical Recipe

Chemicals	Amount (mg L ⁻¹)
Al(NO ₃) ₃ · 9H ₂ O	126.46
H ₃ BO ₃	0.08
Na ₂ CrO ₄	1.91
KOH	4.66
KI	0.10
NaOH	101.75
SiO ₂	0.08
NaCl	5.16
NaF	0.26
Na ₃ PO ₄ · 12H ₂ O	6.57
Na ₂ SO ₄	8.46
NaNO ₂	77.20
NaNO ₃	122.11
Na ₂ CO ₃	7.46
NaC ₂ H ₃ O ₂	0.87
NaHCO ₂	2.22
C ₂ H ₄ O ₃	0.90
Na ₂ C ₂ O ₄	0.79

Table 3.3. AP-101 Simulant and Waste Melter Feed GFCs Additions

GFCs	Chemical Formula	AP-101 Simulant GFCs (mg L ⁻¹)	AP-101 Waste GFCs (mg L ⁻¹)	Chemical Assay (%)	Source
Kyanite	Al ₂ SiO ₅	76.09	66.91	98.1	Kyanite Mining Corp.
Boric Acid	H ₃ BO ₃	183.23	174.45	100.2	Noah
Wollastonite	Ca ₂ SiO ₄	100.01	72.44	97.8	NYCO Mineral
Iron Oxide	Fe ₂ O ₃	53.97	51.43	99.4	JT Baker
Lithium Carbonate	Li ₂ CO ₃	37.06	0.00	99.6	Alfa Aesar
Olivine	Mg ₂ SiO ₄	30.01	28.94	90.5	Unimin Corp.
Silica	SiO ₂	359.82	366.02	99.5	Sil-co-Sil
Rutile	TiO ₂	13.99	13.39	95.4	Chemalloy
Zinc Oxide	ZnO	36.23	34.48	99.9	Noah
Zircon	ZrSiO ₄	46.31	44.07	99.1	Prince Mineral
Sucrose	C ₁₂ H ₂₂ O ₁₁	71.14	66.56	100.0	C+H Sugar
Waste Loading (%)	--	19.50%	21.35%	--	--
Target Glass Yield (g L ⁻¹)	--	726	709	--	--

Actual supernatant from Hanford tank 241-AP-101 was collected by WRPS and received by PNNL. Upon receipt, PNNL diluted the AP-101 waste with Columbia River water to a target of 5.5 M Na and passed the liquid through a backpulse dead-end filter system for solids removal (Allred et al. 2022). The analyzed sodium molarity of the diluted AP-101 waste was 5.72 M. The approximately 14.1 L of resulting liquid were processed through an ion exchange column system at 16 °C, which collected all but 0.05 % of the ¹³⁷Cs activity from waste, while 95% or more of all desired analytes (see Table 3.1) remained in the waste (Westesen et al. 2022). The composition of the AP-101 waste was measured after ion exchange (Westesen et al. 2022) and the primary analyte values used to calculate the melter feed are shown in Table 3.1. Note that the total organic carbon (TOC) in the AP-101 waste was not analyzed and thus the value for the TOC was estimated based on the BBI and known dilution from the analyzed Na molarity.

The AP-101 waste composition was used in the Kim et al. (2012) glass models to calculate the GFCs to be added to the waste to form AP-101 waste melter feed, which are shown in Table 3.3. Two batches of AP-101 waste melter feed were prepared, batch 1 used 7.139 kg of AP-101 waste and batch 2 used 6.828 kg of AP-101 waste. Given a composite density for the AP-101 waste of 1.2367 g mL^{-1} , the volume of waste in batch 1 was 5.77 L and batch 2 was 5.52 L. The GFCs added to each batch were estimated to increase the volume of the melter feed by 0.3804 L per liter of waste. The final AP-101 waste melter feed in batch 1 weighed 12.443 kg with an estimated volume of 7.97 L and batch 2 weighed 11.901 kg with an estimated volume of 7.62 L. Both batches of AP-101 waste melter feed had a resultant density of 1.56 kg L^{-1} with a calculated glass yield of 709 g of glass per liter of melter feed.

The target glass compositions expected from the vitrification of the AP-101 simulant melter feed (referred to as AP-101-S) and AP-101 waste melter feed (referred to as AP-101-W), as calculated by the Kim et al. (2012) glass models, are shown in Table 3.4. It is noted that the slightly lower Na + K level in the AP-101 simulant resulted in the glass model calculating a Li_2CO_3 GFCs addition and Li_2O in the final glass that are not present in the AP-101 waste melter feed or AP-101-W glass composition. Likewise, the wollastonite GFCs addition in the AP-101 simulant was greater than in the AP-101 waste and the final AP-101-S glass had a slightly higher CaO target than the AP-101-W glass. Conversely, the silica GFCs addition was greater in the AP-101 waste melter feed and the SiO_2 target greater in the AP-101-W glass. Table 3.4 also displays multiple target glass compositions previously vitrified in the CLSM system as well as comparable compositions from literature.

Table 3.4. Target Glass Compositions for the AP-101 CLSM Runs and Previous CLSM Run Glasses

Component	AP-101-S (wt%)	AP-101-W (wt%)	AP-107-2R ^(a) (wt%)	AP-107-1R ^(b) (wt%)	AP-107 ^(c) (wt%)	AP107WDFL ^(d) (wt%)	AP-105 ^(a) (wt%)	WDFL1 ^(e) (wt%)
Al ₂ O ₃	6.13	6.12	6.13	6.13	6.12	6.10	6.13	6.10
B ₂ O ₃	9.95	9.95	9.95	9.95	9.95	10.00	9.95	10.00
CaO	4.45	3.39	4.09	4.53	3.69	3.94	2.64	2.08
Cl	0.16	0.17	0.19	0.18	0.15	0.42	0.22	0.45
Cr ₂ O ₃	0.09	0.08	0.08	0.07	0.08	0.08	0.06	0.05
F	0.01	0.00	0.03	0.03	0.00	0.04	0.00	0.01
Fe ₂ O ₃	5.52	5.52	5.52	5.52	5.52	5.50	5.52	5.50
K ₂ O	0.39	0.47	0.49	0.36	0.47	0.38	0.49	0.41
Li ₂ O	1.44	0.00	1.06	1.52	0.50	0.89	0.00	--
MgO	1.49	1.49	1.49	1.49	1.49	1.48	1.49	1.48
Na ₂ O	16.44	17.96	16.89	16.34	17.49	17.20	19.35	21.00
NiO	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.00
P ₂ O ₅	0.12	0.10	0.16	0.19	0.15	0.13	0.11	0.17
SO ₃	0.39	0.36	0.38	0.39	0.37	0.44	0.33	0.30
SiO ₂	45.49	46.45	45.60	45.36	46.08	45.50	45.76	44.54
TiO ₂	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
ZnO	3.51	3.51	3.51	3.51	3.51	3.50	3.51	3.50
ZrO ₂	3.02	3.01	3.02	3.02	3.01	3.00	3.02	3.00
Total	100.0	100.0	100.0	100.0	100.0	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. (2022a)

^(b) Dixon et al. (2020b)

^(c) Dixon et al. (2019)

^(d) Matlack et al. (2018)

^(e) Matlack et al. (2017)

3.2 CLSM System

This section describes the two CLSM systems: the simulant system assembled under a fume canopy in the APEL, and the radioactive system as assembled in a high contamination area (HCA) fume hood in the RPL with supporting equipment located in an adjacent 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 melter, but to reproduce the feed-to-glass conversion process performed in the melter. A simplified flow diagram of both the radioactive and simulant CLSM systems is shown in Figure 3.1.

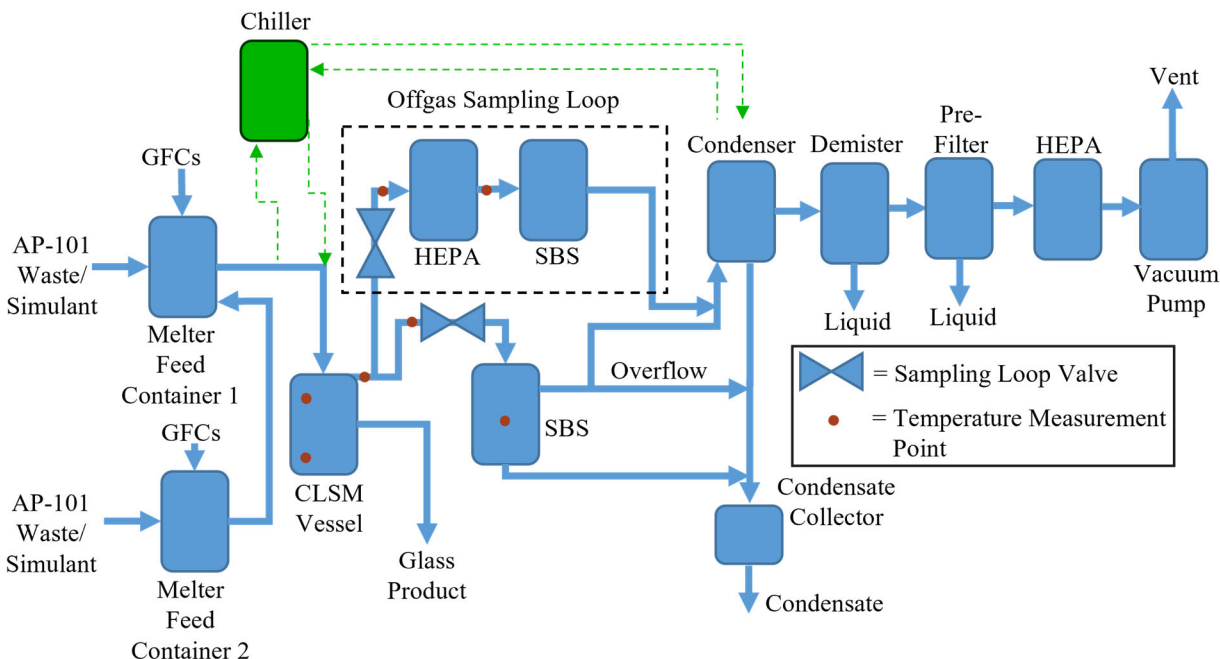


Figure 3.1. Simplified flow diagram of the CLSM systems.

The AP-101 simulant CLSM run used one container of melter feed, placed in the ‘Melter Feed Container 1’ position, while the AP-101 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 radioactive CLSM system, 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. 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 m² with a plenum volume of 0.0018 m³. 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).

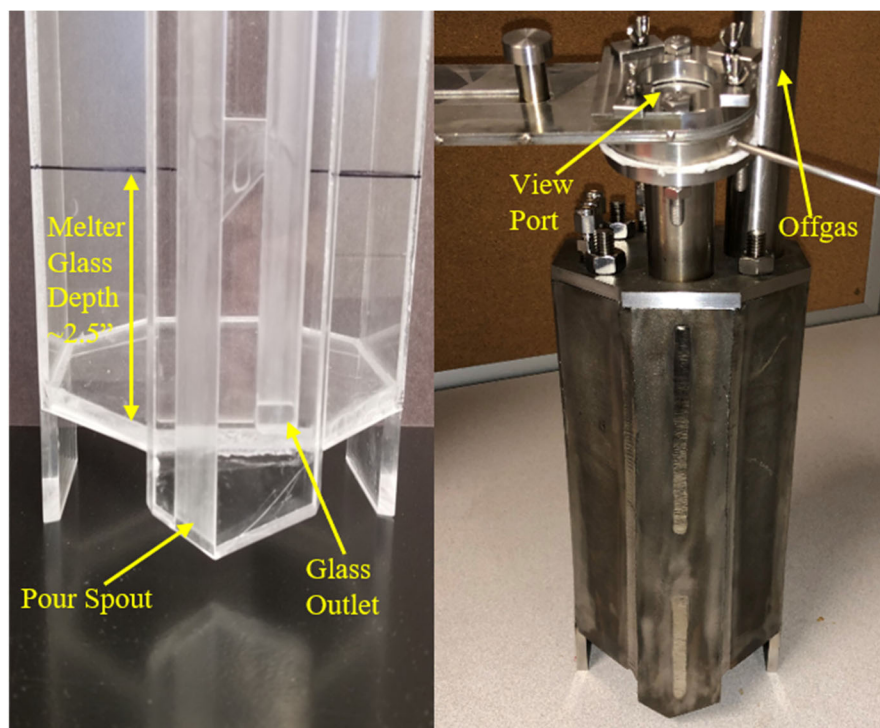


Figure 3.2. Acrylic CLSM vessel model (left) and actual CLSM vessel (right).

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.

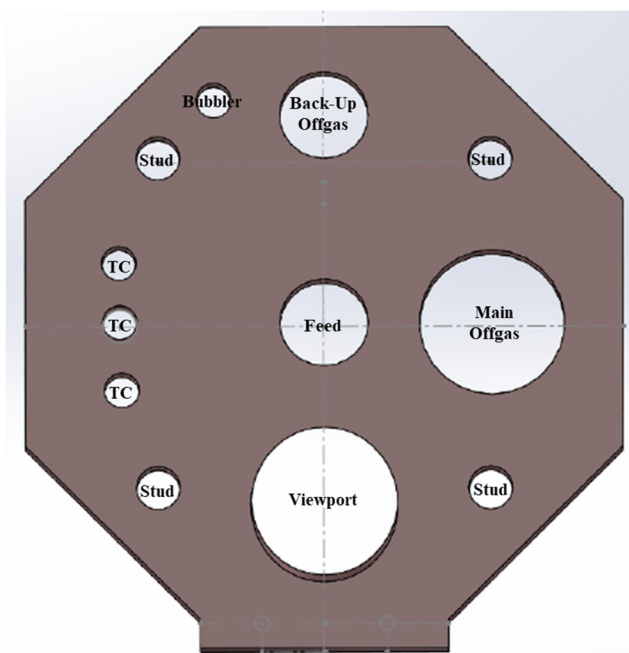


Figure 3.3. CLSM vessel lid and identified ports. The designation ‘TC’ stands for a thermocouple port.

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 to 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 simulant CLSM system layout under the fume canopy in APEL is shown in Figure 3.4 and an image of the radioactive CLSM system layout in the fume hoods in RPL is shown in Figure 3.5.

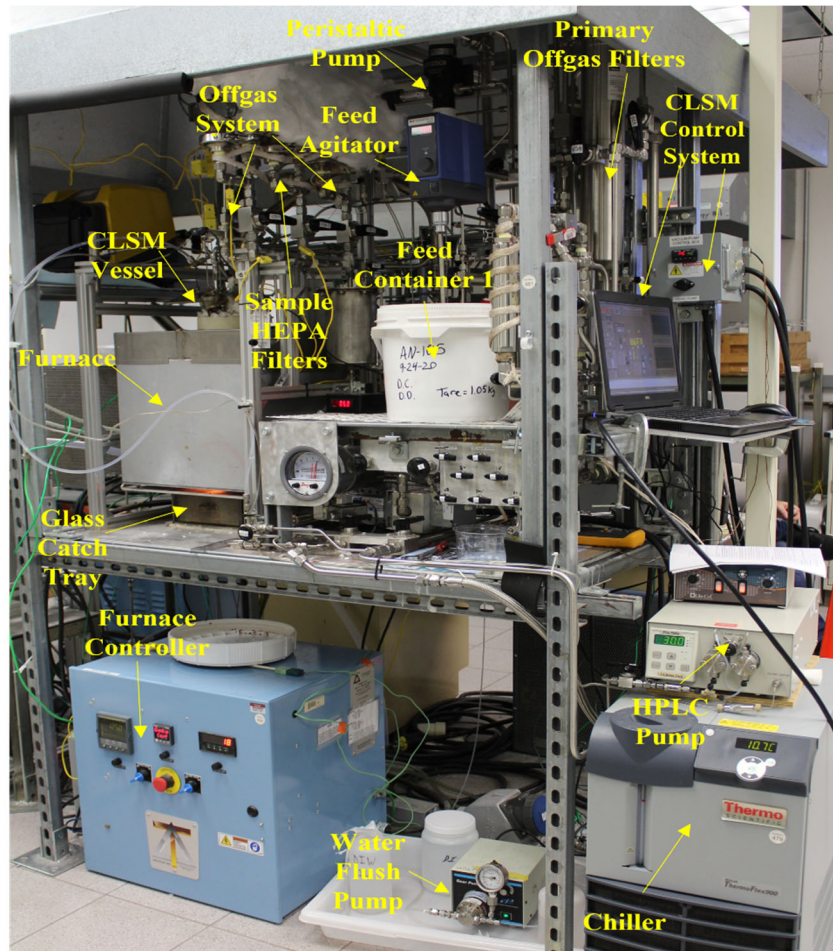


Figure 3.4. The simulant CLSM system layout under the fume canopy in the APEL.

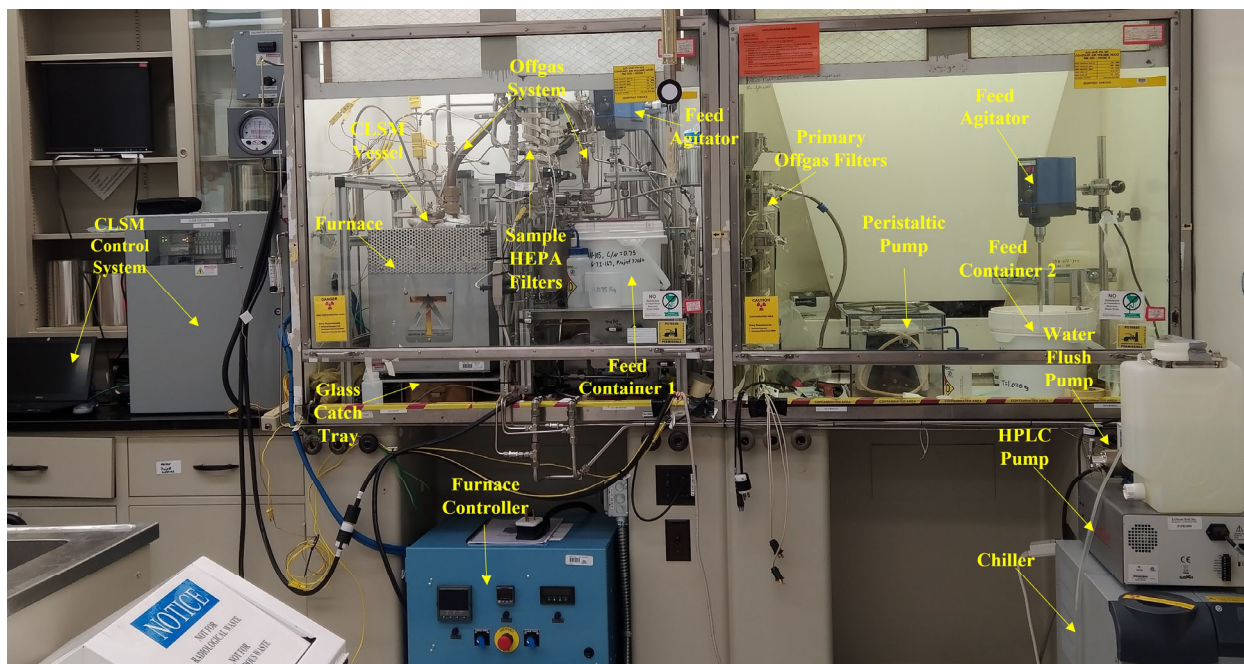


Figure 3.5. The radioactive CLSM system layout in the RPL HCA (left) and CA (right) fume hoods.

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 [scm] 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 AP-101 melter feeds processed in the CLSM were derived from the previous processing of LAW melter feeds in the CLSM (Dixon et al. 2020a, 2020b, and 2022a), which are listed in Table 3.5. However, similar DFLAW melter feed recipes specifically designed after the AP-101 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 3.5. 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-H₂O. 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 AP-101 simulant melter feed was measured upon completion of batching, then before and after processing. For the AP-101 waste melter feed, radioactive limitations prevented the weighing of the containers with the melter feed after batching, thus alternative methods had to be employed to determine the weight AP-101 waste melter feed before and after processing. The masses of the AP-101 waste and each individual GFCs added to the two batches of AP-101 waste melter feed were measured and totaled to determine the initial mass in each container before processing. The mass of AP-101 waste melter feed after processing was determined by emptying out the as much of the leftover melter feed in each batch container as possible after processing and placing it into small, measurable containers. These leftover melter feed containers were measured, and the masses were subtracting from the initial masses of the melter feed batches. This method for measuring the masses of AP-101 waste melter feed after processing resulted in an amount of melter feed leftover in the larger batch containers that was unable to be completely removed into the leftover containers. The value for the total AP-101 waste melter feed processed may therefore be slightly higher than actual due to these measurement limitations.

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 3.6.

Table 3.6. 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)	Cs, 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 ₃ CN)

4.0 CLSM Run Results

This section describes the operation of the CLSM for the AP-101 simulant run in the APEL on January 27th, 2022, and the AP-101 waste run in the RPL on April 5th, 2022. The production and chemical analysis results are also detailed.

4.1 AP-101 Simulant Run

This section describes the performance of the AP-101 simulant CLSM run.

4.1.1 Operational Description

During set-up of the CLSM system, approximately 2.0 kg of AP-107 glass, produced during a run performed on the simulant CLSM on 12-16-2019 and documented in Dixon et al. (2022b), were loaded into the CLSM vessel as the initial glass inventory. An amount of Re had been retained in this AP-107 glass during the previous run. The AP-101 simulant melter feed was initially batched at a low water level. After 2 weeks of stirring at this level, water was added to the melter feed, and it was stirred at the appropriate water level (described in Section 3.1) for two additional days before processing. 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 AP-101 simulant melter feed into the CLSM vessel at 10:24 AM, 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, 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 initial inventory of glass in the CLSM vessel, the mass of glass produced during the CLSM run was 6.55 kg, corresponding to over 3 turnovers of the 2.0 kg glass inventory. Other notes about the performance during the run follow.

Table 4.1. Timing and Mass of Glass Pours During the AP-101 Simulant CLSM Run

Pour Time (h)	Glass Mass Poured (g)	Cumulative Glass Mass Poured (kg)
Initial	68.30	0.07
0.53	364.07	0.43
1.03	541.23	0.97
1.53	488.64	1.46
2.03	578.75	2.04
2.53	558.72	2.60
3.03	514.98	3.11
3.53	711.07	3.83
4.03	645.82	4.47
4.53	541.36	5.01
5.03	603.43	5.62
5.53	499.53	6.12
6.03	639.37	6.76
Final	1795.62	8.55

4.1.2 Production Results

The production results from the AP-101 simulant CLSM run are given in Table 4.2 for the total run. 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 CLSM run are displayed in Figure 4.1a. 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. Two offgas samples were collected during the CLSM run and the occurrence of each offgas sample in the timeline of the run is shown in relation to the processing values in Figure 4.1a.

Table 4.2. CLSM Production Results During Both AP-101 CLSM Runs

Parameter	AP-101 Simulant CLSM Run	AP-101 Waste CLSM Run
Test Date	1/27/2022	4/5/2022
Feeding Duration, h	6.11	12.14
Low Flow Duration, h	0.00	0.00 ^(a)
Downtime, h	0.00	0.00
Glass Produced, kg	6.55	8.75
Melter Feed Consumed (Calculated), kg	13.86	22.19
Average Glass Production Rate, kg m ⁻² d ⁻¹	2275	1530
Average Feeding Rate, kg h ⁻¹	2.27	1.83
Average Bubbling Flux Rate, L m ⁻² min ⁻¹	99	42
Average Glass Temperature, °C	1148	1149
Average Plenum Temperature, °C	610	695

^(a) While no low flow duration occurred, the melter feed pump reached a maximum and it may have been possible to feed at a faster rate than could be achieved.

4.1.3 Sample Chemical Analysis

The samples selected for chemical analysis from the AP-101 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 3.6. 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. 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). Aliquots of all the liquid portions described were sent for chemical analysis. For the collection of each of the three offgas samples, the complete sampling HEPA filters were digested and analyzed independently while the same process was performed for the one used primary HEPA filter. Due to its size, the pre-filter had to be split into 3 portions for shipment, but all 3 portions were digested and combined for analysis.

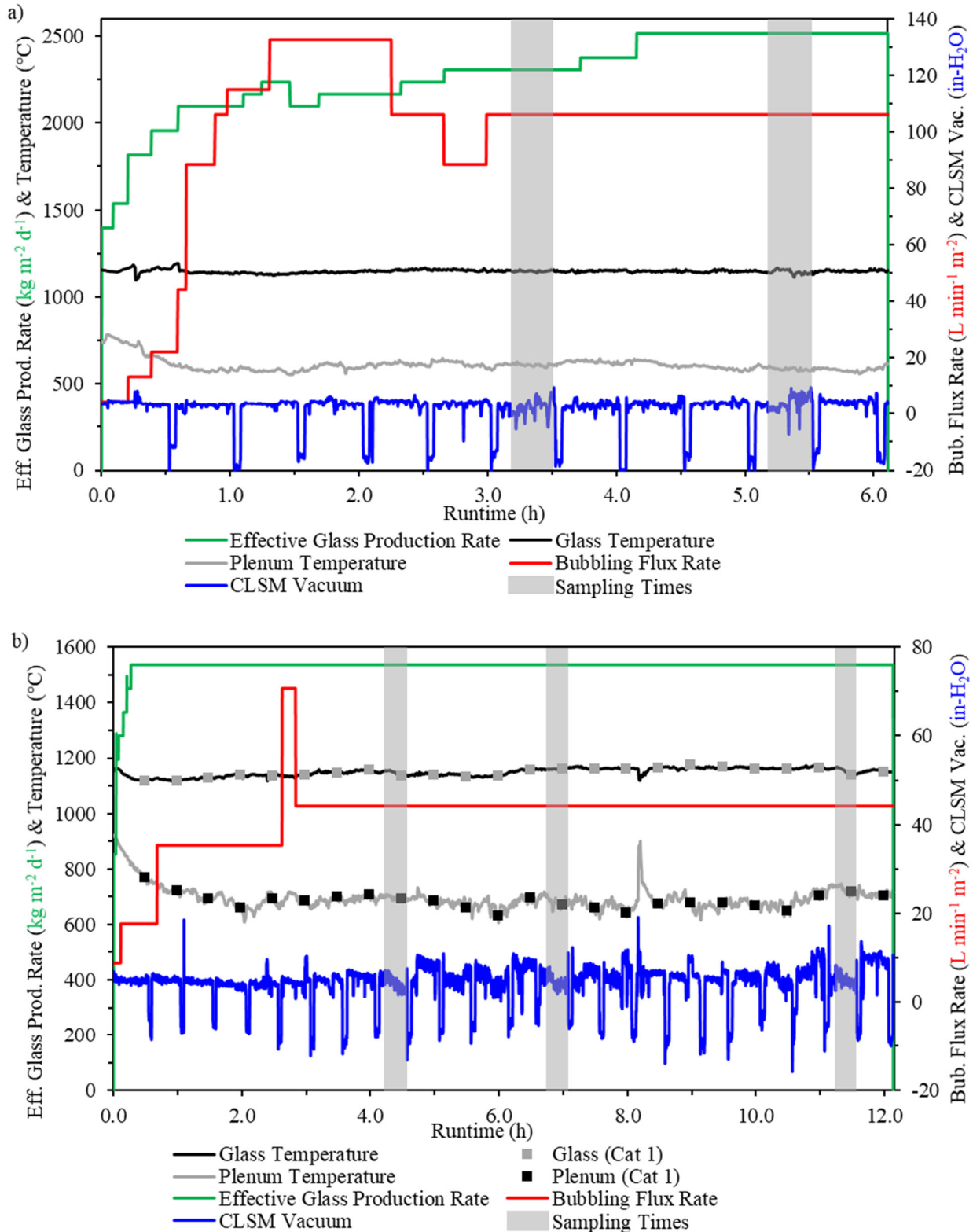


Figure 4.1. Processing values (glass and plenum temperatures, effective glass production rate, bubbling flux rate, and CLSM vacuum measurements) and offgas sample timing recorded during a) the AP-101 simulant CLSM run and b) the AP-101 waste CLSM run.

4.2 AP-101 Waste Run

This section describes the performance of the AP-101 waste CLSM run.

4.2.1 Operational Description

During set-up of the CLSM system, approximately 2.0 kg of AP-101 glass, from the final pour of AP-101-S glass at the end of the processing of the AP-101 simulant melter feed, 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. The CLSM run then began by charging the AP-101 waste melter feed into the CLSM vessel at 10:31 AM, 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 and cumulative mass of glass poured during the run are given in Table 4.3. 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 initial inventory of glass in the CLSM vessel, the mass of glass produced during the CLSM run was 8.75 kg, corresponding to nearly 4.5 turnovers of the 2.0 kg glass inventory. Other notes about the performance during the run follow.

- The melter feed pump reached its maximum operating rate at 0.28 h of the AP-101 waste CLSM run and remained at that maximum for the duration of the run. At this rate, the cold cap was closer to the bottom of its desired coverage range, ~75 – 85 %, and it is believed that if the pump could have delivered the melter feed at a faster rate, the coverage would have reached the upper end of its desired coverage range, ~85 – 95 %. As a result, the average glass production rate, reported in Table 4.2, was likely at the low end of what is possible when processing AP-101 waste melter feed.
- The transfer of AP-101 waste melter feed from ‘Melter Feed Container 2’ into ‘Melter Feed Container 1’, see Figure 3.1 for positioning, began at 5.73 h and ended at 6.56 h when as much feed as possible had been transferred.
- The temporary spike down in the glass temperature and corresponding spike up in the plenum temperature at 8.18 h, see Figure 4.1b, was a result of a partial cold-cap submersion and the temperatures rapidly returned to their steady operating ranges as continuous charging of melter feed built up the cold cap again. Submersion may occur when the cold cap is not connected to the walls of the melter vessel and vigorous bubbling in the glass melt causes a portion of the reacting feed layer of the cold cap to dip into the melt.
- The cold-cap behavior for the AP-101 waste melter feed was similar to the AP-101 simulant melter feed and adhered closest to 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.
- The glass poured from the CLSM vessel during the AP-101 waste run appeared qualitatively more viscous than the glass poured during the AP-101 simulant run.

Table 4.3. Timing and Mass of Glass Pours During the AP-101 Waste CLSM Run

Pour Time (h)	Glass Mass Poured (g)	Cumulative Glass Mass Poured (kg)
Initial	61.75	0.06
0.55	204.40	0.27
1.05	217.22	0.48
1.55	190.41	0.67
2.06	258.56	0.93
2.56	296.10	1.23
3.06	335.31	1.56
3.56	416.80	1.98
4.06	369.35	2.35
4.56	371.14	2.72
5.06	296.88	3.02
5.56	267.83	3.29
6.15	452.46	3.74
6.56	349.82	4.09
7.08	357.73	4.45
7.56	321.05	4.77
8.06	452.35	5.22
8.58	362.16	5.58
9.13	481.01	6.06
9.56	369.40	6.43
10.06	280.53	6.71
10.56	423.87	7.14
11.06	425.22	7.56
11.56	422.37	7.98
12.06	362.84	8.35
Final	2408.74	10.76

4.2.2 Production Results

The production results from the AP-101 waste CLSM run are given in Table 4.2 for the total run. 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. While there was no period of low melter feed flow during the run, it was noted in Section 4.2.1 that the melter feed pump had reached its maximum rate and is believed that the melter feed could have been fed at a higher rate if it was possible. The mass of AP-101 waste melter feed consumed was calculated as described in Section 3.3 and as noted, this value was greater than the actual amount consumed due to limitations in how the weight of melter feed could be measured in the radioactive environment.

The processing values recorded during the 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. The glass and plenum temperatures were monitored by thermocouples with dual reading capabilities, one recorded by the CLSM data acquisition system and the other by a calibrated handheld device, both of which are reported in Figure 4.1b. Three offgas samples were collected during the CLSM run and the occurrence of each offgas sample in the timeline of the run is shown in relation to the processing values in Figure 4.1b.

4.2.3 Sample Chemical Analysis

The samples selected for chemical analysis from the AP-101 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 listed in Table 3.6. The samples of condensate were combined into three portions: 1) all condensate produced while feeding batch 1 of the AP-101 waste melter feed from the start of the run to 5.73 h (denoted in Table A.2 as Condensate A); 2) all condensate produced while feeding batch 2 of the AP-101 waste melter feed from 5.73 h to the end of melter feed charging (denoted in Table A.2 as Condensate B); and 3) all condensate produced after melter feed charging ended (denoted in Table A.2 as Condensate C). Similarly, the liquid that accumulated in the demister was combined into two portions: 1) all liquid produced while feeding batch 1 of the AP-101 waste melter feed from the start of the run to hour 5.73 (denoted in Table A.2 as Demister A); and 2) all liquid produced while feeding batch 2 of the AP-101 waste melter feed from hour 5.73 to the end of melter feed charging (denoted in Table A.2 as Demister B). Liquid accumulated in the pre-filter housing during the run was drained from the housing and collected. The sumps from both the primary SBS and sampling SBS were drained after the run and collected. Aliquots of all the liquid portions described were sent for chemical analysis. For the collection of each of the three offgas samples, the complete sampling HEPA filters were digested and analyzed independently while the same process was performed for the one used primary HEPA filter. Due to its size, the pre-filter had to be split into 3 portions for shipment, but all 3 portions were digested and combined for analysis.

5.0 Discussion

This section discusses the insights gained from the CLSM runs with both the AP-101 simulant and AP-101 waste melter feeds and compares data to previous CLSM runs (Dixon et al. 2018, 2019, 2020a, 2020b, 2022a, and 2022b).

5.1 Glass Composition

This section discusses the glass product from both the AP-101 waste and AP-101 simulant CLSM runs and breaks down the analysis into the different types of components in the glass composition.

5.1.1 Primary Glass Components

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 4.1.1 for the simulant run and Section 4.2.1 for the waste run), both the average composition of glass produced during the runs and the composition of the last glass poured during each run are compared to their respective target compositions 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 primary component measured in the glass product from the AP-101 simulant and waste CLSM runs are displayed in Figure 5.1 and Figure 5.2. Since the AP-101 waste CLSM run began with the glass from the final pour of the AP-101 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 AP-101 simulant CLSM run are associated with the glass pours from 0.00 to 6.56 kg discharged and the glasses from the AP-101 waste CLSM run are associated with the glass pours from 6.61 to 15.30 kg discharged. 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 (—).

The primary components measured in both the AP-101-S and AP-101-W glass compositions were within $\pm 10\%$ 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 $\pm 10\%$ from their target glass compositions during individual glass pours in the CLSM runs, shown in Figure 5.1 and Figure 5.2, while their averages and final pours were within $\pm 10\%$, shown in Table 5.1: Na_2O , CaO , and Li_2O . For all these three components, the initial glass loaded into the CLSM vessel for the AP-101 simulant run (the AP-107 composition given in Table 3.4), the AP-101-S composition, and the AP-101-W composition all had different target values. The Na_2O composition moved from $\sim 18.5\%$ in the initial glass poured during the AP-101 simulant CLSM run to the target 16.44% for the AP-101-S glass by one turnover (2.0 kg of glass poured) of the CLSM vessel inventory. The trends in Figure 5.2 revealed that the CaO reached its target in the AP-101-S glass by two turnovers, while the Li_2O reached its target in both the AP-101-S and AP-101-W glasses in three turnovers. Given the glass-equilibration-in-two-turnovers characteristic that was observed previously for minor impurity spikes in the initial glass in the CLSM

vessel (Dixon et al. 2020a and 2020b), the AP-101 runs indicate that Na₂O is quicker to equilibrate than average, while Li₂O is slower to equilibrate.

Table 5.1. Comparison of AP-101 Simulant and Waste CLSM Run Glass Products with Target Compositions

Component	AP-101-S					AP-101-W				
	Target wt%	Measured Average wt%	% Diff. Target to Average	Measured Final wt%	% Diff. Target to Final	Target wt%	Measured Average wt%	% Diff. Target to Average	Measured Final wt%	% Diff. Target to Final
Al ₂ O ₃	6.13	5.96	-2.7	5.91	-3.5	6.12	6.02	-1.6	6.05	-1.2
B ₂ O ₃	9.95	10.63	6.8	10.27	3.2	9.95	10.69	7.5	10.54	5.9
CaO	4.45	4.30	-3.4	4.24	-4.8	3.39	3.46	2.1	3.43	1.0
Cl	0.16	0.22	--	0.23	--	0.17	0.23	--	0.23	--
Cr ₂ O ₃	0.09	0.08	--	0.12	--	0.08	0.09	--	0.13	--
F	0.01	0.03	--	0.02	--	0.00	0.02	--	0.02	--
Fe ₂ O ₃	5.52	5.43	-1.7	5.36	-2.8	5.52	5.60	1.4	5.57	0.9
K ₂ O	0.39	0.39	--	0.41	--	0.47	0.43	--	0.42	--
Li ₂ O	1.44	1.38	-4.8	1.44	-0.6	0.00	0.04	--	0.04	--
MgO	1.49	1.42	-4.6	1.40	-5.9	1.49	1.46	-1.7	1.45	-2.7
Na ₂ O	16.44	16.19	-1.5	17.08	3.9	17.96	16.39	-8.7	16.24	-9.6
NiO	0.01	0.03	--	0.03	--	0.01	0.01	--	0.02	--
P ₂ O ₅	0.12	0.18	--	0.16	--	0.10	0.03	--	0.03	--
SO ₃	0.39	0.49	--	0.47	--	0.36	0.34	--	0.33	--
SiO ₂	45.49	45.61	0.3	45.32	-0.4	46.45	47.27	1.8	47.66	2.6
TiO ₂	1.40	1.39	-1.2	1.38	-1.7	1.40	1.44	2.9	1.44	2.9
ZnO	3.51	3.46	-1.4	3.29	-6.3	3.51	3.45	-1.6	3.40	-3.2
ZrO ₂	3.02	2.84	-5.9	2.88	-4.6	3.01	3.02	0.1	3.01	-0.2
Total	100.0	100.0		100.0		100.0	100.0		100.0	

Values marked with '--' were not calculated because the component target concentrations were <1%.

For other components, the most frequent reason for a difference between the measured and target values in the AP-101-S and AP-101-W glasses was that the melter feeds charged during each run were slightly deficient or abundant in particular components compared to the glass targets. The expected glass produced from the AP-101 simulant and waste melter feeds, if all components in the melter feeds were 100 % retained during the conversion into glass, are given in Table 5.2 compared with the AP-101-S and AP-101-W target glass compositions. Generally the direction of differences between the glass produced and the glass targets, shown in Table 5.1, were the same as the differences between the expected glass from the melter feeds and the glass targets, shown in Table 5.2.

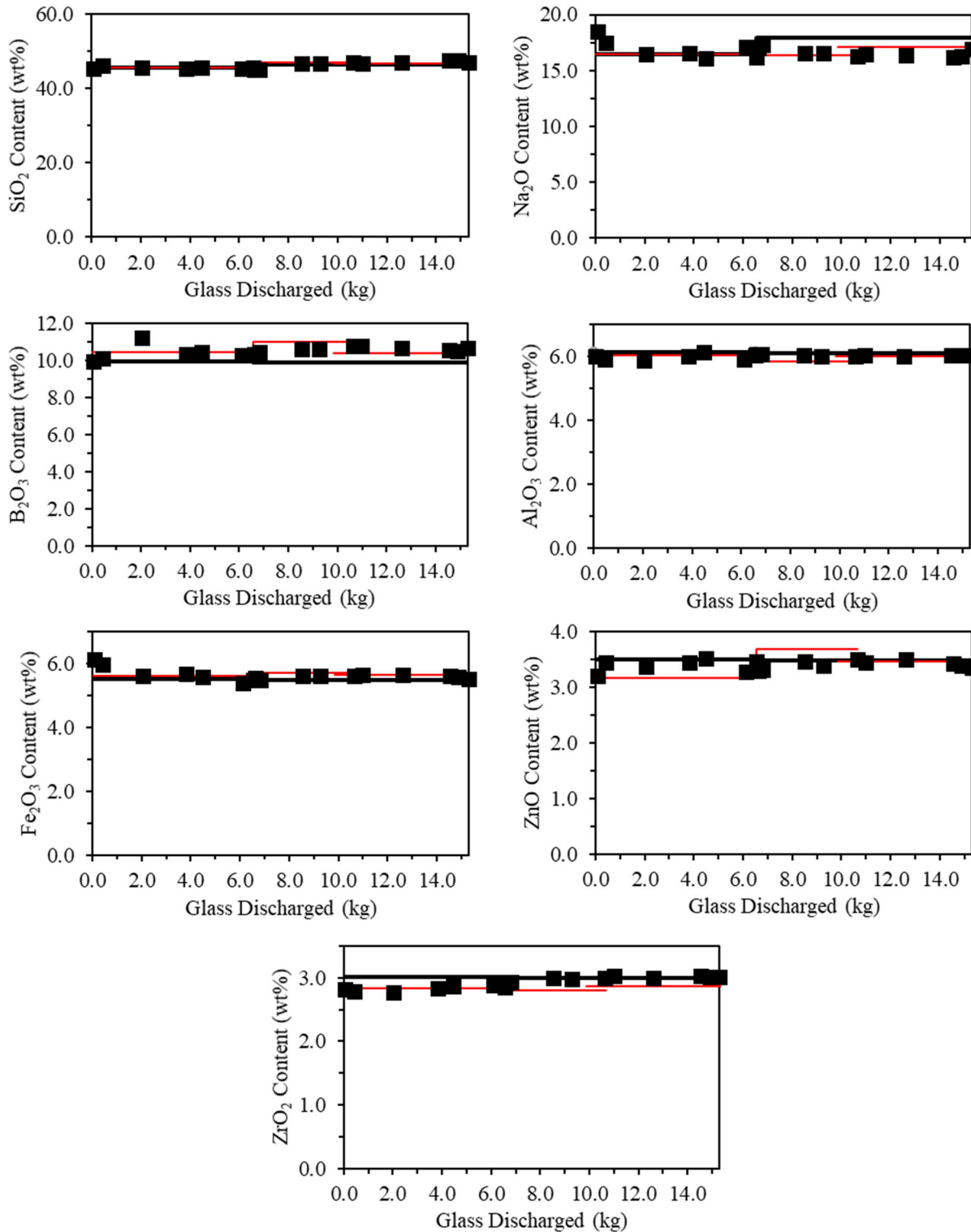


Figure 5.1. Content of a set of primary components (SiO₂, Na₂O, B₂O₃, Al₂O₃, Fe₂O₃, ZnO, and ZrO₂) in the glass produced during the CLSM run with the AP-101 simulant and waste melter feeds. The values in the black squares were measured in the glass, the black lines were the targets in the glass, and the red lines were the expected values from analysis of the melter feeds (AP-101 simulant from 0.00 – 6.56 kg and AP-101 waste from 6.61 – 15.30 kg).

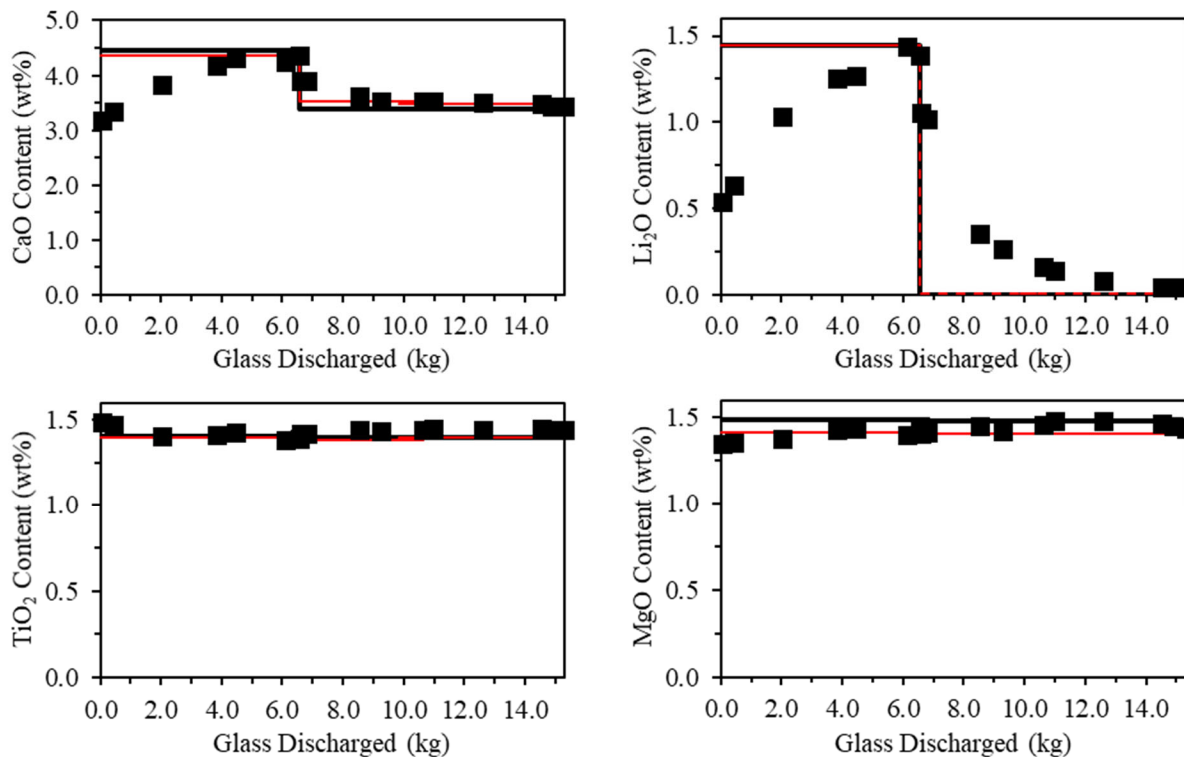


Figure 5.2. Content of a set of primary components (CaO, Li₂O, TiO₂, and MgO) in the glass produced during the CLSM run with the AP-101 simulant and waste melter feeds. The values in the black squares were measured in the glass, the black lines were the targets in the glass, and the red lines were the expected values from analysis of the melter feeds (AP-101 simulant from 0.00 – 6.56 kg and AP-101 waste from 6.61 – 15.30 kg).

Table 5.2. Comparison of AP-101-S and AP-101-W Target Glass Compositions with the Compositions of the Analyzed Melter Feeds

Component	Target	Analyzed	% Diff.	Target	Analyzed	% Diff.
	AP-101-S	AP-101	Target to	AP-101-W	AP-101	Target to
	wt%	Simulant Melter Feed	Analyzed AP-101-S	wt%	Waste Melter Feed	Analyzed AP-101-W
		wt%	%		wt%	%
Al ₂ O ₃	6.13	6.05	-1.3	6.12	5.93	-3.2
B ₂ O ₃	9.95	10.44	5.0	9.95	10.69	7.5
CaO	4.45	4.36	-2.1	3.39	3.50	3.3
Cl	0.16	0.32	--	0.17	0.30	--
Cr ₂ O ₃	0.09	0.10	--	0.08	0.10	--
F	0.01	0.00	--	0.00	0.00	--
Fe ₂ O ₃	5.52	5.60	1.4	5.52	5.66	2.5
K ₂ O	0.39	0.38	--	0.47	0.42	--
Li ₂ O	1.44	1.44	-0.3	0.00	0.01	--
MgO	1.49	1.41	-5.2	1.49	1.41	-5.5
Na ₂ O	16.44	16.43	0.0	17.96	16.74	-6.8
NiO	0.01	0.01	--	0.01	0.01	--
P ₂ O ₅	0.12	0.08	--	0.10	0.12	--
SO ₃	0.39	0.50	--	0.36	0.42	--
SiO ₂	45.49	45.48	0.0	46.45	46.90	1.0
TiO ₂	1.40	1.40	-0.4	1.40	1.39	-1.1
ZnO	3.51	3.17	-9.7	3.51	3.57	1.8
ZrO ₂	3.02	2.83	-6.2	3.01	2.83	-6.0
Total	100.0	100.0		100.0	100.0	

Values marked with '--' were not calculated because the component target concentrations were <1%.

5.1.2 Minor Glass Components

The compositional trends for each minor component (<1.00 wt%) measured in the glass product from the AP-101 simulant and AP-101 waste CLSM runs are displayed in Figure 5.3, with respect to the amount of glass discharged. The glass composition trends from both runs are given in cumulative succession on the same graph with respect to the amount of glass discharged, as described in Section 5.1.1. 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 line (—), and the expected component content in the glass based on the analyzed melter feed samples 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 trends for Cr₂O₃ and NiO in Figure 5.3 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).

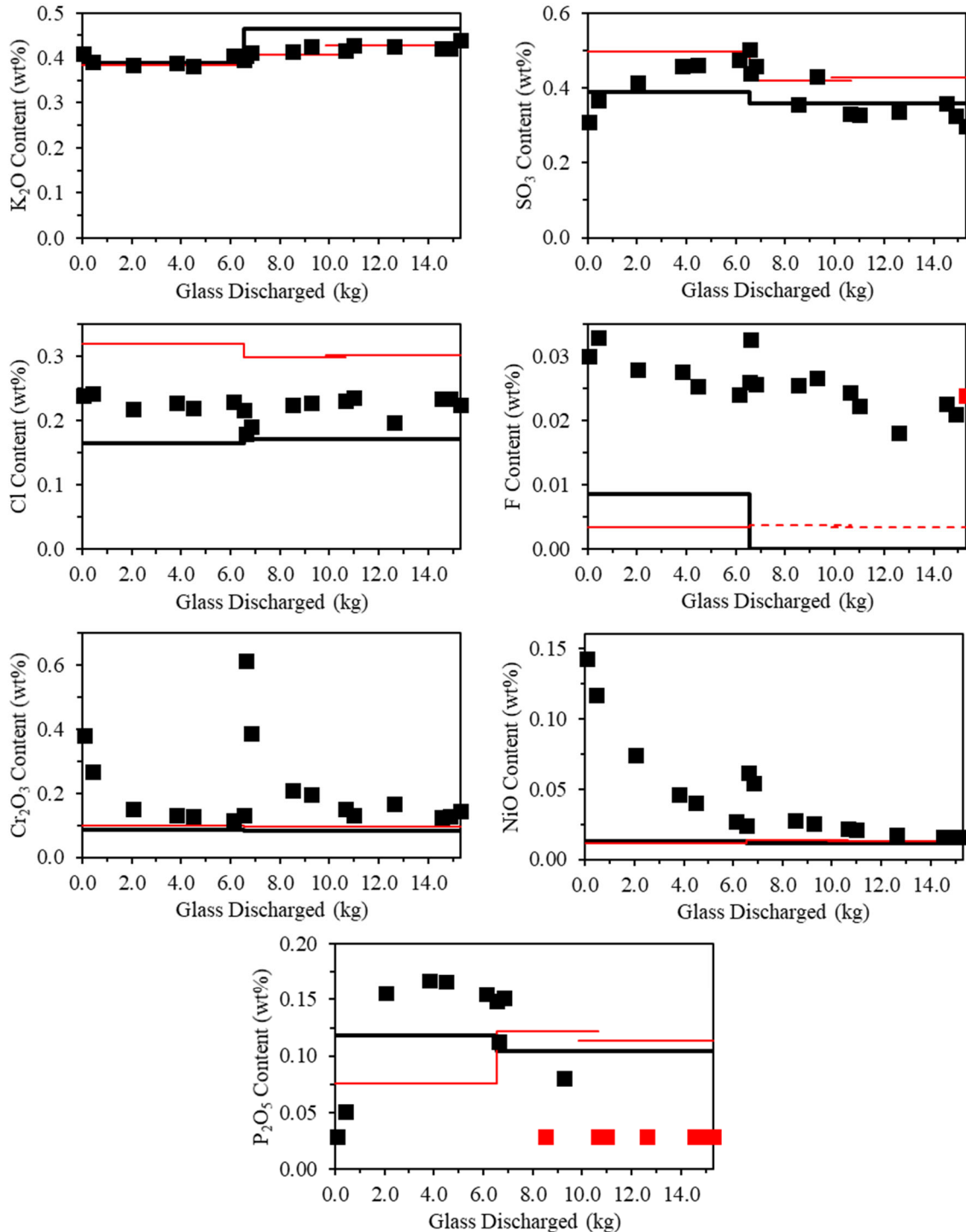


Figure 5.3. Content of a set of minor components (K₂O, SO₃, Cl, F, Cr₂O₃, NiO, and P₂O₅) in the glass produced during the CLSM run with the AP-101 simulant and waste melter feeds. The values in the black squares were measured in the glass, the black lines were the targets in the glass, and the red lines were the expected values from analysis of the melter feeds (AP-101 simulant from 0.00 – 6.56 kg and AP-101 waste from 6.61 – 15.30 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.

Other minor glass components present in the target glass compositions (SO_3 , K_2O , P_2O_5 , Cl, and F) 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, and analytical uncertainty due to the low concentrations compared to the primary components. In particular, the content of F being higher in the glass pours than both the glass target and the amount detected in the melter feed indicates an alternative source of F impurity or measurement difficulty that was also observed in the F content in glass produced from the radioactive CLSM previously (Dixon et al. 2022a). The behavior of S, K, Cl, and F in the CLSM offgas treatment system will be discussed further in Section 5.3.

5.1.3 Minor Impurity and Radioactive Components

Several components were present as minor (1500 ppm or less) impurities in the melter feeds and glass product during the AP-101 simulant and waste CLSM runs. The compositional trends for each minor impurity are shown in Figure 5.4 and Figure 5.5 with respect to the amount of glass discharged. The glass composition trends from both runs are given in cumulative succession on the same graph with respect to the amount of glass discharged, as described in Section 5.1.1. 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 AP-101 glass product followed two general trends. The first trend was a spike 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 AP-101 melter feeds. This trend applied to La, Mo, Ba, Sr, and Mn shown in Figure 5.4 and Pb and Cd in shown Figure 5.5. 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. 2019, 2020a, and 2020b), indicating that the spikes were greater in the AP-107 glass used to start the AP-101 simulant CLSM run.

The second impurity trend was a component level staying relatively constant in all glass pours. This trend applied to W, V, and As shown in Figure 5.4 and Sn, Y, Cu, and Co shown in Figure 5.5. Within this trend, V (~65 ppm) and Y (~40 ppm) remained at a level greater than expected based on the AP-101 melter feeds, as has been previously analyzed in CLSM glass products (Dixon et al. 2019, 2020a, and 2020b). The source of V and Y at these levels in the glass products is likely leaching from the material of the CLSM vessel, as described regarding the Cr_2O_3 and NiO content in the glass product in Section 5.1.2.

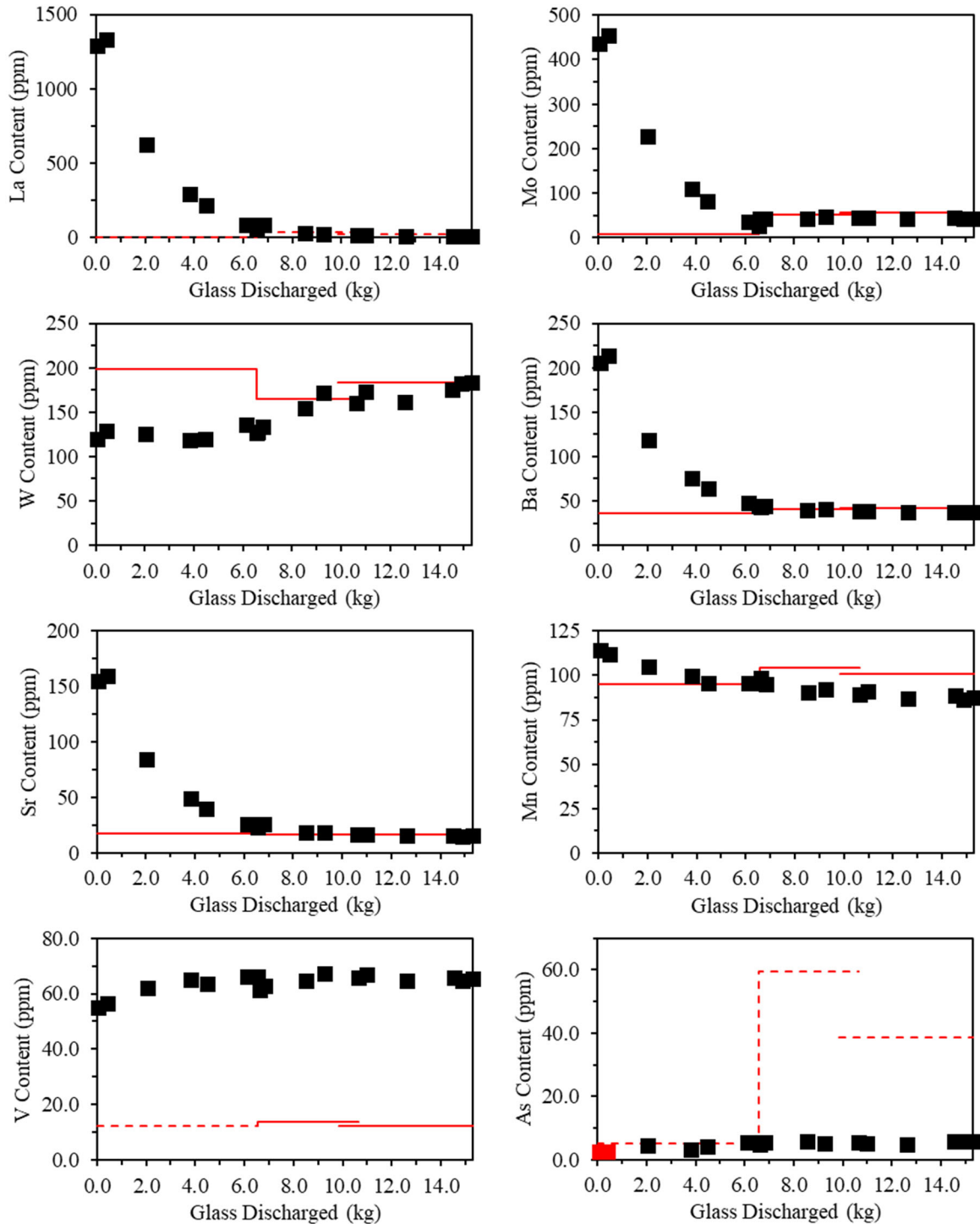


Figure 5.4. Content of a set of minor glass impurities (La, Mo, W, Ba, Sr, Mn, V, and As) in the glass produced during the CLSM run with the AP-101 simulant and waste melter feeds. The values in the black squares were measured in the glass and the red lines were the expected values from analysis of the melter feeds (AP-101 simulant from 0.00 – 6.56 kg and AP-101 waste from 6.61 – 15.30 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.

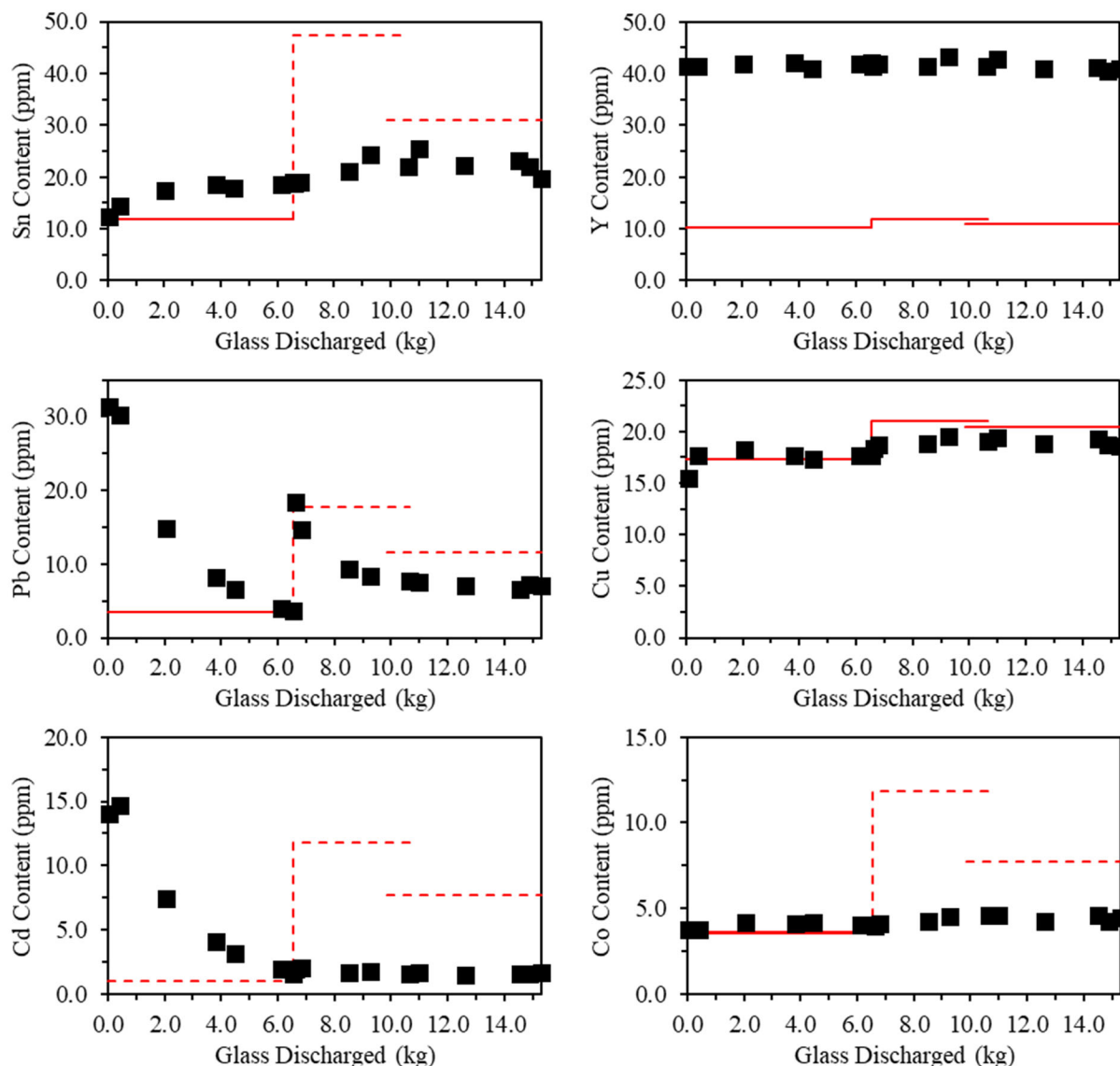


Figure 5.5. Content of a set of minor glass impurities (Sn, Y, Pb, Cu, Cd, and Co) in the glass produced during the CLSM run with the AP-101 simulant and waste melter feeds. The values in the black squares were measured in the glass and the red lines were the expected values from analysis of the melter feeds (AP-101 simulant from 0.00 – 6.56 kg and AP-101 waste from 6.61 – 15.30 kg). 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 measured activity of each analyzed radionuclide in the glass products from the AP-101 waste CLSM run, with respect to the mass of glass discharged, is shown in Figure 5.6. There were no radionuclides present in the AP-101 simulant feed, so only the portion of glass discharged during the AP-101 waste CLSM run, from 6.61 to 15.30 kg discharged are displayed in Figure 5.6. 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.

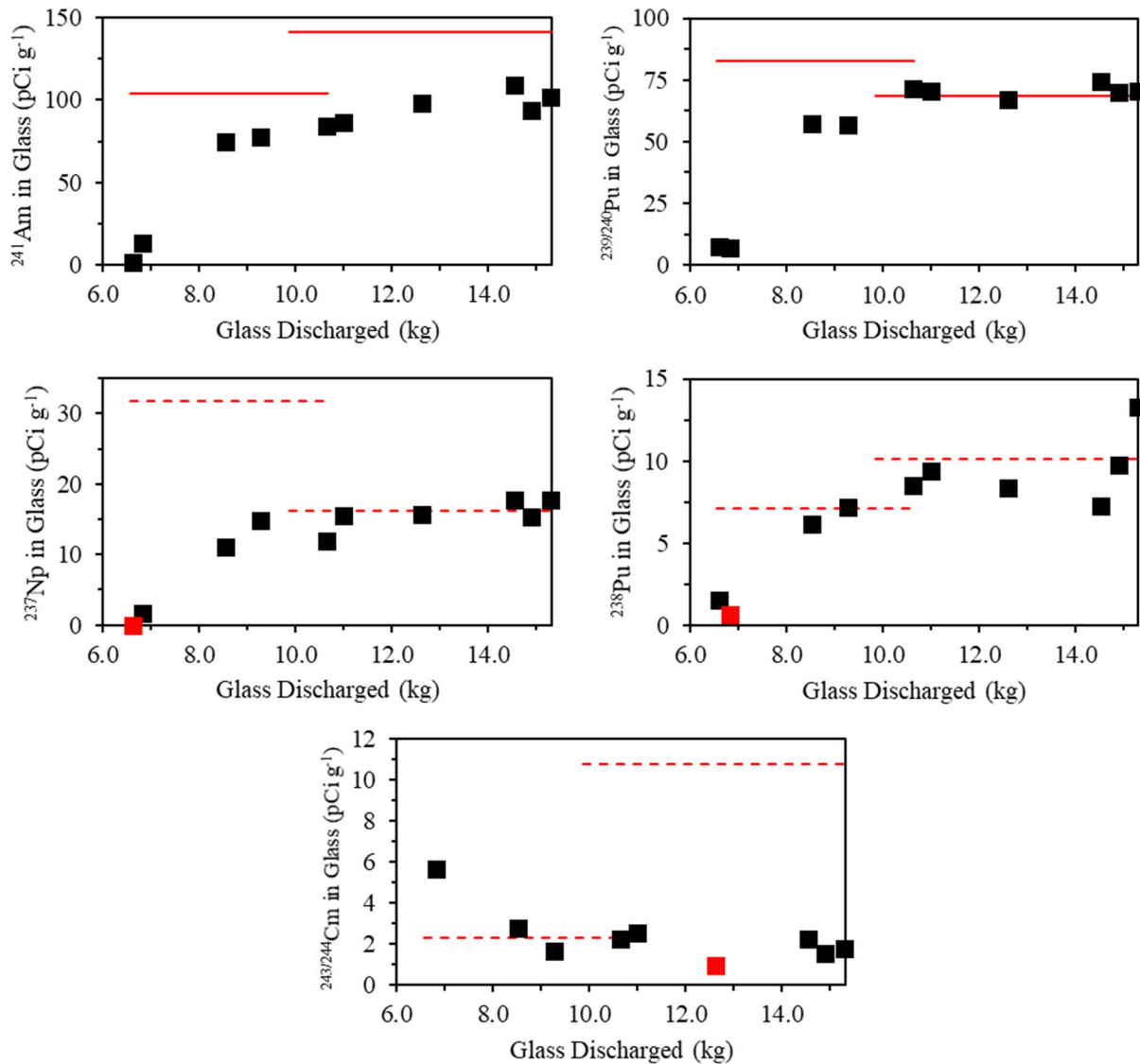


Figure 5.6. Activity of radionuclides (²⁴¹Am, ^{239/240}Pu, ²³⁷Np, ²³⁸Pu, and ^{243/244}Cm) in the glass produced during the CLSM run with the AP-101 waste melter feed. The values in the black squares were measured in the glass and the red lines were the expected values from analysis of the AP-101 waste melter feeds (from 6.61 – 15.30 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):

$$DF_i = \frac{\dot{m}_{i,feed}}{\dot{m}_{i,offgas}} \quad (5.1)$$

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):

$$R_i = \frac{\dot{m}_{i,glass}}{\dot{m}_{i,feed}} \quad (5.2)$$

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):

$$Rec_i = \frac{\dot{m}_{i,glass} + \dot{m}_{i,offgas}}{\dot{m}_{i,feed}} \quad (5.3)$$

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} , R_{Cs} , and R_I values were calculated during the total runtime, each individual glass pour, and during the offgas sampling timeframes 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 AP-101 simulant melter feed and AP-101 waste melter feed. For each component of the AP-101-S and AP-101-W 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 6.11 h for the AP-101 simulant run and 12.14 for the AP-101 waste run.

- 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 AP-101 simulant run of 8.55 kg and in the AP-101 waste run of 10.76 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 AP-101 simulant run, the condensate totaled 6.36 kg, demister liquid 0.15 kg, and primary SBS sump 0.99 kg and for the AP-101 waste run, the condensate totaled 5.18 kg, demister liquid 4.55 kg, and primary SBS sump 1.11 kg.

The mass flow rate data for the entire runtime of the AP-101 simulant CLSM run are given in Table 5.3 and the mass flow rate data for the entire runtime of the AP-101 waste CLSM run are given in Table 5.4. Note that the chemical analysis results for Cs in both the AP-101 simulant and waste melter feeds, and the results for I in the AP-101 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 the both the AP-101 simulant and waste CLSM runs and are reported in Table 5.3 and Table 5.4, respectively.

For the AP-101 simulant run, most all component recoveries were within $\pm 10\%$ of complete recovery. The Rec_i values for Cs, F, 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 5.3 for F and NiO. The Rec_i values for I and P were greater than 110% most likely due to analytical uncertainty with those components being near (or below) the detection limits in the glass and offgas samples.

For the AP-101 waste run, many component recoveries were below $\pm 10\%$ of complete recovery. The primary reason for consistently low recoveries was that the method used to measure the mass of the AP-101 waste melter feed before and after the CLSM run, described in Section 3.3, wasn't able to determine the amount of melter feed leftover as heels in the initial containers and thus the amount of melter feed consumed was calculated to be greater than reality. The values for $\dot{m}_{i, feed}$ are thus expected to be greater, causing the R_i and Rec_i values to be less than reality. 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 5.2 for Li_2O and Figure 5.3 for F.

Table 5.3. Component Mass Flow Rates, DFs, Retentions, and Recoveries During the AP-101 Simulant CLSM Run

Component	$\dot{m}_{i,feed}$ Units	$\dot{m}_{i,glass}$ mg min ⁻¹	$\dot{m}_{i,offgas}$ mg min ⁻¹	Melter		
				DF	R %	Rec %
Re	0.09	0.04	0.05	1.6	42	104
Total Cs	0.00 ^(a)	0.68	0.07	-- ^(b)	-- ^(b)	-- ^(b)
Total I	0.88	0.19 ^(a)	1.21	0.7 ^(c)	21 ^(c)	159 ^(c)
Al	574	572	0	1880	100	100
B	582	598	3	199	103	103
Ca	559	557	0	1437	100	100
Cl	57	40	12	4.8	70	91
Cr	12	11	0	46.7	86	88
F	1	5	0	1.3	801	877
Fe	703	688	1	646	98	98
K	57	58	1	59.4	102	104
Li	120	116	0	685	96	97
Mg	153	155	0	2633	102	102
Na	2188	2177	15	143	100	100
Ni	2	4	0	40.6	241	243
P	6	14	1	5.6	236	254
S	36	35	1	26.9	99	103
Si	3817	3867	1	5931	101	101
Ti	150	151	0	5332	100	100
Zn	457	504	1	686	110	110
Zr	376	381	0	11457	101	101
Total	9851	9935	39	253 ^(d)	101 ^(d)	101 ^(d)

^(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 due to Cs spike in initial glass.

^(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.

Table 5.4. Component Mass Flow Rates, DFs, Retentions, and Recoveries During the AP-101 Waste CLSM Run

Component	$\dot{m}_{i,feed}$ Units	$\dot{m}_{i,glass}$ mg min ⁻¹	$\dot{m}_{i,offgas}$ mg min ⁻¹	Melter		
				DF	R	Rec
	mg min ⁻¹	mg min ⁻¹	mg min ⁻¹		%	%
⁹⁹ Tc	0.08	0.05	0.02 ^(d)	3.9	60	86
Total Cs	0.01 ^(a)	0.01	0.00 ^(d)	2.8 ^(b)	46 ^(b)	82 ^(b)
Total I	0.17 ^(a)	0.06 ^(a)	0.02 ^(d)	8.6 ^(b)	35 ^(b)	47 ^(b)
Al	426	381	0	1893	89	90
B	450	397	2	229	88	89
Ca	340	296	0	1514	87	87
Cl	41	27	5 ^(d)	7.5	67	81
Cr	9	7	0	88.2	79	81
F	0	2	0 ^(d)	1.5	521	588
Fe	537	468	0	1244	87	87
K	47	42	0 ^(d)	105	90	91
Li	0	2	0	16.1	572	578
Mg	115	105	0	2212	92	92
Na	1684	1453	6	295	86	87
Ni	1	1	0	126	95	96
P	7	2	0	63.1	23	24
S	23	16	1 ^(d)	31.3	70	73
Si	2974	2641	0	8195	89	89
Ti	113	103	0	5767	92	92
Zn	389	332	0	1075	85	85
Zr	285	267	0	9567	94	94
Total	7442	6543	16	475 ^(c)	88 ^(c)	88 ^(c)

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

^(b) Values were calculated using best estimates for mass flow rates and should therefore be considered best estimates.

^(c) Values were calculated using the mass flow rate totals from previous columns.

^(d) 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 and 2022a) were ⁹⁹Tc (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 AP-101 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 5.5. The “End Filters” unit described in Table 5.5 includes the liquids that accumulated in the demister and pre-filter housing, as well as the pre-filter and primary HEPA filter, all totaled together.

Table 5.5. Quantities of Selected Components in CLSM Output Streams During the AP-101 Simulant and Waste CLSM Runs

AP-101 Simulant CLSM Run							
	Re (mg)	Cs (mg)	I (mg)	Cl (mg)	F (mg)	K (mg)	S (mg)
Glass	13.5	248	68 ^(b)	14701	1731	21380	12955
Wash + Sampling	4.90	3.21	0.984	1158	58.1	79.7	112
SBS Sump	2.32	1.53	106	631	16.7	46.2	74.4
Condensate	9.92	16.5	315	2530	80.1	167	250
End Filters	2.77	5.23	22.9	43.0	10.3	58.9	49.1
AP-101 Waste CLSM Run							
	⁹⁹ Tc (mg)	Cs (mg)	I (mg)	Cl (mg)	F (mg)	K (mg)	S (mg)
Glass	36.1	3.96	44.4 ^(b)	19990	1809	30842	11732
Wash + Sampling ^(a)	3.08 (1.03)	0.617 (0.107)	2.81 (2.54)	790 (245)	44.2 (4.51)	63.1 (35.5)	106 (26.9)
SBS Sump	1.69	0.344	0.890	567	45.4	37.0	145
Condensate	3.84	0.824	5.13	1200	74.1	72.8	106
End Filters	6.86	1.29	5.21	1403	57.6	143	174

^(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) Iodine concentrations in glass samples were below analytical reporting limits; the value should be considered a best estimate.

The measured sampling loop values for the AP-101 waste CLSM run are given in parentheses in the ‘Wash + Sampling’ row of Table 5.5. From previous offgas analysis in the simulant CLSM system (Dixon et al. 2020a and 2021), when the offgas piping from the CLSM vessel to the sampling loop was washed upon the conclusion of each CLSM run, about 20% 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 AP-101 waste CLSM run. Thus, the estimated quantities of each component, factoring up to 20% in a theoretical offgas piping wash, are shown without parentheses in the ‘Wash + Sampling’ row of Table 5.5 for the AP-101 waste CLSM run.

The quantities of each component in the output streams from Table 5.5 were converted to percentages of the total quantities in the output streams via Eq. (5.4):

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

where $Output\%_{i,s}$ is the percentage (%) of the quantity of a component (i ; ⁹⁹Tc, 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 AP-101 simulant CLSM run is displayed in Figure 5.7a and during the AP-101 waste CLSM run is displayed in Figure 5.7b. The $Output\%_{I,Condensate}$ value in the AP-101 simulant CLSM run, Figure 5.7, is 61.3 %.

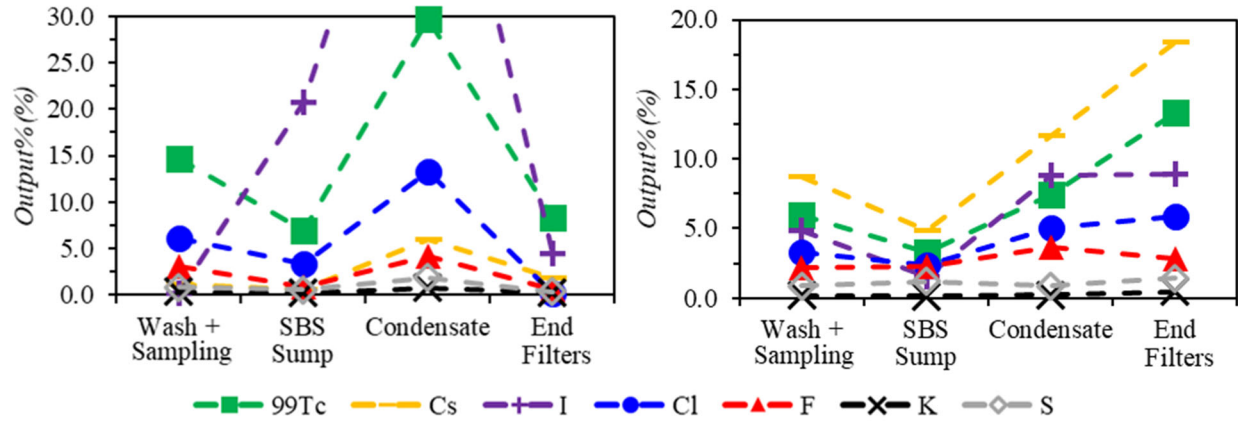


Figure 5.7. Percentage of the quantity of each component in the output stream ($Output\%$) in the CLSM offgas treatment system during a) the AP-101 simulant run and, b) the AP-101 waste run.

Compared to the components collected in the different offgas units during previous runs in the waste CLSM system (Dixon et al. 2022a) and in the AP-101 simulant CLSM, a larger percentage of each component was collected in the ‘End Filters’ unit during the AP-101 waste CLSM run. One of the liquids included as a part of the ‘End Filters’ unit was the liquid collected in the demister. More liquid was collected in the demister during the AP-101 waste CLSM run than any previous CLSM run, leading to more of each component recovered during the ‘End Filters’ unit. It is believed that a restriction in the condensate drainage line in the waste CLSM system caused more liquid to accumulate in the demister. Thus if the $Output\%_{i,s}$ for each of the streams in the offgas treatment system during the AP-101 waste CLSM run is recalculated with the amount collected in the demister added to the ‘Condensate’ instead of the ‘End Filters’ unit, as shown in Figure 5.8, the behavior of the components captured more closely resembles that of the AP-101 simulant CLSM run and the other previous runs (Dixon et al. 2022a).

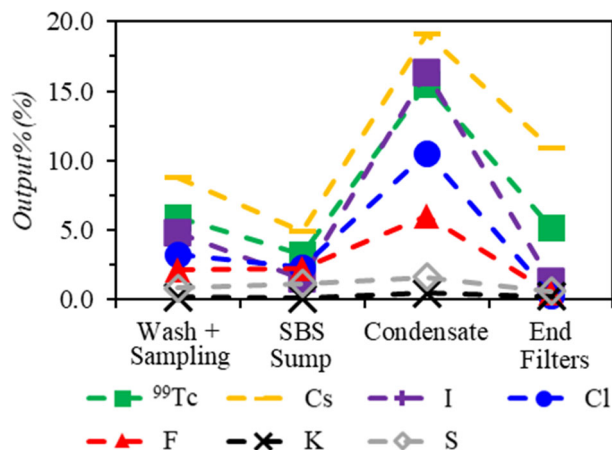


Figure 5.8. Percentage of the quantity of each component in the output stream (*Output%*) in the CLSM offgas treatment system during the AP-101 waste run with demister collection added to the ‘Condensate’ instead of the ‘End Filters’.

5.4 ⁹⁹Tc and Re Retention and Analysis

The measured content of ⁹⁹Tc or Re in the glass product from the AP-101 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 5.9. The ⁹⁹Tc or Re retention values, R_{99Tc} and R_{Re} , calculated for each glass pour are also displayed in Figure 5.9 with respect to the mass of glass discharged. The characteristic relationships between Re or ⁹⁹Tc and Cs are shown in Table 5.6 for the AP-101 simulant CLSM run and in Table 5.7 for the AP-101 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 AP-101 simulant CLSM run and on Figure 4.1b for the AP-101 waste CLSM run.

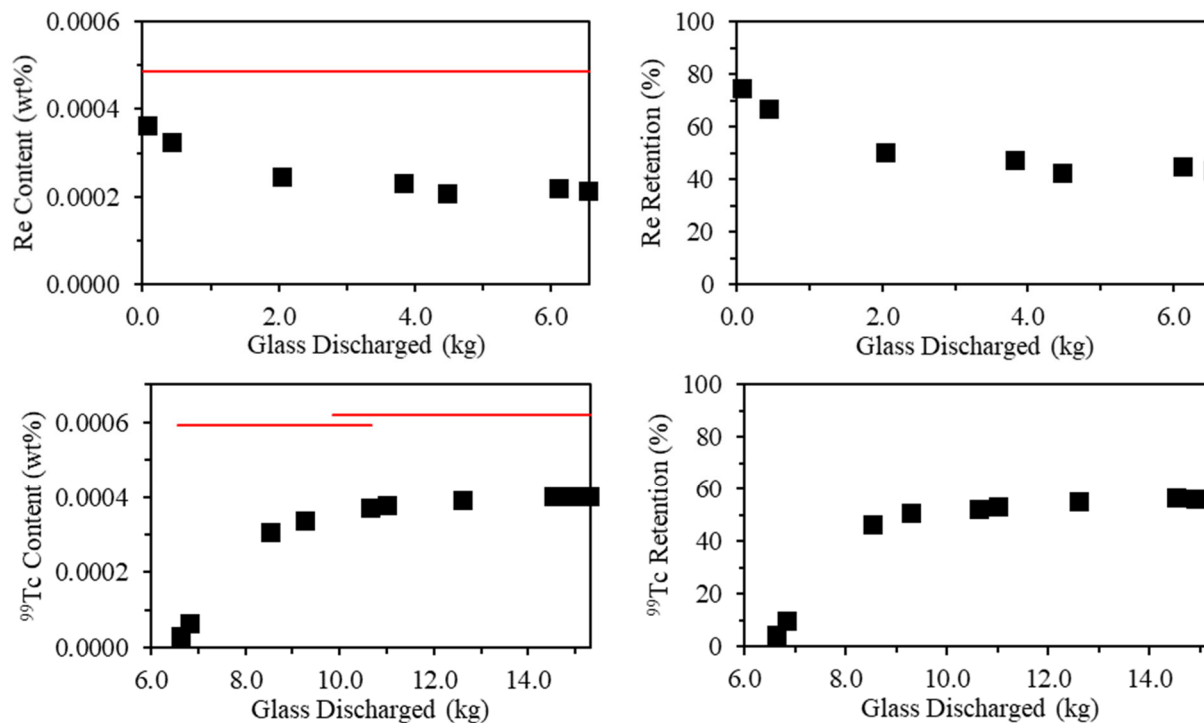


Figure 5.9. Measured Re content and retention in the glass product from the AP-101 simulant CLSM run (top; 0.00 – 6.56 kg discharged) and measured ⁹⁹Tc content and retention in the glass product from the AP-101 waste CLSM run (bottom; 6.61 – 15.30 kg discharged).

Table 5.6. Re and Cs Relationships During the AP-101 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 (%)	
4.89	0.10	47.2	Initial	0.068	3.63	341	74			
4.89	0.10	47.2	0.53	0.432	3.27	358	67			
4.89	0.10	47.2	2.03	2.041	2.51	162	51			
4.89	0.10	47.2	3.53	3.826	2.33	76.0	48	48	90	
4.89	0.10	47.2	4.03	4.472	2.08	56.7	43			
4.89	0.10	47.2	5.53	6.116	2.21	21.0	45	45	89	
4.89	0.10	47.2	Final	6.551	2.16	13.4	44			
							Total, <i>R_i</i>	42		
							Total, <i>Rec_i</i>	104		

^(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 5.7. ⁹⁹Tc and Cs Relationships During the AP-101 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 (%)
6.62	1.18	5.6	Initial	0.062	0.316	21.1	5		
6.62	1.18	5.6	0.55	0.266	0.664	20.1	10		
6.62	1.18	5.6	3.56	1.981	3.06	6.53	46		
6.62	1.18	5.6	4.56	2.721	3.36	4.87	51	51	76
7.09	0.78	9.1	6.56	4.088	3.71	2.89	52		
7.09	0.78	9.1	7.08	4.446	3.76	2.38	53	53	77
7.09	0.78	9.1	9.13	6.062	3.90	1.49	55		
7.09	0.78	9.1	11.56	7.984	4.03	0.780	57	57	81
7.09	0.78	9.1	12.06	8.347	4.00	0.777	56		
7.09	0.78	9.1	Final	8.751	3.97	0.681	56		
							Total, R_i	60	
							Total, Rec_i	86 ^(b)	

^(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) Values reported include the estimate for mass recovered in offgas piping wash, described in Section 5.3.

The 2.0 kg of AP-107 glass loaded into the CLSM vessel for the start of the AP-101 simulant run contained Re that had been retained during a previous run (Dixon et al. 2022b), which accounts for the high R_{Re} value during the first two glass pours. The retention of Re in the glass during the processing of the AP-101 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 45 ± 2 %. Compared to previous CLSM runs processing AP-105 simulant melter feed (Dixon et al. 2018) and AP-107 simulant melter feed (Dixon et al. 2022b), the retention of Re from greatest to least was AP-107 > AP-101 > AP-105.

The 2.0 kg of AP-101-S glass loaded into the CLSM vessel for the start of the AP-101 waste run did not contain any ⁹⁹Tc, thus the retention of ⁹⁹Tc in the glass during the processing of the AP-101 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 55 ± 2 %. Compared to previous CLSM runs processing AP-105 waste melter feed (R_{99Tc} ranged from 24 to 45 %; Dixon et al. 2018 and 2022a) and AP-107 waste melter feed at several different levels of recycled condensate (R_{99Tc} ranged from 30 to 40 %; Dixon et al. 2019, 2020b, and 2022a), the retention of ⁹⁹Tc from greatest to least was AP-101 > AP-105 ≥ AP-107. Uniquely, the AP-101 was the first melter feed processed in the CLSM where $R_{99Tc} > R_{Re}$ 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 AP-101 simulant and waste runs is shown in Figure 5.10 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.

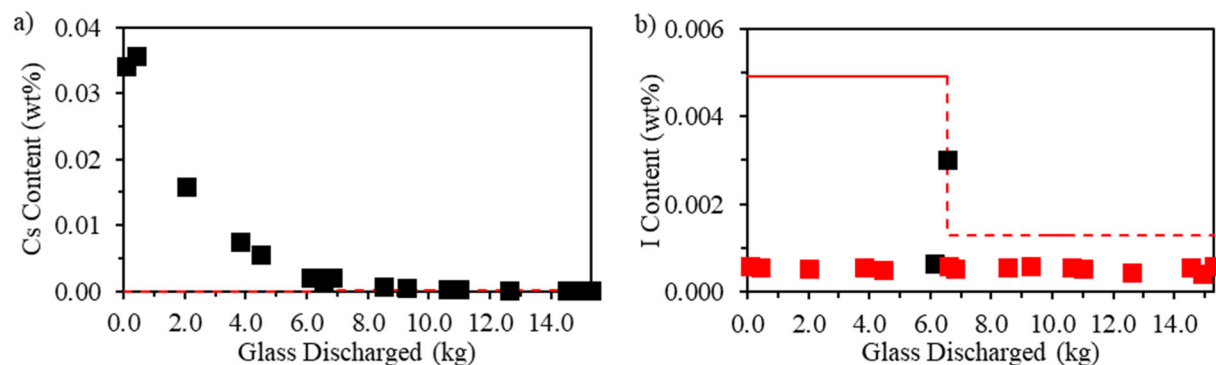


Figure 5.10. Measured a) Cs and b) I content in the glass produced during the CLSM run with the AP-101 simulant and waste melter feeds. The values in the black squares were measured in the glass and the red lines were the expected values from analysis of the melter feeds (AP-101 simulant from 0.00 – 6.56 kg and AP-101 waste from 6.61 – 15.30 kg).

The 2.0 kg of AP-107 glass loaded into the CLSM vessel for the start of the AP-101 simulant run contained a spike of ~340 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 AP-101 waste CLSM run, the Cs content in the glass had fallen to the level that the R_{Cs} value in the glass was 100 % of what was estimated to enter via the AP-101 waste melter feed.

During 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, the AP-101 simulant melter feed was spiked with KI as described in Section 3.1. To this end, I was detected in the AP-101 simulant melter feed at 23.4 ppm (see Table A.1 in Appendix A) for a target I in the glass of 49 ppm if 100 % retained.

The analytical detection limit of I in the CLSM glass product ranged from 5 to 6 ppm for all samples. Only two samples poured during the AP-101 simulant CLSM run were above this analytical detection limit, shown as the black squares in Figure 5.10b. These two samples represented the glass that was poured immediately prior and immediately after the cold cap was burned off. The chemical analysis determined that the I content in the glass prior to cold cap burn off was ~6.5 ppm, which was above the limit of detection, but below the 11.0 ppm limit of quantification. The glass poured after the cold cap burn off was analyzed at 30.7 ppm, which was greater than the limit of quantification. It was understandable that this particular glass pour would have the greatest amount of I compared to other glass pours since any I in the cold cap would have incorporated into the glass melt and poured from the CLSM vessel before the melt had idled long enough for the I to volatilize completely into the offgas system.

The I behavior in the glass pours during the AP-101 simulant CLSM run indicates that it is possible for I to be incorporated in DFLAW glasses, though its volatility appears greater than anticipated based on the ~50 % retention factor used in the Kim et al. (2012) glass models. While the solubility of I in a simplified LAW borosilicate glass in a closed environment has been demonstrated to reach 10,000 ppm (Riley et al. 2014), the environment in a melter is very different since any volatilized I would travel into the offgas system. It is recommended to spike a future melter feed with KI to an even greater level than was used in the AP-101 simulant melter feed in this study to determine if I can be detected in the glass pours prior to cold cap burn off.

5.6 Acetonitrile Analysis

The measured levels of acetonitrile in the liquids collected in the CLSM offgas system are listed for the AP-101 simulant and waste CLSM runs in Table A.1 and Table A.2 of Appendix A, respectively. Generally, 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). There are many reasons for the liquids in the CLSM to have higher acetonitrile levels than other systems including:

- the residence time for gas in the plenum space of the CLSM is less (~2.5 s max) than in the DM10 (DuraMelter 10) system (~5 s average; Matlack et al. 2011),
- the gas exiting the CLSM vessel rapidly cools to a range of ~250 to 150 °C (Dixon et al. 2020a and 2020b), while other systems can be set to a temperature near 300 °C by the presence of a film cooler (Matlack et al. 2011),
- the CLSM vessel construction from two contiguous pieces of metal significantly reduces the expected air in-leakage into the vessel compared to refractory-lined systems with a significant quantity of air leakage (Dixon et al. 2022b), and
- the liquids in the CLSM are collected from earlier units in the offgas treatment system (primarily the ‘Condensate Collector’ and ‘Demister’ shown in Figure 3.1) than in other systems (e.g. after the ‘Vacuum Evaporator’ in the DM10 system of Matlack et al. 2017 and 2018).

Table 5.8 displays the amount of acetonitrile (mg) collected in each liquid, calculated from the acetonitrile concentration in the liquid, the liquid density, and the total mass of liquid collected. For both the AP-101 simulant and waste CLSM runs, it was revealed that ~90 % of the total acetonitrile collected during the run was found in the combination of the condensate and demister liquids. Thus it is recommended that future testing only send these two types of liquid for analysis with an understanding of how they represent a total run.

Table 5.8. Acetonitrile in Liquids from the AP-101 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	150	951	2.101	2.439
Primary SBS Sump	Simulant	98	97	0.213	
Primary Offgas Wash	Simulant	0.44	0	0.000	
Sampling Offgas Wash	Simulant	0.56	0	0.000	
Demister	Simulant	390	50	0.111	
Pre-filter Housing	Simulant	310	6	0.013	
Pre-filter Housing	Waste	600	74	0.124	4.925
Sampling SBS Sump	Waste	48	58	0.097	
Primary SBS Sump	Waste	150	167	0.280	
Condensate A	Waste	170	346	0.582	
Condensate B	Waste	310	680	1.143	
Condensate C	Waste	310	292	0.491	
Demister A	Waste	300	351	0.590	
Demister B	Waste	340	962	1.618	

5.7 Production Comparison

Table 4.2 reported the production characteristics for both the AP-101 simulant and waste CLSM runs. Compared to previous simulant CLSM runs with other compositions (Dixon et al. 2020a and 2022b), the AP-101 simulant melter feed processed at the highest rate. It processed $\sim 300 \text{ kg m}^{-2} \text{ d}^{-1}$ faster than the previous fastest melter feed, the AP-107 simulant (Dixon et al. 2022b), with about a $10 \text{ }^\circ\text{C}$ cooler plenum temperature despite a $\sim 30 \text{ L min}^{-1} \text{ m}^{-2}$ lower bubbling flux rate. However, the $\sim 15 \text{ }^\circ\text{C}$ cooler average glass temperature during the AP-107 simulant CLSM run compared to the AP-101 simulant CLSM run may account for some of these production differences. Observationally, the cold cap in both the AP-101 simulant and AP-107 simulant CLSM runs behaved similarly and it is believed that these two melter feeds were closest characteristically due to the presence of Li_2CO_3 as a GFC, which was not present in other simulant melter feeds, AP-105 and AN-105 (Dixon et al. 2020a).

The AP-101 waste melter feed processed $\sim 700 \text{ kg m}^{-2} \text{ d}^{-1}$ slower than the AP-101 simulant melter feed. As noted in Section 4.2.2, the feed pump rate in the radioactive CLSM system had reached a maximum and it is likely that the AP-101 melter feed could have processed faster, with greater cold cap coverage if the pump had a higher capacity. Resultingly, the average plenum temperature during the AP-101 waste run was $\sim 85 \text{ }^\circ\text{C}$ hotter than the AP-101 simulant run and the bubbling flux rate in the waste run was less than half of that used in the simulant run.

The average glass production rate and average plenum temperature during the AP-101 waste CLSM run were almost equivalent to those values achieved in the previous run with the radioactive CLSM system during the processing of the two-time recycle AP-107 and AP-105 melter feeds (Dixon et al. 2022a). This gives a strong indication that the melter feed pumping system has a restriction that needs cleaned, has worn down with use and needs replaced, or a larger capacity pump is required in order to deliver melter feed at increased rates to maximize cold-cap coverage.

6.0 Conclusions

A simulant version of the AP-101 waste was designed and processed in the simulant CLSM system to prepare for the run with actual AP-101 waste since the AP-101 composition had yet to be processed in the CLSM. The AP-101 waste simulant was designed from the BBI for the Hanford Tank 241-AP-101 liquid (Detrich 2015) and an assumed target dilution of the waste from the BBI sodium molarity of 8.61 M to the desired 5.5 M Na. Over 6.11 hours of processing, 6.55 kg of glass were produced for an average glass production rate of 2275 kg m² d⁻¹ for AP-101 simulant melter feed in the CLSM system.

A sample of AP-101 waste was retrieved by WRPS and received at the RPL by PNNL. The waste went through solids filtration and cesium removal by ion exchange, ending at an actual sodium concentration of 5.72 M. Glass composition was calculated from the Kim et al. (2012) glass models, GFCs were added, and the resultant melter feeds were processed in the CLSM. Over 12.14 hours of processing, 8.75 kg of glass were produced for an average glass production rate of 1530 kg m² d⁻¹ for AP-101 waste melter feed in the CLSM system. It is believed that this value for average glass production rate when processing AP-101 waste melter feed was limited by the capabilities of the pumping system and could be greater if a pump could deliver the feed at a faster rate, as observed during the AP-101 simulant CLSM run. Other conclusions from the AP-101 simulant and waste CLSM runs include:

- The cold-cap behavior for the AP-101 waste melter feed was similar to the AP-101 simulant melter feed and both adhered closest to 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.
- The glass poured from the CLSM vessel during the AP-101 waste run appeared qualitatively more viscous than the glass poured during the AP-101 simulant run.
- Due to the difference in Na molarity between the AP-101 simulant and the AP-101 waste, the target glass composition for simulant glass, called AP-101-S, had a higher CaO target than the target glass composition for waste glass, called AP-101-W, and the AP-101-S had Li₂O, which was not called for in AP-101-W.
- All the primary components in the glass produced during the CLSM runs were within 10 % of their targets based on the AP-101-S and AP-101-W glass compositions.
- The recovery values for most components during the AP-101 waste CLSM run were slightly below the expected range of 100 ± 10 % due to the collection of melter feed after processing in the radioactive space resulting in an unmeasurable portion of feed being leftover in containers.
- Components recovered in the CLSM offgas system (Re, Cs, I, S, K, Cl, and F) during the AP-101 simulant run were recovered in similar proportions in each unit of the offgas system compared to previous CLSM runs.
- For the components recovered in the CLSM offgas system (⁹⁹Tc, Cs, I, S, K, Cl, and F) during the AP-101 waste run, more were recovered in the demister than in previous runs, which indicated a block in the condensate draining system that allowed more gas to survive in the offgas treatment system before being cooled by the demister.

- The relative chemical steady-state retention of Re when processing the AP-101 simulant melter feed was 45 ± 2 %, which when compared with the processing of other LAW simulant melter feeds showed that the retention of Re from greatest to least was AP-107 > AP-101 > AP-105.
- The relative chemical steady-state retention of ^{99}Tc when processing the AP-101 waste melter feed was 55 ± 2 %, which when compared with the processing of other LAW melter feeds showed that the retention of ^{99}Tc from greatest to least was AP-101 > AP-105 \geq AP-107.
- A spike of ~ 340 ppm Cs was present in the initial glass used for the AP-101 simulant CLSM run and the Cs had decreased to ~ 30 ppm when the glass was used in the AP-101 waste CLSM run, before reaching a relative chemical steady-state retention of ~ 100 % based on the low amount of Cs in the AP-101 waste.
- Iodine was added as a spike into the AP-101 simulant melter feed and I was analyzed above the detection limit in the glass poured immediately after the cold cap had burned off, indicating that it can be incorporated into a LAW glass melt, but that the retention of I in the melt during the relative chemical steady state with consistent cold-cap coverage is less than 50%.
- Acetonitrile was detectable in the liquids collected from the CLSM system, ~ 90 % of which was found in the condensate and demister liquids.

7.0 References

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Appendix A – Chemical Analysis of Samples Collected from the AP-101 Simulant and Waste CLSM Runs

The table in this section displays the complete chemical analytical results for all samples from the AP-101 simulant and waste CLSM run that were sent to SwRI for analysis. Values noted with “<” and 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 AP-101 Simulant CLSM Run

Sample Name	Sample Mass (kg)	Component Concentration (mg kg ⁻¹)										
		Re	Total Cs	Total I	Al	Ag	As	B	Ba	Be	Bi	Ca
AP-101 Simulant Melter Feed	13.856	2.31	< 0.0489	23.4	15200	< 0.978	< 2.44	15400	17.1	< 0.489	< 3.91	14800
Glass Pour Initial	0.068	3.63	341	< 5.91	31700	< 9.88	< 2.47	30900	205	< 4.94	< 39.5	22700
Glass Pour 0.53	0.364	3.27	358	< 5.56	31300	< 9.80	< 2.45	31500	213	< 4.90	< 39.2	23900
Glass Pour 2.03	1.609	2.51	162	< 5.48	31800	< 9.65	4.57	35700	119	< 4.83	< 38.6	28000
Glass Pour 3.53	1.785	2.33	76.0	< 5.73	32100	< 9.91	3.26	32400	75.6	< 4.95	< 39.6	30100
Glass Pour 4.03	0.646	2.08	56.7	< 5.15	32700	< 9.85	4.15	32600	64.2	< 4.92	< 39.4	31000
Glass Pour 5.53	1.644	2.21	21.0	6.54	31600	< 9.91	5.55	32200	48.0	< 4.96	< 39.7	30600
Glass Pour Final	2.435	2.16	13.4	30.7	32400	< 9.89	5.40	32400	44.1	< 4.94	< 39.6	31600
Primary HEPA Filter A	0.015	< 0.901	1.62	6.01	12000	< 0.969	2.94	12500	16600	< 0.485	< 3.88	4790
Sampling HEPA Filter 1	0.015	38.4	60.9	< 5.70	11800	< 0.941	2.74	10800	16100	< 0.470	< 3.76	4660
Sampling HEPA Filter 2	0.015	45.6	22.6	< 5.81	12000	< 0.957	< 2.39	11800	16200	< 0.479	< 3.83	4550
Pre-filter	0.327	7.58	14.7	2.04	< 4.70	0.586	< 1.18	68.0	< 0.235	< 0.235	< 1.88	9.36
Condensate	6.357	1.56	2.60	49.5	9.13	< 0.504	< 1.26	111	< 0.252	< 0.252	< 2.02	11.3
Primary SBS Sump	0.986	2.35	1.55	108	13.0	< 0.502	< 1.26	154	< 0.251	< 0.251	< 2.01	16.1
Primary Offgas Wash	0.295	11.2	5.98	2.18	78.8	< 0.499	< 1.25	321	< 0.250	< 0.250	< 2.00	118
Sampling Offgas Wash	0.083	4.13	2.33	2.05	38.2	< 0.504	< 1.26	269	< 0.252	< 0.252	< 2.02	47.8
Demister	0.147	1.28	1.77	127	10.2	< 0.444	< 1.11	72.9	< 0.222	< 0.222	< 1.78	10.3
Pre-filter Housing	0.019	4.60	7.16	182	3.98	< 0.388	< 0.969	79.0	0.494	< 0.194	< 1.55	18.6

Table A.1. Chemical Analysis of Samples Produced During the AP-101 Simulant CLSM Run (cont.)

Sample Name	Component Concentration (mg kg ⁻¹)											
	Cd	Co	Cr	Cu	Fe	K	La	Li	Mg	Mn	Mo	Na
AP-101 Simulant Melter Feed	< 0.489	1.69	323	8.18	18600	1510	< 1.47	3180	4040	44.9	3.16	57900
Glass Pour Initial	14.0	3.74	2600	15.5	42900	3390	1290	2480	8140	114	436	137000
Glass Pour 0.53	14.7	3.76	1820	17.7	41800	3250	1330	2940	8190	112	455	130000
Glass Pour 2.03	7.46	4.16	1060	18.2	40200	3250	625	4910	8490	105	227	125000
Glass Pour 3.53	4.09	4.15	907	17.7	40000	3260	292	5870	8670	99.6	109	124000
Glass Pour 4.03	3.21	4.19	869	17.3	39200	3180	214	5920	8710	95.8	81.9	120000
Glass Pour 5.53	1.94	4.08	795	17.7	37900	3400	85.5	6740	8530	95.8	36.4	128000
Glass Pour Final	1.61	4.07	900	17.7	38800	3330	57.1	6530	8880	95.4	26.8	122000
Primary HEPA Filter A	< 0.485	< 24.2	59.6	2.09	339	8940	< 1.45	2.51	634	11.4	29.9	25000
Sampling HEPA Filter 1	< 0.470	< 23.5	145	1.20	390	9120	< 1.41	105	651	7.20	24.5	33700
Sampling HEPA Filter 2	< 0.479	< 23.9	154	1.32	482	8920	< 1.44	114	683	5.46	25.4	33100
Pre-filter	< 0.235	0.335	43.5	0.840	101	131	< 0.705	13.8	< 2.35	1.31	3.06	1590
Condensate	< 0.252	< 0.252	6.69	< 0.252	27.9	26.3	< 0.756	5.73	< 2.52	< 0.252	< 0.504	456
Primary SBS Sump	< 0.251	< 0.251	11.9	< 0.251	33.3	46.9	< 0.753	10.6	< 2.51	< 0.251	< 0.502	727
Primary Offgas Wash	< 0.250	< 0.250	31.2	0.317	269	146	< 0.749	25.0	7.55	0.583	1.20	3160
Sampling Offgas Wash	< 0.252	< 0.252	17.2	< 0.252	143	70.3	< 0.756	27.2	< 2.52	0.307	0.619	1640
Demister	< 0.222	< 0.222	10.1	0.230	54.5	20.9	< 0.667	2.91	< 2.22	0.668	0.631	336
Pre-filter Housing	< 0.194	8.02	516	13.7	2340	70.3	< 0.581	4.74	2.01	37.7	63.5	819

Table A.1. Chemical Analysis of Samples Produced During the AP-101 Simulant CLSM Run (cont.)

Sample Name	Component Concentration (mg kg ⁻¹)											
	Ni	P	Pb	Pd	S	Sb	Se	Si	Sn	Sr	Th	Ti
AP-101 Simulant Melter Feed	42.9	156	1.65	< 2.44	945	< 2.44	< 2.44	101000	5.60	8.06	< 2.44	3980
Glass Pour Initial	1120	124	31.4	< 24.7	1240	< 24.7	< 24.7	212000	12.4	155	< 24.7	8910
Glass Pour 0.53	918	220	30.3	< 24.5	1470	< 24.5	< 24.5	216000	14.3	159	< 24.5	8850
Glass Pour 2.03	598	697	14.9	< 24.1	1700	< 24.1	< 24.1	218000	17.4	84.3	< 24.1	8610
Glass Pour 3.53	363	737	8.22	< 24.8	1850	< 24.8	< 24.8	214000	18.5	48.6	< 24.8	8510
Glass Pour 4.03	316	730	6.56	< 24.6	1860	< 24.6	< 24.6	214000	17.8	39.6	< 24.6	8600
Glass Pour 5.53	213	684	4.03	< 24.8	1920	< 24.8	< 24.8	214000	18.5	26.1	< 24.8	8350
Glass Pour Final	193	657	3.70	< 24.7	2050	< 24.7	< 24.7	217000	18.9	23.1	< 24.7	8460
Primary HEPA Filter A	23.7	14.5	2.08	< 2.42	151	< 2.42	< 2.42	391000	< 1.94	216	< 2.42	< 31.0
Sampling HEPA Filter 1	4.11	28.9	2.05	< 2.35	1150	< 2.35	< 2.35	379000	3.40	228	< 2.35	< 46.0
Sampling HEPA Filter 2	4.79	28.2	3.46	< 2.39	1130	< 2.39	< 2.39	383000	32.2	236	< 2.39	< 41.1
Pre-filter	16.0	< 5.88	1.51	< 1.18	131	< 1.18	< 1.18	< 5.88	< 0.940	< 0.235	< 1.18	< 0.235
Condensate	< 0.252	47.1	< 0.378	< 1.26	39.4	< 1.26	< 1.26	24.7	< 1.01	< 0.252	< 1.26	0.892
Primary SBS Sump	< 0.251	72.4	< 0.377	< 1.26	75.4	< 1.26	< 1.26	29.8	< 1.00	< 0.251	< 1.26	1.04
Primary Offgas Wash	1.27	9.58	< 0.375	< 1.25	236	< 1.25	< 1.25	144	< 0.999	< 0.250	< 1.25	9.55
Sampling Offgas Wash	1.15	< 6.30	< 0.378	< 1.26	161	< 1.26	< 1.26	67.7	< 1.01	< 0.252	< 1.26	2.15
Demister	3.76	41.8	< 0.333	< 1.11	24.3	< 1.11	< 1.11	9.76	< 0.889	< 0.222	< 1.11	2.45
Pre-filter Housing	321	116	0.450	< 0.969	141	< 0.969	< 0.969	< 4.84	2.32	< 0.194	< 0.969	0.559

Table A.1. Chemical Analysis of Samples Produced During the AP-101 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
AP-101 Simulant Melter Feed	< 7.33	< 24.4	5.87	93.9	4.80	12100	9940	< 34.2	1520	15.6	15500	7060
Glass Pour Initial	< 74.1	< 24.7	55.0	120	41.3	25800	20800	< 237	2390	300	--	--
Glass Pour 0.53	< 73.5	< 24.5	56.5	129	41.5	27800	20700	< 222	2420	330	--	--
Glass Pour 2.03	< 72.4	< 24.1	62.0	125	41.8	27700	21000	< 219	2230	285	--	--
Glass Pour 3.53	< 74.3	< 24.8	65.0	118	42.0	28000	21100	< 229	2290	278	--	--
Glass Pour 4.03	< 73.8	< 24.6	63.6	120	40.9	28500	21400	< 206	2200	255	--	--
Glass Pour 5.53	< 74.3	< 24.8	66.0	136	41.8	26700	21500	< 220	2320	243	--	--
Glass Pour Final	< 74.2	< 24.7	66.2	126	42.1	28300	21400	< 203	2200	264	--	--
Primary HEPA Filter A	< 7.27	< 24.2	< 0.485	86.4	2.46	10900	106	< 0.963	17.3	< 0.963	674	< 0.963
Sampling HEPA Filter 1	< 7.06	< 23.5	< 0.470	78.2	2.13	8500	90.8	1.68	11200	117	1240	4.66
Sampling HEPA Filter 2	< 7.18	< 23.9	0.751	85.0	2.23	9460	94.8	1.70	13100	139	606	139
Pre-filter	< 3.53	< 11.8	< 0.235	< 1.18	< 0.235	11.9	< 0.705	< 1.88	5.09	8.29	3860	< 1.88
Condensate	< 3.78	< 12.6	< 0.252	< 1.26	< 0.252	25.3	1.27	< 9.88	398	12.6	3150	< 9.88
Primary SBS Sump	< 3.77	< 12.6	< 0.251	< 1.26	< 0.251	32.9	0.800	< 10.1	640	16.9	1690	< 10.1
Primary Offgas Wash	< 3.75	< 12.5	< 0.250	< 1.25	< 0.250	129	9.29	< 9.84	2470	171	527	38.7
Sampling Offgas Wash	< 3.78	< 12.6	< 0.252	< 1.26	< 0.252	121	2.28	< 9.92	826	46.2	391	128
Demister	< 3.33	< 11.1	< 0.222	< 1.11	< 0.222	19.8	1.54	17.8	167	50.5	54100	< 8.74
Pre-filter Housing	< 2.91	< 9.69	2.86	3.15	< 0.194	185	< 0.581	< 8.13	861	10.2	111000	< 8.13

Table A.1. Chemical Analysis of Samples Produced During the AP-101 Simulant CLSM Run (cont.)

Sample Name	Component Concentration (mg kg ⁻¹)		Component Concentration (μg L ⁻¹)	
	P as PO ₄	Total S (Solids) or SO ₄ (All Others)	TOC	Acetonitrile
AP-101 Simulant Melter Feed	< 8.56	2590	12000	--
Glass Pour Initial	--	1460	--	--
Glass Pour 0.53	--	1510	--	--
Glass Pour 2.03	--	1590	--	--
Glass Pour 3.53	--	1700	--	--
Glass Pour 4.03	--	1730	--	--
Glass Pour 5.53	--	1750	--	--
Glass Pour Final	--	1870	--	--
Primary HEPA Filter A	< 0.963	23.5	--	--
Sampling HEPA Filter 1	< 0.956	2910	--	--
Sampling HEPA Filter 2	2.53	2900	--	--
Pre-filter	< 1.88	741	--	--
Condensate	< 9.88	228	255	150000
Primary SBS Sump	< 10.1	324	223	98000
Primary Offgas Wash	< 9.84	696	36.6	< 440
Sampling Offgas Wash	< 9.92	490	21.4	560
Demister	< 17.4	163	838	390000
Pre-filter Housing	< 40.1	634	3150	310000

Table A.2. Chemical Analysis of Samples Produced During the AP-101 Waste CLSM Run

Sample Name	Sample Mass (kg)	Component Concentration (mg kg ⁻¹)										
		⁹⁹ Tc	Total Cs	Total I	Al	Ag	As	B	Ba	Be	Bi	Ca
AP-101 Waste Melter Feed 1	11.193	2.61	< 0.467	< 5.66	13600	< 9.35	< 23.4	15000	16.3	< 4.67	< 37.4	11100
AP-101 Waste Melter Feed 2	10.999	2.80	< 0.306	< 5.82	14350	< 6.11	< 15.3	14550	16.6	< 3.06	< 24.4	11200
Glass Pour Initial	0.062	0.316	21.1	< 5.72	32000	< 9.91	4.78	32050	42.7	< 4.96	< 39.7	27800
Glass Pour 0.55	0.204	0.664	20.1	< 5.34	31800	< 9.51	5.40	32200	44.8	< 4.75	< 38.0	27700
Glass Pour 3.56	1.714	3.06	6.53	< 5.69	31800	< 9.79	5.95	32900	40.0	< 4.89	< 39.2	25800
Glass Pour 4.56	0.740	3.36	4.87	< 5.79	31600	< 9.85	5.25	32800	40.2	< 4.93	< 39.4	25000
Glass Pour 6.56	1.367	3.71	2.89	< 5.69	31600	< 9.79	5.33	33300	38.3	< 4.89	< 39.2	25100
Glass Pour 7.08	0.358	3.76	2.38	< 5.15	31600	< 9.91	5.15	33200	38.9	< 4.95	< 39.6	25000
Glass Pour 9.13	1.617	3.90	1.49	< 4.29	31700	< 9.77	4.87	33000	37.1	< 4.89	< 39.1	25000
Glass Pour 11.56	1.921	4.03	0.780	< 5.49	32000	< 9.92	5.88	32900	37.1	< 4.96	< 39.7	24800
Glass Pour 12.06	0.363	4.00	0.777	< 4.13	31900	< 9.98	5.64	32600	36.9	< 4.99	< 39.9	24400
Glass Pour Final	2.409	3.97	0.681	< 5.89	31700	< 9.79	5.76	32800	37.6	< 4.90	< 39.2	24300
Primary HEPA Filter A	0.032	0.232	0.313	< 5.70	5940	< 0.860	< 2.15	5310	8090	< 0.430	< 3.44	2420
Sampling HEPA Filter 1	0.015	22.5	3.53	< 6.04	12200	< 0.998	2.74	10300	16700	< 0.499	< 3.99	4830
Sampling HEPA Filter 2	0.015	22.6	2.03	< 6.00	12050	< 0.970	2.77	11200	16800	< 0.485	< 3.88	4755
Sampling HEPA Filter 3	0.015	22.7	1.45	< 5.86	12200	< 0.970	3.45	11100	17000	< 0.485	< 3.88	4680
Pre-filter	0.316	6.91	1.86	0.529	92.0	< 0.480	< 1.20	290	0.694	< 0.240	< 1.92	107
Pre-filter Housing	0.123	4.11	1.40	3.72	7.01	< 0.416	< 1.04	221	< 0.208	< 0.208	< 1.66	5.74
Sampling SBS Sump	1.207	0.00755	< 0.0258	0.692	< 5.15	< 0.515	< 1.29	62.3	< 0.258	< 0.258	< 2.06	< 2.58
Primary SBS Sump	1.112	1.52	0.309	0.800	26.4	< 0.502	< 1.25	204	< 0.251	< 0.251	< 2.01	35.1
Condensate A	2.041	0.457	0.228	1.01	8.27	< 0.511	< 1.28	84.8	< 0.256	< 0.256	< 2.05	6.26
Condensate B	2.198	0.870	0.124	1.01	7.11	< 0.500	< 1.25	98.3	< 0.250	< 0.250	< 2.00	6.51
Condensate C	0.944	1.05	0.0909	0.903	7.30	< 0.504	< 1.26	118	< 0.252	< 0.252	< 2.02	8.10
Demister A	1.332	0.709	0.182	1.13	9.32	< 0.506	< 1.26	98.1	< 0.253	< 0.253	< 2.02	7.08
Demister B	3.223	1.00	0.0875	0.902	6.60	< 0.498	< 1.24	109	< 0.249	< 0.249	< 1.99	6.39

Table A.2. Chemical Analysis of Samples Produced During the AP-101 Waste CLSM Run (cont.)

Sample Name	Component Concentration (mg kg ⁻¹)											
	Cd	Co	Cr	Cu	Fe	K	La	Li	Mg	Mn	Mo	Na
AP-101 Waste Melter Feed 1	< 4.67	< 4.67	288	8.27	17500	1480	< 14.0	< 14.0	3730	41.2	20.6	53300
AP-101 Waste Melter Feed 2	< 3.06	< 3.06	297	8.06	17750	1605	< 9.17	< 9.17	3820	39.7	21.9	57300
Glass Pour Initial	1.98	3.97	4165	18.4	38550	3340	87.8	4880	8430	98.3	41.4	126000
Glass Pour 0.55	2.03	4.10	2620	18.7	38100	3390	85.6	4700	8470	94.8	42.8	127000
Glass Pour 3.56	1.71	4.25	1430	18.8	39100	3430	31.2	1640	8720	90.1	42.7	122000
Glass Pour 4.56	1.74	4.56	1330	19.5	38900	3510	25.3	1220	8530	92.2	46.6	122000
Glass Pour 6.56	1.60	4.62	1020	19.0	38900	3440	15.6	733	8740	89.4	43.7	120000
Glass Pour 7.08	1.69	4.60	892	19.4	39100	3510	13.9	626	8820	90.8	44.6	121000
Glass Pour 9.13	1.54	4.28	1140	18.8	39300	3520	9.42	381	8870	87.0	43.4	121000
Glass Pour 11.56	1.58	4.62	862	19.3	39200	3500	6.57	199	8850	88.4	44.5	120000
Glass Pour 12.06	1.59	4.24	869	18.7	38800	3480	6.48	201	8700	86.4	43.1	120000
Glass Pour Final	1.68	4.48	982	18.6	38100	3610	6.02	177	8570	87.6	41.5	124000
Primary HEPA Filter A	< 0.430	< 21.5	52.8	2.04	367	4340	< 1.29	2.25	333	11.4	14.3	12500
Sampling HEPA Filter 1	< 0.499	< 24.9	62.6	1.45	310	8970	< 1.50	9.99	699	5.92	28.0	29000
Sampling HEPA Filter 2	< 0.485	< 24.3	52.3	1.21	298	8895	< 1.46	6.46	659	5.75	25.4	29250
Sampling HEPA Filter 3	< 0.485	< 24.2	65.5	1.29	278	8850	< 1.45	3.94	651	5.02	28.2	28700
Pre-filter	< 0.240	0.449	58.7	1.53	120	149	< 0.720	22.0	24.6	0.603	1.22	2025
Pre-filter Housing	< 0.208	< 0.217	50.9	0.519	106	87.4	< 0.624	2.18	< 2.08	1.32	3.22	1095
Sampling SBS Sump	< 0.258	< 0.258	< 0.258	< 0.258	< 5.15	< 7.73	< 0.773	< 0.773	< 2.58	< 0.258	< 0.515	< 7.73
Primary SBS Sump	< 0.251	< 0.251	6.14	< 0.251	40.9	33.3	< 0.752	< 0.752	< 2.51	< 0.251	< 0.502	614
Condensate A	< 0.256	< 0.256	6.72	< 0.256	26.6	11.3	< 0.767	< 0.767	< 2.56	< 0.256	< 0.511	186
Condensate B	< 0.250	< 0.250	3.07	< 0.250	18.1	15.2	< 0.750	< 0.750	< 2.50	< 0.250	< 0.500	247
Condensate C	< 0.252	< 0.252	2.69	< 0.252	12.5	17.3	< 0.756	< 0.756	< 2.52	< 0.252	< 0.504	300
Demister A	< 0.253	< 0.253	4.72	< 0.253	25.8	13.5	< 0.758	< 0.758	< 2.53	< 0.253	< 0.506	219
Demister B	< 0.249	< 0.249	2.46	< 0.249	17.4	16.6	< 0.747	< 0.747	< 2.49	< 0.249	< 0.498	279

Table A.2. Chemical Analysis of Samples Produced During the AP-101 Waste CLSM Run (cont.)

Sample Name	Component Concentration (mg kg ⁻¹)											
	Ni	P	Pb	Pd	S	Sb	Se	Si	Sn	Sr	Th	Ti
AP-101 Waste Melter Feed 1	48.4	233	< 7.01	< 23.4	737	< 23.4	< 23.4	96400	< 18.7	6.68	< 23.4	3640
AP-101 Waste Melter Feed 2	46.8	223	< 4.59	< 15.3	775	< 15.3	< 15.3	98850	< 12.2	6.61	< 15.3	3770
Glass Pour Initial	482	489	18.5	< 24.8	1755	< 24.8	< 24.8	210500	18.7	25.3	< 24.8	8480
Glass Pour 0.55	420	654	14.7	< 23.8	1820	< 23.8	< 23.8	209000	19.0	25.4	< 23.8	8430
Glass Pour 3.56	219	< 122	9.30	< 24.5	1420	< 24.5	< 24.5	217000	21.1	18.5	< 24.5	8590
Glass Pour 4.56	199	350	8.38	< 24.6	1720	< 24.6	< 24.6	218000	24.3	18.0	< 24.6	8540
Glass Pour 6.56	168	< 122	7.68	< 24.5	1320	< 24.5	< 24.5	219000	22.0	16.5	< 24.5	8590
Glass Pour 7.08	163	< 124	7.54	< 24.8	1300	< 24.8	< 24.8	217000	25.5	16.5	< 24.8	8600
Glass Pour 9.13	138	< 122	7.00	< 24.4	1340	< 24.4	< 24.4	219000	22.3	15.4	< 24.4	8610
Glass Pour 11.56	125	< 124	6.64	< 24.8	1440	< 24.8	< 24.8	222000	23.1	15.1	< 24.8	8670
Glass Pour 12.06	124	< 125	7.14	< 24.9	1300	< 24.9	< 24.9	222000	21.9	15.0	< 24.9	8620
Glass Pour Final	123	< 122	7.04	< 24.5	1180	< 24.5	< 24.5	218000	19.6	15.2	< 24.5	8560
Primary HEPA Filter A	45.7	< 10.7	1.60	< 2.15	193	< 2.15	< 2.15	186000	1.93	117	< 2.15	< 36.1
Sampling HEPA Filter 1	5.69	27.9	3.37	< 2.49	733	< 2.49	< 2.49	391000	5.22	241	< 2.49	< 45.6
Sampling HEPA Filter 2	4.09	21.8	2.58	< 2.43	718	< 2.43	< 2.43	393000	4.14	231	< 2.43	< 38.6
Sampling HEPA Filter 3	4.08	22.2	2.47	< 2.42	785	< 2.42	< 2.42	387000	3.52	229	< 2.42	< 43.4
Pre-filter	1.28	< 6.00	< 0.405	< 1.20	191	< 1.20	< 1.20	26.2	< 0.960	< 0.240	< 1.20	17.5
Pre-filter Housing	15.7	< 6.82	0.450	< 1.04	121	< 1.04	< 1.04	< 5.20	< 0.831	< 0.208	< 1.04	0.674
Sampling SBS Sump	0.316	< 6.44	< 0.387	< 1.29	< 3.87	< 1.29	< 1.29	< 6.44	< 1.03	< 0.258	< 1.29	< 0.258
Primary SBS Sump	0.320	< 6.27	< 0.376	< 1.25	130	< 1.25	< 1.25	56.4	< 1.00	< 0.251	< 1.25	1.28
Condensate A	0.629	< 6.39	< 0.384	< 1.28	20.3	< 1.28	< 1.28	22.0	< 1.02	< 0.256	< 1.28	0.549
Condensate B	0.272	< 6.25	< 0.375	< 1.25	18.1	< 1.25	< 1.25	19.4	< 1.00	< 0.250	< 1.25	0.443
Condensate C	< 0.252	< 6.30	< 0.378	< 1.26	26.1	< 1.26	< 1.26	21.6	< 1.01	< 0.252	< 1.26	0.741
Demister A	0.646	< 6.32	< 0.379	< 1.26	16.4	< 1.26	< 1.26	21.9	< 1.01	< 0.253	< 1.26	0.534
Demister B	0.269	< 6.22	< 0.373	< 1.24	22.9	< 1.24	< 1.24	17.6	< 0.996	< 0.249	< 1.24	0.433

Table A.2. Chemical Analysis of Samples Produced During the AP-101 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
AP-101 Waste Melter Feed 1	< 70.1	< 234	5.46	65.2	< 4.67	13000	9110	< 39.9	1310	< 16.0	12400	6140
AP-101 Waste Melter Feed 2	< 45.9	< 153	4.83	72.6	4.34	12550	9580	< 38.4	1360	< 15.3	13300	6690
Glass Pour Initial	< 74.3	< 24.8	61.3	128	41.5	26400	21450	< 229	1780	324	--	--
Glass Pour 0.55	< 71.3	< 23.8	62.7	133	41.8	26500	21500	< 214	1885	254	--	--
Glass Pour 3.56	< 73.4	< 24.5	64.5	154	41.3	27700	22100	< 228	2230	253	--	--
Glass Pour 4.56	< 73.9	< 24.6	67.2	172	43.2	27100	22000	< 232	2260	264	--	--
Glass Pour 6.56	< 73.4	< 24.5	65.7	160	41.3	28100	22100	< 228	2300	242	--	--
Glass Pour 7.08	< 74.3	< 24.8	67.0	173	42.8	27400	22200	< 206	2330	220	--	--
Glass Pour 9.13	< 73.3	< 24.4	64.6	161	40.9	28000	22100	< 172	1960	179	--	--
Glass Pour 11.56	< 74.4	< 24.8	65.6	175	41.1	27500	22400	< 220	2340	226	--	--
Glass Pour 12.06	< 74.8	< 24.9	64.7	182	40.5	27200	22200	< 165	2330	208	--	--
Glass Pour Final	< 73.5	< 24.5	65.4	183	40.9	26700	22100	< 236	2230	< 236	--	--
Primary HEPA Filter A	< 6.45	< 21.5	< 0.430	30.4	1.04	5130	43.9	< 4.48	20.0	6.58	45300	3.08
Sampling HEPA Filter 1	< 7.48	< 24.9	< 0.499	83.1	2.26	8320	96.5	33.5	5480	145	181	1.07
Sampling HEPA Filter 2	< 7.28	< 24.3	< 0.485	84.2	2.18	8330	90.9	35.4	5290	62.1	169	1.06
Sampling HEPA Filter 3	< 7.27	< 24.2	< 0.485	83.2	2.14	8980	91.4	34.6	5390	89.0	38.3	2.61
Pre-filter	< 3.60	< 12.0	0.295	< 1.20	< 0.240	91.6	39.3	< 4.80	199	8.43	9420	< 4.80
Pre-filter Housing	< 3.12	< 10.4	< 0.208	< 1.04	< 0.208	20.3	< 0.624	< 8.21	148	55.8	81500	< 8.21
Sampling SBS Sump	< 3.87	< 12.9	< 0.258	< 1.29	< 0.258	0.482	< 0.773	< 9.96	< 9.96	< 9.96	95.3	554
Primary SBS Sump	< 3.76	< 12.5	< 0.251	< 1.25	< 0.251	62.1	1.34	< 9.98	510	40.8	2100	< 9.98
Condensate A	< 3.84	< 12.8	< 0.256	< 1.28	< 0.256	16.6	< 0.767	< 10.0	168	20.3	1560	< 10.0
Condensate B	< 3.75	< 12.5	< 0.250	< 1.25	< 0.250	18.7	< 0.750	< 9.82	258	< 9.82	3300	< 9.82
Condensate C	< 3.78	< 12.6	< 0.252	< 1.26	< 0.252	19.9	0.783	< 9.92	307	11.7	3050	< 9.92
Demister A	< 3.79	< 12.6	< 0.253	< 1.26	< 0.253	21.4	< 0.758	< 9.90	237	12.1	4250	11.9
Demister B	< 3.73	< 12.4	< 0.249	< 1.24	< 0.249	17.7	< 0.747	< 9.86	312	< 9.86	4720	13.3

Table A.2. Chemical Analysis of Samples Produced During the AP-101 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
AP-101 Waste Melter Feed 1	20.0	1980	13300	--	4.09E+01	<2.57E+00	<9.05E-01	<1.25E+01	<2.80E+00	3.26E+01	<0.00E+00
AP-101 Waste Melter Feed 2	28.9	2110	14300	--	5.58E+01	<1.08E+00	<4.24E+00	<6.37E+00	<4.00E+00	2.70E+01	<7.25E-01
Glass Pour Initial	--	1650	--	--	1.57E+00	<0.00E+00	<1.84E-01	<0.00E+00	1.55E+00	7.34E+00	<4.13E-01
Glass Pour 0.55	--	1660	--	--	1.29E+01	<1.62E+00	5.61E+00	1.63E+00	<6.75E-01	7.03E+00	<2.89E-01
Glass Pour 3.56	--	1570	--	--	7.45E+01	<1.41E-01	2.77E+00	1.10E+01	6.16E+00	5.75E+01	<3.73E-01
Glass Pour 4.56	--	1590	--	--	7.74E+01	<2.56E-01	1.62E+00	1.49E+01	7.17E+00	5.69E+01	<2.05E-01
Glass Pour 6.56	--	1490	--	--	8.43E+01	<7.98E-01	2.24E+00	1.20E+01	8.51E+00	7.13E+01	<0.00E+00
Glass Pour 7.08	--	1520	--	--	8.62E+01	<3.84E-01	2.52E+00	1.55E+01	9.40E+00	7.05E+01	<0.00E+00
Glass Pour 9.13	--	1230	--	--	9.79E+01	<1.31E-01	<9.19E-01	1.57E+01	8.38E+00	6.71E+01	<0.00E+00
Glass Pour 11.56	--	1430	--	--	1.09E+02	<5.33E-01	2.25E+00	1.77E+01	7.23E+00	7.46E+01	<0.00E+00
Glass Pour 12.06	--	1540	--	--	9.34E+01	<2.71E-01	1.53E+00	1.53E+01	9.72E+00	6.99E+01	<2.00E-01
Glass Pour Final	--	1460	--	--	1.02E+02	<4.95E-01	1.74E+00	1.78E+01	1.33E+01	7.04E+01	<0.00E+00
Primary HEPA Filter A	< 17.9	314	--	--	<1.75E-01	<0.00E+00	<0.00E+00	<0.00E+00	<0.00E+00	<6.14E-01	<1.75E-01
Sampling HEPA Filter 1	< 0.956	1320	--	--	<1.03E+00	<2.65E-01	<2.80E-01	<9.85E-02	<1.01E-01	<7.03E-01	<2.01E-01
Sampling HEPA Filter 2	< 0.961	1270	--	--	<8.54E-01	<0.00E+00	<4.65E-02	<9.55E-02	<2.37E-01	1.65E+00	<9.25E-02
Sampling HEPA Filter 3	1.21	1460	--	--	<2.80E-01	<1.33E-01	<0.00E+00	<9.23E-02	<2.93E-01	<4.88E-01	<1.95E-01
Pre-filter	< 4.80	979	--	--	2.65E-02	<6.70E-04	<9.42E-04	<6.14E-03	<2.69E-03	1.97E-02	<0.00E+00
Pre-filter Housing	< 41.0	719	1300	600000	<1.76E-01	<8.00E-02	<1.92E-02	<9.85E-03	<0.00E+00	<1.90E-01	<4.23E-02
Sampling SBS Sump	< 9.96	< 9.96	172	48000	<2.50E-02	<1.73E-01	<0.00E+00	<0.00E+00	<0.00E+00	<2.64E-02	<1.05E-01
Primary SBS Sump	<9.98	509	297	150000	<1.85E-01	<7.31E-02	<0.00E+00	<7.38E-02	<1.26E-01	<1.26E-01	<5.03E-02
Condensate A	< 10.0	135	253	170000	<2.58E-01	<3.25E-02	<7.01E-02	<0.00E+00	<5.13E-02	<1.79E-01	<5.12E-02
Condensate B	< 9.82	146	409	310000	<2.12E-01	<3.26E-02	<9.38E-02	<4.73E-02	<2.58E-02	<2.07E-01	<1.03E-01
Condensate C	< 9.92	173	403	310000	<1.25E-01	<1.39E-01	<2.49E-02	<4.39E-02	<2.49E-02	<1.74E-01	<0.00E+00
Demister A	< 9.90	133	405	300000	<9.69E-02	<6.70E-02	<0.00E+00	<5.02E-02	<2.74E-02	<8.22E-02	<0.00E+00
Demister B	< 9.86	155	441	340000	<1.64E-01	<0.00E+00	<2.34E-02	<0.00E+00	<8.27E-02	<5.51E-02	<0.00E+00

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