This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

DISCLAIMER

WSRC-TR-2002-00093, Rev. 0
SRT-RPP-2001-00190, Rev. 0

KEYWORDS:
Hanford River Protection Project, Envelope C, Vitrification, Rheology, EPA Method, Offgas, Glass Durability, Active Vitrification, Melter, Low Activity Waste

Large Scale Vitrification of 241-AN-102 (Envelope C) Sample

SAVANNAH RIVER TECHNOLOGY CENTER

John R. Zamecnik
Charles L. Crawford
David C. Koopman

Publication Date: July 18, 2002

Westinghouse
Savannah River Company
Aiken, SC 29808

Prepared for the U.S. Department of Energy under Contract No. DE-AC09-96SR18500

DOCUMENT: WSRC-TR-2002-00093, Rev. 0
SRT-RPP-2001-00190, Rev. 0

TITLE: Large Scale Vitrification of 241-AN-102 (Envelope C) Sample

APPROVALS

Date: 7-17-02
John R. Zamecnik, Co-Author (Process Development – Hanford RPP Group/SRTC)

Date: 7/17/02
Charles L. Crawford, Co-Author (Process Development – Hanford RPP Group/SRTC)

Date: 7/17/02
David C. Koopman, Co-Author (Glass Formulation and Process Development Group/SRTC)

Date: 7/18/02
Erich K. Hansen,
SRTC Technical Reviewer (Process Development – Hanford RPP Group/SRTC)

Date: 7/17/02
Paul R. Burket,
SRTC Technical Reviewer (Process Development – Hanford RPP Group/SRTC)

Date: 7/17/02
David A. Crowley (Process Development, RPP Vitrification Manager, SRTC)

Date: 7/18/02
G. Todd Wright (WTP Research & Technology Manager)

Acknowledgements

This Large Scale Vitrification Melter task was a long-term, complex study that involved melter design, procurement, fabrication, installation, and surrogate test runs that culminated in the radioactive Large C AN-102 melter run. Many individuals made valuable contributions to the success of this project. The authors thank the following personnel for their efforts.

Design, fabrication, and installation of the melter system were led by the team of Jack Zamecnik, Rick Minichan, Doug Witt, and Charles Crawford of the SRTC Immobilization Technology Section, and John Gordon, George Weeks, John McIntosh, Terry Fields and Susan Collins of the SRTC Engineered Equipment and Systems Section (EES). Technical support for fabrication and testing from EES was provided by George Crow, Elandus Mays, Doug Holiday, Virgil Hughes, Kevin Tietze and George Graham. Facility electrical support was provided by Carey Miller of the Laboratory Services Department. Project management assistance was provided by Joe Wheeler, William Ryans, and Daro Ferrara.

System testing and operation of the melter was performed by the SRTC team above with additional assistance from Nick Hutson, Paul Burket, Terri Fellinger, and Dave Herman. Technical support for melter operations, led by Joe Wheeler and Francis Williams, consisted primarily of the following technicians: Sarah Brown, Mike Lee, Shirley McCollum, Adrienne Williams, Sammie McDuffie, Pat Toole, Mary Moss, John Duvall and Vickie Williams.

Tommy McCoy, Janet Brewer and many of the SRTC Development Machine Shop personnel provided fabrication of key components. The SRTC Analytical Glass Fabrication shop personnel Gary Dobos and Curt Sexton performed the glassware fabrication for the melter and offgas system.

Personnel from Oak Ridge's Y-12 National Security Complex: Luther Gibson, Mark Burdette, Eddie Warren and Brad Stinnett provided all of the melter offgas system technical support, consultation and offgas sample preparation for the project.

Other individuals were responsible for key contributions in the area of simulant development (Russ Eibling), melter feed tank design and testing (Erich Hansen) and quality assurance/ training records management (Terri Snyder). Technicians Sammie King, Sara Brown, Sherry Vissage and post-graduate researcher Crystal Biddle performed the surrogate and radioactive rheology testing under the direction of David Koopman. Technicians Debbie Marsh and Pat Toole conducted the durability testing on the glasses under the direction of Ned Bibler.

Table of Contents

Table of Contents

List of Figures

List of Figures

List of Figures

List of Tables

List of Tables

List of Tables

List of Acronyms

BNFL	British Nuclear Fuels Limited, Inc.
cfm	cubic feet per minute
CHG	CH2MHill Hanford Group
DF	decontamination factor (= quantity entering unit / quantity leaving unit)
DGM	dry gas meter
dpm(s)	Disintegrations per minute (second)
DWPF	Defense Waste Processing Facility
EDTA	ethylenediaminetetraacetic acid
EPA	Environmental Protection Agency
GC	gas chromatograph
GTOP	Glass Technology group Operating Procedure
HEDTA	hydroxyethylenediaminetetraacetic acid
inwc	inches water column
ISMS	Integrated Safety Management System
ITS	Immobilization Technology Section
L	Liter
LAW	Low Activity Waste
LC	Large (envelope) C
LFL	Lower Flammable Limit
lpm	liters per minute
mol	gram mole
Mt/d	metric ton/day (1000 kg/day)
NA or N/A	Not Available
ND	Not Detected, no detection limit specified
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
Nm^3/hr	standard cubic meters per hour (standard conditions: 273.16 K, 1 atm)
RPP	River Protection Project
scfm	standard cubic feet per minute (standard conditions: 273.16 K, 1 atm)
slpm	standard liters per minute (standard conditions: 273.16 K, 1 atm)
spgr or sg	specific gravity
SRS	Savannah River Site
SRTC	Savannah River Technology Center
TC	total carbon
TIC	total inorganic carbon
TOC	total organic carbon
TNX	Laboratory facility at the SRS
VSL	Vitreous State Laboratory (at Catholic University of America)

1. Executive Summary

The Large C Melter tests were successfully completed, meeting all of the experimental objectives. Waste-containing glass was produced in kilogram quantities and characterization of the metals and radionuclides present was performed. Additional glass samples were submitted to another task for regulatory characterization. The Large C Melter system was a resistance heated Inconel™ pot that was continuously fed, with continuous glass pouring and offgas treatment. The reference WTP design is a joule-heated melter; at the scale required for this demonstration, a joule-heated melter was impractical.

The work presented in this technical report supports use of the technology being proposed by RPP-WTP personnel for pretreatment and immobilization of pretreated Hanford tank 241-AN-102 waste. The AN-102 active waste stream was immobilized into a durable LAW waste glass that meets the applicable LAW product requirement specifications pertaining to waste loading, chemical composition, crystalline phase identification, radionuclide concentration limits and waste form durability testing. Sodium oxide loading in the LAW Envelope C glass is greater than 10 wt% as shown by the normalized characterization data. Analyzed activities from the glass for Cs^{137}, Sr^{90} and Tc^{99} indicate these radionuclides are present below the average target values in the Hanford RPP contract specifications. The transuranic concentrations are well below the contract specification limit. X-ray diffraction and microscopy analyses of active AN-102 glass show this waste form to be amorphous with no evidence of the presence of crystals. The ASTM standard Product Consistency Test (PCT) performed at 90°C on the AN-102 radioactive glass and the Low Activity Reference Material (LRM) standard glass showed similar measured releases for the B, Si, Na components. The PCT results indicate that normalized release for B, Si, and Na are well below the specification limit of 2 g glass/m^2.

Successful sampling of the melter offgas for volatile and particulate emissions was performed. Quantification of fixed gas emissions was also accomplished. The results showed that the relative emission rates for most of the non-radioactive elements were in the ranges expected. The volatile sampling showed that the most volatile element was boron, as expected. The overall particulate decontamination factor (DF) was found to be about 2.7E4 and the DF for Cs^{137} and Tc^{99} were 82 and 7, respectively. The DFs for Co^{60}, alpha and beta count, Sr^{90}, mass 238, and mass 232 are all over 10^3. The decontamination factor is defined as (quantity of component "x" in the feed / quantity of component "x" in the offgas). Offgas composition measurements showed the main offgas component from the feed was CO_2. NO_x was also present, as seen visually in the offgas glassware, but these compounds were not quantified. Small quantities of H_2 and CO were also found during feeding. Scaled to the LAW melter, the offgas % Lower Flammable Limit would be about 2%. Trace quantities of what was probably N_2O, and possibly ethane, propane, and isobutane were also found.

Rheological properties of the pretreated Hanford tank 241-AN-102 waste were measured at 5, 6 and 7.1 M sodium prior to and following the addition of the glass former chemicals. The region between 5M and 6M sodium seemed to be optimal for mixing and transferring with minimal settling of the melter feed. An AN-102 surrogate was developed. The rheological properties of the surrogate were the same as that of the radioactive waste without glass formers. When glass formers were added to the supernates, the rheological properties of the radioactive melter feed were more viscous than the surrogate melter feed. Settling characteristics, densities, and pH data were also obtained.

2. Introduction

2.1. Task Description

This task, the Large Scale Vitrification of 241-AN-102 (Envelope C) Sample (Large C Vitrification), was to vitrify a large (7-30 liter) sample of pretreated Envelope C sample in a small-scale continuously-fed melter, herein referred to as the "Large C Melter" or "LC Melter". The sample that was vitrified had been subjected to the complete pretreatment sequence (current at the time of the experimental work) at SRTC: 1) Sr/TRU precipitation[1]; 2) filtration to remove entrained solids and solids from Sr/TRU precipitation[2]; 3) Cs removal by ion exchange (IX)[3]; 4) Tc removal by ion exchange[3]; and 5) concentration by evaporation.[4] Glass formers, specified by the Vitreous State Laboratory at the Catholic University of America and approved by BNFL Inc., were then added to makeup the melter feed. This melter feed was then melted in the melter. Specific objectives are given in Section 3.1.

3. Background

3.1. Objectives

The following were the major objectives of this task Note that Tasks 1-4 were part of original planning for the Large C Melter project. Task 5 was added after melter processing and Task 6 was carryover work from previous physical properties measurement scope:

1. Produce waste-containing glass for characterization of metals and radionuclides.

2. Produce waste-containing glass to be archived for regulatory characterization of metals and radionuclides.[5]

3. Sample and analyze the offgas from the melter for metals and radionuclides by modified EPA SW-846 Method 0060.[6]

4. Sample and analyze the offgas from the melter for fixed gases, including combustion gases.

5. A task added after completion of this work was to analyze the offgas condensates for organics (not regulatory analyses).

6. Perform rheological measurements on three radioactive 241-AN-102 concentrated supernates and three melter feed slurries. Perform a parallel study to the above tasks using AN-102 surrogates instead of radioactive starting material.[#]

[#] Note: Rheology measurements were originally specified to SRTC in **BNFL, Inc. Document 000115**, October 1, 1998, Letter from Michael E. Johnson to Steve Wach, 'TWRS-P Contract No. DE-AC06-96-RL13398 – W375 – Physical Properties Measurements for Process Solutions – Action Item 09/17/98-21'. A SRTC Task Technical Plan was developed for the Physical Properties Measurements, 'Task Technical and Quality Assurance Plan for Physical Characterization', S. W. Rosencrance and C. A. Nash, **BNF-003-98-0037, Rev. 0**, January 12, 1999. However, the SRTC testing program did not perform rheology measurements on the AN102 pretreated and concentrated supernate with and without glass formers as indicated in Table I of the SRTC technical report for physical characterization, 'Physical Characterization for Hanford Tank Waste Samples AN-102, AN-103, and AZ-102', S. W. Rosencrance, W. D. King and C. A. Nash, **WSRC-TR-2000-00352, SRT-RPP-2000-00026**, April 2002. Therefore, the rheological measurements for AN-102 samples are presented in this present Large C Vitrification Report.

3.2. Melter System Design

3.2.1. Design Criteria for the Melter System[7]

The design criteria used for the design for the Large C Melter System were based on scaling the design of the RPP Low Activity Waste (LAW) melter. These criteria are described herein. Comparisons of these criteria with proposed LAW melter operating conditions and actual operating conditions from the Vitreous State Laboratory (VSL) melter runs will be shown.

The vitrification of the radioactive pretreated Envelope C (Tank AN-102) waste required containment in an appropriate radiological enclosure. The levels of radionuclides and the potential for exposure indicated that this work needed to be conducted, at a minimum, in a radiohood. The melter feed system, melter, and offgas treatment systems all needed to function so that no listed RCRA hazardous material was emitted into the laboratory ventilation or drain systems.

Containment of the melter glass, feed system melter feed, and offgas scrubbing liquids was accomplished with appropriate spill containment. Containment of the offgases required scrubbing and removal equipment to remove both the hazardous and radioactive components. Specific details of the offgas treatment system are given in Section 3.2.2.3. The offgas treatment and sampling system used was very similar to the offgas sampling system that is part of EPA SW-846 Method 0060 for sampling of metals.

3.2.1.1. Offgas Flammability

A major concern, when vitrifying material containing organics, is the potential for offgas flammability. The major organics in the Envelope C waste are chelating agents and their radiolytic breakdown products (EDTA, HEDTA, gluconate, glycolic acid, citric acid, nitrilotriacetic acid, iminodiacetic acid, formate, acetate, oxalate). The major contributions to offgas flammability come from the hydrogen, carbon monoxide, and smaller organic (e.g., methane) emissions from the combustion and/or pyrolysis of the less volatile organics. Many organics in this waste, although important from a hazardous emissions point of view, are not present in sufficient amounts to significantly affect the flammability of the offgas.[8]

Control of offgas flammability is governed by Standard 69 from the National Fire Protection Association (NFPA 69).[9] The rules that specifically apply are:

1. 25% of the Lower Flammable Limit (LFL) must not be exceeded if the concentrations of the flammables species are not measured in real time such that automatic interlocks can safely shut down the process. The concentration of flammable species must be the most conservative estimate.

2. 60% of the LFL must not be exceeded if the concentrations of flammable species are monitored and automatic interlocks are provided.

or

3. If the parameters which determine the concentration of combustibles are measured and interlocked, then direct measurement of the combustibles is not required, and NFPA 69 allows for operation up to 60% of the LFL.

The Defense Waste Processing Facility (DWPF) uses the last method as their basis for operation.[10] Management of explosive hazards in the RPP-WTP has been described.[11]

Credit for dilution by air inleakage could not be taken. For the DWPF system, the area of concern for flammability control is the condensate tank downstream of the melter. At this point, much of the water has been removed and the temperature is less than 100°C. Flammability in the melter is not a concern because the melter is designed, and operating conditions are maintained, to promote continuous combustion in the melter plenum.

SRS experience with the DWPF melter has shown that monitoring systems are ineffective to handle surges in flammable gases. A surge can cause the LFL to be exceeded with no opportunity for any control mechanism to mitigate the formation of the flammable gases. The flammable mixture is formed due to offgas surges from the layer of non-melted feed on top of the melter molten glass pool, i.e., the melter 'cold cap' that cannot be fully mitigated. These surges are of short duration, on the order of several seconds to a minute or two. Therefore, control of offgas flammability in the DWPF relies heavily on maintaining appropriate melter chemistry that will reduce instabilities in the cold cap, thereby minimizing both the intensity and frequency of surges. However, SRTC experience with small melters has shown that surging is much less likely since a thick cold cap that traps a substantial amount of liquid and/or gases cannot be built up. Moreover, the Large C melter has agitation by a bubbler that reduces the chances of surging.

The current approach taken by DWPF is to identify the most conservative basis for surges with a given feed chemistry and apply it to a conservatively calculated flammable gas generation rate. These calculations are based on small and pilot-scale melter data obtained under controlled test conditions. If no appropriate data on flammable gas generation as a function of 1) melter feed chemistry, 2) melter operating conditions (cold cap vs. hot top), and 3) melter plenum temperature exists, very conservative assumptions about the generation of flammable gases must be made. SRTC experience is that these assumptions can severely limit the operating range (feedrate, temperatures, air purges) of the melter.

The amount of flammable gases emitted from a melter depends on the redox chemistry in the melt cold cap and on the residence time, temperature, and excess oxygen available in the melter plenum. For the RPP LAW melter, there should be sufficient excess oxygen and the residence time for combustion will be significantly greater than in the DWPF melter. However, the design plenum temperature of as low as 400°C is below SRS experience with the DWPF melter. For DWPF, the latest modeling has

shown that inadequate combustion occurs below about 300°C actual gas temperature, or about 450°C measured plenum temperature.[12]

Since the plenum operating temperature range was to be below SRTC's experience and the likelihood of surging small, online measurement of the flammable species was determined to be the best way to assure compliance with the NFPA guidelines. On-line gas chromatographs were used to measure the concentrations of hydrogen and carbon monoxide, along with He, O_2, N_2, CO_2, and CH_4. Helium was introduced into the offgas system as a tracer gas for flowrate determination. Nitric oxide (NO) could also be measured, but only at concentrations greater than about 0.5%.

3.2.1.2. Estimation of Melter Feed Properties

The melter feed properties chosen for the design basis are shown in Table 3.1. The initial sample properties are based on data from the TWINS2 database. The Na^+ molarity was assumed to be 10.0M, with a total solids content of 50 wt% and an estimated specific gravity (spgr) of 1.38. The initial volume was assumed to be 7.5 liters.

For the purpose of estimating the melter feed properties, this "sample" is then "diluted" to a Na^+ concentration of 5.0 M and pretreated, resulting in ~16.4 liters at ~4.6 M Na^+. At the time the design of the LC Melter was undertaken, the pretreatment steps upon which this calculation was based were 1) filtration, 2) Sr/TRU precipitation using $SrNO_3$ and $Fe(NO_3)_3$, 3) filtration, 4) ion exchange, and then 5) evaporation.[13] The current Sr/TRU precipitation flowsheet[1] using $SrNO_3$ and $NaMnO_4$ results in some differences in the composition and amount of oxide-forming species in the pretreated waste. In addition, the elimination of sulfate removal[14] from the flowsheet, and the subsequent decrease in the waste loading also results in differences in composition.

The overall effect of any differences in the feed composition on the operation of the melter is insignificant since the rated melter performance was the mass of glass produced per unit time. The rate of introduction of the glass forming materials to the melter is dependent more on the total solids concentration and the actual feedrate. To give the same glass production rate at a different total solids concentration, the feedrate is simply scaled.

The predicted properties of the feed that would be generated from this pretreated sample were then estimated. First, the sample was assumed to be concentrated back to the original volume of 7.5 liters and glass formers added. The resulting melter feed was predicted to have a total volume of 10.09 liters and a Na+ concentration of 7.43M (not including any Na+ from the glass formers). The total solids content and specific gravity of this feed were predicted to be 75.7 wt% and 1.97, respectively. These predictions were compared to VSL results from making up surrogate melter feed (Table 3.1 "Low Water Content"). The melter feed described by VSL had a total solids content of 73.8 wt% and a spgr of ~1.95, which matches the predicted values well. The volume of feed made by VSL, adjusted for different amounts of starting material, is 10.2 liters

compared to the predicted 10.09 liters. Therefore, the melter feed estimation method appeared to be reasonable.

The reference melter feed properties from the BNFL preliminary design basis[15] indicated a total solids content of about 62.3 wt% and a spgr of 1.6-1.8, which was similar to the VSL "High Water Content" feed. The pretreated sample was then calculated to be concentrated to a volume of 11.36 liter. After addition of glass formers, the total solids content was 62.3 wt%, the estimated spgr was 1.71, and the total volume was 14.08 liters. VSL reported the "High Water Content" feed with about 6M Na^+ to be about 14.6 liters in volume (compared to the prediction of 14.08 liters). Estimation of the total solids and spgr of this VSL feed gave 59.5 wt% and 1.67, respectively, which again compare well with the predicted values. Therefore, we assumed that the melter feed for this task would have properties similar to those given in the last column of Table 3.1.

Table 3.1 Predicted Melter Feed Composition for Design of Large C Melter

				"Low" Water Content			"High" Water Content	
		Estimate	Calc'd	Calc'd	Calc'd	VSL Result	Calc'd	VSL Result
Waste:		Initial Sample based on TWINS2 Data	Diluted Sample based on TWINS2 Data	Uncon-centrated Pretreated Sample based on TWINS2	Pretreated Sample Concen-trated to Original Volume	From "Results of Melter Tests Using TWRS LAW Envelope C Simulants" (1)	Pretreated Sample Concentrated to BNFL Reference Melter Feed Total Solids Content	From "Results of Melter Tests Using TWRS LAW Envelope C Simulants" (2)
Mol Na+ from Waste	mol	75	75	75	75		75	
Na Molarity before Glass Formers Added	M	10.00	5.00	4.57	10.00	10.00	6.60	~6
Volume before Glass Formers Added	liter	7.50	15.00	16.43	7.50		11.36	
Na Molarity after Glass Formers Added	M			3.90	7.43		5.33	
Volume after Glass Formers Added	liter			19.24	10.09	10.20	14.08	14.57
Total Sample	kg	10.34	18.22	19.87	10.34		14.60	
Solids in Sample	kg	5.17	5.17	5.50	5.50		5.50	
Increase in Solids on Pretreatment	kg			0.33				
Water	kg	5.17	13.05	14.37	4.84		9.10	
Water Evaporated	kg				9.53		5.27	
Glass Formers	kg			9.55	9.55		9.55	
Total Solids in Sample	%	50.00	28.37	27.67	50.00		37.65	
Estimated Specific Gravity (3)		1.38	1.21	1.21	1.38		1.28	
Melter Feed:								
Total Solids	kg			15.04	15.04	14.67	15.04	14.44
Total Melter Feed	kg			29.41	19.88	19.88	24.15	24.27
Total Solids	wt%			51.1	75.7	73.8	62.3	59.5
Estimated Specific Gravity (4)				1.53	1.97	1.95	1.71	1.67
Glass Produced	kg			11.51	11.51	11.70	11.51	11.51
Wet Calcine (mass glass/ mass feed)				0.391	0.579	0.588	0.477	0.474
Dry Calcine (mass glass/ mass dry feed)				0.765	0.765	0.797	0.765	0.797
Glass Mass/Feed Volume	kg/liter			0.598	1.140	1.150	0.817	0.790

(1) Results given for "Low" water content feed in Reference 16, Table 2.3 adjusted to 7.5 liter initial un-pretreated waste.

(2) Results given for "High" water content feed in Reference 16, Table 2.3 adjusted to 7.5 liter initial un-pretreated waste.

(3) Specific Gravity = 0.007567 * (Total Solids, wt%) + 1

(4) Specific Gravity = 0.9963 + 0.0053 * (Total Solids, wt%) + 0.0001 * (Total Solids, wt%) [17]

3.2.1.3. Scaling of LC Melter to the Hanford RPP (BNFL) LAW Melter

Table 3.2 and Table 3.3 show comparisons of the full-scale LAW melter and the LC melter. The LAW melter melt pool and plenum are rectangular in construction. These tables give the design sizing criteria that the melter, feed system, and offgas system must meet. Additional requirements are described in Section 3.2.1.4.

The surface area of the LAW melter melt pool is 10 m^2 (107.6 ft^2), the glass production rate is 10 Mt/d, giving a melt flux of 41.67 kg/hr/m^2 (8.52 lb/hr/ft^2). Since the LC melter will be cylindrical, the equivalent diameter of the LAW melter was calculated for comparison; this diameter is 3.57 m (140.5 in).

The LC melter is scaled to the LAW melter based on the melt surface area. The LC melter is 4.026 inches in diameter (10.23 cm), giving a surface area of 0.00771 m^2 (0.0830 ft^2), so the melt surface area scale factor between the LAW melter and the LC melter is then 1296.6. The melter feed rate is then scaled by the same factor, giving a feed rate of 0.393 liter/hr (6.56 ml/min, 1.48 lb/hr) and a glass production rate of 0.321 kg/hr (0.707 lb/hr). (LAW feed rate = 510 liter/hr, glass production rate = 416.7 kg/hr.)

In scaling the LC melter to the LAW melter, compromises had to be made so that a practical melter could be designed. The only way to scale all parameters would be to build a full-scale melter. Glass residence time is the major parameter that was compromised; the LC melter glass residence time is substantially less that the LAW melter (due to the glass depth not being the same- a 4” OD x 30” deep melter is impractical). The implication of this compromise could have been that the glass might have had insufficient residence time to produce acceptable quality glass; however, the results show that this is not true (see section 4.3.8).

Cold cap behavior in such a small melter will not truly mimic the behavior in the much larger LAW melter. The cold cap for a very small melter, regardless of heating method, will be much thinner than that in a large melter. Offgas surges in the small melter will be much less likely than in a large melter. This, however, does not prevent obtaining useful data for characterization of combustion of organics. The effect of cold cap thickness on the composition of the offgas is believed to be negligible. Steady state combustion data obtained on the small melter can be used along with surge information obtained on larger melters to predict combustion efficiency in the presence of surging.

Glass pool dynamics will, of course, be different when scaling a 10 m^2 surface area melter to a 0.00771 m^2 melter. It would not matter what type of heating was used; the gross difference in physical size is the most significant factor. Glass pool convective currents, for both the actual melter and the Large C melter, are greatly affected by the presence of the bubbler(s), which introduces forced convection. The (forced or free) convection currents are no doubt different between the melters, and these differences are due more to the difference in physical size than due to the method of heating.

The evolution of metals and radionuclides from a melter is generally a combination of entrainment and volatilization. A small melter such as the LC melter can be used adequately to quantify volatilized metals and radionuclides since the physical process of volatilization is essentially the same regardless of melter size. However, the process of entrainment is extremely dependent on the melter plenum configuration, including its dimensions, airflow patterns, locations of heaters, etc. Small (short) plenums tend to result in more entrainment than larger ones. The LAW melter plenum is 1.42 m (56 in) tall, which is impossible to implement in a small melter. Therefore, a compromise on the height of the plenum of the LC melter was made.

Table 3.2 Comparison of LC Melter and LAW Melter Designs
(Values in bold fixed by design basis.)
(Formulas shown in Appendix 6.5.)

MELTER		LAW Melter[15]	LC Melter
Cylindrical Diameter (equivalent diameter for LAW)	in	140.48	4.026
Glass Height	in	**30.00**	4.026
Surface Area	m^2	**10.0**	0.00771
	ft^2	107.6	0.0830
Surface Area Scale Factor to Full-Scale Melter			1296.6
Glass Volume	liter	7620	0.840
Mass of Glass in Melter	kg	20955	2.31
Glass Sp Gr		**2.75**	2.75
Melter Feed Total Solids	wt %	**62.3**	62.3
Glass Production Flux (glass/hr/melt surface area)	$kg/hr/m^2$	41.67	41.67
	$lb/hr/ft^2$	8.52	8.52
Glass Production Rate	Mt/d	**10**	-
	kg/hr	416.7	0.321
	lb/hr	916.7	0.707
Glass Mass/Feed Volume	kg/liter	0.817	0.817
Melter Feed Wet Calcine (mass glass/mass feed)		0.477	0.477
Melter Feed Dry Calcine (mass glass/mass dry feed)		0.765	0.765
Feedrate	liter/hr ml/min kg/hr lb/hr	**510** - 874.5 1923.8	0.393 6.56 0.674 1.484
Volume of Feed per Melter Volume	liter	25649	2.83
Volume of Feed for 3 Melter Volumes	liter	76948	8.48
Total Volume of Feed	liter		14.08
Melter Volumes Produced from 7.5 liters of Envelope C (Large C) Waste*			4.98
Mass of Glass Produced from 7.5 liters of Envelope C (Large C) Waste	kg		11.51
Total Time for 7.5 liters of Envelope C (Large C) Waste	hr		35.8
* i.e., the incoming 241-AN-102 Envelope C waste from Hanford			

Table 3.3 Comparison of LC Melter and LAW Melter Offgas System Designs

OFFGAS		LAW Melter	LC Melter
Glass Surface Area / Vapor Space Volume	m^{-1}	0.538	0.538
Melter Vapor Space Volume	m^3	**18.58**	0.0143
	ft^3	656	0.506
	liter	18580	14.33
Feedrate / Surface Area	liter/hr/m^2	51.00	51.00
Vapor Space Volume / Glass Volume		2.44	17.06
Plenum Gas Temperature	°C	**600**	600
Offgas Flow (from Feed only)	kg/hr	457.8	0.353
	Nm^3/hr	459.3	0.354
	m^3/hr	1468.3	1.132
	scfm	270.4	0.208
	cfm	864.1	0.666
	slpm	-	5.9
	lpm	-	18.9
Offgas Flux from Feed	kg/hr/m^2	45.8	45.8
Bubbler Air	Nm^3/hr	**125.0**	0.096
	scfm	73.6	0.0567
	slpm	-	1.61
Air Inleakage (estimated = 100 scfm, 485 lb/hr)	Nm^3/hr	170.0	0.131
	scfm	100.1	0.077
	slpm	-	2.19
Air Flows (Bubbler + Inleakage)	Nm^3/hr	295.0	0.228
	scfm	173.7	0.134
	slpm	-	3.79
Total Offgas Flow	Nm^3/hr	754.3	0.582
	m^3/hr	2411.	1.860
	scfm	444.0	0.342
	cfm	1419.1	1.09
	slpm	-	9.70
	lpm	-	30.99
Total Offgas Residence Time	sec	27.7	27.7
Vapor Space Diameter	in	-	10.00
Vapor Space Height for this Diameter	in	-	10.81

The LAW melter plenum has a volume of 18.58 m^3 (676 ft^3) which we have scaled based on the melt surface area scaling factor. The LC melter then has a plenum volume of 0.0143 m^3 (0.506 ft^3). In the LAW melter, the bubbler air flow is 125 Nm^3/hr (73.6

scfm), while the offgases generated from the feed to the melter are approximately 459.3 Nm^3/hr (270.3 scfm).

ASSUMPTION: The air inleakage has been assumed to be 170 Nm^3/hr (100 scfm, 485 lb/hr).

No value for this quantity was supplied by BNFL, so an assumed value was used. This value is about five times the inleakage in the DWPF melter, which is, by design, an exceedingly tight melter, whereas the inleakage found for the similarly sized Transportable Vitrification System melter (found to be a "leaky" melter) was about 400 scfm.

Given these air flows and an assumed plenum temperature of 600°C, the total residence time in the LAW melter plenum is about 27.7 sec. (The plenum temperature specified for the LAW melter was 400-600°C.) In incinerators, a general rule of thumb is to have about 2 sec of residence time and a temperature of around 800°C to get 99.99% destruction of organics. The LAW melter has more than enough residence time for combustion (27.7 sec), but operates at a temperature of only 400 to 600°C. Had the plenum temperature been near 800°C, we could reduce the residence time in the LC melter (by reducing the plenum volume) and be assured that there would be little effect on organic destruction efficiency. However, since the temperature is much lower, we strove to maintain the plenum residence time near the prototypic value.

The prototypic total offgas flow rate from the LC melter, including "film cooler" air, is about 0.582 Nm^3/hr (0.342 scfm, 16.1 slpm). Because this offgas flow is so low, the entire offgas flow was designed to be sent through the offgas sampling train (see Section 3.2.2.3), so the need to maintain isokinetic sampling conditions for particulates and metals was not necessary.

3.2.1.4. Offgas System Design Requirements

3.2.1.4.1. Offgas Treatment to Meet Requirements for Studying Listed Wastes

To treat listed wastes from Hanford at SRTC, the systems used must have essentially zero emissions. The offgas system for the LC melter was for the most part a system of offgas sampling systems. These systems contain filters, impingers (scrubbers), and silica gel to remove particulates, metals, and water. Because these components become loaded with the offgas components and efficiency decreases with time, at least two systems were required for continuous operation. For the LC melter, three systems were provided: one sampling train and two scrubbing trains. To protect against the release of organics and other volatiles, the offgas from all trains was sent through carbon beds and filters with efficiencies similar to HEPA filters.

3.2.1.4.2. Offgas Sampling System and Composition and Flow Measurements

Sampling for metals by EPA SW-846 Method 0060[18] (similar to EPA Method 29[19]) was required by the customer. By extension of this method, sampling for additional

metals beyond those described by the method and sampling for radionuclides was requested.[20]

The Method 60 sampling train is specified for 17 hazardous air pollutant metals, as given in Table 3.4. Additional metals that were of particular interest to Hanford RPP (BNFL, Inc.) are shown in Table 3.5.

Table 3.4 EPA Method 60 Metals

antimony (Sb)	arsenic (As)	barium (Ba)
beryllium (Be)	cadmium (Cd)	chromium (Cr)
cobalt (Co)	copper (Cu)	lead (Pb)
manganese (Mn)	mercury (Hg)	nickel (Ni)
phosphorus (P)	selenium (Se)	silver (Ag)
thallium (Tl)	zinc (Zn)	

Table 3.5 Additional Metals Requested for Sampling

aluminum (Al)	boron (B)	bismuth (Bi)
calcium (Ca)	cobalt (Co)	iron (Fe)
potassium (K)	lithium (Li)	magnesium (Mg)
manganese (Mn)	molybdenum (Mo)	sodium (Na)
phosphorous (P)	platinum (Pt)	palladium (Pd)
rhodium (Rh)	silicon (Si)	tin (Sn)
tantalum (Ta)	uranium (U)	vanadium (V)
tungsten (W)	yttrium (Y)	zinc (Zn)
zirconium (Zr)		

Application of Method 60 for metals other than those listed in Table 3.4 has not been qualified by the EPA, but both SRTC and BWXT Y-12 at Oak Ridge (formerly Lockheed Martin Energy Systems) experience has shown that this method can be used for many metals. Metals that are listed as being of interest by the customer that have proven to be difficult to quantify are B, Ca, Si, Na, and K. These are difficult due to their abundance either throughout the environment or in the glassware used in the method (borosilicate glass and quartz). SRTC has also had some difficulty with determining Fe, Cr, and Al. Measurement of mercury emissions was requested, but a mutual decision to not measure it was made by the customer and SRTC. The justification for not quantifying Hg is that virtually all mercury present in any melter feed will be emitted to the offgas due to the volatility of mercury and its compounds. Determination of the amount of mercury in the glass produced is much more accurate than to measure it in the offgas. The amount in the vapor is then determined by difference. Therefore, the Method 0060 sampling system was simplified by removing the components dedicated to mercury measurement.

Radionuclides of interest are shown in Table 3.6.

Table 3.6 Radionuclides to be Sampled

Americium^{241}	Neptunium^{237}	Technetium^{99}
Antimony^{125}	Niobium^{94}	Tin^{113}
Cerium^{144}	Plutonium^{238}	Total Alpha
Cesium^{134}	Plutonium$^{239/240}$	Total Beta
Cesium^{137}	Plutonium^{241}	Uranium^{233}
Cobalt^{60}	Radium^{224}	Uranium^{234}
Curium^{242}	Ruthenium^{103}	Uranium^{235}
Curium^{244}	Ruthenium^{106}/Rhodium^{106}	Uranium^{236}
Europium^{152}	Selenium^{79}	Uranium^{238}
Europium^{154}	Strontium^{90} (Yttrium^{90})	Zinc-65
Europium^{155}		

The radionuclides carbon^{14}, iodine^{129}, and tritium were also requested to be analyzed in the offgas emissions, but similarly to mercury, it was decided that more accurate measurement of these could be done on the glass, with the difference going to the offgas system. The only information that is lost in quantifying these species in this way is the distribution between volatile and particulate emissions. However, each of these is expected to be volatile (as $^{14}CO_2$, ^{129}I vapor, and T_2O, respectively).

Accurate measurements of the melter offgas flowrates and melter air purges were required. Measurement of the offgas flow for EPA Methods is usually accomplished by use of a calibrated orifice meter for the instantaneous flowrate and a calibrated dry gas meter to totalize the volumetric flow.[21] Both of these methods suffer from the restriction that the molecular weight of the gas being measured needs to be known because the flow measurement depends on the density. If the molecular weight can be determined, corrections can be applied. An alternative method is to use a tracer gas and an analyzer to measure the concentration resulting from the addition of a known amount of tracer gas into the offgas.[22]

Both the calibrated dry gas meter and the tracer gas methods were implemented. Additionally, thermal mass flowmeters were also used to give instantaneous approximate flow readings. For air additions and the tracer gas, calibrated mass flowmeters were used.

SRTC suggested to the customer that the composition of fixed (non-condensable at room temperature) gases in the offgas also be measured, and the customer agreed it would be desirable to do so. The fixed gases were measured with the two gas chromatographs (GC). The gases that could be measured and the concentrations that were expected are given in Table 3.7. Evolution of or generation in the offgas system of NO_2 was also expected, but no practical on-line method could be implemented, given the radiohood space limitations.

Table 3.7 Gases Measured by Gas Chromatography and Expected Concentrations

Gas	Approximate Composition
N_2	65-79 %
O_2	15-21 %
CO	0.3 %
CO_2	3 %
H_2	Unknown
NO	<2 %
CH_4	Unknown
He (tracer)	0.1-0.3 %

3.2.2. Design and Fabrication of the Melter System

Diagrams of the LC melter system are shown in Figure 3.1-Figure 3.4.

3.2.2.1. Feed System

The melter feed system consisted of an approximately 19-liter cylindrical feed tank (10.625" inside diameter) with four 1" wide baffles located about 1" off the wall of the tank. This tank was contained in a secondary containment vessel. Agitation was provided by a U-shaped blade as shown in Figure 3.5. The feed tank, secondary containment, agitator motor, and motor support were all placed on a calibrated balance with a capacity of about 110 lb. The equipment weighed about 40 lb. A ¼" x 0.035" wall stainless steel tube was immersed into the feed tank and connected to the inlet of a peristaltic pump that was located about 28" above the top of the feed tank. The peristaltic pump pumped directly to the water-cooled melter feed tube. Provision for flushing the feed line both forwards and backwards was made, as shown in Figure 3.1.

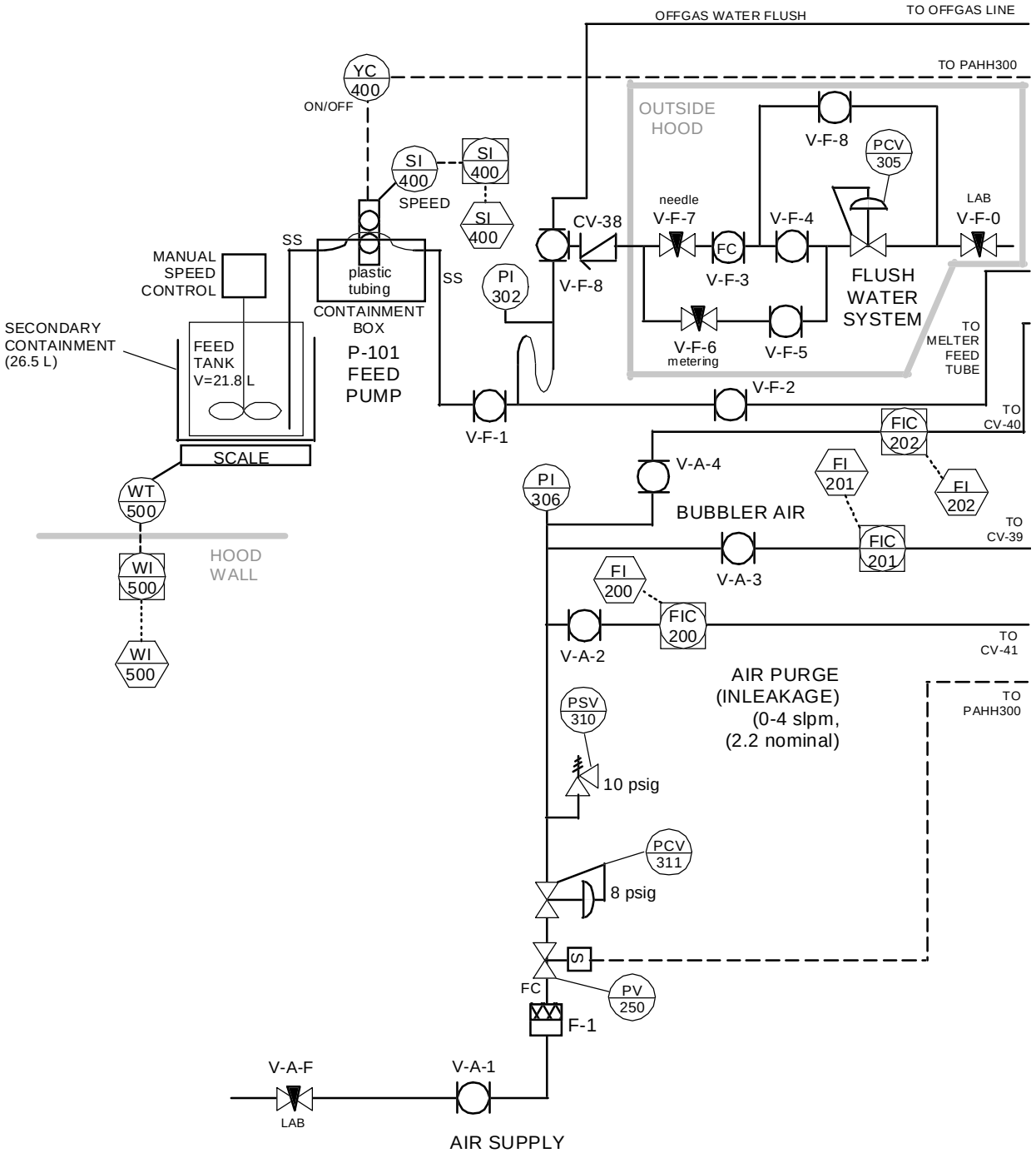


Figure 3.1 Large C Melter System Process & Instrument Diagram Sheet 1

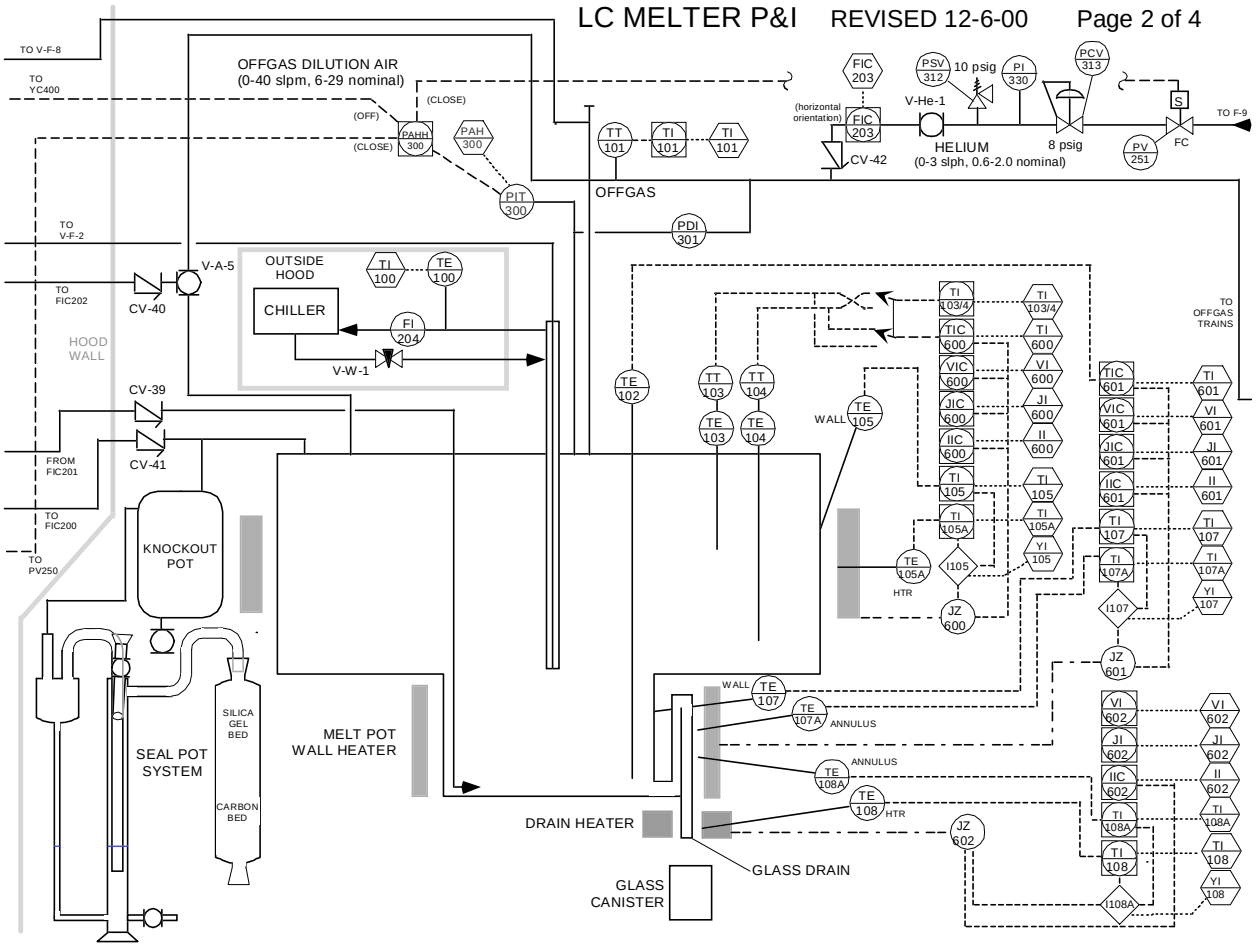


Figure 3.2 Large C Melter System Process & Instrument Diagram Sheet 2

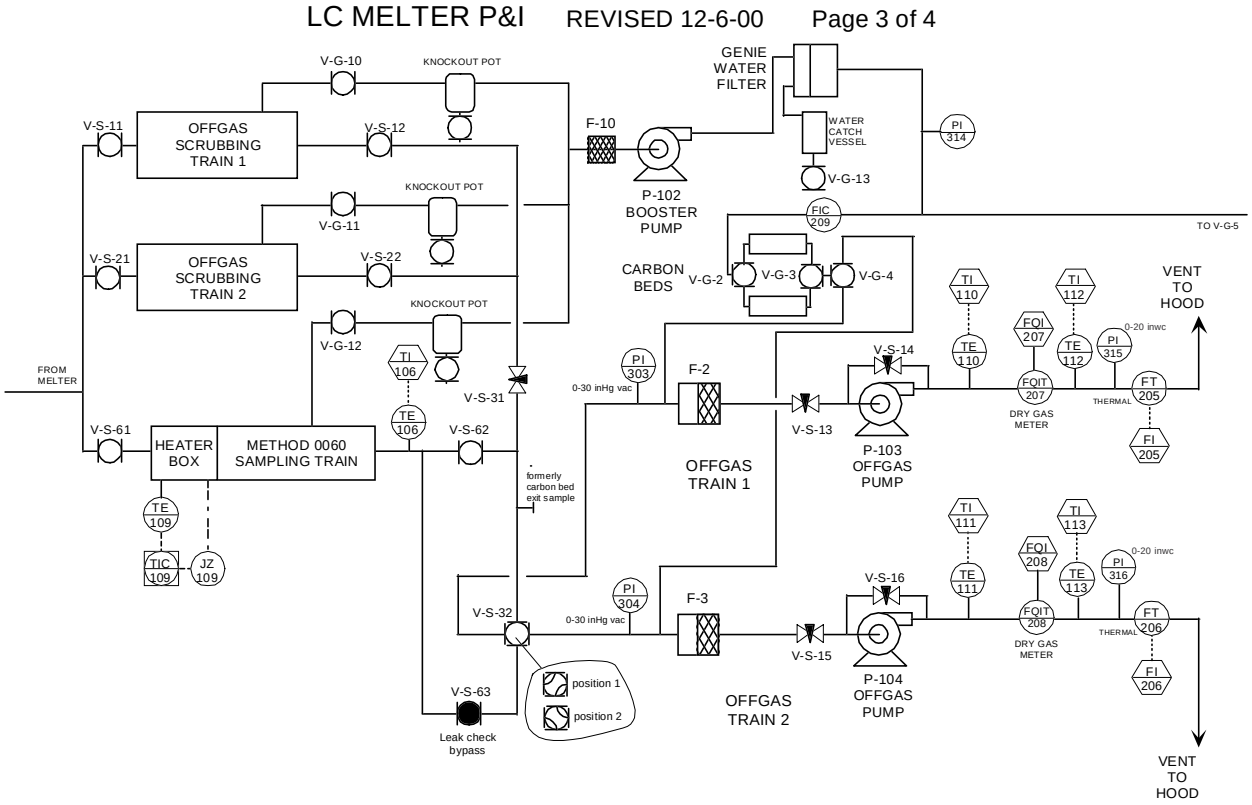
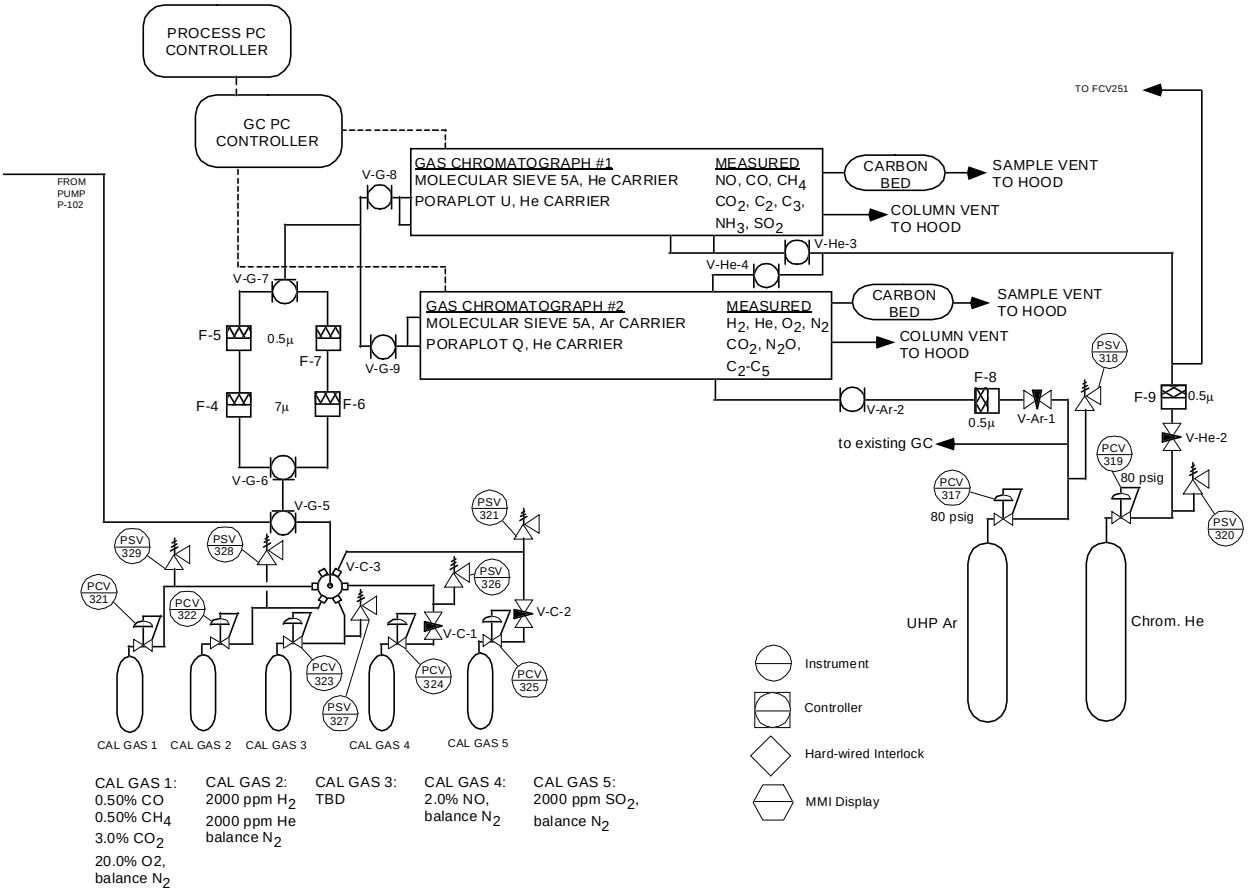


Figure 3.3 Large C Melter System Process & Instrument Diagram Sheet 3



CAL GAS 1: 0.50% CO, 0.50% CH_4, 3.0% CO_2, 20.0% O2, balance N_2

CAL GAS 2: 2000 ppm H_2, 2000 ppm He balance N_2

CAL GAS 3: TBD

CAL GAS 4: 2.0% NO, balance N_2

CAL GAS 5: 2000 ppm SO_2, balance N_2

Figure 3.4 Large C Melter System Process & Instrument Diagram Sheet 4

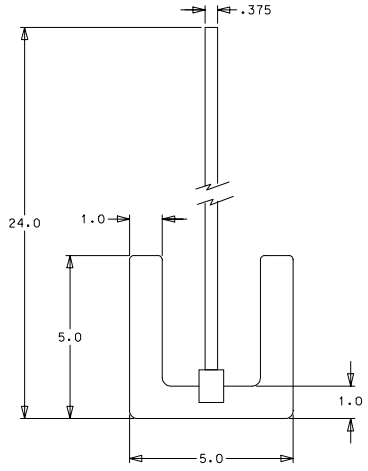


Figure 3.5 Feed Tank Agitator

3.2.2.2. Melter & Heating

The melter is heated with three zones of external resistance heating. The original design of the melter pot is shown in Figure 3.6 and the top head design in Figure 3.7. The design of the melter system is documented in a number of design drawings (see Appendix 6.2). The melt pot, plenum, and pour spout each are heated by a set of two half-cylindrical or four ¼-cylindrical heaters. These plenum and melter heaters are wired in a series-parallel configuration, while the drain tube heater is wired in parallel. Glass temperature is measured using a type-K thermocouple installed in an Inconel™ 690 thermowell. The plenum temperature is measured by two type-K Inconel™ 600 sheathed thermocouples. Heater and melter wall temperatures are measured by type-R thermocouples.

A ¼" bubbler tube introduces air into the glass through a small hole in the bottom of the tube. Air can be added to the plenum through a port in the top head. The offgas exits the melter plenum through a port on the top. A melter pressure tap and sight glass are also provided.

The melt pot section of the melter is a 4.026" I.D. Inconel™ 690 pipe with a flat bottom. The normal glass level is about 3.5 – 4 inches, depending on the vacuum in the melter; the total height of the melt pot section is 6 inches. Glass pouring is via an underflow weir into an overflow pipe and is accomplished by building up sufficient feed and glass in the melter such that the hydrostatic head forces the glass to be poured. A vent to atmosphere at the top of the drain tube prevents siphoning of glass. There is no mechanism for starting or stopping glass pouring. The melter is fed via a single water-cooled feed tube. In the original design, the underflow/ overflow weir was contained inside the melt pot. Operation during the surrogate runs showed that when the melter plenum was operated with the heaters off so that prototypic temperatures could be achieved, the top of the drain was too cold for glass to be poured. The glass solidified at the top of the pour spout and the plenum heaters had to be turned on to resume pouring. Moreover, the temperature in the plenum was usually higher than prototypic, even with the plenum heaters turned off.

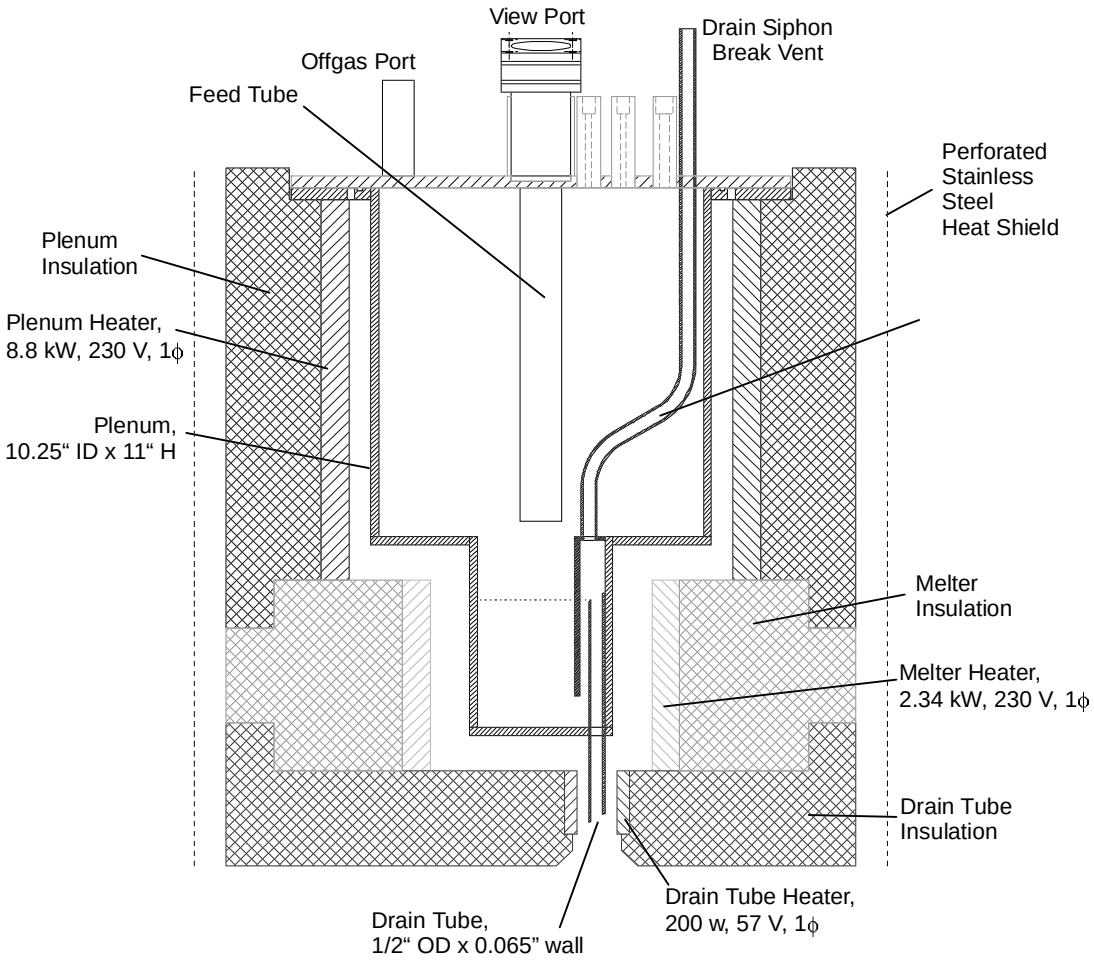


Figure 3.6 Original Melter Pot, Plenum, and Heater Design

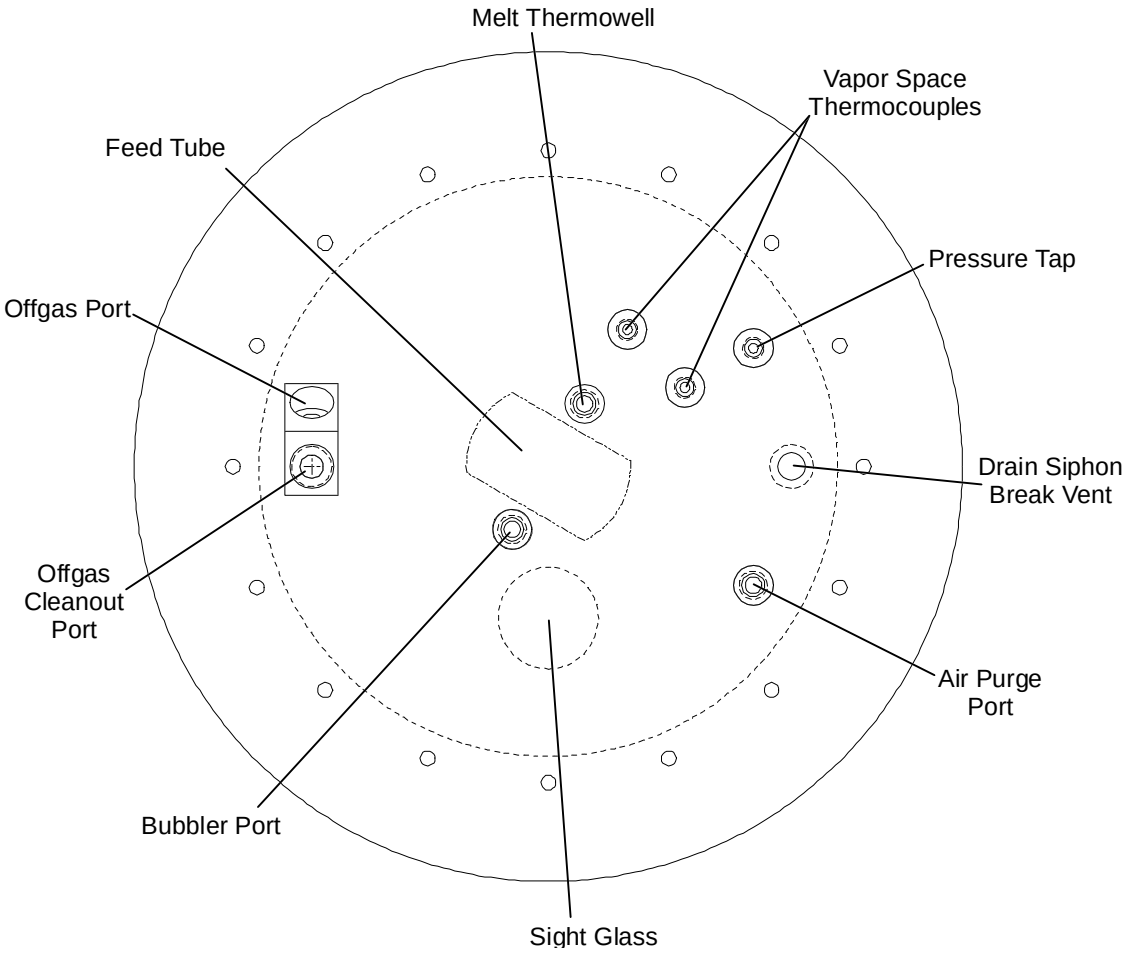


Figure 3.7 Original Melter Plenum Top Head Design

Therefore, during surrogate run 2, the melt pot was redesigned to have the pour spout external to the melt pot so it would not be in contact with the relatively cold plenum. This modified design is shown in Figure 3.8. The underflow/ overflow weir design of the drain tube is similar, but it is located about 1" radially from the melt pot and receives direct radiant heating from the melter heater and indirect and direct heating from the drain tube heater.

In addition to modifying the pour spout design, all of the heaters were redesigned. The plenum heater maximum power was reduced from 8.8 kW to 4.4 kW since the plenum heaters were usually not needed to achieve prototypic temperatures. Isolation insulation on the bottom of the plenum was also added to reduce the radiant and convective heat transfer from the melt pot to the plenum. The maximum power in the melter zone was increased from 2.34 kW to 4.06 kW; this increase could be accomplished by increasing the diameter of this heater so that more resistance heating wire could be added. The maximum power to the drain tube was also increased, from 200 W to 500 W. The placement of thermocouples was also changed to decrease the likelihood that a thermocouple element would contact one of the resistance heaters. The thermocouple sheath material was also changed from Pt/Rh to ceramic. These changes were made in

response to two incidents where a metal-sheathed thermocouple contacted a heater and shorted it out (see also Section 4.1.1).

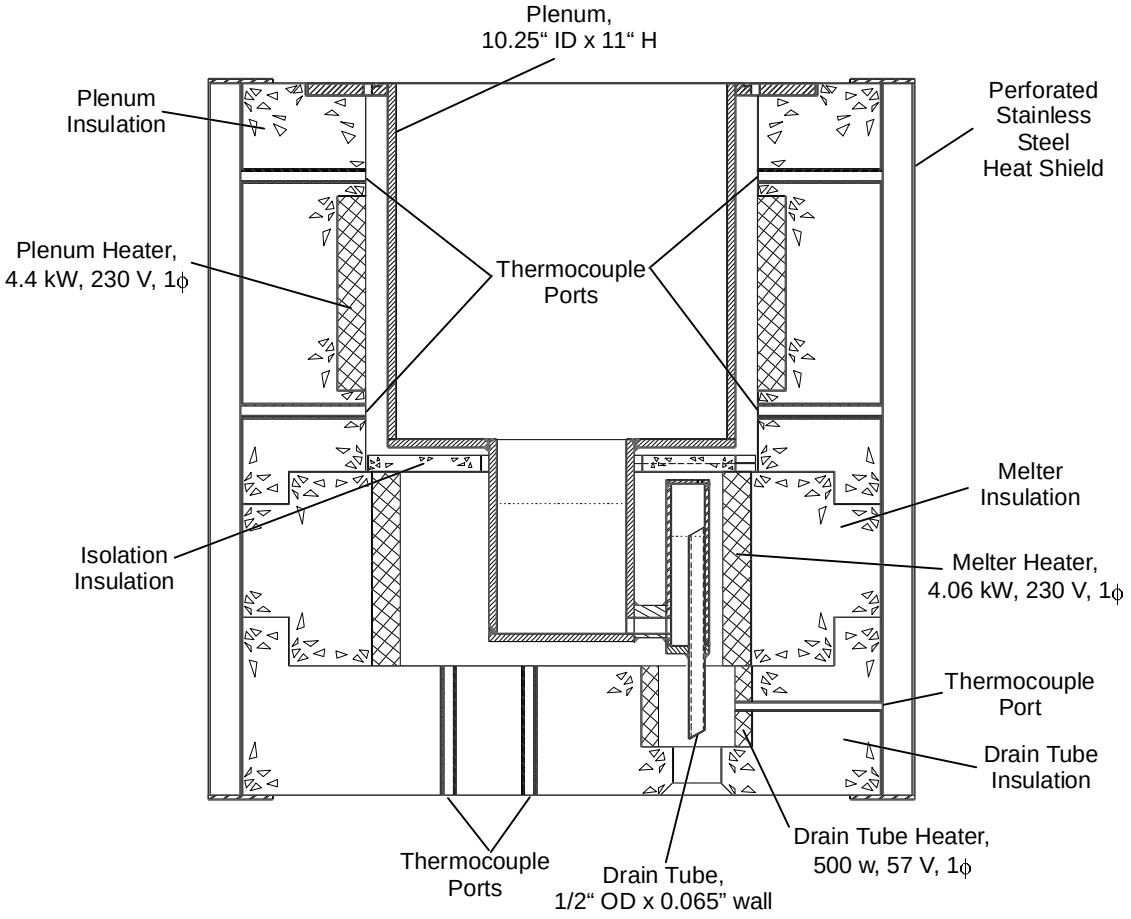


Figure 3.8 Modified Melter Pot and Heater Design

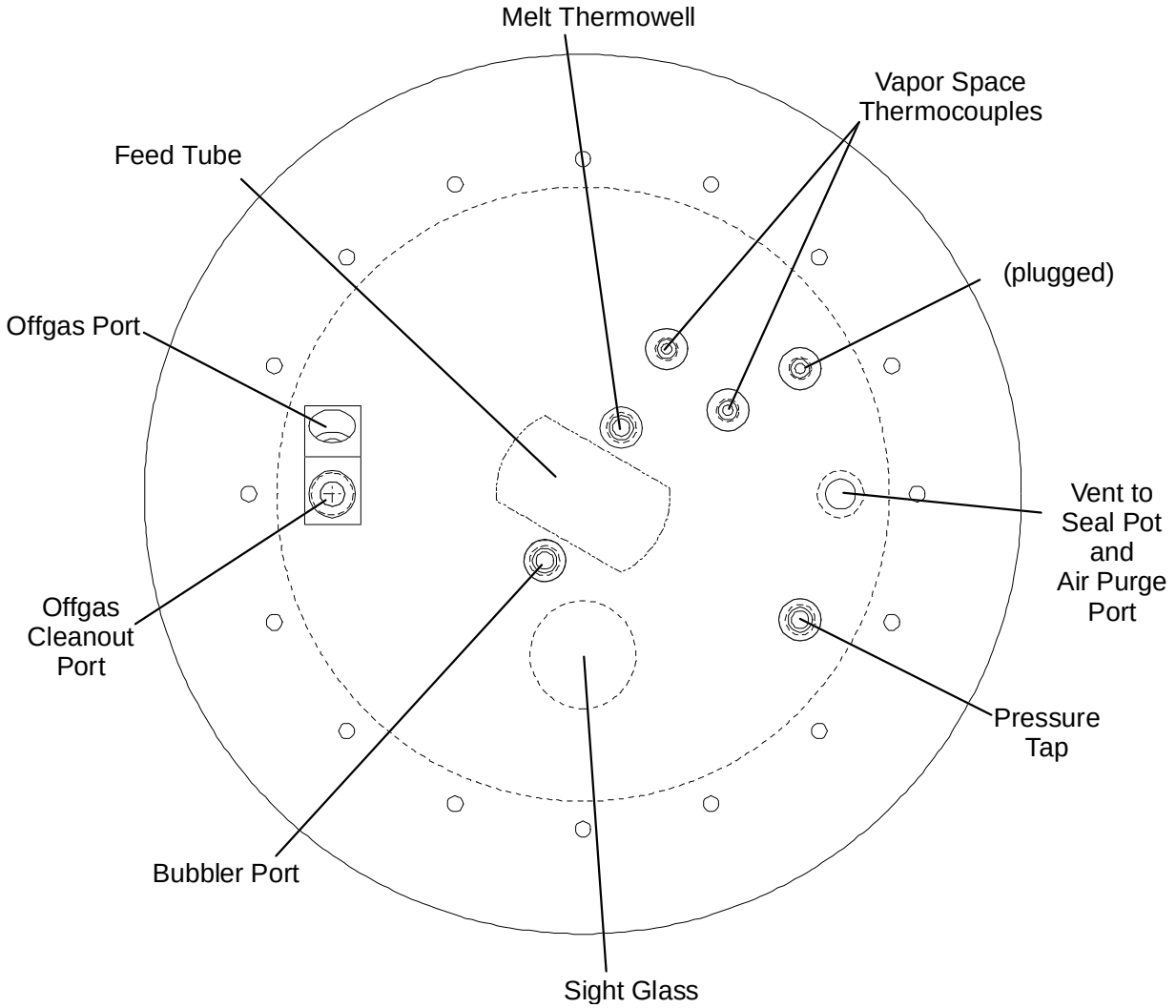


Figure 3.9 Modified Plenum Top Head Design

The plenum top head configuration was also slightly changed due to two problems that occurred during the surrogate runs. For reasons described in Section 3.2.2.3, the connection to the seal pot needed to be moved from the offgas line to the melter plenum top head. As part of the change of the pour spout configuration, the siphon break port was no longer needed, so it was converted to being the seal pot vent line and also the point at which the melter air purge could be introduced (Figure 3.9). Near the end of surrogate run 2, the melter pressure tap port became plugged and could not be cleared, so the pressure tap was moved to the former melter air purge port.

3.2.2.3. Offgas Sampling & Treatment System

At the melter exit, air was immediately introduced to cool the offgas from the melter exit temperature to about 200-350°C. This air addition is similar to the film cooler air that would be introduced in the RPP melter; however, the LC melter did not actually have a film cooler. Since there was no film cooler, it was deemed likely that problems

with offgas line plugging would occur. Since SRTC had typically seen pluggage almost always occur directly at the exit of the melter, a clean out port was installed on the offgas line that will allow manual reaming of the offgas line. However, during operation, pluggage occurred downstream of the initial exit from the melter. To combat this problem, the clean out port was modified to allow the addition of a water flush into the offgas line. This modification proved effective in removing pluggage directly downstream of the offgas port.

The melter seal pot was designed to both relieve pressure in the melter and to act as a vacuum breaker. The vacuum break capability was needed so that air would not be pulled in through the pour spout. The maximum pressure difference between the pour spout exit and the melter plenum, to prevent air from entering via the pour spout, is calculated by a hydrostatic pressure balance on the melt pot and pour spout; this value is approximately 6.9-7.6 inches water column (inwc), depending on the glass specific gravity assumed. The seal pot was designed to admit air to the melter if the melter pressure was less than -5 inwc and to relieve if it exceeded approximately +2 inwc.

Originally, the pressure relief line to the seal pot was in the offgas line about 3.5 ft downstream of the melter exit. During the surrogate runs, it was determined that the pressure drop from the melter to this point was too high for the seal pot to be effective. The actual melter pressure or vacuum at which the seal pot relieved was different from the intended values due to this pressure drop. When the melter was modified to move the pour spout outside of the melt pot, the now unused vacuum break port was connected to the seal pot so that the seal pot would relieve at the correct pressures (see Figure 3.9).

The offgas from the melter can be directed to any of three offgas scrubbing trains. Two of these were specifically only for scrubbing the offgas, while the third was for sampling via EPA Method 60 (see Figure 3.1-Figure 3.4). Switching between the trains is performed by manual valving. The offgas system configuration also allows for leak checking of the Method 60 sampling train. Details of the offgas scrubbing trains (2) and the Method 60 sampling train are shown in Figure 3.10 and Figure 3.11, respectively.

The LC melter offgas system design was by necessity different in many ways from the EPA Method 60 sampling train. Differences in both the physical equipment and the methods employed were necessary to accomplish the required goals. A detailed list of exceptions is given in Appendix 6.1.

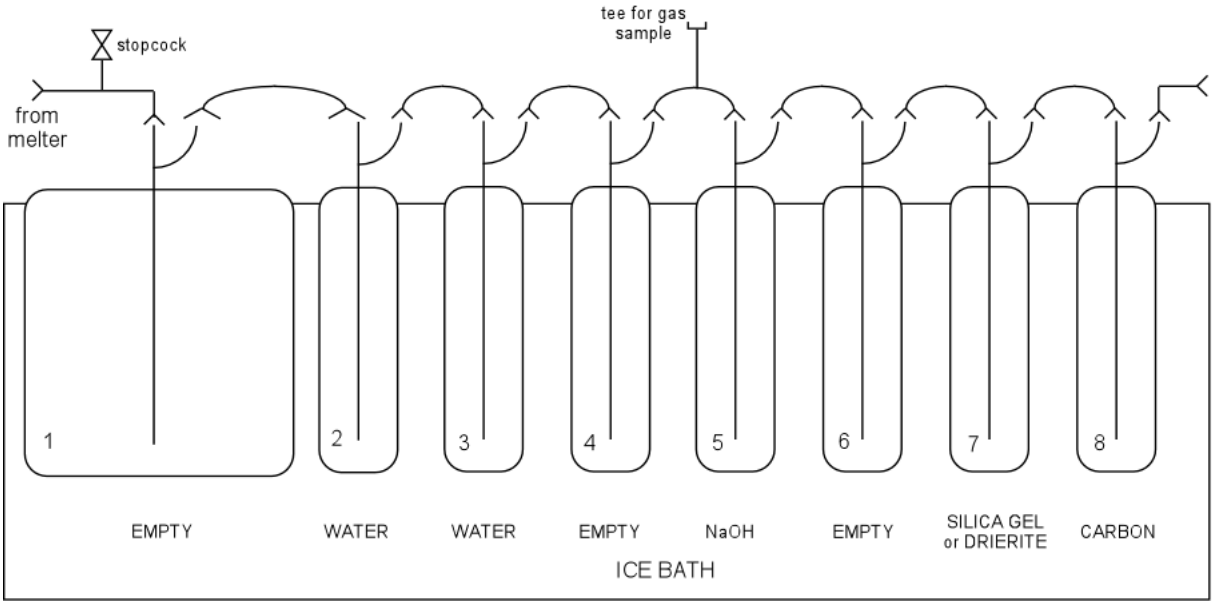


Figure 3.10 Offgas Treatment Scrubbing System

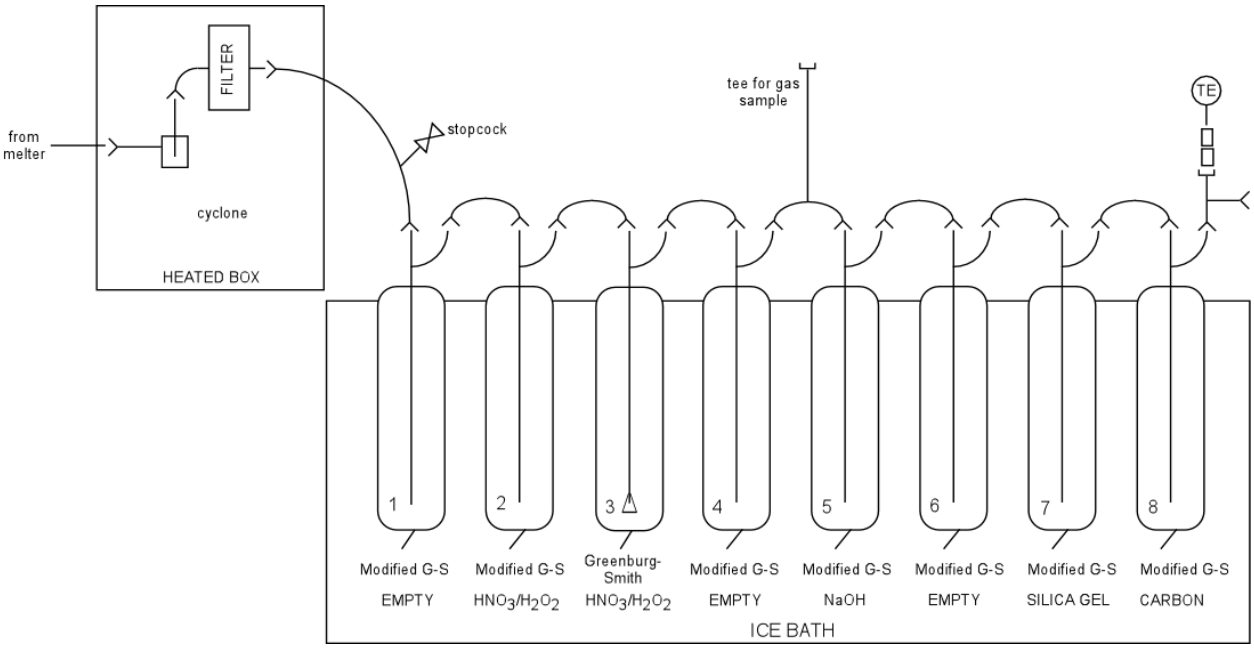


Figure 3.11 EPA Method 60 Sampling Train

3.3. Experimental Methods – Rheology and Settling Tests

The rheological properties of the radioactive AN-102 streams associated with the LAW melter operation were characterized. Streams included the pretreated AN-102 LAW waste as well as the AN-102 LAW Melter Feed. Two sets of measurements were made. The first set used a pretreated AN-102 LAW waste surrogate. The second set used pretreated radioactive AN-102 LAW waste from a sample taken during the Large C evaporator test.[4] Rheological

properties were measured for 5M, 6M, and 7.1M sodium in both the surrogate and radioactive waste streams. This provided three surrogate and three radioactive supernate viscosity determinations plus three surrogate and three radioactive LAW Melter Feed rheology determinations. A portion of the recovered rheology sample was used to conduct a simple settling test for each of the six slurries. All rheological data in this study was obtained in a four-month period from May to August 2001.

3.3.1. Surrogate and Melter Feed Preparations

The LAW AN-102 surrogate supernate was prepared according to recipes developed by SRTC researchers[23]. AN102 surrogate at 7.1M sodium, was pretreated using the Sr/TRU precipitation process developed by PNNL researchers.[24] This surrogate was sulfate-rich to reflect the actual LAW AN-102 waste stream. Early work at SRTC[25] was based on a low-sulfate surrogate recipe, though later work was based on a high-sulfate surrogate recipe. Details of the sulfate-rich surrogate preparation and Sr/TRU precipitation recipes are located in Appendix 6.15. No action was taken to remove or dissolve any (post-precipitation) solids that formed in the AN102 surrogate after the Sr/TRU precipitation process was complete. The type and quantity of glass former chemicals added to the pretreated An-102 LAW waste surrogates to form melter feed slurries (to be called “melter feed” in the rheology section) was based on spreadsheets supplied by the Vitreous State Laboratory (VSL). Examples for both radioactive and high-sulfate surrogate supernates are located in Appendix 6.15, Table 6.8 and Table 6.9 respectively. Surrogate density data was available from Hansen[25], which enabled the dilution of the starting supernate to various endpoint sodium molarities. The dilution details per gram of 7.1M solution are provided in Appendix 6.15 for the 5 and 6M solutions. Glass former mass was based on the number of moles of sodium in the sample, while glass former makeup was based on the chemical analysis of the supernate composition.

The surrogate and radioactive melter feed slurries were prepared at approximately 20 to 25°C. Cold work was done in a cold chemical hood, and hot work was done in a radioactive containment hood. The supernate was first added to a mixing jar, then sugar was added and mixed for one hour. The supernate and sugar mixture was covered during the hour of mixing to minimize evaporation losses. This mixing took place at 200 rpm. The glass former chemicals were then added into the supernate and sugar mixture over a 15-30 minute period as a well-mixed blend of the ten glass former components. Hansen[25] utilized this method of adding the glass former chemicals to the supernate and sugar mixture. Mixer speed was increased step-wise during the addition of the glass former chemicals so as to maintain a vortex to entrain/disperse the glass former chemicals. The final mixing speed ranged from 300 rpm for 5M slurries to 350 rpm for 7M slurries.

The method in which Duratek[26] blends in the glass former chemicals with the LAW surrogate is by taking a pre-blended composition of glass former chemicals as specified by a VSL for a given waste stream and loading the glass former chemicals into a storage silo. The sugar is added separately to the blend tank, typically 24 hours before the contents of the blend tank are transferred to the feed tank. The addition of sugar at a later time was shown to be more effective as a reductant. The mass of glass former chemicals can range up to 40,000 pounds, given the waste stream being processed. The glass former chemicals are discharged from the

storage silo via a rotor valve and pneumatically (vacuum) transferred to 5-gallon receiver bucket. When the bucket is full, it discharges its contents into the blend vessel as a slug. The process of adding all the glass formers typically takes up to 18 hours. The blend vessel has two high flow impellers. The top of the impeller is located 21 inches from the bottom of the tank and the top impeller is 60 inches above the bottom impeller. The ratio of impeller to tank diameter is 0.87 with a rotational speed of 26 rpm. The contents from this tank are then fed to a melter feed tank.

The RPP-WTP vitrification processes are still in the process of being developed. There is no design basis physical property for any of the unit operations in the vitrification plant as of 1/1/2002. The proposed method for blending the glass formers is to have the sugar blended with the other glass former chemicals. The blended glass former chemicals are then pneumatically transferred to a final feed hopper, located approximately 20 to 30 feet above the top of the blend vessel. The glass former chemicals feed rate is controlled by a rotor valve, which feeds the glass former chemicals through an 8-inch pipe that discharges into the vapor space of the blend vessel. The glass former chemicals, up to 35,000 pounds are fed to the blend vessel within 3 hours. There is no information on the design of the blend vessel.

The methods of blending the glass former chemicals are very different, which can effect how the glass former chemicals are ultimately entrained, dispersed and sheared. SRTC's approach was to entrain and disperse the glass formers throughout the resulting melter feed, resulting in a uniform composition. For this reason, and the fact the melter feeds are non-Newtonian, a scalability between the bench and full-scale systems is not practical. Concerns raised in this task will be noted.

VSL personnel have shown that the order in which glass former chemicals are added affects melter feed rheological properties for some surrogate melter feed recipes.[27] During the addition of the glass former chemicals at SRTC, the agitator speed was increased to maintain a vortex so that the solids would be drawn into the impeller. The melter feed was mixed for 24 hours following glass former chemical addition. A lid that had been modified to include a hole equal to the diameter of the agitator shaft covered the mixing jar. A secondary seal was placed around the shaft to jar opening using Parafilm. The 24-hour period was chosen to simulate the preliminary mixing time for the Large C melter feed tank. The jars used in these tests had a brim-full capacity of about 165-ml (nominal capacity of 150-ml). The jar had a flat bottom and an inside diameter of 2.5 inches. The agitator used a 45°, 1.5 inch outside diameter, pitched-blade, turbine impeller with four blades. The agitator was mounted along the centerline of the jar. The ratio of the impeller to jar diameter is 0.6. The same set-up was used for both the surrogate and radioactive testing. A picture of the apparatus is shown in Figure 3.12.

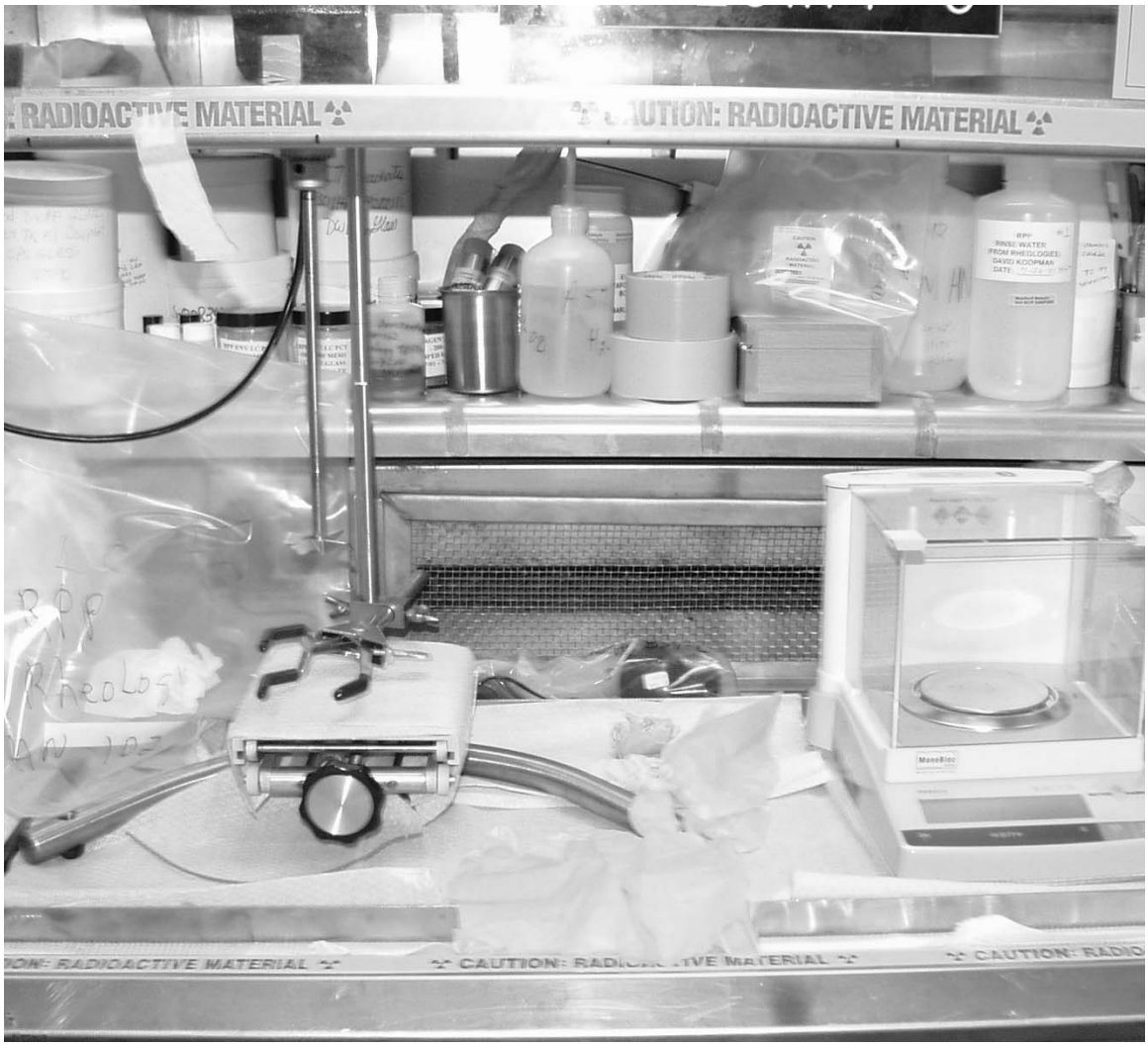


Figure 3.12 Mixing Stand for Preparing Glass Former Slurries

Mass lost during the 24-hour mixing period was assumed to be water. No gas evolution was observed during glass former chemical addition. Control of moisture loss was a serious concern, especially for the recipes at higher molarity. Early surrogate testing showed that small moisture losses had a large impact on melter feed rheological properties (10-100% increases). When moisture loss was well controlled, the melter feed appeared to maintain a relatively stable flow pattern during the mixing period. The melter feed possibly became a little thinner over time as some of the glass former chemicals went into solution. All parts in contact with the melter feed were weighed clean. Parts were re-weighed following the 24-hour mixing period in every case. In some cases, the parts were also re-weighed sooner due to moisture loss concerns. Any moisture losses greater than one gram were made up with de-ionized water additions.

The basic experimental program was based on the availability of a predetermined amount of the 7.1M sodium supernate. Two aliquots were removed for de-ionized water dilution to 5M and 6M. The three supernate viscosities were measured sequentially. One supernate was

selected and transferred to the mixing rig. Sugar and glass former chemicals were weighed out per the VSL recipe given the total moles of sodium in a sample. The sugar was added to the supernate. The supernate was mixed for one hour with the sample covered. Then the glass former chemical mixture was slowly added over roughly thirty minutes. The melter feed was covered and mixed for 24 hours. Overnight mixing was at 350 rpm for the 7.1M and 6M slurries and at 300 rpm for the 5M slurries. The melter feed was removed and checked for evaporation loss. If the loss was minor, i.e., less than about 0.5 to 1 gram in 24-hour period, then the rheological measurements on the melter feed were made. The three LAW melter feed slurries were prepared sequentially in the order 7.1M first, 6M second, and 5M third.

The primary restriction to the breadth of the study arose from the limited starting volume of radioactive, pretreated, AN-102 LAW waste supernate relative to the sample sizes needed by the rheometer. Surrogates were used to demonstrate the feasibility of the work with the radioactive sample beforehand. This occurred after scoping experiments with surrogates had identified the downstream requirements of the rheometer. A secondary restriction to the breadth of the study arose during surrogate testing, where the 7.1M melter feed sometimes required a less sensitive sensor than the 5M and 6M melter feeds. The rheological test program was designed to make a measurement with two different sensors at 6M to facilitate comparisons with the 5M and 7.1M data.

The rheological properties of the 7.1M samples were particularly sensitive to evaporation losses, rate of glass former addition, etc. Both a too rapid addition of glass formers and/or a larger than normal evaporation loss led to the formation of a clay-like semi-solid during work with surrogates. When moisture loss was poorly controlled the melter feed could set up into a clay-like mass. This mass would draw in to the agitator blades and shaft and pull free from the walls and bottom of the jar. It would then undergo rigid body rotation with the agitator blade rather than mixing. This was only seen with 7.1M sodium starting supernates. These two observations from bench-scale tests concerning the effects of evaporative losses and glass former addition rate on the rheological properties of the 7.1M melter feed slurry should be noted for future consideration in larger scale LAW melter feed design and testing at the pilot or plant scale. On the present bench-scale tests, the evaporative losses were considered significant if more than 1 gram of water was lost in a 24-hour period and the glass former addition rate was considered too rapid if all glass formers (~ 54 grams) were added in less than a thirty minute interval to the ~ 38.5 mL of 7.1M supernate.

3.3.2. Rheology Test Program

Rheological measurements were obtained using a Haake RV20 rheometer, M5 measuring head, and various rotors. See Figure 3.13 for a typical rheological measurement setup. The M5 instrument is a controlled rate rheometer. The NV, MV1, and SV1 rotors were used to complete all of the rheological measurements. The NV rotor is a double gap, concentric cylinder configuration. It was used to measure the flow curves for the surrogate and radioactive supernate samples. The rheometer was functionally calibrated using a 29.0 centipoise (cP) oil standard at 25°C with the NV rotor prior to sample measurements. The MV1 and SV1 rotors have a concentric cylinder configuration with an air gap on the bottom of the rotors. They were used for medium-viscosity and high-viscosity melter feeds

respectively. The rheometer was functionally calibrated using a 102.5 cP oil standard at 25°C with the MV1 rotor when that rotor was used for melter feed measurements. The rheometer was functionally calibrated with a 406.3 cP oil standard at 25°C using the SV1 rotor when that rotor was used for melter feed measurements. The temperature indications on the rheometer sample jacket and the cooling bath were cross-checked against other devices. The actual temperatures of the rheograms were within ±0.1°C of the target value to high confidence.

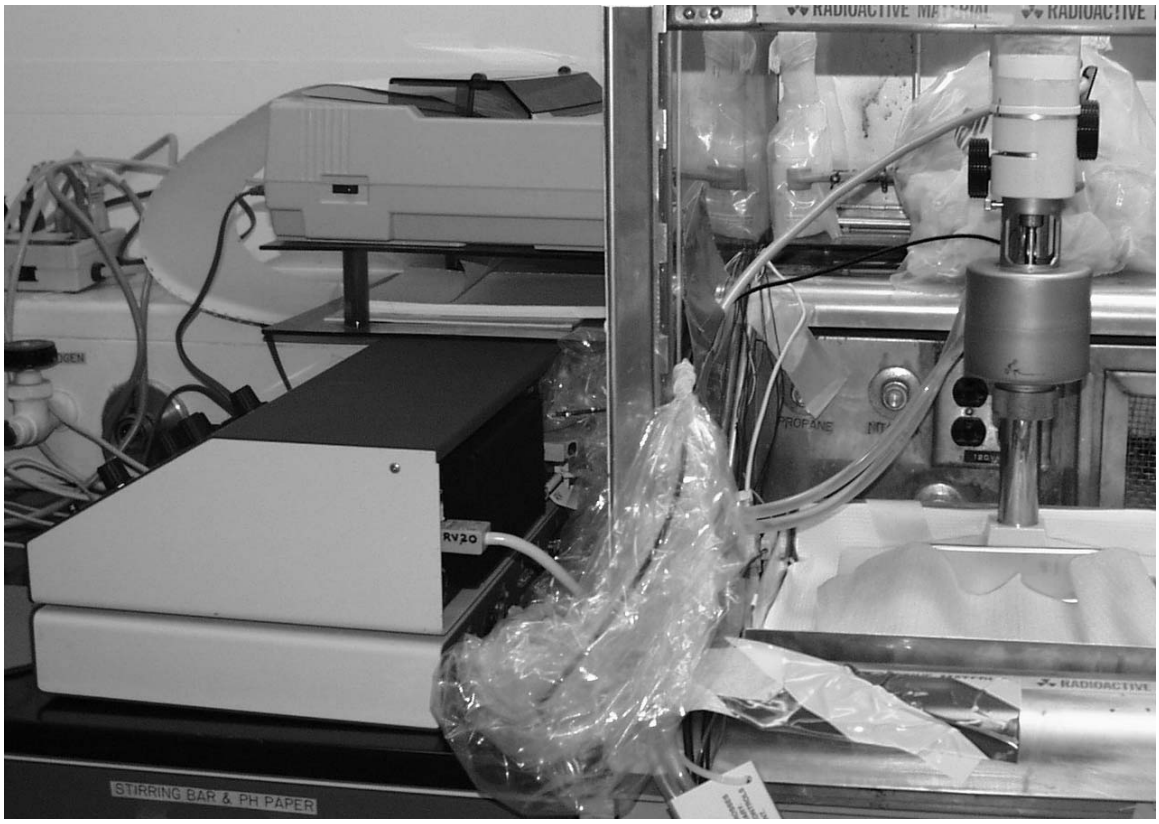


Figure 3.13 Haake RV20 Rheometer

Technical Reference Procedure 2.16, "Haake Rheometer", ITS/TNX L27 Procedure Manual, was used to operate the Haake rheometer during work with waste surrogates. Technical Reference Procedure GTOP-3-151, "Haake RV20 Rheometer in Radiohood", Glass Technology Procedure Manual 13.1 was used to operate the Haake rheometer during work with radioactive waste streams. The rotors and beakers were inspected for physical damage prior to starting any measurements. The rheometer passed all of its functional calibrations. The rheometer was considered functionally calibrated when the measured viscosity was within ±10% of the nominal viscosity of the oil standard.

Table 6.6, located in Appendix 6.14, lists the errors associated with using the M5 measuring head and the physical parameters of each rotor. Since the M5 uses a mechanical bearing and lacks inertial compensation, it is desirable to make flow curve measurements in the range of 1-100% of available shear rate at shear stresses greater than 1% of maximum. This was

successfully accomplished, although the thinnest supernate solution only pulled about 2.5% of maximum torque at the maximum measured shear rate of 2000 sec^{-1} at 40°C.

Table 6.7, located in Appendix 6.14, lists the shear rate ranges and sweep times for the various rotors used in this task. Samples were held for about five minutes surrounded by the temperature jacket before performing the measurements. Replicate trials established that this length of time was sufficient for measurements at 25°C. Surrogate melter feed samples were transferred directly from the mixing rig to the measuring cup. Radioactive samples had to be bagged and transferred from the mixing rig radiohood to the rheometer radiohood, so a small amount of settling could occur in the time that elapsed. Nonetheless, it was considered important to not excessively pre-shear the melter feed samples before transfer into the measuring cup. The time required for any melter feed structure to reform was unknown. Radioactive and surrogate melter feed samples were re-mixed gently by hand prior to transfer into the measuring cup. It was assumed that the five minute temperature equilibration period would restore the majority of any of the melter feed structure.

Analysis of the raw flow curve data (shear stress vs. shear rate) was made without corrections for slip, non-Newtonian behavior, etc. E. K. Hansen[25] has investigated some of these issues in his report and made preliminary estimates of their significance. Raw flow curve data was fit to one or more of the following four rheological equations of state.

Equation 3.1 *Newtonian fluid:* $\tau = \mu \cdot \dot{\gamma}$

Where τ is the shear stress, μ is the Newtonian viscosity, and $\dot{\gamma}$ is the shear rate.

Equation 3.2 *Bingham Plastic fluid:* $\tau = \tau_{o,B} + \eta_B \cdot \dot{\gamma}$

Where $\tau_{o,B}$ is the Bingham plastic yield stress, η_B is the plastic viscosity, or consistency, and τ and $\dot{\gamma}$ are as defined above.

Equation 3.3 *Casson fluid:* $\sqrt{\tau} = \sqrt{\tau_{o,C}} + \sqrt{\eta_C \cdot \dot{\gamma}}$

Where $\tau_{o,C}$ is the Casson model yield stress, η_C is the Casson viscosity and τ and $\dot{\gamma}$ are as defined above. This equation can be solved algebraically for shear stress to give:

Equation 3.4 *Casson fluid alternate:* $\tau = \tau_{o,C} + \eta_C \cdot \dot{\gamma} + 2\sqrt{\tau_{o,C} \cdot \eta_C \cdot \dot{\gamma}}$

It is easier to see the similarities and differences between the Casson fluid model and the other models in this form. The primary difference is the dependence on two different, although fixed, powers of shear rate $\dot{\gamma}$. The shear stress in the other three models discussed here depends only on a single power of $\dot{\gamma}$ (either one or n).

Equation 3.5 *Power-Law fluid:* $\tau = a \cdot \dot{\gamma}^n$

Where "a" is the consistency index and n is the power law exponent (or flow behavior index). If n is less than one, then the fluid is considered to be pseudo-plastic (shear thinning). If n is greater than one, then the fluid is considered to be dilatant (shear thickening). If n=1, then it is a Newtonian fluid. $\dot{\gamma}$ and τ are as defined above.

Equation 3.6 *Herschel-Bulkley fluid:* $\tau = \tau_{o,H} + a \cdot \dot{\gamma}^{n}$

Where $\tau_{o,H}$ is the Herschel-Bulkley model yield stress, "a" is the shear rate multiplier, and n is the shear rate index. $\dot{\gamma}$ and τ are as defined above. This model often gives a better visual fit to the raw flow curve data because it has one more adjustable parameter than the other non-Newtonian models above. The Herschel-Bulkley model includes the Bingham plastic and power law models as special cases.

One more definition will be helpful in the discussion to follow. The *apparent viscosity* is defined as $\tau/\dot{\gamma}$. It is the equivalent viscosity a Newtonian fluid would possess at that shear rate, $\dot{\gamma}$, and shear stress, τ. The apparent viscosity of non-Newtonian fluids varies with shear rate. The apparent viscosity of a Newtonian fluid is constant for any given shear rate. Viscosities (μ, η_B, η_C, and apparent viscosity) are typically reported in the units of centipoise, cP, where 1000 cP = 1 Pascal·second (Pa·s). In this report, however, viscosity is reported in Pa·s. Shear stress and yield stress are given in Pascals (Pa). Shear rate is given in inverse seconds. The shear rate index, n, in the Herschel-Bulkley model is dimensionless. The shear rate multiplier, "a", has units of Pascal·(seconds)^n.

The fluid parameters in Equations 3.1 through 3.3 were calculated using Microsoft Excel linear regression. All data points were used. The raw flow curve data was regressed directly for the Newtonian and Bingham models. A regression was made of the square roots of τ and $\dot{\gamma}$ for the Casson model. The Herschel-Bulkley fluid model parameters were calculated using SigmaPlot, version 4.1. A custom function was programmed into the regression wizard. A nonlinear regression simultaneously determined the three parameters from the raw τ and $\dot{\gamma}$ data. The regression was constrained so that both $\tau_{o,H}$ and "a" would be non-negative. (An alternative approach would be to take the natural logarithm of the equation, regress $\ln(\tau)$ and $\ln(\dot{\gamma})$ to find n, then regress τ and $\dot{\gamma}^{n}$ to get $\tau_{o,H}$ and "a". This would not necessarily produce non-negative constants.) Separate regressions of the up and down flow curves were made for the melter feed samples. These samples were all shear thinning, and also showed evidence of mild thixotropy (decrease in apparent viscosity with time under shear).

3.3.3. Gravity Settling Tests and Miscellaneous Data

Setting tests were performed for approximately 200 hours per sample. Approximately 10 ml of melter feed was introduced into a 10-ml, glass, graduated cylinder for each test. There was one test per sample (three cold, three radioactive). Start time was recorded when the sample was completely loaded into the graduated cylinder. Data included the thickness of the clear supernate layer on the top of the sample mass as a function of time. Beneath the clear supernate was a red solid-rich zone. Consequently, the test was more of a clarification test

than a settling test. The presence of a more dense, settled solid layer within the red solid-rich zone could not be detected visually. Probing the settled surrogate melter feeds with a slender rod seemed to indicate that the solids had stratified within the red layer with noticeably more solids in the bottom third than in the top third. Hansen[25] also reported having a compacted settled solids region from the settling tests he performed. The compacted solids zone can be a process issue, in the case where agitation is lost and the dense compaction zone covers the lower impeller. The mechanical design of the agitation system must be capable of re-suspending this compacted zone. The settling results reported is that of the interface produced between the clear supernate and solids that settle the slowest. These tests were necessarily simple due to the small mass of material available. Such effects as wall or hinder settling were not considered. Tests were conducted at room temperature. Loading the graduated cylinders was an issue with the high viscosity melter feeds, since the opening to the top of the graduated cylinder was small and the melter feeds were not free-flowing.

Density data was obtained during the testing for some of the surrogate and radioactive LAW waste solutions. These came primarily from the weighed masses of fixed volumes delivered by calibrated air pipettes. Some pH data was obtained for the surrogate melter feeds using a portable pH meter. The pH meter probe was calibrated in pH 4 and 10 standard buffer solutions, checked against a pH 7 standard buffer solution, and then the measurements were made. Surrogate melter feed pH values were about 9, and consequently were within the instrument's calibration range. The pretreated AN-102 supernate pH was greater than 12 and outside the range of the calibrated instrument.

3.4. Quality Assurance & Records

Quality Assurance requirements were covered by the Task Technical and Quality Assurance Plan.[28] Data taken in this work is recorded in Laboratory Notebooks.[29,30,31] Raw data that were archived by the process control computer and the gas chromatograph computer are contained in CD archives. The calculations (data sheets, analyses, spreadsheets) used to complete this report are also stored in CD archives. Design drawings are tabulated in Appendix 6.2 Operation was performed per approved procedures, listed in Appendix 6.3. ISMS References are listed in Appendix 6.4.

4. Results and Discussion

4.1. Surrogate Run #1

4.1.1. Surrogate Run #1 Objectives – Run Plan[32,33]

The primary objective of Surrogate Run #1 was to start-up and operate the melter, offgas system, feed system, and associated controls using a surrogate feed to identify modifications/changes needed to obtain acceptable equipment and process performance. A secondary objective was to obtain operating experience in preparation for the subsequent high sulfate surrogate run and the radioactive run.

4.1.2. Surrogate Run #1 Chronology & Results

The melter heaters were initially started on 5/11/00. Shortly thereafter, an internal short in the plenum heater near the bus bars occurred, requiring the assembly to be returned to the vendor for repair. The melter heaters were restarted on 6/22/00. From this time until 7/31/00, most effort was made on checkout of the offgas system operation; several modifications to equipment and operating procedures were required.

On 7/31/00, the melter heaters were started and glass frit was fed to the melter while the heater control loops were tuned. During this time, the feed tube became stuck in the top head of the melter, so modifications to the attachment system were made. Slurry feeding was started on 8/18/00 with an AN-102 low sulfate surrogate. Additional fine tuning of the offgas system operating procedures and several modifications were made during this period. During feeding of the melter so that about 100% cold cap coverage was achieved, the glass pour spout area was found to be relatively cold, such that no glass could be poured. To maintain high cold cap coverage, the plenum heaters had been turned off. On 8/31/00, the melter pot heater failed, so the assembly again was returned to the vendor for repair. The cause of this failure was not determined.

The repaired heater assembly was restarted on 11/7/00, at which time one half of the plenum heater assembly failed. The plenum and melter heater assemblies each consisted of two 180° cylindrical heater assemblies (two 90° cylindrical heaters wired in series) wired in parallel, so it was possible for one half to fail while the other half remained operational. On 11/9/00, it was noticed that the thermocouple on the remaining operational portion of the melter heaters was arcing to the grounded shell of the melter. This remaining heater element subsequently failed. The cause of the failure was determined to be a short of the heater element to the Inconel™ sheathed thermocouple that was grounded. The gap between the thermocouples and the heating elements was found to be much less than expected. The previous heater failure probably occurred in the same manner, although the first failure did not.

The melter heater design was then modified to prevent contact of the heating elements with the thermocouples. Ceramic sheaths were used on all thermocouples, and the location of the melter and plenum thermocouples was moved away from the heating elements such that they could not short. At this time, modification of the melter pot design was also completed so that pouring could occur during feeding (see Section 3.2.2.2 and Figure 3.8). Surrogate Run #1 was completed on 11/29/00.

4.1.3. Surrogate Run #1 Feed Composition & Glass Formulation

The feed material prepared for Surrogate Run #1 targeted the actual pretreated AN-102 composition basis. At the time the recipe for this surrogate was being developed, the RPP LAW flowsheet included sulfate removal. However, just prior to making up the surrogate, SRTC was informed by RPP that sulfate would not be removed from this waste and that the glass formulations would be altered to accommodate higher sulfate loadings. SRTC proceeded with making up a low sulfate surrogate so that testing of the

Large C melter system could commence. An additional reason for starting with a low sulfate surrogate was concerns that a sulfate layer, if it were to form, would severely corrode the melter's Inconel™ pot. The melter was started up with a frit that was similar in composition to the glass composition for the LAW flowsheet before sulfate removal was eliminated. This frit composition is shown in Table 4.1. This composition differs from the surrogate #1 expected glass composition because surrogate #1 was made up for the lower waste loading for the flowsheet without sulfate removal.

Table 4.1 Startup Frit Composition

Oxide	wt%	Oxide	wt%
Al_2O_3	12.08	Na_2O	20.13
B_2O_3	9.18	SiO_2	39.55
CaO	1.61	TiO_2	3.44
Fe_2O_3	5.87	ZnO	4.29
MgO	1.39	ZrO_2	2.47

The surrogate feed analyses, given in Table 4.2, were performed by the SRTC Mobile Laboratory and used by VSL for the glass formulation. The recipe for making up this supernate surrogate did not use the Sr/TRU precipitation step.

Table 4.2 Surrogate #1 Feed Composition

Metals	(mg/L)	Anions (IC)	(mg/L)
Al	11400	Fluoride	1230
B	59.9	Formate	11500
Ca	412	Chloride	3090
Cd	<0.040	Nitrite	64800
Cr	142	Nitrate	158000
Cu	22.7	Sulfate	2090
Fe	25	Phosphate	968
K	3060	Oxalate	<1000
Li	0.873		
Mg	20.6	Other	(mg/L)
Mn	11.6	TIC	29300
Mo	41.5	TOC	18149
Ni	315	Sp gr	1.387
Pb	111	pH	13.71
Si	13.6		
Ti	0.292	Solids	(wt%)
Zn	3.23	Total	44.42
Zr	5.63	Soluble	43.29
Na	200000	Insoluble	1.13
	(8.7 M)		
Ag	<0.100		

The glass formulation was provided by VSL and is shown in Table 4.3. The detailed VSL glass formulation spreadsheet is shown in Appendix 6.6. The specific glass formers (source) and amounts were specified by Vitreous State Laboratory; VSL also specified the glass formers for surrogate run #2 and the radioactive run. The glass formers used were all the same type that were specified (at the time of the experiments) for the full-scale LAW plant.

Table 4.3 Glass Formers and Other Additives for Surrogate Run # 1 (per 1.45 liters of surrogate)

Glass Former	**Batch (g)**
Kyanite Raw (Al_2SiO_5) 325 Mesh	319.39
Boric Acid (H_3BO_3) Technical Granular	599.79
Wollastonite ($CaSiO_3$) NYAD 325 Mesh	446.47
Fe_2O_3 (Iron III oxide, -325 Mesh)	200.16
Li_2CO_3 (Chemetall Foote Co. Tech. Gr.)	225.55
Olivine (Mg_2SiO_4) 325 Mesh (#180)	104.80
SiO_2 (Sil-co-Sil 75)	1086.64
TiO_2 (Rutile Airfloated)	38.78
ZnO (Kadox-920)	99.90
Zircon $ZrSiO_4$ (Flour) Mesh 325	154.54
Sugar	59.65

The feed was made up by combining 1.45 L of surrogate (at 8.7M Na^+), 1.7 L of water, and one batch of glass formers, as given in Table 4.3. The surrogate was initially made up to 8.7M Na^+ concentration since that was the design concentration specified by RPP. The expected glass composition is given in Table 4.4.

Table 4.4 Target Glass Composition for LC Melter Surrogate #1

Component	wt%	Component	wt%
Al_2O_3	6.15	Na_2O	11.80
B_2O_3	10.15	NiO	0.0175
CaO	6.44	PbO	0.0052
Cr_2O_3	0.0182	SiO_2	46.98
CuO	0.0012	TiO_2	1.13
Fe_2O_3	6.51	ZnO	3.04
K_2O	0.161	ZrO_2	3.04
Li_2O	2.75	Cl	0.135
MgO	1.52	F	0.0538
MnO_2	0.0008	P_2O_5	0.0317
MoO_3	0.0027	SO_3	0.0762

4.1.4. Surrogate Run #1 Melter Performance Results

As noted in section 3.2.2.2, it was difficult to maintain a low enough plenum temperature and to pour glass with a low plenum temperature. Figure 4.1 shows data during a period of feeding. The plenum heaters were turned off just after 10:00, at which time the glass temperature quickly dropped about 24°C and the plenum temperature began to drop. At about 11:00, feeding was begun. Both the glass and plenum temperatures continued to drop. To compensate for the drop in glass temperature, the output of the melter heaters was increased. When the glass temperature had dropped to about 1050°C, the cold cap covered 100% of the glass surface, even with the bubbler operating at 0.11 slpm flow. At this time, the bubbler was turned off. The glass temperature immediately began to rise and equilibrated just below 1100°C. Feeding was continued until about 13:20, when the melter level was too high to continue feeding.

The plenum heaters were turned on so that pouring could commence. Pouring started when the glass temperature reached about 1135°C and the plenum temperature reached 880°C. Note that the rise in temperature of the melter and plenum increased the drain tube heater temperature from 1015 to 1095°C. Visually, the top of the pour spout, which was inside the melt pot, was dark red to brown in color, which verified that it was at a low temperature.

The lowest plenum temperature, which occurred at the end of the two hours of feeding, was 750°C. The desired temperature for the plenum was 400-600°C. From this and other tests done during surrogate run #1, it was apparent that it would be difficult to achieve a plenum temperature of 400-600°C. The plenum temperatures were reduced in

to near the desired range in surrogate run #2 and to within the range in the radioactive run; these data are discussed in sections 4.2.5 and 4.3.5, respectively.

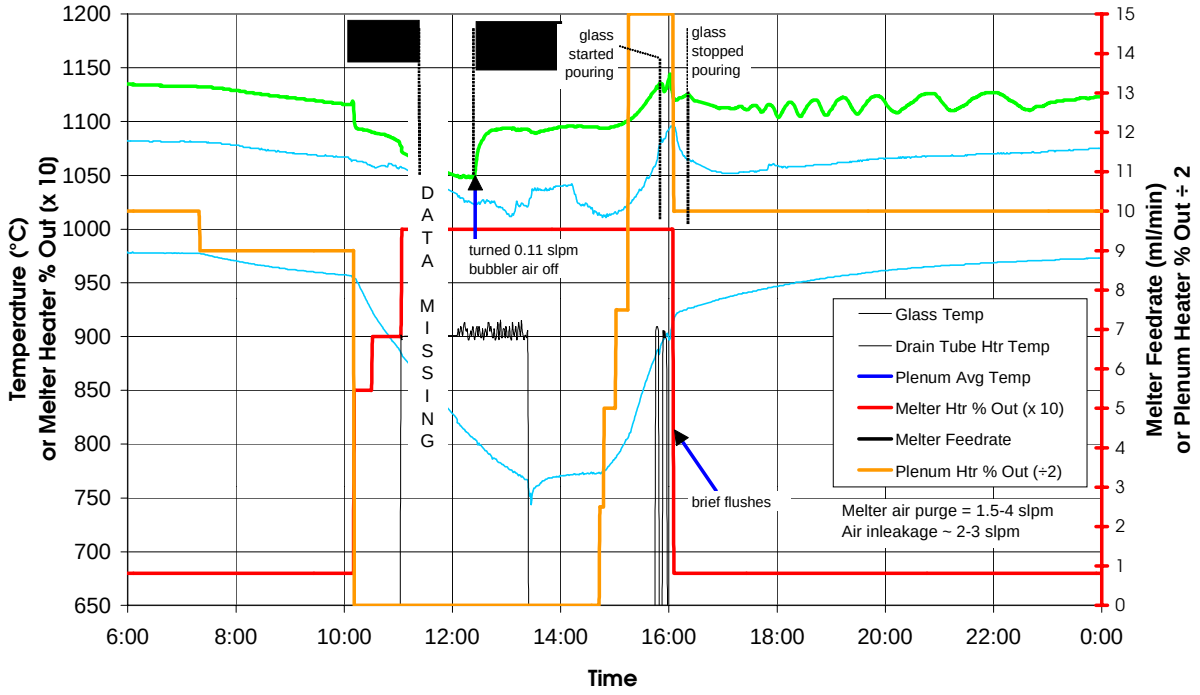


Figure 4.1 Surrogate Run #1 Melter Temperatures During Feeding (8/22/00)

4.2. Surrogate Run #2

4.2.1. Surrogate Run #2 Objectives – Run Plan[34]

The objectives of Surrogate Run #2 were similar to those for #1, with the additions of testing with a high sulfate feed and sampling with the Modified EPA Method 60 sampling train.

4.2.2. Surrogate Run #2 Chronology

On 11/30/00, approximately 7.5 liters of surrogate feed was added to the melter feed tank (see Section 4.2.3 for composition data). Sugar was then added, followed by the glass formers. This feed was then agitated overnight. By the next day, it was determined that about 200 g of water had evaporated. A feed sample was taken for analysis for total solids and density. The resulting values were found to be lower than expected (see Section 4.2.4 for further discussion). A material balance spreadsheet was used to estimate the concentration of organic carbon (TOC) in the feed so that the required minimum offgas dilution could be determined.

On 12/1, feeding the melter was attempted. Several pluggages of the offgas scrubbing system were found and needed to be corrected. Both the offgas line directly exiting the

melter and the scrubbing train silica gel impinger were plugged. Upon fixing these problems, continual problems with feeding the melter were encountered. Only about 2.0 lb of slurry was fed to the melter.

At this time, the melter feed was diluted with approximately 1.1 liter of water. After this, the melter feed line from the feed tank to the feed pump constantly plugged to the point where it could not be unplugged and had to be replaced. About 0.5 lb was fed. When the feed was diluted by the water, the Na^+ concentration, on a before glass former addition basis (for comparison to the initial 6.02 M Na^+) was 5.23 M. It was decided that the water addition should not have been done, so the feed was allowed to concentrate by evaporation. Approximately 0.9 lb of water were removed.

On 12/2, feeding was restarted. Immediately, problems with offgas pressure control occurred. The entire offgas line from the melter to a 90° bend prior to the impingers was removed and cleaned out. Feeding was then resumed and approximately 10.0 lb was fed, which includes about 1.3 lb of flush water that was added.

On 12/3, severe feeding problems then began. The feed pump inlet tubing was again replaced. Chunks of clay-like feed were found to be plugging the feed line. A sample of the chunks was taken for analysis. During intermittent feeding on 12/3, a total of 5.9 lb was fed and 1.5 lb of flush water added to the feed tank.

On 12/4, an additional 1.5 lb was evaporated from the feed tank and about 3.2 lb was fed. Feeding was more successful on 12/5, when enough feeding was done to take two modified Method 60 offgas samples. Method 60 run #2 occurred while about 4.81 lb was fed and during run #3, about 4.20 lb was fed (total fed ~9.0 lb). A small amount of feeding was also done on 12/6; about 0.6 lb was evaporated and 2.6 lb fed. The total amount of slurry fed during this run was about 30.7 lb on an original (before additional water added) basis; a net addition of 2.5 lb of water occurred.

4.2.3. Surrogate Run #2 Feed Composition and Glass Formulation

The Surrogate #2 composition is shown in Table 4.5. The first two data columns show analytical data for sample analysis #1 and sample analysis #2. The third data column shows the average for these two replicate analyses for the Surrogate #2. For comparison, the composition of the actual AN-102 pretreated waste, adjusted to the same sodium concentration, is also given in the last data column. As indicated in the notes to Table 4.5, the original actual AN-102 pretreated waste characterization was previously reported in Reference #4. The Surrogate #2 was first made up to be similar to the feed to the Sr/TRU precipitation process.[1] The surrogate was then actually subjected to the precipitation process so that a more realistic surrogate would result. The concentrations of most of the major components in the surrogate were very similar to the actual waste. The major exception was TIC. Several of the trace components were significantly different from the actual waste, but these would be expected to have little effect on the glassmaking process.

The feed was made up by combining 2.5 L of surrogate (at ~6.0M Na^+) and one batch of glass formers, as given in Table 4.6. The Na^+ concentration, ~6.0M, was chosen based on rheological measurements made at both SRTC[25] and VSL on melter feeds at several sodium concentrations. Table 4.7 briefly summarizes the VSL rheological measurements[35] on an Envelope C AN-102 surrogate at a 13.7 wt% loading based on waste oxide.

The glass formers and sugar additive specifications shown in Table 4.6 were provided by VSL for the Surrogate Run #2 glass. The detailed formulation spreadsheet is given in Appendix 6.6, Table 6.2. The expected glass composition is given in Table 4.8. It should be noted that the VSL rheology data shown in Table 4.7 for the 13.7 wt% waste loading (oxide basis) and 86.3 wt% loading glass formers (oxide basis) is very similar to the actual Surrogate Run #2 formulation that is shown in Table 6.2 of Appendix 6.6 to be 13.34 wt% waste loading (oxide basis) and 86.66 wt% loading glass formers (oxide basis). Both the data sets from Table 4.7 below, and Table 6.2 of Appendix 6.6 targeted waste sodium loading in the glass at about 12 wt% as Na_2O.

Table 4.5 Pretreated AN-102 Surrogate # 2 (6M [Na^+]) and Actual Pretreated AN-102 Evaporator Concentrate (adjusted to 6M [Na^+]).

Element	Analysis #1 mg/L	Surrogate Analysis #2 mg/L	Average mg/L	Actual Rad* mg/L
Al	6433	6265	6349	6600
B	25.3	24.7	25	17.5
Ca	95.9	95.9	95.9	139
Cd	0.04	0.04	0.04	25.9
Cr	86	86.2	86.1	91.9
Cu	9.92	9.88	9.9	4.41
Fe	1.98	1.78	1.88	2.78
K	1260	1260	1260	971
Li	7.78	1.64	4.71	0.155
Mg	0.256	0.019	0.138	0.082
Mn	26.3	44	35.15	1.01
Mo	24.1	24.1	24.1	27.3
Ni	142	142	142	157
Pb	52	52.2	52.1	62.7
Si	18.8	19.5	19.15	55.9
Ti	0.01	0.01	0.01	0.155
Zn	0.868	0.84	0.854	1.50
Zr	0.239	0.223	0.231	0.959
Na	137000	140000	138500	138000
Na (M)	5.96	6.09	6.02	6.00
Anions				
Fluoride	1020	995	1007.5	935
Formate	5710	5180	5445	5068
Chloride	3400	3230	3315	1464
Nitrite	38200	34900	36550	36679
Nitrate	94600	83400	89000	94165
Sulfate	5800	5260	5530	5953
Phosphate	1570	1460	1515	1705
Oxalate	1190	1150	1170	796
Carbon				
TOC	8958	8406	8682	8624
TIC	7674	8372	8023	16936

* See Appendix B, Table B-2 ‘Characterization of Envelope C (AN-102) Evaporator: Concentrate’ from Reference #4 for original data.

Table 4.6 Glass Formers and Other Additives for Surrogate Run #2 (per 2.5 liters of 6M Na^+ surrogate)

Glass Former	batch (g)
Kyanite Raw (Al_2SiO_5) 325 Mesh	396.7
Boric Acid (H_3BO_3) Technical Granular	719.26
Wollastonite ($CaSiO_3$) NYAD 325 Mesh	535.39
Fe_2O_3 (Iron III oxide, -325 Mesh)	239.87
Li_2CO_3 (Chemetall Foote Co. Tech. Gr.)	270.48
Olivine (Mg_2SiO_4) 325 Mesh (#180)	125.67
SiO_2 (Sil-co-Sil 75)	1289.77
TiO_2 (Rutile Airfloated)	46.50
ZnO (Kadox-920)	119.80
Zircon $ZrSiO_4$ (Flour) Mesh 325	185.33
Sugar	67.70

Table 4.7 Rheological Characterization of 13.7% Waste Loading Envelope C AN-102 Surrogate: Yield Point

Description	Temperature	Yield Point (Pa)
5 Molar + Additives Fine	25°C	1
6 Molar + Additives Fine	25°C	18
7 Molar + Additives Fine	25°C	500
8 Molar + Additives Fine	25°C	600

Table 4.8 Target Glass Composition for LC Melter Surrogate #2

Component	wt%	Component	wt%
Al_2O_3	6.14	Na_2O	11.8
B_2O_3	10.14	NiO	0.0114
CaO	6.42	PbO	0.0035
Cr_2O_3	0.0159	SiO_2	46.8
CuO	0.0008	TiO_2	1.13
Fe_2O_3	6.50	ZnO	3.03
K_2O	0.0959	ZrO_2	3.03
Li_2O	2.75	Cl	0.210
MgO	1.52	F	0.0637
MnO_2	0.0035	P_2O_5	0.0716
MoO_3	0.0023	SO_3	0.291

4.2.4. Surrogate Run #2 Feed Addition Material Balance

A material balance to check the consistency of the feed addition was performed. The input data to this material balance consisted of the following quantities:

1. Volume of supernate surrogate added to the feed tank
2. Measured composition, density, and total solids content of supernate surrogate
3. Mass of each glass former compound added and mass of sugar added
4. Feed tank scale weights
5. Measured density and total solids content of the mixed melter feed

Note that the composition of the mixed melter feed was not determined, so the material balance can only check the consistency of the data regarding the density, total solids, and the weight measurements.

Upon completion of the radioactive run, it was determined that the feed tank scale readings were incorrect. Based on the feed addition data from the radioactive run and a calibration check of the balance, a correction factor was determined for the scale weights. The determination of this correction factor is given in Appendix 6.7.

The compositions given in Table 4.5 and Table 4.6 were used to predict the composition and properties of the melter feed. These calculations are summarized in Table 4.9 (see also Appendices 6.9 and 6.10). The masses shown matched well with the known weights of the surrogate and glass formers added and also with the corrected scale weights. Another indication of the consistency of the data is shown by the surrogate density. To close the material balance, the surrogate density needed to be set to 1.244 kg/L, compared to the density of 1.242 kg/L calculated from the measured total solids content. The measured density of the surrogate was 1.257 kg/L, which is only 1.2% different from the calculated value. The calculated density is often more reliable than the measured density since the measurement of total solids is more accurate than the measurement of density and the calculated values are determined from a correlation that includes many data points. This correlation is described in Appendix 6.8.

As shown in Table 4.9, the measured total solids content and density of the melter feed (62.0 wt % and 1.66 kg/L, respectively) did not match the predicted values (70.33 wt% and 1.80 kg/L). Both measured quantities were lower than expected. The predicted values are those calculated from the known addition of surrogate waste and glass formers. An analysis of this discrepancy showed that the amount and concentration of the surrogate and the amount of glass formers could not result in the measured properties unless it was assumed that 2.82 L of water had been added to the feed (see Appendix 6.10). An addition of this amount of water had not occurred. The conclusion that would seem most reasonable from these data is that the sample taken was low in the insoluble solids, and hence also low in total solids. However, data from the radioactive run will show that this conclusion is probably incorrect (see Section 4.3.4).

The amount of sugar added as a reductant for this run was incorrect. The required amount per 2.5 L of surrogate was 67.70 g, but 118.79 g per 2.5 L was actually added. The first spreadsheet received from VSL did not include the reduction in sugar necessary to account for the organic carbon content of the surrogate. A revised spreadsheet was later received, but the change in the sugar requirement was missed. A possible effect of the additional sugar would be to make the glass from this feed more reducing than desired. However, as discussed later in this report, there were no measurable, significant effects pertaining to glass composition, degree of crystallinity or durability performance as result of this excess sugar reductant used in the surrogate run #2 glass product. The actual effect this excess added sugar had on the redox of the product glass was not obtained in this Large C melter testing since no redox tests were scheduled for any of the melter product glasses.

As noted in Section 4.2.2, one liter of water was added soon after starting surrogate run #2 and then some of this water was evaporated. Throughout this run, water was added during feed system backflushes and also evaporated during idling periods. As a result, the wet basis composition of the feed changed some throughout the run.

Table 4.9 Surrogate and Melter Feed Compositions and Material Balance Information for Surrogate Run #2

		Surrogate Feed (Measured)	Surrogate Feed + Sugar (Calculated)	Glass Formers for 1 liter of 5 M Na^+ Surrogate	Glass Formers for Actual Amount of Surrogate		Feed: Waste + Glass Formers (Calculated)	
Na Molarity	M	6.02	5.93				3.79	
Volume	liter	7.50	7.62				11.9	
		mg/L	mg/L	g	g	wt %	mg/L	wt % dry
NO_3^-		89000					56061	3.11
NO_2^-		36550					23023	1.28
SO_4^{-2}		5530					3483	0.193
Cl^-		3315					2088	0.116
F^-		1008					635	0.0352
CO_3^{-2}		8023	7900				5054	0.280
TOC		8682	10189				6518	0.362
Al		6349	6252	42.9	388	3.29	36572	2.03
B		25.0	24.6	41.2	372	3.16	31257	1.73
Ca		95.9	94.4	60.7	548	4.65	46093	2.56
Cd		0.0400	0.0394				0.0252	1.40E-06
Cr		86.1	84.8				54.2	0.00301
Cu		9.90	9.75				6.24	3.46E-04
Fe		1.88	1.85	59.4	537	4.56	45106	2.50
Li		4.71	4.64	16.7	151	1.28	12675	0.703
Mg		0.138	0.135	13.2	119	1.01	10001	0.555
Mn		35.2	34.6				22.1	0.00123
Mo		24.1	23.7				15.2	8.42E-04
Na		138500	136375				87241	4.84
Ni		142	140				89.4	0.00496
P		494	487				311	0.0173
Pb		52.1	51.3				32.8	0.00182
Si		19.2	18.9	281	2543	21.6	213575	11.9
Ti		0.0100	0.00985	8.69	78.5	0.666	6593	0.366
Zn		0.854	0.841	31.9	288	2.44	24177	1.34
Zr		0.231	0.227	30.3	274	2.32	23005	1.28
K		1260	1241				794	0.0440
Total Elements, Ions, TC	g	2244	2257	586	5298			
Oxides, O, H	g	702	1046	718	6488	55.0		35.1
Total Sample	g	9312	9668	1304	11786		21454	
Solids in Sample	g	2946	3303				15089	
Water	g	6366	6366				6366	
Total Sample	lb	20.53	21.31		25.9		47.30	
							Calculated:	**Measured:**
Total Solids in Sample	wt %	31.64	34.16				**70.33**	**62.00**
Measured Density	kg/L	1.257						**1.66**
Estimated Density	kg/L	1.244	1.269				**1.80**	
Density to Close Material Balance	kg/L	1.242						

4.2.5. Surrogate Run #2 Melter System Performance Results

Melter system temperatures, offgas flows, and offgas compositions are discussed in this section. Melter temperatures, melter power, and feedrate are shown for several time periods in Figure 4.2, Figure 4.3, and Figure 4.4. Note that for all data shown, the plenum heaters were turned off. The feed rates shown were derived from the feed tank weight as a function of time. The values used were from a linear regression of the feed tank weight with non-feeding periods removed. See Appendix 6.12 for more details. The Figures show that upon initiation of feeding, the glass temperature quickly dropped and then slowly recovered as the melter heater power was increased. Temperature drops of up to 130°C were seen. In Figure 4.2, the large drop just after 13:00 was due to a large water flush of the feed tube to remove a pluggage. The other melter temperatures (melter heater, drain tube, melter wall) tracked the glass temperature, but with smaller overall changes. This correlation shows that the removal of heat from the melter system by evaporation of feed water was a significant effect. The ability to compensate with increased heater output was very slow compared to the rate of the temperature drop.

The plenum and offgas temperatures are shown in Figure 4.5, Figure 4.6, and Figure 4.7. The offgas temperature was taken in the offgas line after the addition of dilution air. Many of the spikes in temperature were due to feed system water flushes. Typically, the offgas temperature rose from about 200°C to 300°C upon feeding or flushing. The offgas flow surge just before 2:00 in Figure 4.5 was caused by an interlock of the dilution air due to high melter pressure. The interlock of dilution air resulted in pulling a high vacuum on the melter. At high vacuum, a large amount of air is pulled in through the seal pot.

Upon feeding, the plenum temperatures dropped at about 50-100°C per hour, with the typical starting temperature being about 650°C, whereas the plenum temperatures during surrogate run #1 were between 750 and 950°C. The nominal temperature range specified for the RPP LAW melter is 400-600°C. Most of the plenum temperature data during feeding for surrogate run #2 ranged from 580-650°C, which is at and above the high end of the nominal range. Plenum temperatures for the radioactive run are discussed in section 4.3.5.

Figure 4.8 shows typical temperatures measured by the upper and lower plenum thermocouples. The lower thermocouple generally read 50-60°C hotter than the upper thermocouple. This difference is due to the greater radiant shine on the lower thermocouple from the melt surface and the hotter upper portion of the melter pot.

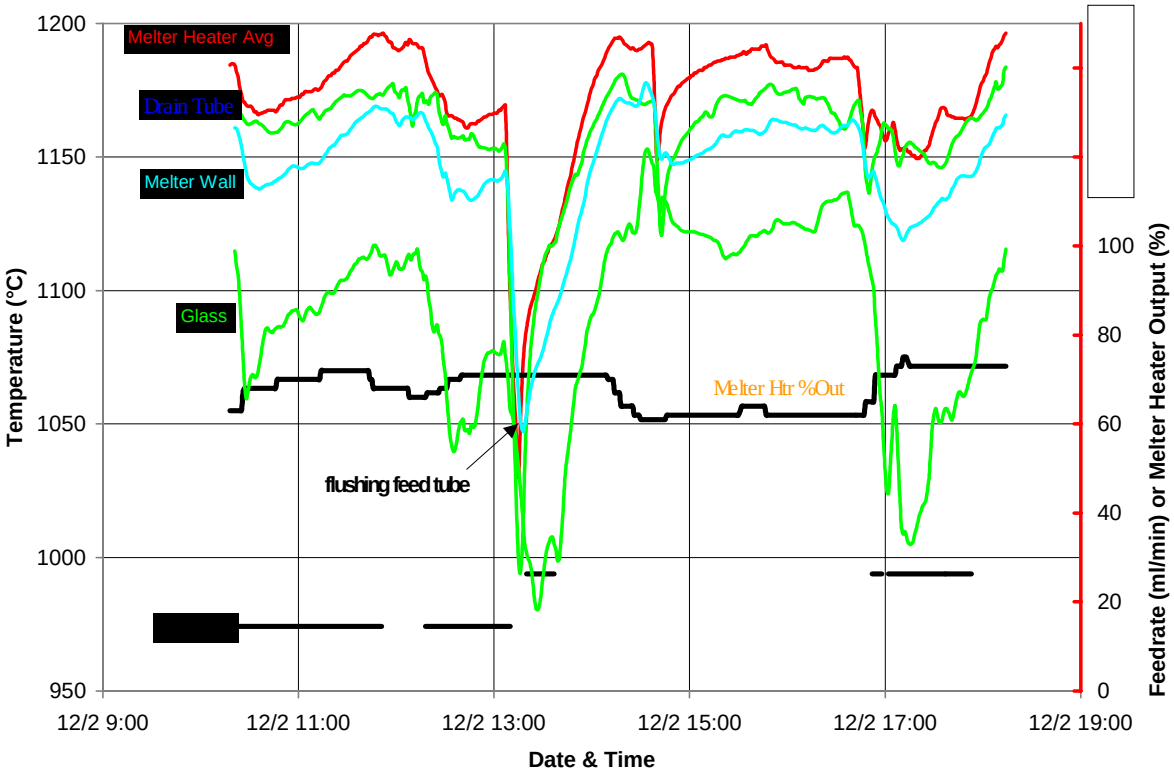


Figure 4.2 Surrogate Run #2 Melter Operation Data (12/2 09:00)

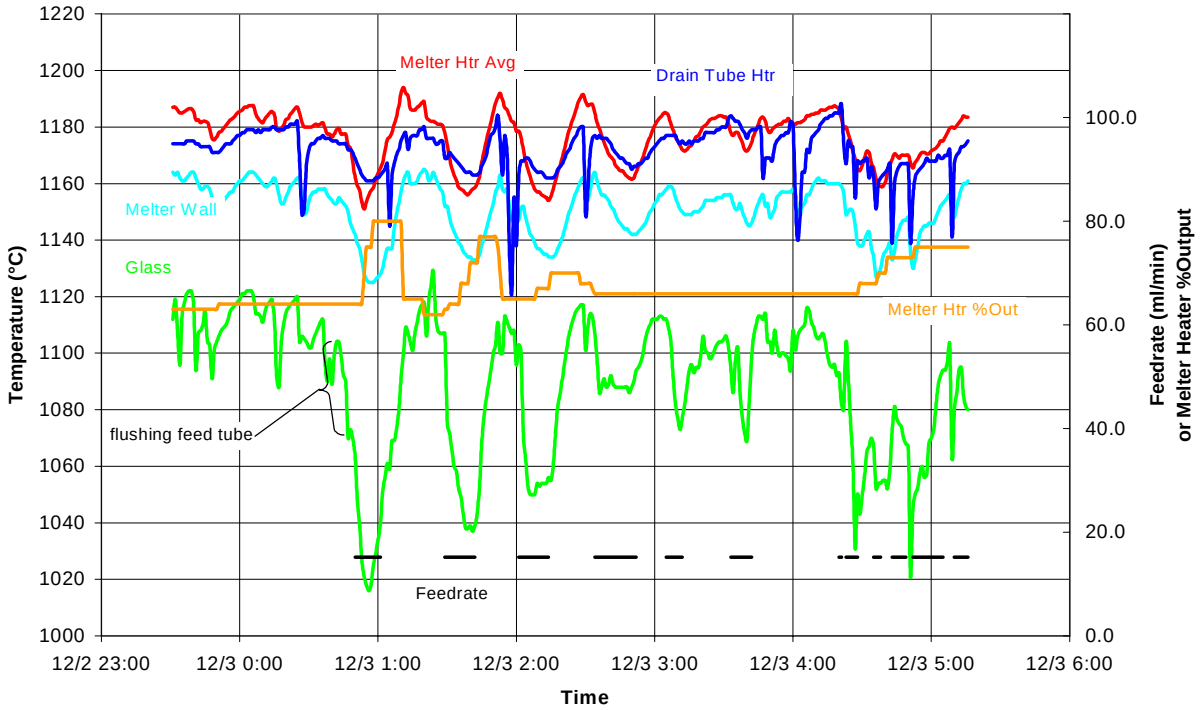


Figure 4.3 Surrogate Run #2 Melter Operation Data (12/2 23:00)

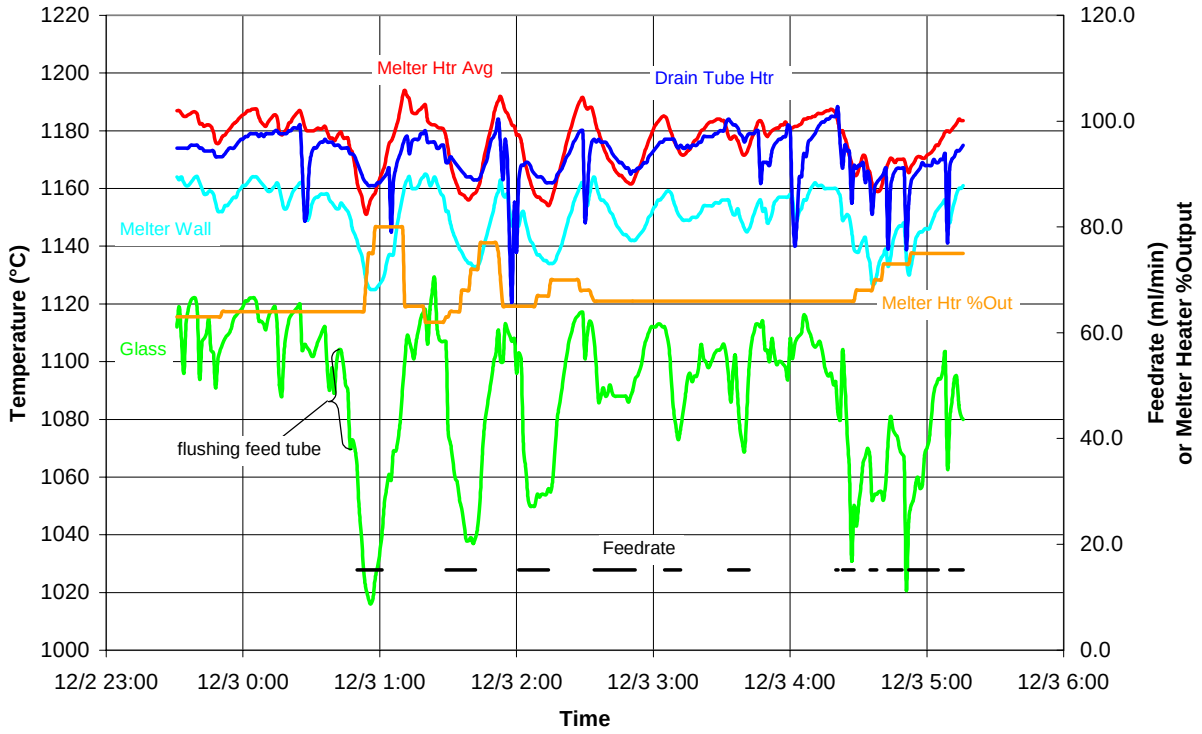


Figure 4.4 Surrogate Run #2 Melter Operation Data (12/5)

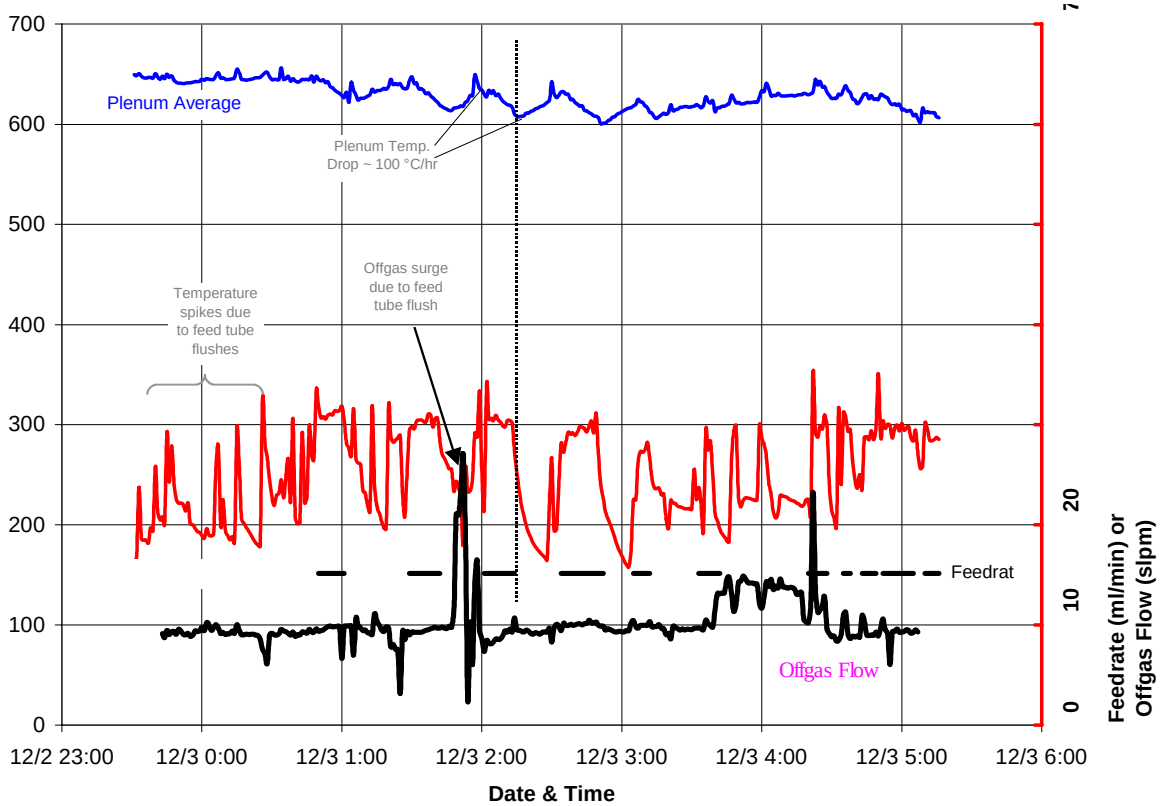


Figure 4.5 Surrogate Run #2 Offgas & Plenum Temperature and Offgas Flow Data (12/2 23:00)

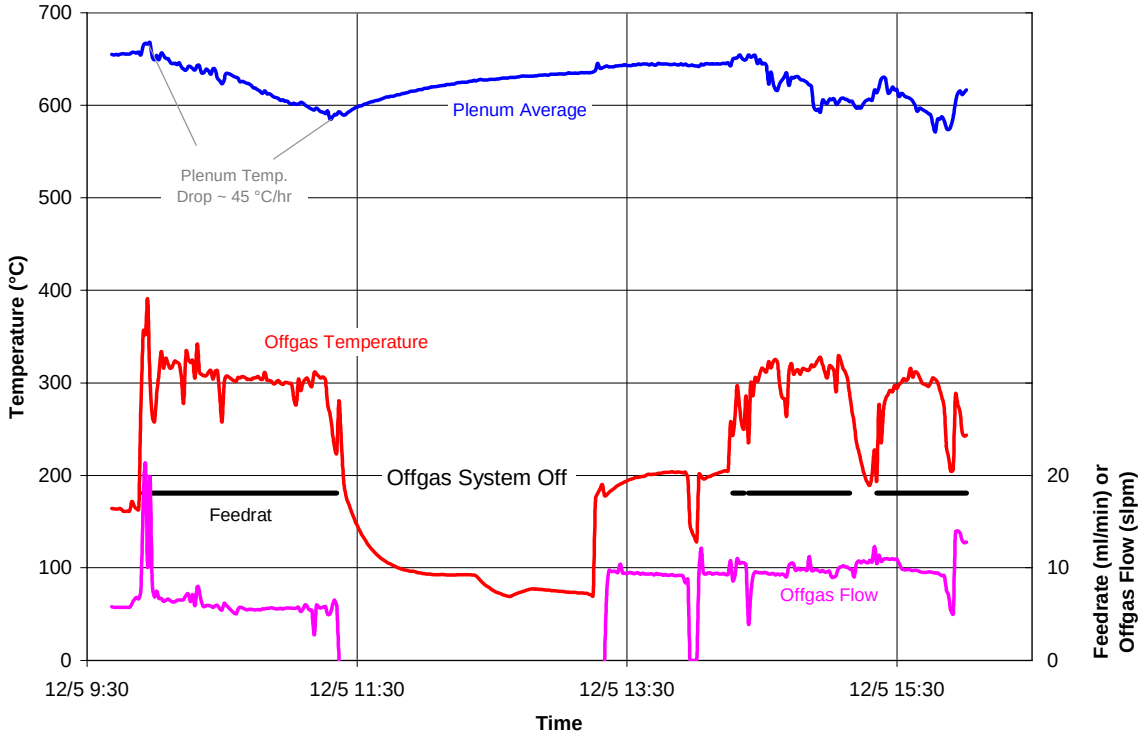


Figure 4.6 Surrogate Run #2 Offgas & Plenum Temperature and Offgas Flow Data (12/5)

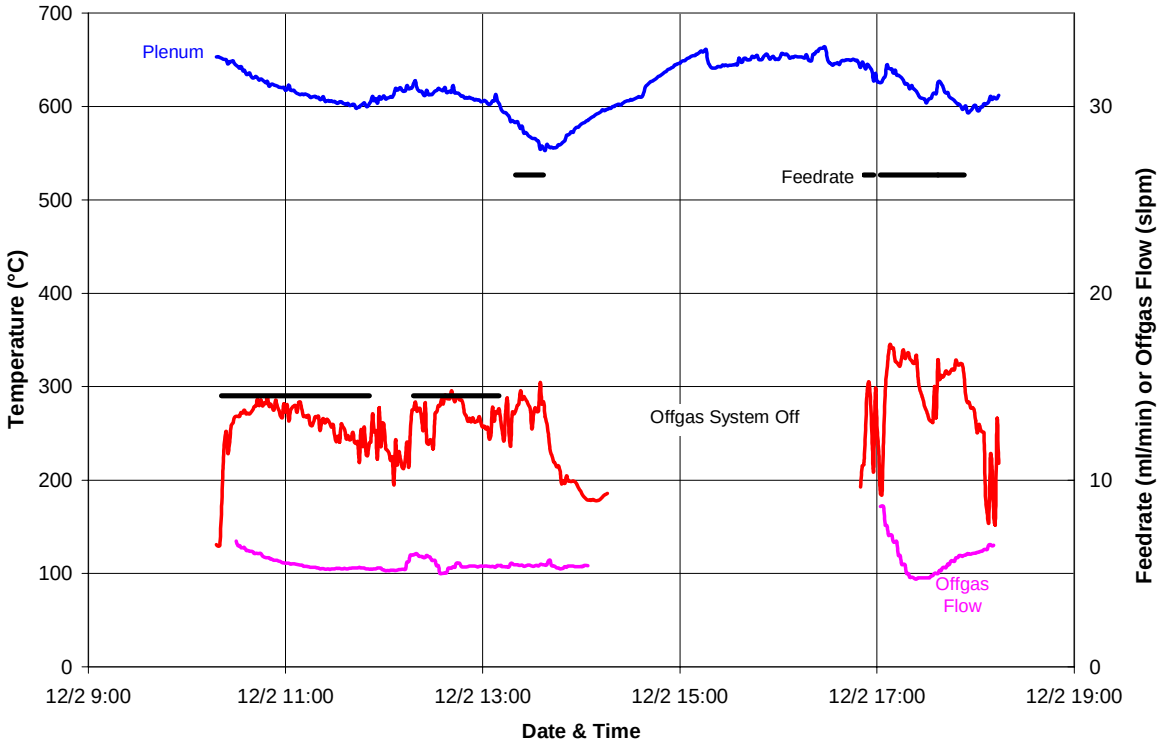


Figure 4.7 Surrogate Run #2 Offgas & Plenum Temperature and Offgas Flow Data (12/2 09:00)

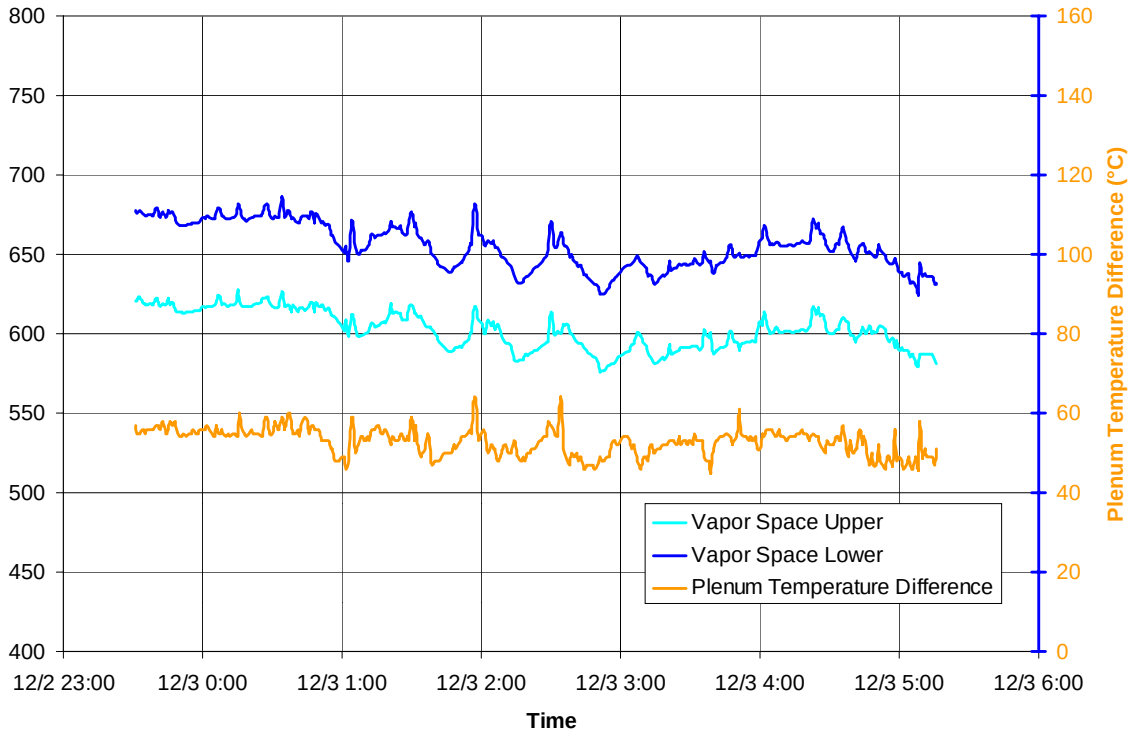


Figure 4.8 Surrogate Run #2 Plenum Temperatures (12/2 23:00)

4.2.6. Surrogate Run #2 Offgas Characterization

The rate of generation of offgases from the feed (CO, CO_2, H_2, NO_x, etc.) is essentially controlled by the temperature and redox chemistry in the cold cap. These offgases generated then react in the plenum via the water-gas shift reaction ($CO_2 + H_2 = CO + H_2O$), oxidation reactions ($H_2 + ½ O_2 = H_2O$, $CO + ½ O_2 = CO_2$, $NO + ½ O_2 = NO_2$), and other gas phase reactions. The rate of these reactions is essentially dependent on the "true gas temperature" in the melter plenum (see section 4.3.6). At true gas temperatures below about 300°C, the rate of the offgas reactions, except those of NO_x, becomes negligible, so the temperature of the offgas after the dilution air is added is low enough that little further reaction will take place. Therefore, the amounts of offgases measured, except NO_x, are representative of the amounts of each gas in the melter plenum. The measurements are not representative of the amounts of each gas evolved from the cold cap due to the plenum reactions.

Measured offgas flows are shown in Figure 4.9 and Figure 4.10. Redundant offgas flow measurements were made by a dry gas meter (DGM), a helium tracer method, and by a thermal flowmeter. As expected, the thermal flowmeter readings were usually incorrect because these meters were calibrated for dry air, whereas the actual gas measured contained offgases from the melter and water vapor. The thermal flowmeter readings were used only as a fast, real-time approximation to the flow for process operating purposes; they were not used in any calculations.

The He tracer and DGM flow measurements generally track each other well. The average difference (of smoothed data) was 0.94 slpm; an approximate 95% confidence interval on the average flow is the flow reading ± 20% of the value. (See Appendix 6.13 for error estimates.) The air inleakage typically ranged from 1-3 slpm; the "prototypic" design air inleakage was 2.18 slpm (see Section 3.2.1.3). The inleakage was calculated as the difference between the average offgas flow and the total offgas (air) purges. The prototypic air inleakage is the inleakage just into the melter. The inleakage for the LC melter reported here is all inleakage from the melter to the offgas flow measurement point, so the actual melter air inleakage is less than or equal the reported amount. The equipment downstream of the melter was subjected to inleakage tests that showed that the inleakage was less than 0.1 slpm at about 0.05 atm pressure.

The concentrations of offgases measured by the gas chromatographs are shown for two feeding periods in Figure 4.11 and Figure 4.12. None of the feeding periods were sufficiently long to reach steady state concentrations of the offgases. At a constant feedrate and air purge rate, the rate of offgas evolution would be constant rather than the concentrations, but the general shape of the concentration and evolution rate peaks is very similar. The H_2/CO ratio was usually less than 1.0, with some spikes to values greater than 1.0. Figure 4.13 and Figure 4.14 show the ratios of H_2/CO and CO/CO_2, respectively. The H_2/CO ratio was typically around 0.8 and the CO/CO_2 ratio around 0.017.

Virtually all of the carbon in the feed was evolved as CO_2, as expected. For reference, the measured concentrations of O_2, N_2, and He are also shown in Figure 4.11. The concentration of water shown was estimated to be the saturation concentration at the offgas impinger temperature (approximately 25°C). This concentration estimate for water was chosen because the offgas sample was taken after the scrubbing impingers but before the silica gel impinger.

Figure 4.15 shows that some methane (CH_4) was emitted during one time period. The maximum concentration was only about 0.02 vol%, or about six times less than the CO. One of the GCs was capable of measuring nitric oxide (NO) if above about 0.1 vol%, but none was detected in the surrogate runs. Evolution of NO and NO_2 (NO_x) would be expected given the high concentration of nitrites and nitrates in the feed. However, it appears that the impingers (scrubbers) removed most of the NO_x. NO_x was emitted, because the yellow-brown color of NO_2 was seen in some of the glassware.

The concentration of CO_2 was measured by both GCs, so a comparison of the values measured gives some indication of the accuracy of the GC data. Note that GC column "B" measured the CO_2 in both instruments, whereas the H_2, He, O_2, N_2, and CO were measured by column "A". Redundant measurements were not made for these gases. Figure 4.16 shows these CO_2 measurements for two time periods. For one period, the difference is virtually zero, whereas for the other, it is about 0.7 vol%, or 10% of the typical measurement.

The material balance on carbon closed to within 3.1%. The total carbon in the feed was the total organic carbon plus the total inorganic carbon (TOC+TIC), while the total carbon in the offgas was the sum of the CO and CO_2. Contributions of trace carbon-bearing compounds were ignored. Good closure of the material balance confirms that the offgas CO and CO_2 readings were good.

Table 4.10 Surrogate Run #2 Carbon Material Balance

	Feed (mol)	Offgas (mol)	% Closure of Material Balance
Total Carbon	6.76	6.97	103.1
Total Organic Carbon	5.85		
Total Inorganic Carbon	0.91		

One particulate sample taken during surrogate run #2 was taken while the melter was idled for about 35 minutes, so most of the particulate collected was due to volatilization from the melter glass surface. Note that some of the particulate collected could have been due to dislodged material from the offgas lines. The sample results are shown in Table 4.11. The elements present above the blanks are highlighted in bold. Most of these are components of the feed. Notably, the amount of boron collected was rather significant, indicating that loss of boron by volatilization during idling could be a concern.

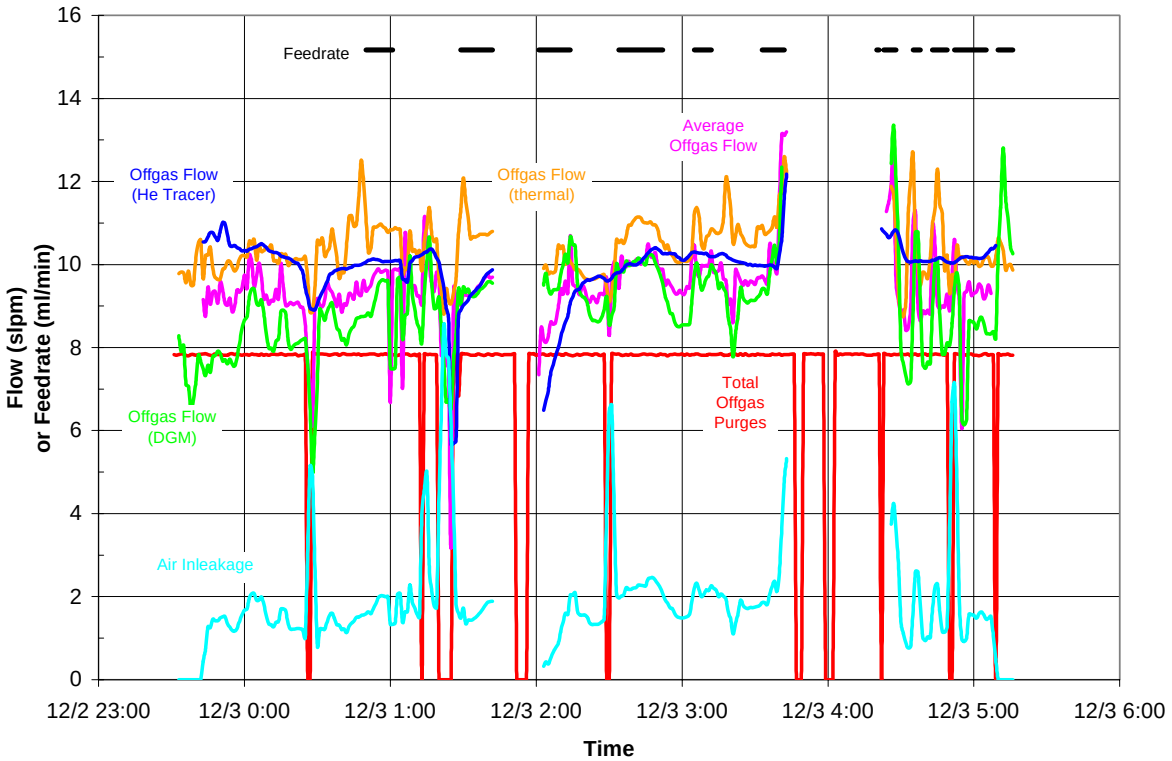


Figure 4.9 Surrogate Run #2 Offgas Flows (12/2 23:00)

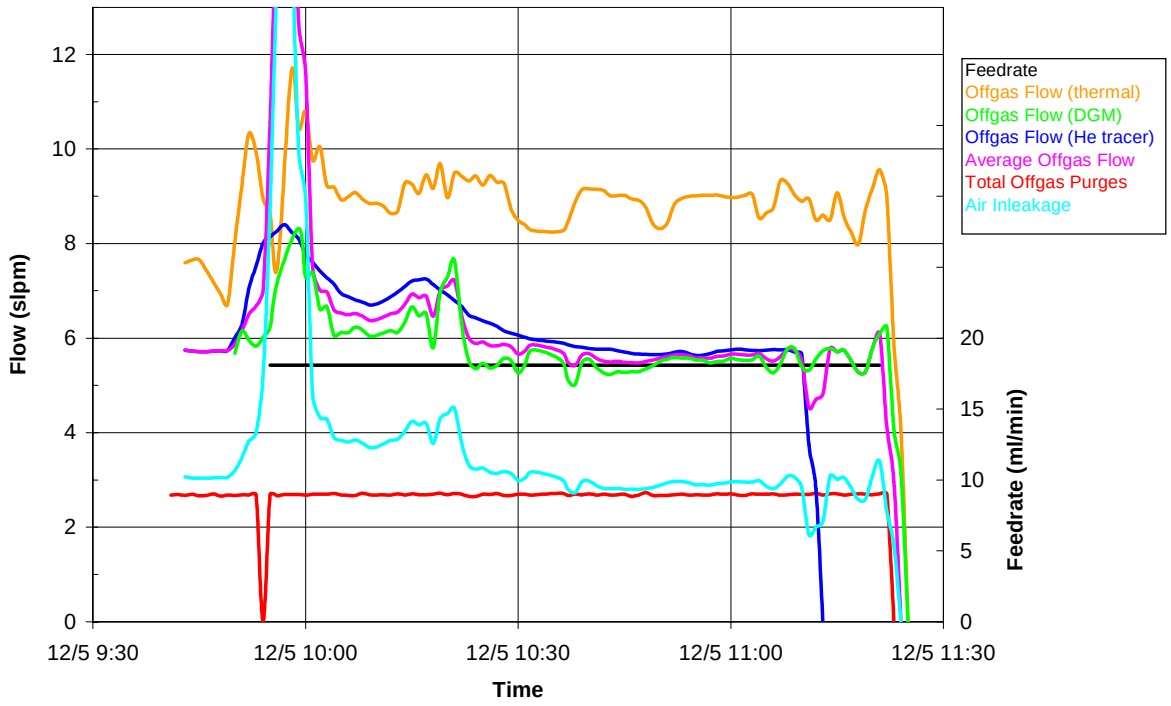


Figure 4.10 Surrogate Run #2 Offgas Flows (12/5)

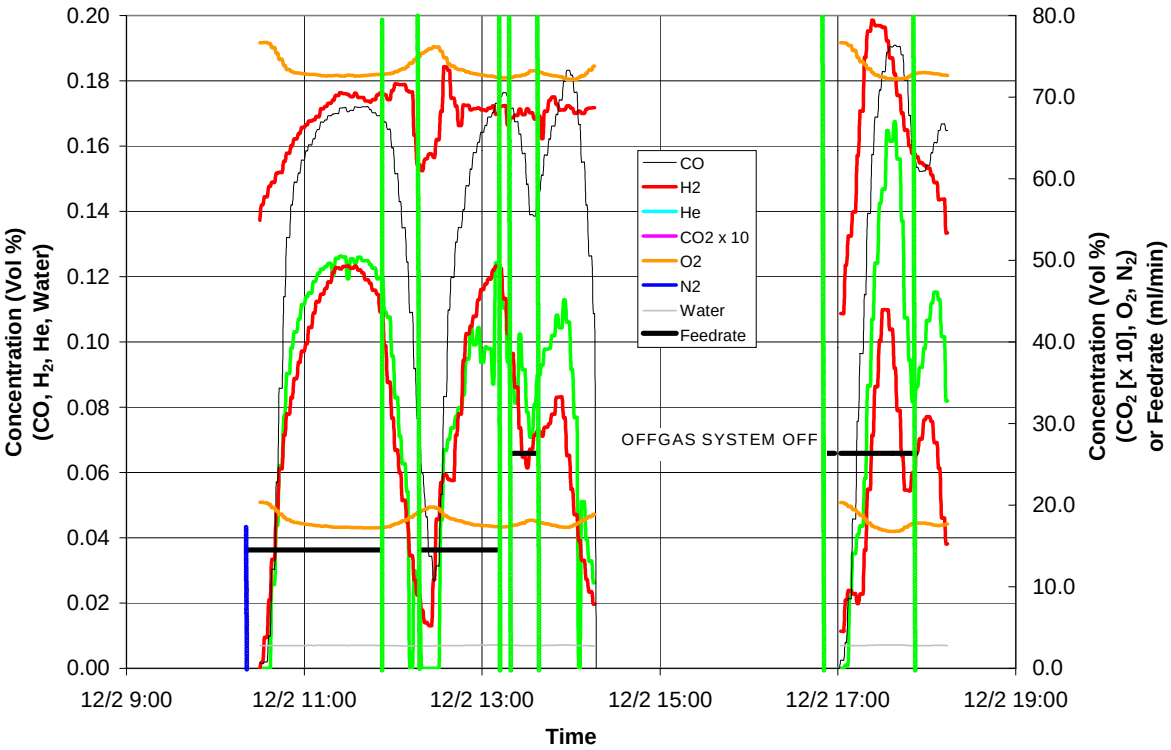


Figure 4.11 Surrogate Run #2 Offgas Composition (12/2 09:00)

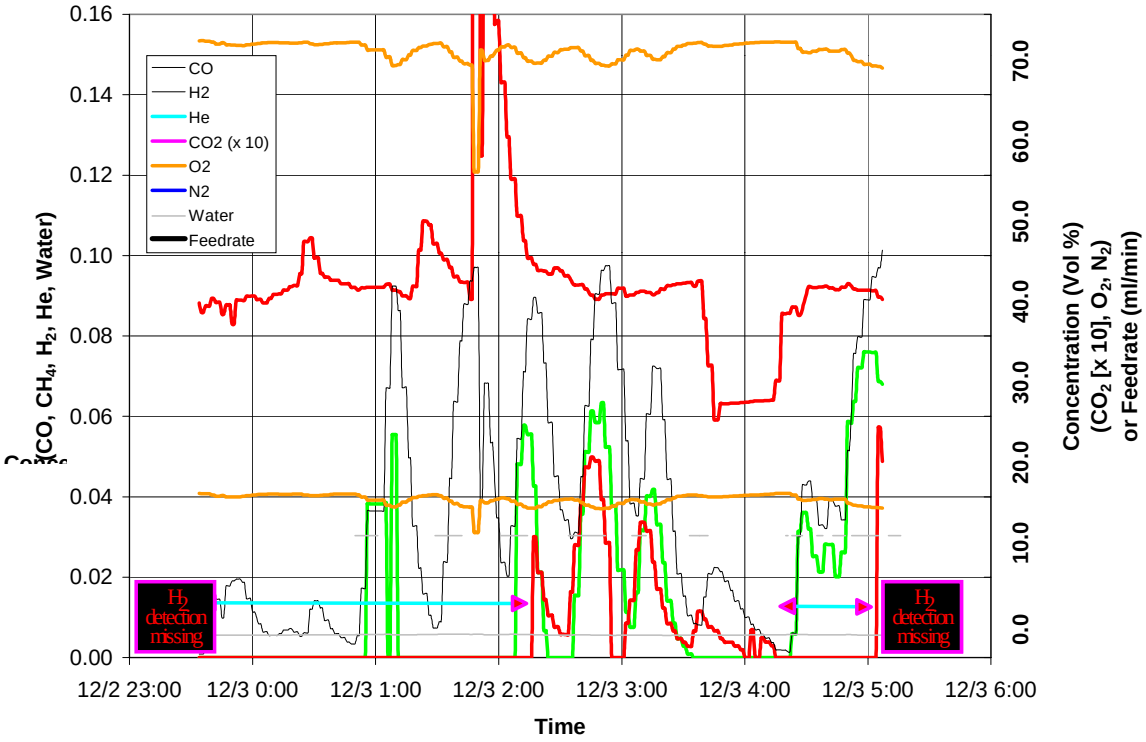


Figure 4.12 Surrogate Run #2 Offgas Composition (12/2 23:00)

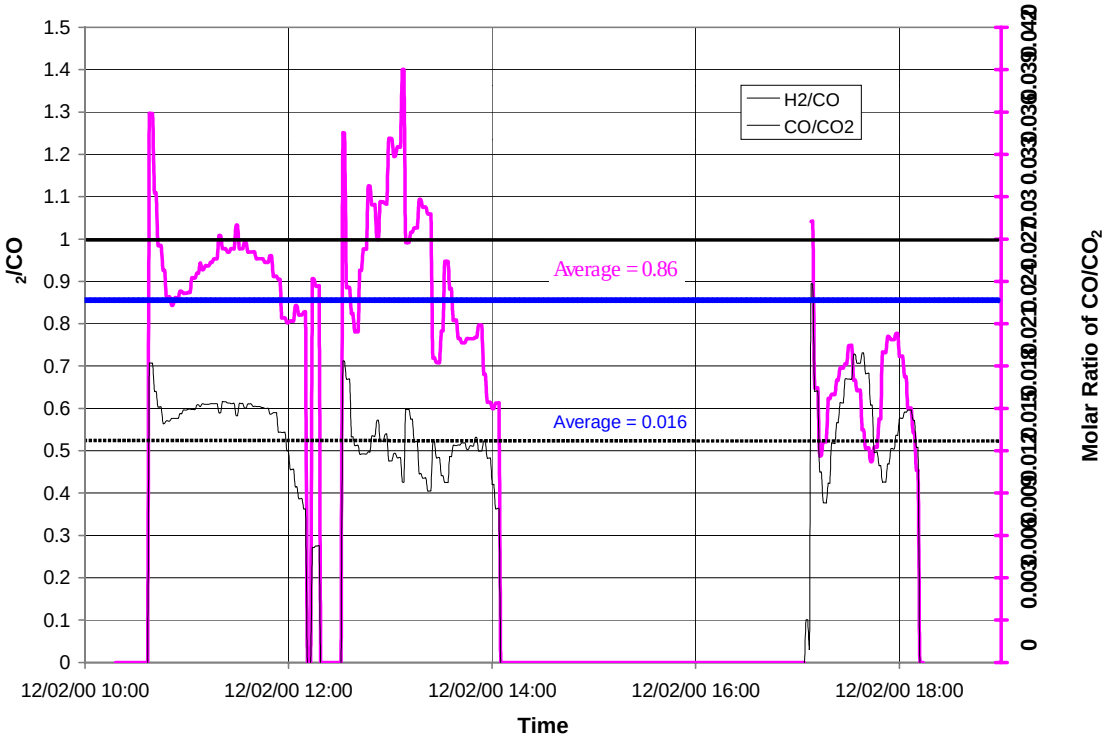


Figure 4.13 Surrogate Run #2 Ratios of H_2/CO and CO/CO_2 (12/2 10:00)

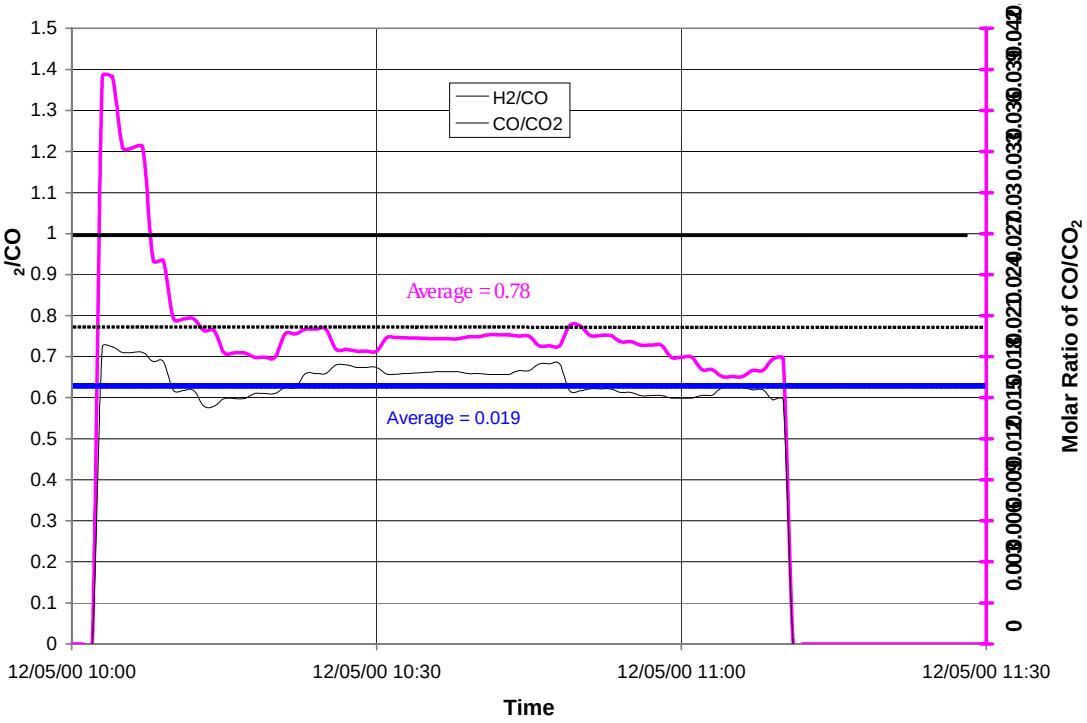


Figure 4.14 Surrogate Run #2 Ratios of H_2/CO and CO/CO_2 (12/5)

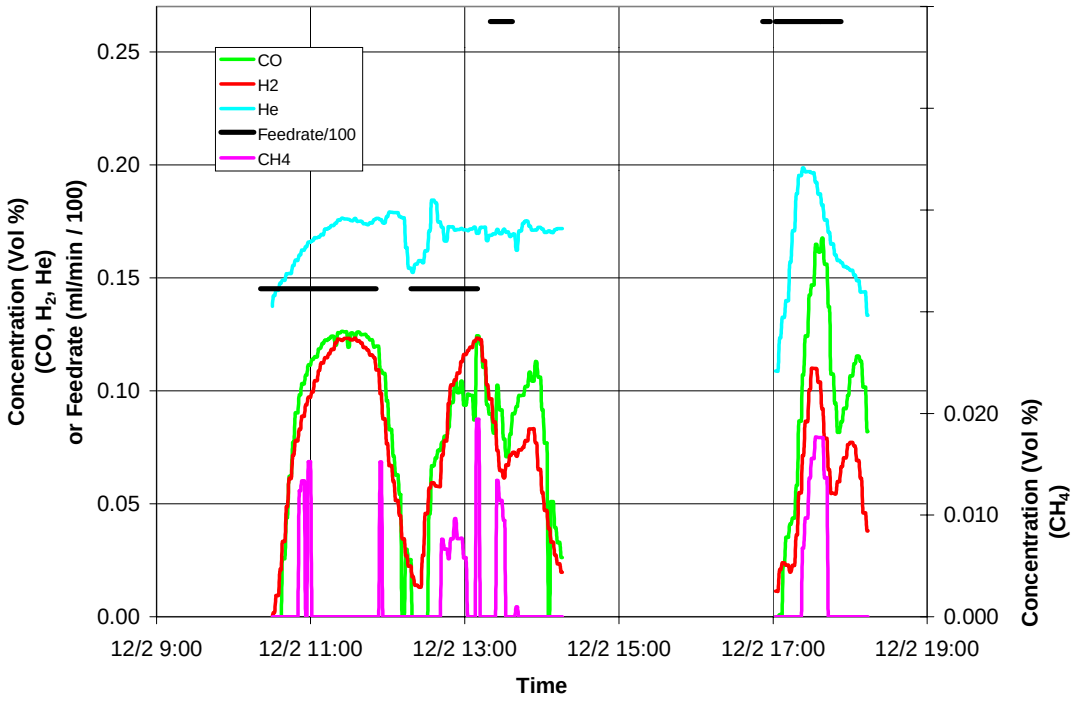


Figure 4.15 Surrogate Run #2 Flammable Species Offgas Concentrations (12/2 09:00)

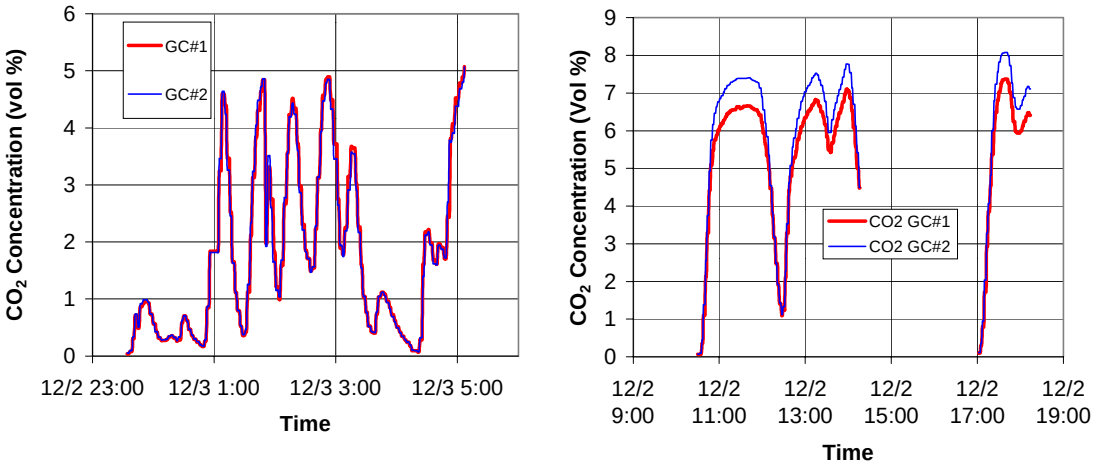


Figure 4.16 Surrogate Run #2 Comparison of Measured CO_2 Concentrations

Table 4.11 Surrogate Run #2 Particulate Collected During Idling

Element	Sample (µg/g filter)	Average Blank (µg/g filter)
Al	1016	3544
B	**25609**	**15749**
Ba	<7.70	24.9
Ca	926	5943
Cd	<10.0	34.6
Co	<30.0	47.3
Cr	**402**	**41.1**
Cu	<35.0	111
Fe	**1891**	**253**
La	<50.0	<14.0
Li	**504**	**<2.44**
Mg	<50.0	360
Mn	9.65	9.00
Mo	<70.0	31.3
Na	10633	12066
Ni	**639**	**44.3**
P	<500	64.9
Pb	<500	232
Si	**859968**	**448889**
Sn	**276**	**73.2**
Sr	7.49	126
Ti	**519**	**60.1**
V	<100	<9.00
Zn	**1328**	**42.3**
Zr	NA	87.0
K	532	536

4.3. Radioactive Run

4.3.1. Radioactive Run Objectives – Run Plan[36]

The specific objectives of this task are given in the Task Technical and QA Plan[28]. These objectives were:

1. Sample and analyze the offgas from the melter for metals and radionuclides by modified EPA SW-846 Method 0060.
2. Sample and analyze the offgas from the melter for fixed gases, including combustion gases.
3. Produce approximately 1 kg of waste-containing glass for characterization of metals and radionuclides.
4. Produce approximately 1 kg waste-containing glass to be archived for future regulatory characterization of metals and radionuclides.

The EPA Method 60 sampling was specified to start when the number of melter volumes of glass produced since starting radioactive feeding reached 2.25. This number of melter volumes was equivalent to about 17.0 lb of feed. Upon reaching 3.0 melter volumes (22.65 lb feed), a new glass can was to be installed to segregate the glass produced prior to and after 3.0 melter volumes. The minimum amount of feed that needed to be fed was 70% of the initial amount, or 33.8 lb.

Note that three melter volumes corresponds to 22.65 lb of feed, whereas in the design, three melter volumes corresponded to 31.9 lb of feed. The specific gravity, total solids content, and the calcine (mass of glass formed / mass of dried feed) for the design case and the actual radioactive feed were different, which results in different feed masses per melter volume. In addition, in the original design, the glass spgr was assumed to be 2.75; this value was adjusted in the actual batching calculations to a more correct estimate of 2.5 for glass at 1100-1200°C.[37]

4.3.2. Radioactive Run Chronology

The evaporator concentrate produced from the evaporation tests[4] was first composited into one large sample prior to addition to the Large C melter feed tank. This feed was transferred into the laboratory in seven one-liter bottles. The total volume of feed was approximately 6.7 liters. Some slight precipitation of solids in the feed was noticed prior to addition. Therefore, the bottles were shaken so that most of the solids would be added to the feed tank. On 12/8/00, this feed was added to the melter feed tank.

The glass formers were then added individually, with the sugar being added first. The melter feed was then agitated for 10 hours prior to taking a sample for analysis. During agitation, the feed tank cover was on to prevent evaporation and possible spread of contamination from splashing of the feed material. The cover had been modified since the surrogate runs to better contain the melter feed slurry, which also cut down on evaporation.

On 12/9/00, feeding of the melter was attempted. The feed tube immediately plugged, requiring flushing and rodding out. During these operations, a hairline crack occurred in a polypropylene portion of the feed line and resulted in a small amount of radioactive feed contaminating a technician's lab coat. All operations were stopped, and meetings were held to determine the proper path forward. A Job Hazards Analysis was conducted on the feed tube rodding procedure and the area outside the radiohood was posted as a contamination area.

Most of 12/10/00 was spent removing the pluggage from the feed tube. On 12/11/00, feeding was attempted again, but the feed tube again immediately plugged. Additional rodding, cleaning with oxalic acid, and flushing was performed. The feed was then successfully pumped through a mockup feed tube and the actual feed tube to a bottle outside of the melter. However, when the feed tube was reinstalled into the melter and feeding was attempted, the feed tube again plugged.

On 12/12/00, a new feed tube was fabricated. Prior to installation in the system, it was noticed that there was some weld material inside the feed tube near the exit. The feed tube was sent back to the fabrication shop to have this material removed so the bore of the feed tube would be smooth. It was suspected that this same problem existed in the first feed tube and was the main cause of the plugging within the feed tube.

During all the attempts to feed, water was added many times to the feed tank during backflushing. Additionally, on 12/12/00, about 1.1 lb (500 ml) of water was added to the feed tank to dilute the feed because poor feed rheology was also suspected as a contributor to the feeding problems. Based on the recorded scale weights, the total amount of water added was 6.95 lb.

On 12/14/00, feeding was successfully started. A Method 60 sample (#1) was also started, but a pluggage in the offgas line was found upstream of the entrance to the Method 60 filter. The Method 60 scrubbing solutions were sucked backwards through the impingers, so the volatile metals sampling portion of this set became unusable. Sampling for just particulate on the filter was performed. Method 60 sample #2 was then taken.

On 12/15/00, the walls of the feed tank were scraped down because a substantial amount of solids had accumulated above the liquid level line. Some of this material stuck to the walls as the level was lowered during feeding and some was deposited there by splatter from the agitator blade. The feed that was scraped off had a thick liquid consistency rather than being a hard cake. The feed tank was allowed to agitate for about 4 hours. The second melter feed sample was taken at this time.

The next attempt at feeding resulted in immediate pluggage of the feed system. Pluggages in the feed tube and the tubing from the pump to the feed tube repeatedly occurred. Chunks of the material scraped from the tank sides were suspected as the cause of the pluggages. The agitator could not be run fast enough to break up these chunks because if it had been, the solids would have been splattered back up onto the

sides of the tank. Finally, the dip tube from the feed tank to the pump inlet was replaced with tubing with a 90° bend that was oriented with the inlet pointing in the direction of the flow in the tank (tangent to the wall). After this modification was made, no additional problems with feeding were encountered. Method 60 sample #3 was completed. A final melter feed sample (#3) was taken much later after the run was completed; a substantial amount of feed water had evaporated, so this sample was much more concentrated than the previous sample.

4.3.3. Radioactive Run Feed Composition and Glass Formulation

The Large C Evaporator concentrate was the feed stream for the Large C Melter. The composition of the concentrate is given in Table 4.12. This analysis is for the composite sample. Note that a number of the radiochemical species were found to be below the detection limits.

The amount of evaporator concentrate feed was estimated to be 7 liters based on the approximate volume in the storage vessel. This material was then transferred to seven 1-liter bottles for transport to the melter feed tank. The actual amount of this feed, based on the approximate volumes in the seven bottles, was estimated to actually be about 6.7 liters.
The glass formulation was specified by VSL and is shown in Table 6.3. The total glass formers added are summarized in Table 4.13. The glass former requirements were based on the above analyses and the assumption that there was 7.0 liters of this material. Therefore, the amount of glass formers added was about 4.5 wt% higher than intended. The glass formers all contain impurities.
Table 4.14 shows the nominal composition and assay of these glass formers.

Table 4.12 Composition of Waste Feed (Evaporator Concentrate)

Physical Properties		
Total Solids	40	wt%
Density	1.29	g/mL
Ion Chrom.	**mg/L**	
NO_3^-	119684	
NO_2^-	46619	
SO_4^{-2}	7567	
Cl^-	1861	
F^-	1061	
ICPES or AA	**mg/L**	**M**
Ag	<0.592	
Al	8388	
B	22.2	
Ba	<0.197	
Ca	176	
Cd	32.9	
Co	2.8	
Cr	117	
Cu	5.60	
Fe	3.53	
La	6.20	
Li	<0.197	
Mg	0.104	
Mn	1.28	
Mo	34.7	
Na (ICPES)	175396	7.63
Na (AA)	157571	6.85
Ni	200	
P	1055	
Pb	79.6	
Si	71.1	
Sn	24.4	
Sr	203	
Ti	<0.197	
V	0.582	
Zn	1.91	
Zr	1.22	
K (AA)	1235	
ICPMS	**mg/L**	
Y	0.57	
Rh	4.28	
Pd	1.45	
Sb	<0.01	

Wet Chemical	mg/L	M
OH-	24820	1.46
CO_3^{-2}	54807	
TOC	21500	
Radiochemical	**µCi/mL**	
Co^{60}	0.0496	
Cs^{134}	ND	
Cs^{137}	0.0724	
Eu^{154}	0.0445	
Eu^{155}	0.0300	
Am^{241}	0.0285	
Sr^{90}	1.79	
Tc^{99}	0.0554	
Total Alpha	0.104*	
Total Beta	6.85*	
ICP-Mass Spectroscopy	**mg/L**	
mass 99	3.20	
mass 230	<0.00622	
mass 231	<0.00622	
mass 232 (Th)	1.71	
mass 233	<0.00622	
mass 234 (U)	<0.00622	
mass 235 (U)	0.0113	
mass 236 (U)	<0.00622	
mass 237 (Np)	0.0853	
mass 238 (Pu & U)	1.07	
mass 239 (Pu)	0.0169	
mass 240 (Pu)	<0.00622	
mass 241 (Am & Pu)	0.00879	
mass 242 (Pu)	<0.00622	
mass 243 (Am)	<0.00622	
mass 244 (Cm)	<0.00622	
mass 245 (Cm)	<0.00622	
mass 246	<0.00622	
	µCi/mL	
Tc^{99} (uCi/ml)	0.0543	
ICPMS	**mg/L**	
Ta	<0.01	
W	73.1	
Pt	<0.01	
Hg**	<0.003	

*Calculated from evaporator feed data, see reference 4.

** Mercury value from associated Regulatory Analyses. See 'Sample Analysis Results for a Benchscale Evaporator Test Using a Hanford Tank 241-AN102 Sample'**, WSRC-TR-2001-00288, SRT-RPP-2001-00014, Rev. 1**, DRAFT-April 2002.

Table 4.13 Glass Formers (Actual Additions) for Radioactive Run

Glass Former	Mass Used (g)
Kyanite Raw (Al_2SiO_5) 325 Mesh	1402.17
Boric Acid (H_3BO_3) Technical Granular	2556.6
Wollastonite ($CaSiO_3$) NYAD 325 Mesh	1902.9
Fe_2O_3 (Iron III oxide, -325 Mesh)	852.7
Li_2CO_3 (Chemetall Foote Co. Tech. Gr.)	961.4
Olivine (Mg_2SiO_4) 325 Mesh (#180)	446.7
SiO_2 (Sil-co-Sil 75)	4592.3
TiO_2 (Rutile Airfloated)	165.25
ZnO (Kadox-920)	425.8
Zircon $ZrSiO_4$ (Flour) Mesh 325	658.75
Sugar	83.7

Table 4.14 Nominal Impurities and Assays of Glass Formers (wt%)

Glass Former	Formula	Fe_2O_3	SiO_2	Li_2O	Al_2O_3	Na_2O	CaO	MgO	MnO
Kyanite	Al_2SiO_5	1.16	40.70		57.00	0.42	0.03	0.01	
Boric Acid	H_3BO_3								
Wollastonite	$CaSiO_3$	0.40	51.00		0.20		47.50	0.10	0.10
Iron III Oxide	Fe_2O_3	100.00							
Li2CO3	Li_2CO_3			40.44		0.10			
Olivine	Mg_2SiO_4	7.68	42.52		0.19		0.02	48.01	
Silica	SiO_2	0.02	99.70		0.14		0.01	0.01	
Titanium Dioxide	TiO_2	0.71	0.91			0.71			
Zinc Oxide	ZnO								
Zircon	$ZrSiO_4$	0.08	33.00		0.25				

Glass Former	Formula	K_2O	NiO	ZnO	ZrO_2	Cr_2O_3	CO_2*	TiO_2	Total	Assay
Kyanite	Al_2SiO_5							0.79	100.11	99.0
Boric Acid	H_3BO_3									98.6
Wollanstonite	$CaSiO_3$								99.30	99.3
Iron III Oxide	Fe_2O_3								100.00	99.8
Li2CO3	Li_2CO_3	0.05					59.41		100.00	99.0
Olivine	Mg_2SiO_4		0.37			0.13			98.92	99.0
Silica	SiO_2	0.02						0.01	99.91	99.7
Titanium Dioxide	TiO_2				0.90	0.19		95.40	98.82	95.4
Zinc Oxide	ZnO			99.80					99.80	99.7
Zircon	$ZrSiO_4$				66.00			0.10	99.43	99.9

* (carbonate)

4.3.4. Radioactive Run Feed Addition Material Balance

Based on the radioactive feed and glass former additions, the composition of the melter feed was estimated, and is compared to the measured composition in Table 4.17. Two

additional melter feed samples were taken during the radioactive run. Sample #2 was taken about 75% of the way through feeding, while sample #3 was taken after the run was completed. Sample #2 had a lower total solids content due to water added to improve the rheology for pumping and from feed tube backflushes. A significant amount of water had evaporated before sample #3 was taken, so the solids content of this sample was higher than sample #2. The measured and calculated compositions for these samples are shown in Table 4.18 and Table 4.19.

The predicted and measured values for the major elements agree reasonably well for each sample, with most elements within ±15%. The measured total solids and density were always less than the predicted values by 3-11%. The analyses for the anions nitrate, nitrite, and sulfate were all 15-30% lower than the expected values, which tends to indicate there may have been a systematic error in the measurement of the anions. Another explanation would be that the evaporator concentrate analyses were 15-30% high, resulting in high calculated values, but this explanation seems unlikely since lower nitrite and nitrate would have resulted in lower total solids than measured in the evaporator concentrate. Comparisons of the chloride and fluoride cannot be made since the analyses of these were below the detection limits. Comparisons of hydroxide, carbonate, and TOC also could not be made since these were not measured. Many of the minor element analyses were 2-10 times the calculated values. The glass former impurities, discussed in section 4.3.3, do not seem to explain these discrepancies. These impurities, at the nominal levels shown in
Table 4.14, have been included in the calculated values. However, these are only nominal values and the actual values could be higher, but for the actual impurity levels to be 2-10 times higher seems unlikely. A combination of higher impurities and the analytical variation at low concentrations may account for the differences.

The lower than expected value for the total solids and density suggest that the sample was not representative. A sample with low total solids would also have to be low in insoluble solids. The only ways an unrepresentative sample could be taken would be for the contents of the feed tank to be inhomogeneous or for the sampling device to separate the sample in some way as it was being taken. In either case, low total solids implies low insoluble solids, which then implies that the insoluble elemental species would be lower and the soluble elements would be higher than expected. However, this is not the case for any of the melter feed samples. Table 4.15 shows the relative amounts of solids, insoluble elements, and soluble elements for each sample.

Table 4.15 Comparison of Relative Amounts of Total Solids, Insoluble Elements, and Soluble Elements

(Measured relative to Calculated)

Sample #	Total Solids (TS)	Insoluble (I) Elements	Soluble (S) Elements	Comments
1	<	7 >, 1 <	4 >	TS inconsistent with I, S elements.
2	<	8 <	2 <, 1 >	Consistent, sample *may* have been more dilute than calc'd.
3	<	4 >, 4 <	3 >	TS inconsistent with I, S elements.

This comparison shows that for samples #1 and #3, the data are inconclusive. If the predicted values are assumed to be the correct values, then the error seen, ±15% for most elements, and 3-11% for total solids and density are on the order of the expected accuracy, so the apparent effect of the low total solids and density measurements could be attributed to normal analytical error. One caveat is that the total solids and density are consistently lower than the calculated values; this fact could indicate a systematic error in these measurements.

The actinides measured by ICPMS show large differences for the minor species, with the measured values being about an order of magnitude larger than predicted from the analysis of the evaporator concentrate. Masses 232 (Th) and 238 (U) were adjusted to account for the approximate amount of Th and U that are present in the zircon (ZrSiO4) glass former. The data (for all three melter feed samples) matched the measured Th and U best if the concentration of total Th+U in the zircon was 832 ppm, with 58.8% as U. Vendor information[38] gives the nominal range expected to be 400-500 ppm total, with 33% U. Note that there is an order of magnitude more Th^{232} and U^{238} in the zircon glass former than in the actual waste feed.

Also note that the predicted total solids content is 7% higher than the measured value. The calculated value was determined from the masses of the evaporator concentrate and glass formers added, the changes in mass indicated by the scale, and the volume after mixing. The volume was visually estimated to be about 12.25 liters; the calculated value that best fit the data was 12.2 liters, so the calculated total solids (77.2 wt%) was deemed to be closer to the correct value. The measured density was used for this calculation. An alternate calculation was also performed using the calculated density (Appendix 6.8). Using this value resulted in a total volume of 11.7 liters, which was farther from the observed volume that when the measured density was assumed.

The overall agreement between the measured and calculated values is good for most of the major non-radioactive species, with most values within 20% and many within 10%. However, the measured nitrate and nitrite concentrations were consistently less than the calculated values by about 20-30%, indicating that the evaporator concentrate analysis may have been 20-30% high.

In Table 4.20, all of the analyses have been converted to a dry solids only basis. On this basis, the concentration of each species should be the same regardless of sample. Again, for most of the major species, the agreement between measured values and between measured and calculated is reasonably good.

Table 4.16 Evaporator Concentrate and Melter Feed Compositions and Material Balance Information for Radioactive Run

		Evaporator Concentrate Feed (Measured)	Glass Formers* for 1 liter of 5 M Na^+ Evaporator Concentrate	Glass Formers for Actual Amount of Evaporator Concentrate		Feed: Waste + Glass Formers (Calculated)	
Na Molarity	M	7.63				4.37	
Volume	liter	6.68				12.3	
		mg/L	g	g	wt %	mg/L	wt % dry
NO_3^-		119684				68143	3.53
NO_2^-		46619				26543	1.37
SO_4^{-2}		7567				4308	0.223
Cl^-		1861				1059	0.0549
F^-		1061				604	0.0313
OH^-		24820				14138	0.732
CO_3^{-2}		54807	111	779	5.55	97588	5.05
TOC		21500	5.03	35.2	0.251	15243	0.789
Ag		0.592				0.337	1.75E-05
Al		8388	61.3	429	3.06	41340	2.77
B		22.2	63.9	447	3.18	38087	2.56
Ba		0.197				0.112	7.53E-06
Ca		176	92.4	647	4.60	55183	3.70
Cd		32.9				18.7	0.00126
Cr		117	0.0874	0.612	0.00436	119	0.00796
Cu		5.60				3.19	2.14E-04
Fe		3.53	91.3	639	4.55	54423	3.65
La		6.20				3.53	2.37E-04
Li		0.197	25.8	181	1.29	15382	1.03
Mg		0.104	18.7	131	0.931	11146	0.748
Mn		1.28	0.211	1.47	0.0105	126	0.00847
Mo		34.7				19.8	0.00133
Na		175396	0.850	5.95	0.0423	100370	6.73
Ni		200	0.186	1.30	0.00925	224	0.0150
P		1055				601	0.0403
Pb		79.6				45.3	0.00304
Si		71.1	436	3051	21.7	259947	17.4
Sn		24.4				13.9	9.33E-04
Sr		203				116	0.00775
Ti		0.197	14.5	102	0.725	8672	0.582
V		0.582				0.331	2.22E-05
Zn		1.91	48.8	341	2.43	29080	1.95

Table 4.16 (continued)

		Evaporator Concentrate Feed (Measured)	Glass Formers* for 1 liter of 5 M Na^+ Evaporator Concentrate	Glass Formers for Actual Amount of Evaporator Concentrate		Feed: Waste + Glass Formers (Calculated)	
		mg/L	g	g	wt %	mg/L	wt % dry
Zr		1.22	46.1	323	2.30	27510	1.85
K		1235	0.166	1.16	0.00827	802	0.0538
			* includes sugar				
Total Elements, Ions, TC	g	3108	1017	7116			
Oxides, O, H	g	341	990	6932	49.3		45.1
Total Sample	g	8623	2007	14048		22671	
Solids in Sample	g	3449				17497	
Water	g	5174				5174	
Total Sample	lb	19.0		31.0		50.0	
						Calculated:	**Measured:**
Total Solids in Sample	wt %	40.0				**77.18**	**70.21**
Measured Density	kg/L	1.29					**1.86**
Estimated Density	kg/L	1.34				**1.931**	

Table 4.17 Comparison of Measured Melter Feed Sample #1 with Calculated Composition Estimate
(major species in boldface, mostly soluble species in italics)

	Measured	Calculated	
Ion Chrom.	**mg/L**	**mg/L**	**%Diff.**
NO_3^-	***55134***	***65635***	***17.4***
NO_2^-	***19044***	***25566***	***29.2***
SO_4^{-2}	*3365*	*4150*	*20.9*
Cl^-	*<3380*	*1020*	
F^-	*<3380*	*582*	
Wet Chem.	**mg/L**	**mg/L**	
OH^-	*NA*	*13617*	
CO_3^{-2}	***NA***	***93998***	
TOC	*NA*	*14682*	
ICPES	**wt%**	**wt%**	
Ag	NA	0.0000175	
Al	**1.98**	**2.14**	**7.82**
B	***2.28***	***1.97***	***-14.3***
Ba	0.00268	<5.81E-06	
Ca	**2.93**	**2.86**	-2.38
Cd	0.00372	0.000970	-117
Co	0.0156	NA	
Cr	0.0191	0.00614	-103
Cu	0.00329	0.000165	-181
Fe	**2.99**	**2.82**	**-6.00**
La	<0.0352	<0.000183	
Li	***0.870***	***0.797***	***-8.86***
Mg	**0.579**	**0.577**	**-0.353**
Mn	0.0346	0.00654	-136
Mo	<0.00426	0.00102	
Na ICP	***6.24***	***5.20***	***-18.2***
Na AA	***6.33***		***-19.7***
Ni	0.0207	0.0116	-56.2
P	*0.0616*	*0.0311*	*-65.8*
Pb	<0.0230	0.00235	
Si	**13.9**	**13.5**	**-3.40**
Sn	<0.0121	0.000720	
Sr	0.00549	0.00598	8.57
Ti	**0.523**	**0.449**	**-15.2**
V	<0.00436	0.0000172	
Zn	**1.68**	**1.51**	**-11.0**
Zr	**1.44**	**1.42**	**-1.03**
K	*0.0532*	*0.0415*	*-24.7*

	Measured	Calculated	
Physical Properties			**%Diff**
Total Solids (wt%)	70.2	77.2	9.5
Measured Density (g/mL)	1.86	1.93	3.7
Radiochemical	**µCi/mL**	**µCi/mL**	
Co^{60}	0.0333	0.0272	-20.2
Cs^{134}	ND	ND	
Cs^{137}	0.0510	0.0397	-24.9
Eu^{154}	ND	0.0244	
Eu^{155}	ND	0.0164	
Am^{241}	ND	0.0156	
Sr^{90}	*NA*	0.769	
Tc^{99}	*NA*	0.0304	
Total Alpha	0.0363	0.0570	44.3
Total Beta	4.99	3.76	-28.2
ICP-Mass Spectroscopy	**mg/L**	**mg/L**	
mass 230	<0.0165	<0.00341	
mass 231	<0.0165	<0.00341	
mass 232 (Th)	17.0	14.8 *	-13.6
mass 233	<0.0165	<0.00341	
mass 234 (U)	<0.0165	<0.00341	
mass 235 (U)	0.140	0.00617	-183
mass 236 (U)	0.0333	0.00341	-163
mass 237 (Np)	0.116	0.0468	-85.4
mass 238 (Pu & U)	18.9	20.4 *	7.31
mass 239 (Pu)	0.0232	0.00926	-85.9
mass 240 (Pu)	<0.0165	<0.00341	
mass 241 (Am & Pu)	<0.0165	0.00482	
mass 242 (Pu)	<0.0165	<0.00341	
mass 243 (Am)	<0.0165	<0.00341	
mass 244 (Cm)	<0.0165	<0.00341	
mass 245 (Cm)	<0.0165	<0.00341	
mass 246	<0.0165	<0.00341	
mass 99 (Tc^{99})	NA	1.75	
		0.0298	µCi/mL
* Estimated Fraction U+Th in ZrSiO4		856	ppm
Estimated Fraction U in U+Th		58.8	wt%

Table 4.18 Comparison of Measured Melter Feed Sample #2 with Calculated Composition Estimate
(major species in boldface, mostly soluble species in italics)

	Measured	Calculated	
Ion Chrom.	**mg/L**	**mg/L**	**%Diff.**
NO_3^-	***40869***	***50033***	***20.2***
NO_2^-	***14290***	***19489***	***30.8***
SO_4^{-2}	*3428*	*3163*	*-8.04*
Cl^-	*<2562*	*778*	
F^-	*<2779*	*444*	
Wet Chem.	**mg/L**	**mg/L**	
OH^-	*NA*	*10380*	
CO_3^{-2}	***NA***	***71653***	
TOC	*NA*	*11192*	
ICPES	**wt%**	**wt%**	
Ag	NA	0.000015	
Al	**1.47**	**1.89**	**24.8**
B	***1.55***	***1.74***	***11.1***
Ba	<0.00378	<5.12E-06	
Ca	**2.25**	**2.52**	**10.9**
Cd	0.00323	0.000854	-116
Co	0.00738	NA	
Cr	0.0126	0.00541	-80.1
Cu	<0.00250	0.000145	
Fe	**2.36**	**2.48**	**4.85**
La	<0.00730	<0.000161	-191
Li	***0.660***	***0.702***	***5.82***
Mg	**0.471**	**0.508**	**7.34**
Mn	0.0244	0.00576	-124
Mo	<0.00280	0.000901	
Na ICP	***4.49***	***4.58***	***1.60***
Na AA	***4.75***		***-3.99***
Ni	0.0154	0.0102	-40.7
P	*0.0574*	*0.0274*	*-71.1*
Pb	<0.0234	0.00207	
Si	**11.1**	**11.9**	**6.34**
Sn	<0.0120	0.000634	
Sr	0.00483	0.00527	8.51
Ti	**0.240**	**0.396**	**48.5**
V	<0.00405	0.000015	
Zn	**1.26**	**1.33**	**4.95**
Zr	**1.06**	**1.25**	**16.7**
K	*0.0394*	*0.0366*	*-7.63*

	Measured	Calculated	
Physical Properties			**%Diff**
Total Solids (wt%)	61.1	67.8	10.4
Measured Density (g/mL)	1.62	1.76	8.4
Radiochemical	**µCi/mL**	**µCi/mL**	
Co^{60}	0.0189	0.0207	9.26
Cs^{134}	ND	ND	
Cs^{137}	0.0340	0.0303	-11.6
Eu^{154}	0.015	0.0186	83.5
Eu^{155}	0.0072	0.0125	109
Am^{241}	ND	0.0119	
Sr^{90}	*NA*	0.586	
Tc^{99}	*NA*	0.0231	
Total Alpha	0.0161	0.0435	92.1
Total Beta	2.26	2.86	23.4
ICP-Mass Spectroscopy	**mg/L**	**mg/L**	
mass 230	<0.0811	<0.00260	
mass 231	<0.0811	<0.00260	
mass 232 (Th)	11.7	11.3	-4.06
mass 233	<0.0811	<0.00260	
mass 234 (U)	<0.0811	<0.00260	
mass 235 (U)	0.148	0.00470	-188
mass 236 (U)	<0.0811	0.00260	
mass 237 (Np)	<0.0811	0.0357	
mass 238 (Pu & U)	24.3	15.5	-43.9
mass 239 (Pu)	<0.0811	0.00706	
mass 240 (Pu)	<0.0811	0.00260	
mass 241 (Am & Pu)	<0.0811	<0.00367	
mass 242 (Pu)	<0.0811	0.00260	
mass 243 (Am)	<0.0811	<0.00260	
mass 244 (Cm)	<0.0811	<0.00260	
mass 245 (Cm)	<0.0811	<0.00260	
mass 246	<0.0811	<0.00260	
mass 99 (Tc^{99})	NA	1.34	
		0.0227	µCi/mL

Table 4.19 Comparison of Measured Melter Feed Sample #3 with Calculated Composition Estimate
(major species in boldface, mostly soluble species in italics)

	Measured	Calculated	
Ion Chrom.	**mg/L**	**mg/L**	**%Diff.**
NO_3^-	***58622***	***67733***	***14.4***
NO_2^-	***21109***	***26383***	***22.2***
SO_4^{-2}	*3662*	*4282*	*15.6*
Cl^-	*<3409*	*1053*	
F^-	*<3409*	*601*	
Wet Chem.	**mg/L**	**mg/L**	
OH^-	*NA*	*14053*	-
CO_3^{-2}	***NA***	***97002***	-
TOC	*NA*	*15151*	-
ICPES	**wt%**	**wt%**	
Ag	0.00245	0.000018	-197
Al	**2.07**	**2.20**	**6.12**
B	***2.23***	***2.02***	***-9.86***
Ba	<0.00225	<5.96E-06	
Ca	**3.03**	**2.93**	**-3.35**
Cd	0.00230	0.000996	-79.1
Co	0.00315	0	
Cr	0.0143	0.00631	-77.7
Cu	<0.00155	0.000170	
Fe	**3.12**	**2.89**	**-7.67**
La	<0.00795	<0.000188	
Li	***1.08***	***0.818***	***-27.8***
Mg	**0.657**	**0.592**	**-10.3**
Mn	0.0192	0.00671	-96.4
Mo	<0.00205	0.00105	
Na ICP	***5.63***	***5.34***	***-5.33***
Na AA	***4.93***		***7.83***
Ni	0.0189	0.0119	-45.3
P	*0.0571*	*0.0319*	*-56.5*
Pb	<0.0732	0.00241	
Si	**13.0**	**13.8**	**6.19**
Sn	<0.118	0.000739	
Sr	0.00680	0.00614	-10.2
Ti	**0.370**	**0.461**	**21.8**
V	<0.00383	0.000018	
Zn	**1.67**	**1.55**	**-7.46**
Zr	**1.42**	**1.46**	**2.95**
K	*0.0525*	*0.0426*	*-20.8*

	Measured	Calculated	
Physical Properties			**%Diff**
Total Solids (wt%)	76.4	77.6	3.1
Measured Density (g/mL)	1.87	1.93	3.2
Radiochemical	**µCi/mL**	**µCi/mL**	
Co^{60}	0.0291	0.0281	-3.69
Cs^{134}	ND	ND	
Cs^{137}	0.0442	0.0410	-7.61
Eu^{154}	0.0269	0.0252	-6.72
Eu^{155}	0.0161	0.0170	4.92
Am^{241}	0.0141	0.0161	13.0
Sr^{90}	*NA*	0.794	
Tc^{99}	*NA*	0.0313	
Total Alpha	<0.120	0.0589	-68.7
Total Beta	6.54	3.88	-51.1
ICP-Mass Spectroscopy	**mg/L**	**Mg/L**	
mass 230	<0.0985	<0.00352	
mass 231	<0.0985	<0.00352	
mass 232 (Th)	12.6	15.3	19.4
mass 233	<0.0985	<0.00352	
mass 234 (U)	<0.0985	<0.00352	
mass 235 (U)	0.162	0.00637	-185
mass 236 (U)	<0.0985	0.00352	
mass 237 (Np)	0.117	0.0483	-83.2
mass 238 (Pu & U)	15.6	21.0	29.5
mass 239 (Pu)	0.101	0.00955	-165
mass 240 (Pu)	<0.0985	<0.00352	
mass 241 (Am & Pu)	<0.0985	0.00497	
mass 242 (Pu)	<0.0985	<0.00352	
mass 243 (Am)	<0.0985	<<0.00352	
mass 244 (Cm)	<0.0985	<0.00352	
mass 245 (Cm)	<0.0985	<0.00352	
mass 246	<0.0985	<0.00352	
mass 99 (Tc^{99})	NA	1.81	
		0.0307	µCi/mL

Table 4.20 Dry Basis Comparison of Measured Composition of Melter Feed Samples 1-3 and Calculated Values (major species in boldface)

	Sample #1	Sample #2	Sample #3	Calculated
Ion Chromatography	wt % dry			
NO_3^-	**3.84**	**3.73**	**4.10**	**4.57**
NO_2^-	**1.33**	**1.31**	**1.48**	**1.78**
SO_4^{-2}	0.234	0.313	0.256	0.289
Cl^-	<0.235	<0.234	<0.239	0.0711
F^-	<0.235	<0.254	<0.239	0.0405
ICPES & AA	wt % dry			
Ag	NA	NA	0.00321	<2.26E-05
Al	**2.57**	**2.16**	**2.71**	**2.77**
B	**2.95**	**2.29**	**2.92**	**2.56**
Ba	0.00348	0.00557	0.00295	<7.53E-06
Ca	**3.79**	**3.32**	**3.97**	**3.70**
Cd	0.00482	0.00476	0.00301	0.00126
Co	0.0202	0.0109	<0.00412	1.1E-4
Cr	0.0248	0.0186	0.0188	0.00796
Cu	0.00427	<0.00369	<0.00203	2.14E-04
Fe	**3.88**	**3.48**	**4.09**	**3.65**
La	0.0456	<0.0108	<0.0104	2.37E-04
Li	**1.13**	**0.974**	**1.42**	**1.03**
Mg	**0.750**	**0.695**	**0.860**	**0.748**
Mn	0.0449	0.0360	0.0251	0.00847
Mo	0.00552	<0.00413	<0.00268	0.00133
Na ICP	**8.08**	**6.63**	**7.37**	**6.73**
Na AA	**8.21**	**7.01**	**6.46**	
Ni	0.0268	0.0227	0.0247	0.0150
P	0.0798	0.0847	0.0747	0.0403
Pb	0.0298	<0.0345	<0.0958	0.00304
Si	**18.0**	**16.4**	**17.0**	**17.4**
Sn	0.0157	<0.0176	<0.155	9.33E-04
Sr	0.00712	0.00712	0.00890	0.00775
Ti	**0.677**	**0.355**	**0.485**	**0.582**
V	0.00565	<0.00598	<0.00501	2.22E-05
Zn	**2.18**	**1.86**	**2.18**	**1.95**
Zr	**1.87**	**1.56**	**1.86**	**1.85**
K (AA)	0.0689	0.0581	0.0687	0.0538
ICP MS				
Y	6.8E-3	4.7E-3	5.2E-3	2.2E-5
Rh	3.4E-4	3.4E-4	1.5E-4	1.6E-4
Pd	3.3E-4	3.4E-4	2E-4	5.5E-5
Sb	2.1E-4	1.1E-4	1E-5	<3.8E-7
Ta	2.3E-4	4.85E-4	2E-5	<3.8E-7
W	4.2E-3	3.9E-3	2.4E-3	2.8E-3
Pt	3.2E-4	5E-4	3E-4	<3.8e-7

(table continued below)

Table 4.20 Continued

	Sample #1	Sample #2	Sample #3	Calculated
Radiochemical	µCi/g solids			
Co^{60}	0.0232	0.0173	0.0204	0.0190
Cs^{134}	ND	ND	ND	ND
Cs^{137}	0.0355	0.0311	0.0310	0.0277
Eu^{154}	ND	0.0139	0.0189	0.0170
Eu^{155}	ND	0.0067	0.0113	0.0114
Am^{241}	ND	ND	0.00990	0.0109
Sr^{90}	NA	NA	NA	0.536
Tc^{99}	NA	NA	NA	0.0211
Total Alpha	0.0253	0.0147	<0.0843	0.0397
Total Beta	3.48	2.07	4.57	2.62
ICP-Mass Spectroscopy	wt %			
mass 230	<1.15E-06	<7.42E-06	<6.90E-06	<2.38E-07
mass 231	<1.15E-06	<7.42E-06	<6.90E-06	<2.38E-07
mass 232 (Th)	0.00118	0.00107	8.80E-04	6.55E-05
mass 233	<1.15E-06	<7.42E-06	<6.90E-06	<2.38E-07
mass 234 (U)	<1.15E-06	<7.42E-06	<6.90E-06	<2.38E-07
mass 235 (U)	9.79E-06	1.35E-05	1.13E-05	4.30E-07
mass 236 (U)	2.32E-06	<7.42E-06	<6.90E-06	<2.38E-07
mass 237 (Np)	8.11E-06	<7.42E-06	8.19E-06	3.26E-06
mass 238 (Pu & U)	0.00132	0.00222	0.00109	4.08E-05
mass 239 (Pu)	1.62E-06	<7.42E-06	7.06E-06	6.45E-07
mass 240 (Pu)	<1.15E-06	<7.42E-06	<6.90E-06	<2.38E-07
mass 241 (Am & Pu)	<1.15E-06	<7.42E-06	<6.90E-06	3.36E-07
mass 242 (Pu)	<1.15E-06	<7.42E-06	<6.90E-06	<2.38E-07
mass 243 (Am)	<1.15E-06	<7.42E-06	<6.90E-06	<2.38E-07
mass 244 (Cm)	<1.15E-06	<7.42E-06	<6.90E-06	<2.38E-07
mass 245 (Cm)	<1.15E-06	<7.42E-06	<6.90E-06	<2.38E-07
mass 246	<1.15E-06	<7.42E-06	<6.90E-06	<2.38E-07
mass 99	NA	NA	NA	1.22E-04
	µCi/g solids			
Tc^{99} (uCi/ml)	NA	NA	NA	0.0207

4.3.5. Radioactive Run Melter System Performance Results

Figure 4.17 shows melter temperature data for the entire radioactive run. As was seen in the surrogate runs, the melter glass temperature dropped quickly upon initiation of feeding, and then recovered as the heater output was increased to compensate. The plenum temperature, offgas flowrate, and offgas temperature are shown in Figure 4.18. The plenum temperature dropped to about 550°C for the two longest feeding periods. Temperatures less than the maximum of 600°C by RPP were achieved during feeding for several hours of each feeding period. As noted, the minimum temperature measured was about 550°C, so no data was taken near the low end of the range specified by RPP.

In the first feeding period, on 12/14, the plenum temperature appears to have reached a steady state temperature. The time from the start of feeding to reaching steady state was about 4-5 hours. Only one other time during the radioactive run was there a long feeding period; this was on 12/15 near the end of the run when continuous feeding of about three hours was achieved. During the feeding periods, the cold cap coverage was typically 80-90% of the surface area of the melter. Figure 4.19 shows the plenum temperatures and the plenum temperature difference. The temperature drop during the two long feeding periods was about 125°C. As in the surrogate run, the difference in the plenum temperatures measured by the upper and lower thermocouples was about 60°C.

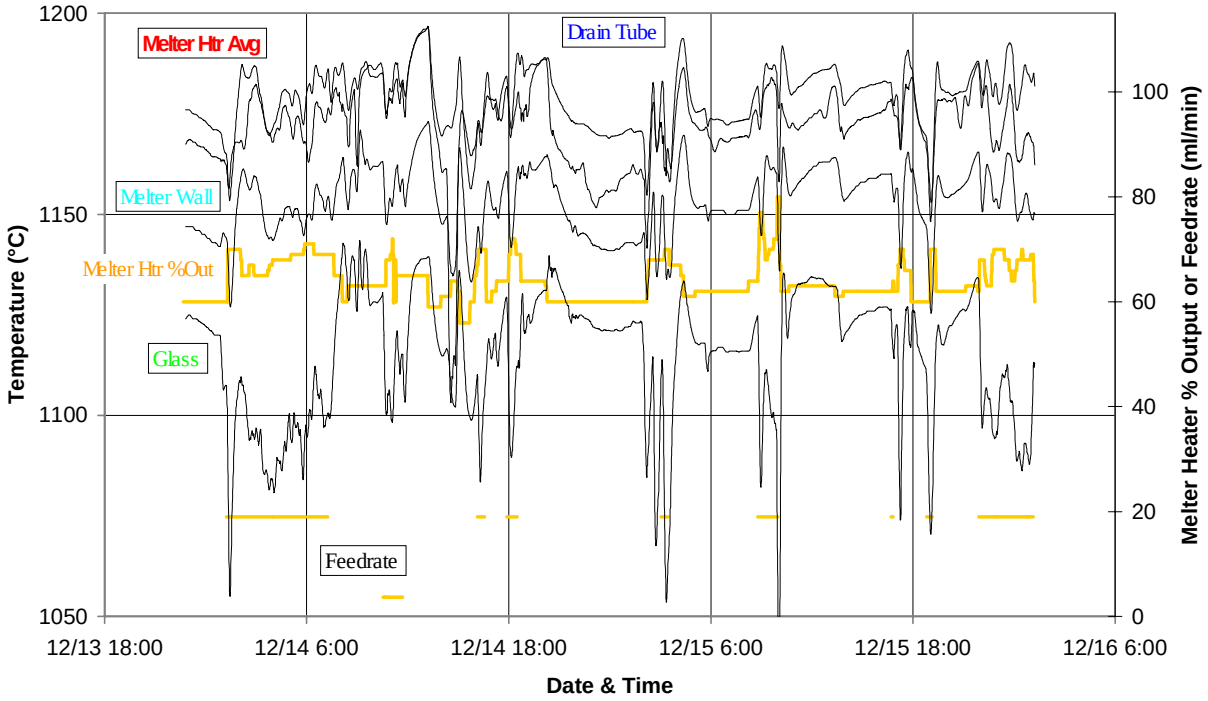


Figure 4.17 Radioactive Run Melter Operation Data

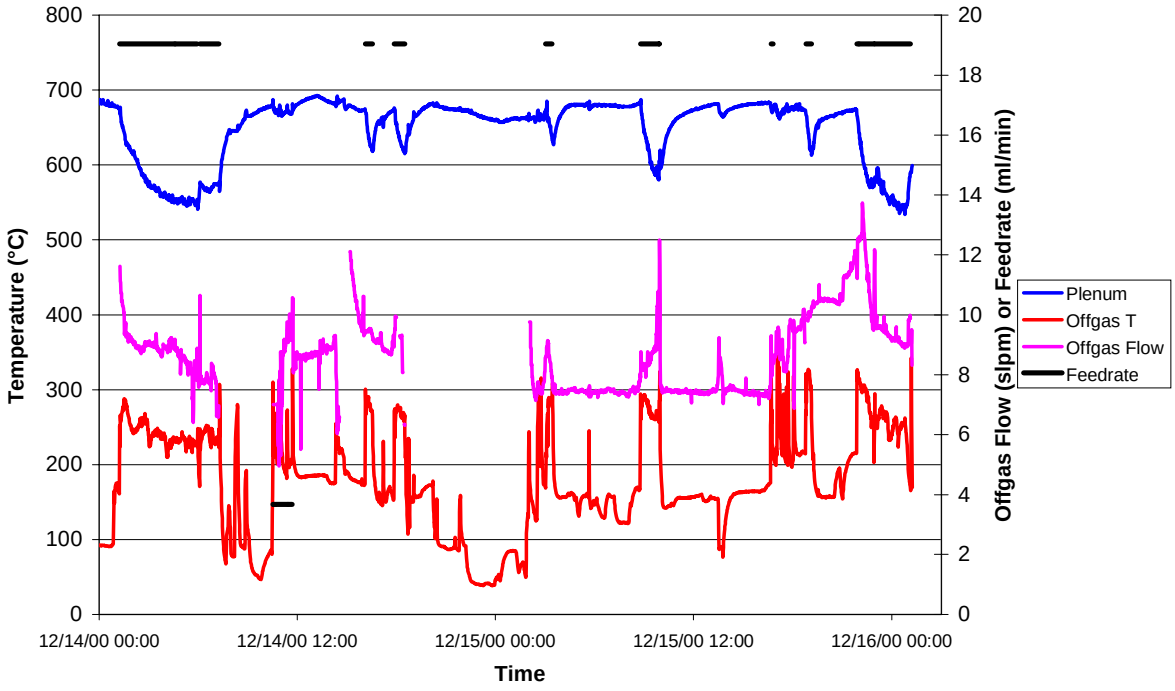


Figure 4.18 Radioactive Run Offgas & Plenum Temperature and Offgas Flow Data

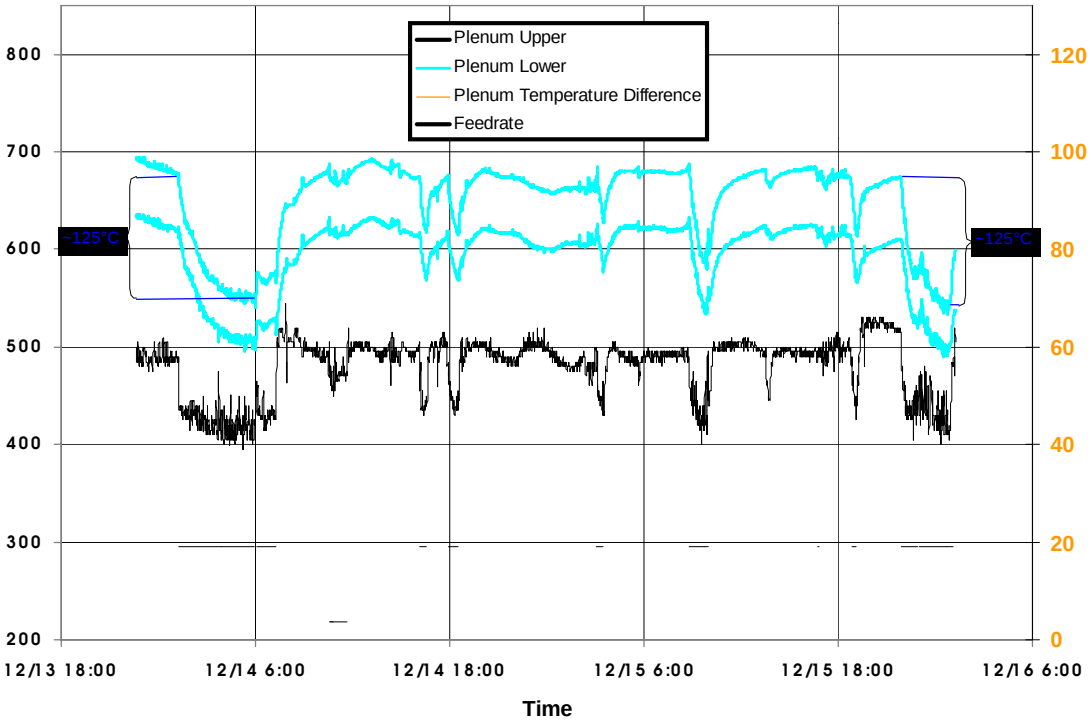


Figure 4.19 Radioactive Run Plenum Temperatures

4.3.6. Radioactive Run Offgas Characterization

The measured offgas flows are shown in Figure 4.20 and Figure 4.21. The redundant offgas flow measurements made by the dry gas meter and the helium tracer method agreed reasonably well, with a typical difference of about 1 slpm. The air inleakage ranged from 1-3 slpm for most of the time, but reached as high as 5-6.5 slpm for several short periods.

The concentrations of offgases measured by the gas chromatographs for the entire run are shown in Figure 4.22. Each of the offgases tended to reach the same values during any given feeding period. The offgas concentrations are shown in more detail for two periods in Figure 4.22 and Figure 4.23. Note that a small quantity of "other" gases, assumed to be NO_x, was calculated from the measured composition data. The NO_x was assumed to be the difference between 100% and the sum of the measured concentrations and the estimated water. The concentration of CO was again always greater than or equal to the hydrogen. The ratios of H_2/CO and CO/CO_2 versus time are shown in Figure 4.25. The H_2/CO ratio for the radioactive run was around 0.25, which is much lower than the 0.8 ratio found during the surrogate run. The CO/CO_2 ratio of 0.013 was similar to that (0.017) seen in the surrogate run. Figure 4.26 shows the H_2/CO ratios for surrogate run #2, the radioactive run, and DWPF minimelter runs plotted versus true gas temperature. This ratio was much lower for the radioactive run than the surrogate run or the DWPF minimelter runs.

Figure 4.27 shows that a small amount of methane was again seen during the radioactive run. During several chromatograms, a number of additional very small peaks were seen. One of these chromatograms is shown in Figure 4.29, along with a less magnified version in Figure 4.29. Based on literature data for Varian chromatographs, the peaks seen are likely to be N_2O, ethane, propane, and isobutane, or similar C_2-C_4 species. The less magnified plot shows that even the largest minor peak, N_2O, is much smaller than the approximately 7% CO_2 peak. The concentrations of CO_2 measured by both GCs are shown in Figure 4.30. Again, the agreement between these was good.

The material balance on carbon closed to within 5.3%. The total carbon in the feed was the total organic carbon plus the total inorganic carbon (TOC+TIC), while the total carbon in the offgas was the sum of the CO and CO_2. Contributions of trace carbon-bearing compounds were ignored. Good closure of the material balance confirms that the offgas CO and CO_2 readings were good.

Table 4.21 Radioactive Run Carbon Material Balance

	Feed (mol)	Offgas (mol)	% Closure of Material Balance
Total Carbon	23.76	25.01	105.3
Total Organic Carbon	10.41		
Total Inorganic Carbon	13.34		

A model for the evolution of H_2 and CO from glass melters has been developed by SRTC.[39,40] This model predicts the concentrations of H_2 and CO as a function of the true plenum gas temperature and the concentrations of oxidizing and reducing species in the feed. To use this model, the "true plenum gas temperature" must be determined from the available measurements. The thermocouples in the plenum do not measure the true gas temperature. The temperature indicated by these thermocouples is higher than the gas temperature because of the radiant shine on the thermocouple. Therefore, an energy balance on the offgas was used to determine the true gas temperature.

$$H_P(T_{P,true}) + H_D(T_D) = H_{OG}(T_{OG})$$

where H_P = enthalpy of gases leaving the plenum (water and combustion gases from feed, air purges, air inleakage)
$T_{P,true}$ = true gas temperature in the plenum (unknown)
H_D = enthalpy of dilution air added to the offgas stream
T_D = temperature of dilution air
H_{OG} = enthalpy of offgas after dilution air added
T_{OG} = temperature of offgas after dilution air added

This equation is solved for $T_{P,true}$ for each data point. In solving this equation, it was found that the measured offgas temperature, T_{OG}, was too high during idling (not feeding) of the melter either with or without the offgas system operating. It appears that conduction of heat along the offgas tubing to the offgas thermocouple resulted in this temperature measurement being higher than the actual temperature. The data in Figure 4.5, Figure 4.6, Figure 4.7, and Figure 4.19 show that the offgas temperature during idling ranged from 50-200°C. During idling, if there were no conduction, this temperature would be the same as ambient.

The true gas temperatures calculated are plotted versus the measured gas temperatures in Figure 4.31. All of the data applies to periods when the melter was being fed. The scatter in the data is substantial, and there appears to be a definite difference between the radioactive run and surrogate run data. Nonetheless, the approximate correlation provided by these data show that the true gas temperature is 200-250°C less than the measured temperature. The ratios of the rates of H_2 and CO generation (mol/time) to the feedrate of organic carbon (mol/time) for the LC melter runs are plotted in Figure 4.32 and Figure 4.33, respectively. The true gas temperature used for these graphs is the calculated value, not the value predicted from the curvefit equations of Figure 4.31.

The data from Figure 4.32 and Figure 4.33 are plotted in Figure 4.34 and Figure 4.35 with additional data from a run of the SRTC DWPF minimelter ("774-A" minimelter), in which a DWPF feed containing formate was used. Slightly higher generation rates for CO were seen in the DWPF minimelter runs; the hydrogen generation rates in these runs were much higher than those from the LC runs. The DWPF minimelter run had H_2 generation of up to 0.15 mol/mol organic, whereas the LC maximum values were 0.032

for the surrogate run and 0.010 for the radioactive run. Based on these results, it seems that the evolution of hydrogen may be dependent on the type of organic species present. It should be noted that the model predictions result in a temperature boundary that is about 25°C low. The maximum CO evolution rate for the LC melter was about 0.033 mol/mol C fed.

Given the observed rates of H_2 and CO evolution, the percent of the Lower Flammable Limit (LFL) can be determined. The equation for determining the %LFL for a mixture is:

Equation 4.1 $$\%LFL = 100\left(\frac{C_{CO}}{12.5} + \frac{C_{H_2}}{4.0}\right)$$

where %LFL = %LFL in offgas system after dilution air added
C_i = concentration in volume %

The data shown in Figure 4.32 and Figure 4.33 give the evolution of H_2 and CO in terms of moles of flammable gas per mole of (total organic) carbon (TOC) fed. Therefore, the concentration of these gases can be calculated for any feed flowrate, offgas flowrate, and feed total organic carbon content. The design flowrates for the LAW melter were shown in Table 3.2 and Table 3.3. The melter feedrate is 510 L/hr and the offgas flowrate is 444 scfm. Assume the TOC is bout 15000 mg/L, which is approximately what it was for the Large C melter radioactive run.

Equation 4.1 in terms of the flowrates and the TOC is:

$$\%LFL = 0.011\left(\frac{R_{CO/TOC}}{12.5} + \frac{R_{H_2/TOC}}{4.0}\right)\frac{C_F F}{G}$$

where $R_{CO/TOC}$ = molar ratio of CO to TOC
$R_{H_2/TOC}$ = molar ratio of H_2 to TOC
C_F = concentration of TOC (mg/L)
F = feedrate (L/hr)
G = offgas flowrate (scfm)

Inputting the values from above result in a %LFL of only 2.0%, so flammability concerns for the LAW melter with the C envelope feed do not appear to be of concern.

The %LFL equation above can be rewritten:

$$\frac{G}{0.011 C_F F}\,\%LFL = \frac{R_{CO/TOC}}{12.5} + \frac{R_{H_2/TOC}}{4.0}$$

which is equivalent to:

$$\text{Constant} \times \%\text{LFL} = \frac{R_{CO/TOC}}{12.5} + \frac{R_{H_2/TOC}}{4.0}$$

To compare data from experiments with different gas flowrates, feed flowrates and feed TOC, this equation can be used to put all data on the same basis; the "Constant x %LFL" term is dependent only on the ratios of the H_2 and CO to the TOC level. Therefore, a plot of "Constant x %LFL" versus temperature should give a comparison of the %LFL of offgases generated from different feeds in different systems. Figure 4.36 shows such a plot.

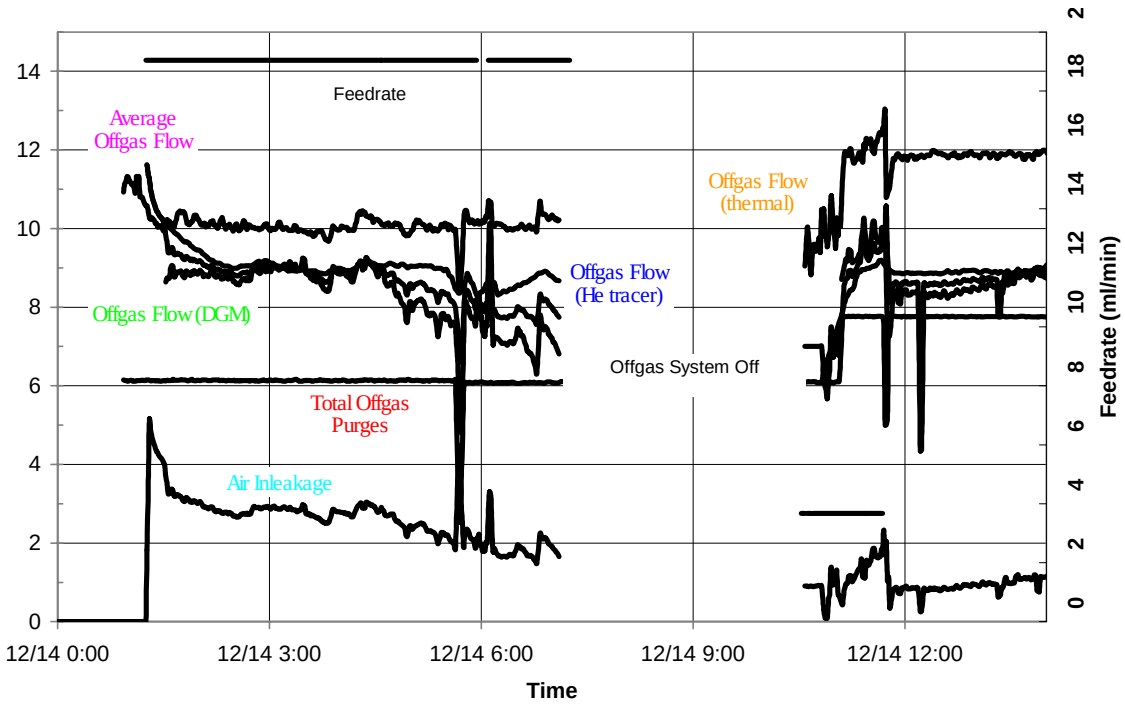


Figure 4.20 Radioactive Run Offgas Flows (12/14)

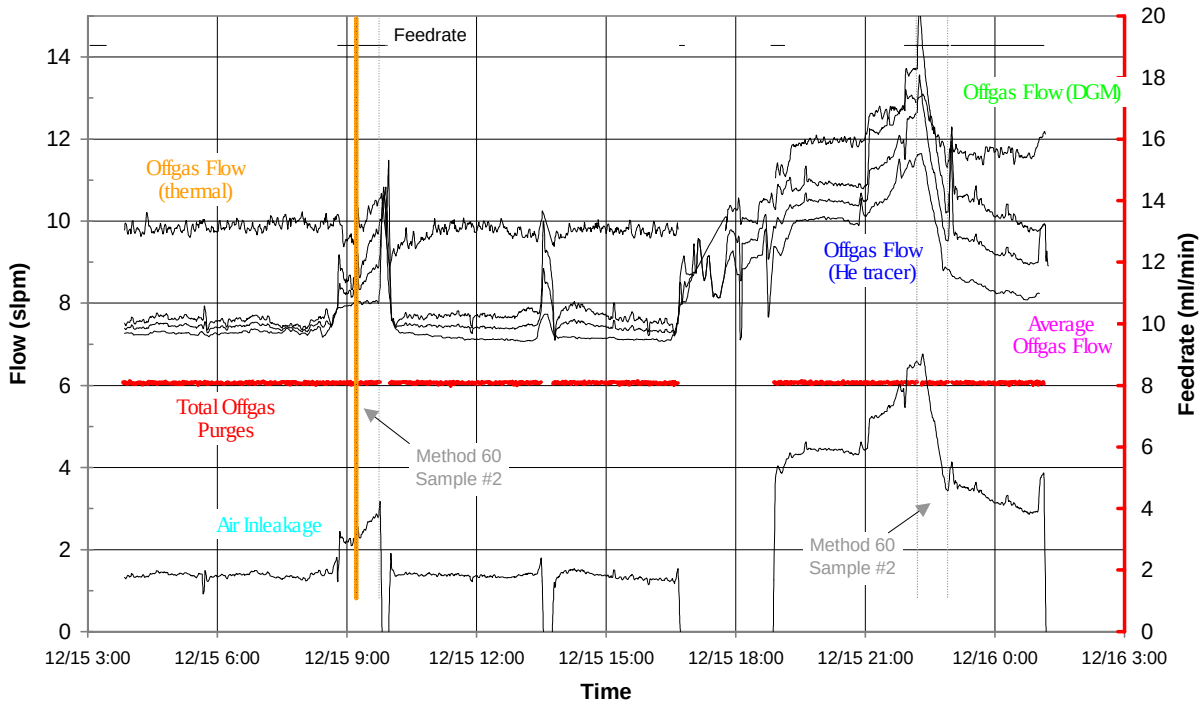


Figure 4.21 Radioactive Run Offgas Flows (12/15)

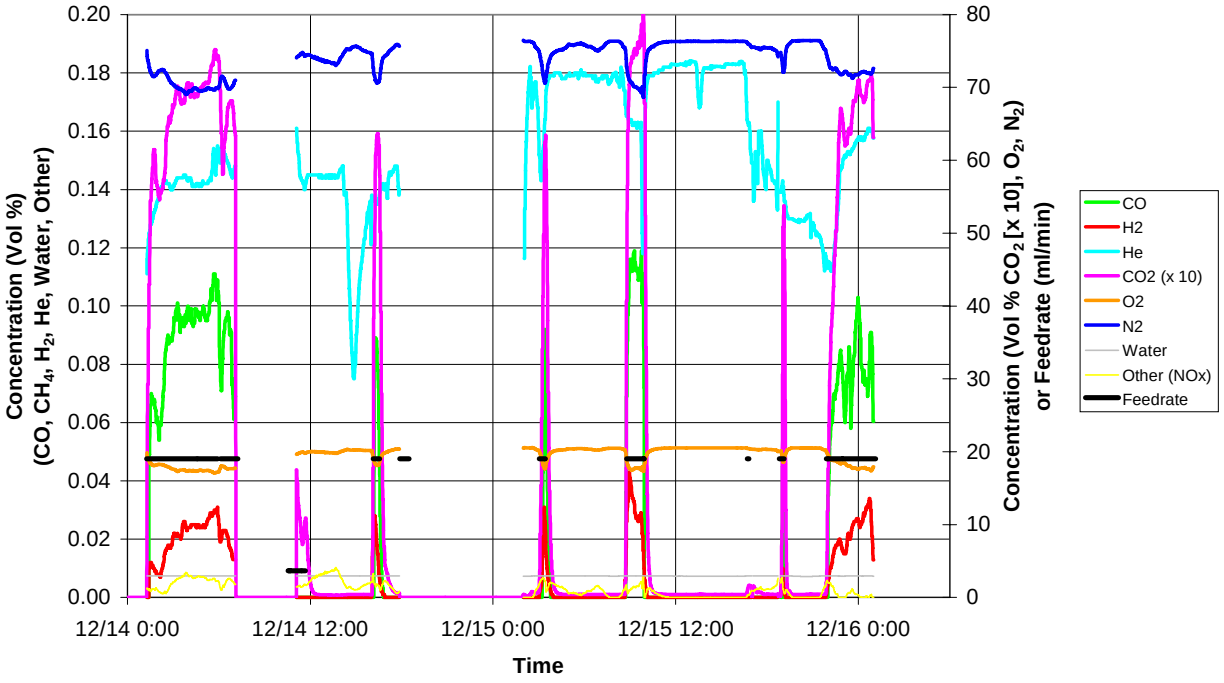


Figure 4.22 Radioactive Run Offgas Compositions

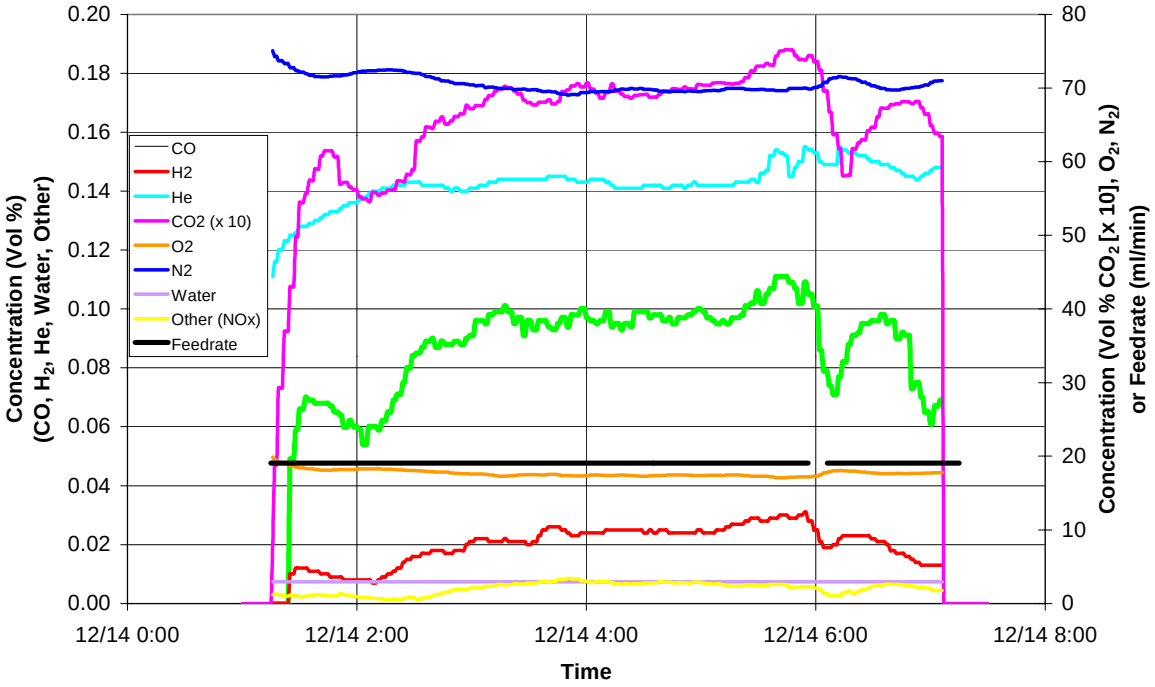


Figure 4.23 Radioactive Run Offgas Composition (12/14)

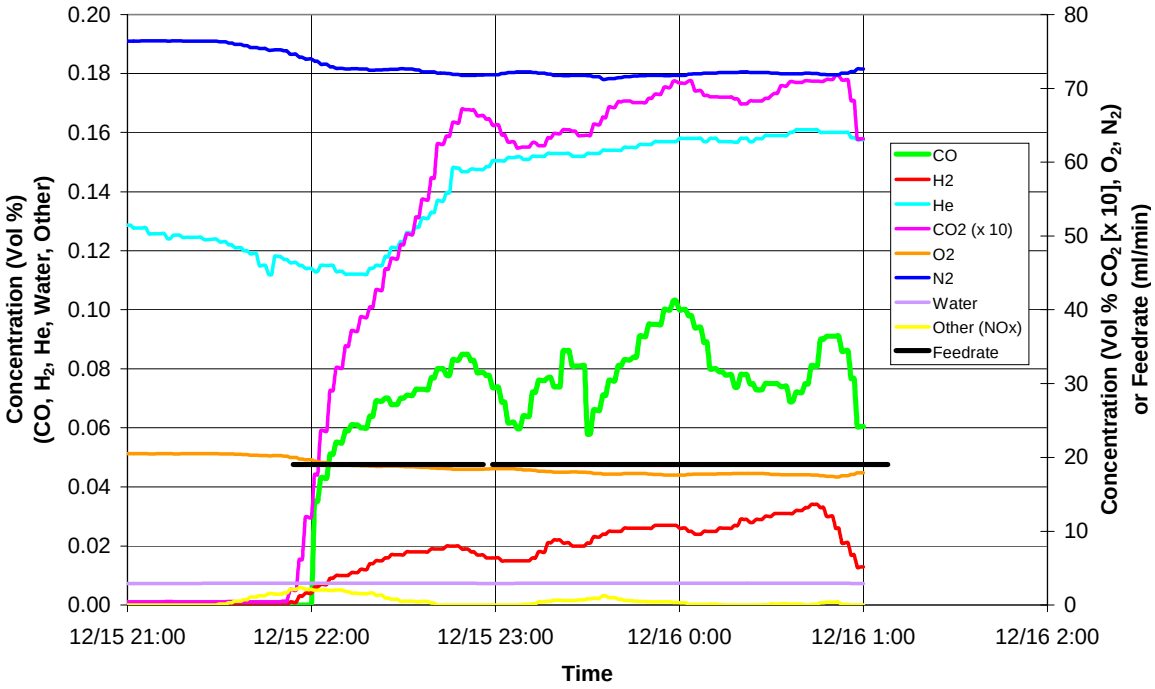


Figure 4.24 Radioactive Run Offgas Composition (12/15)

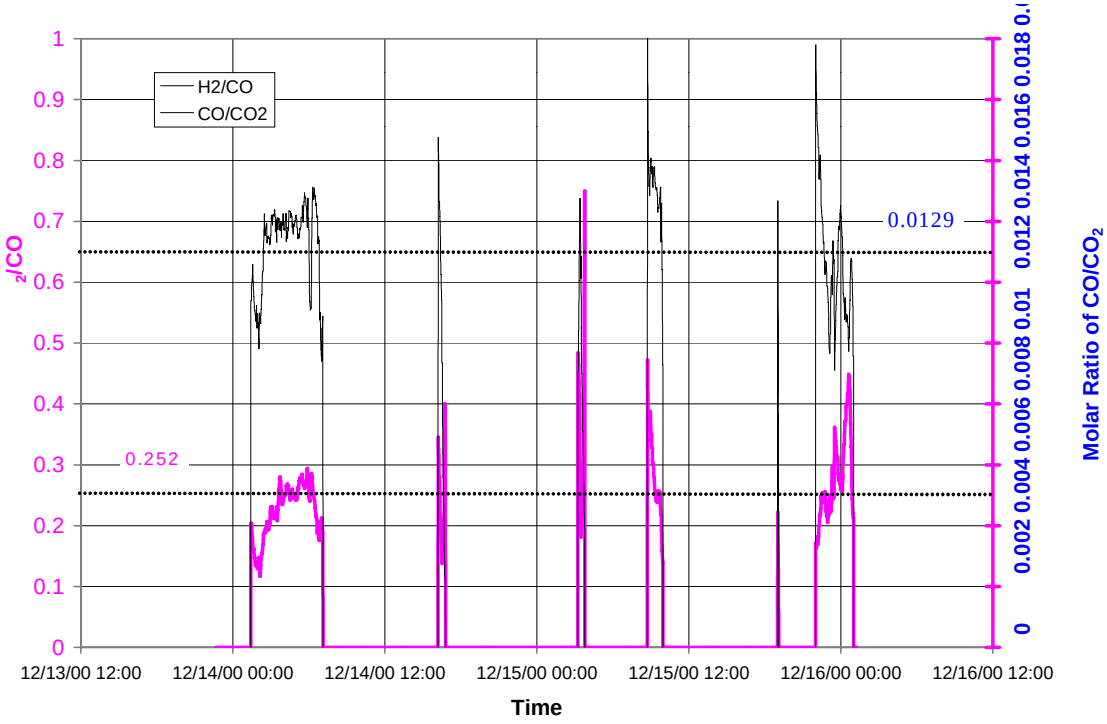


Figure 4.25 Radioactive Run Ratios of H_2/CO and CO/CO_2

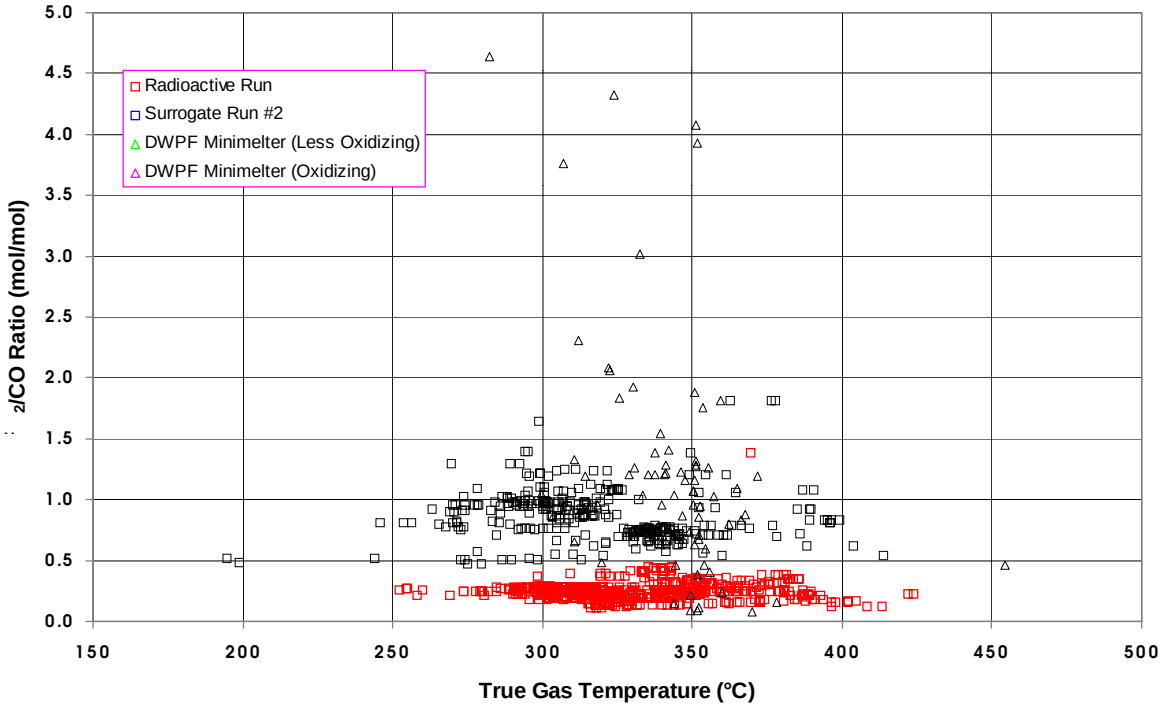


Figure 4.26 Hydrogen to Carbon Monoxide Ratios

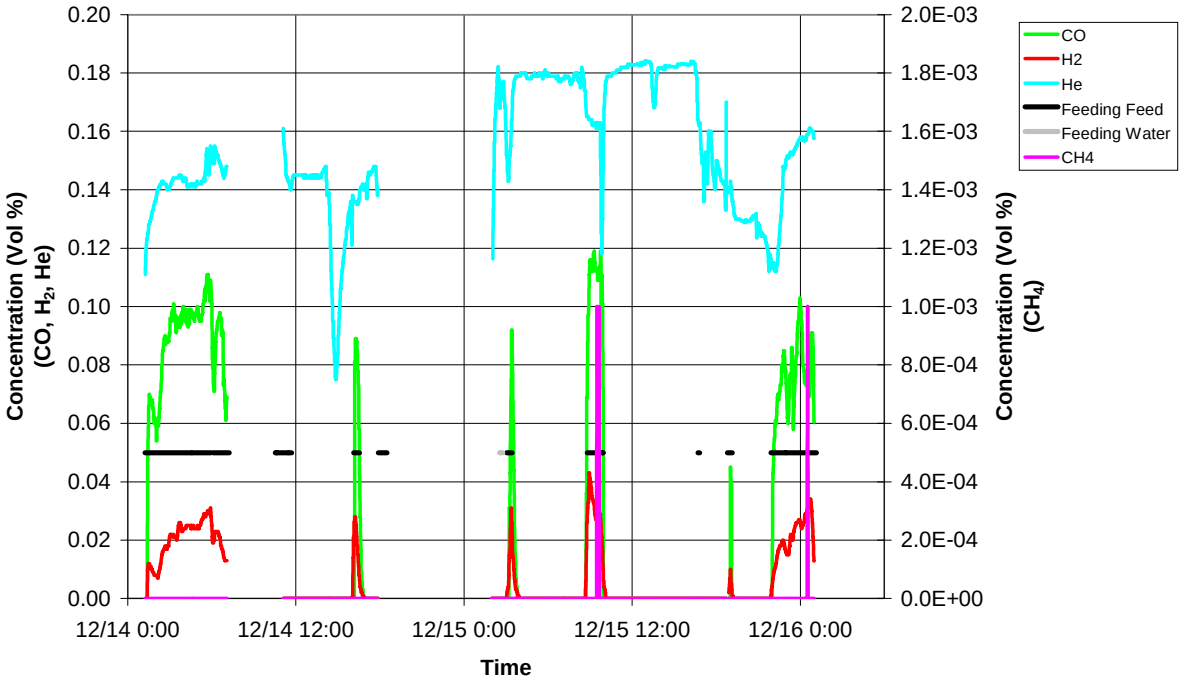


Figure 4.27 Radioactive Run Flammable Species Offgas Concentrations

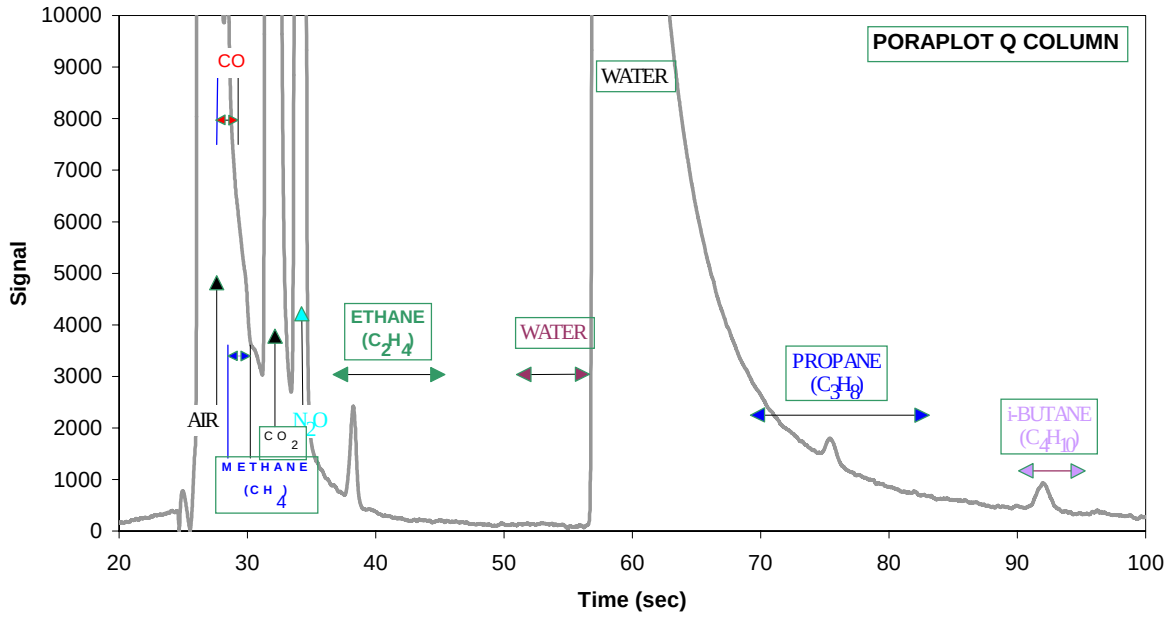


Figure 4.28 Chromatogram Showing Trace Gases Detected.

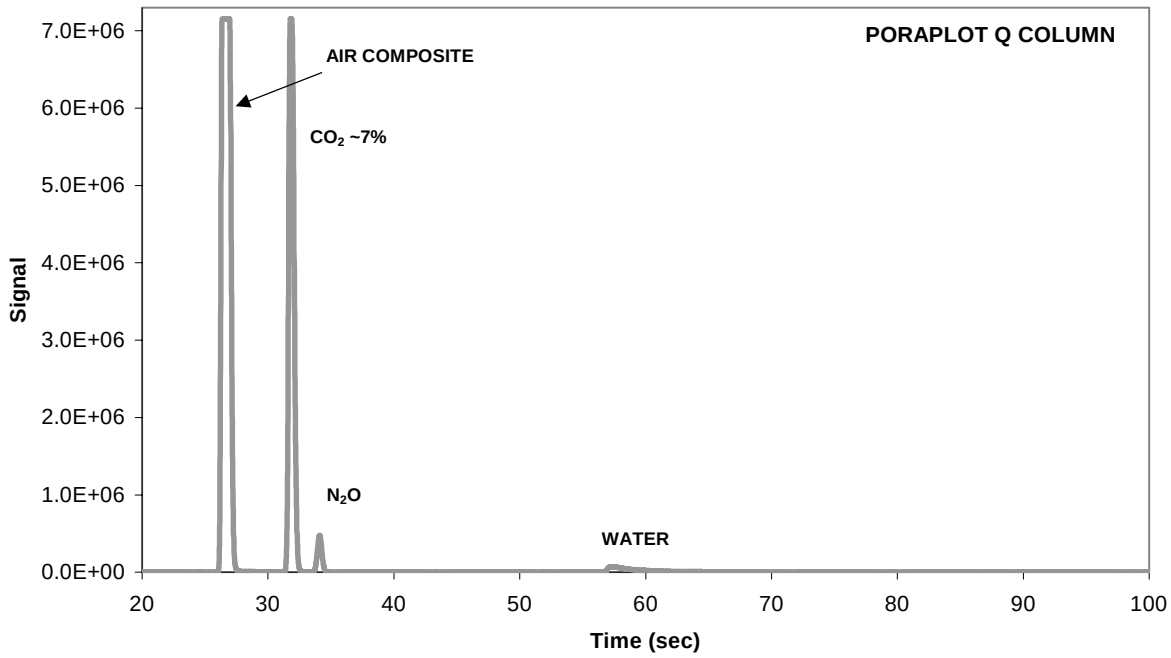


Figure 4.29 Chromatogram from Figure 4.28 at Lower Magnification.

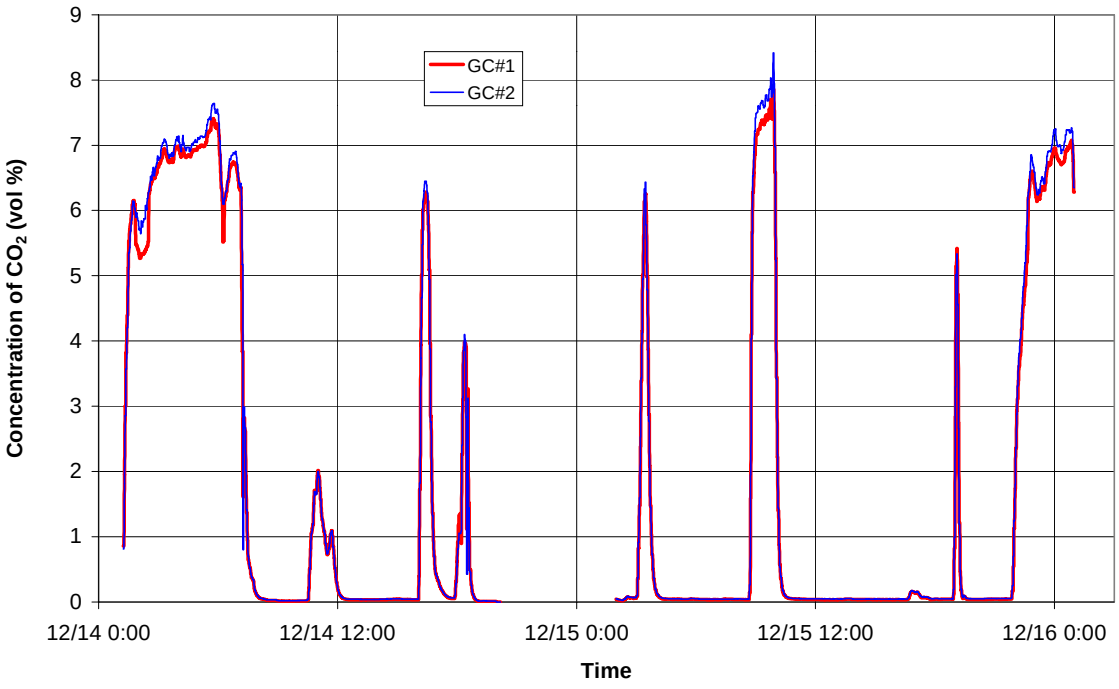


Figure 4.30 Radioactive Run Comparison of Measured CO_2 Concentrations

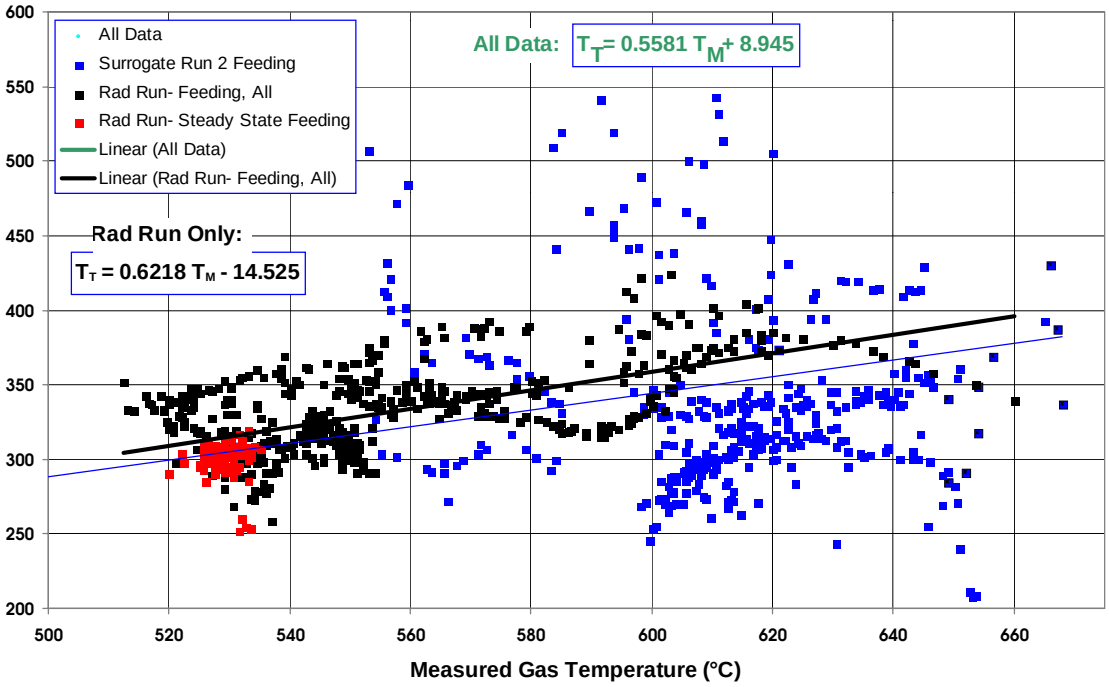


Figure 4.31 Correlation of Calculated True Gas Temperature to Measured Gas Temperature.

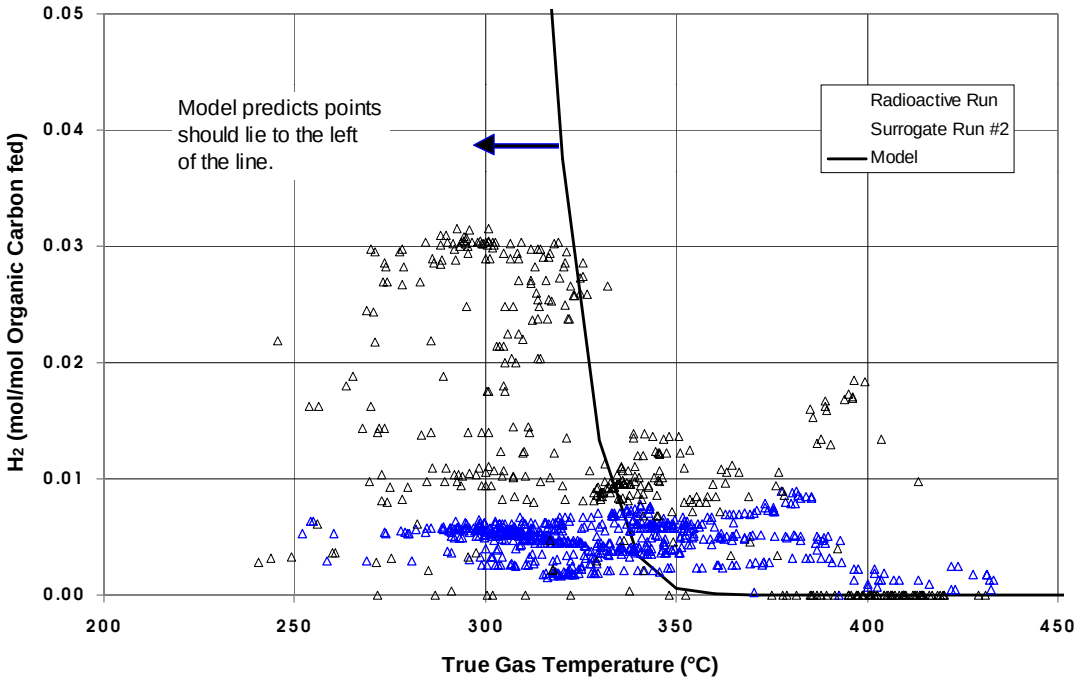


Figure 4.32 Hydrogen Generation as a Function of Temperature – LC Melter Data

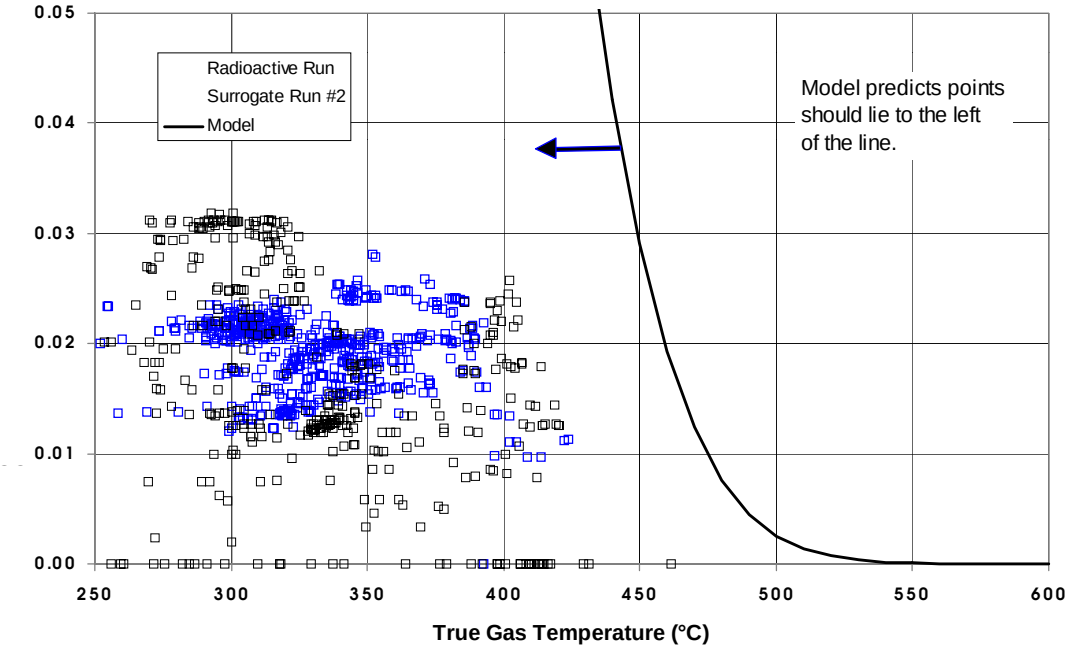


Figure 4.33 Carbon Monoxide Generation as a Function of Temperature – LC Melter Data

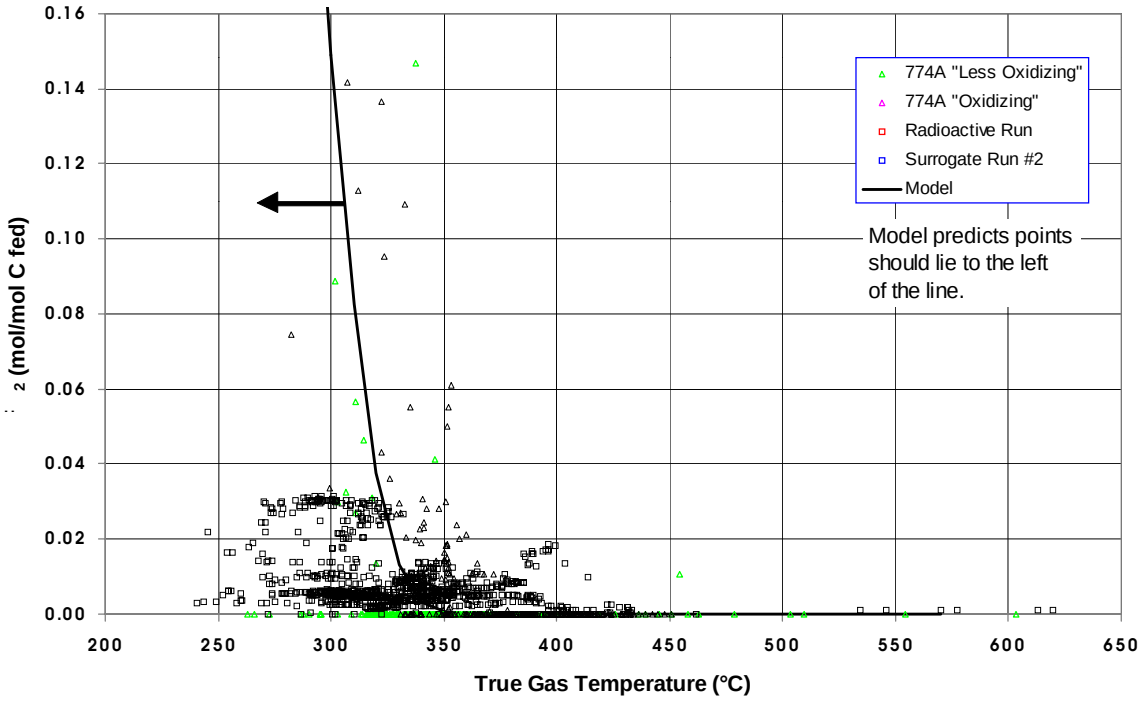


Figure 4.34 Hydrogen Generation as a Function of Temperature – LC Melter and DWPF Minimelter Data

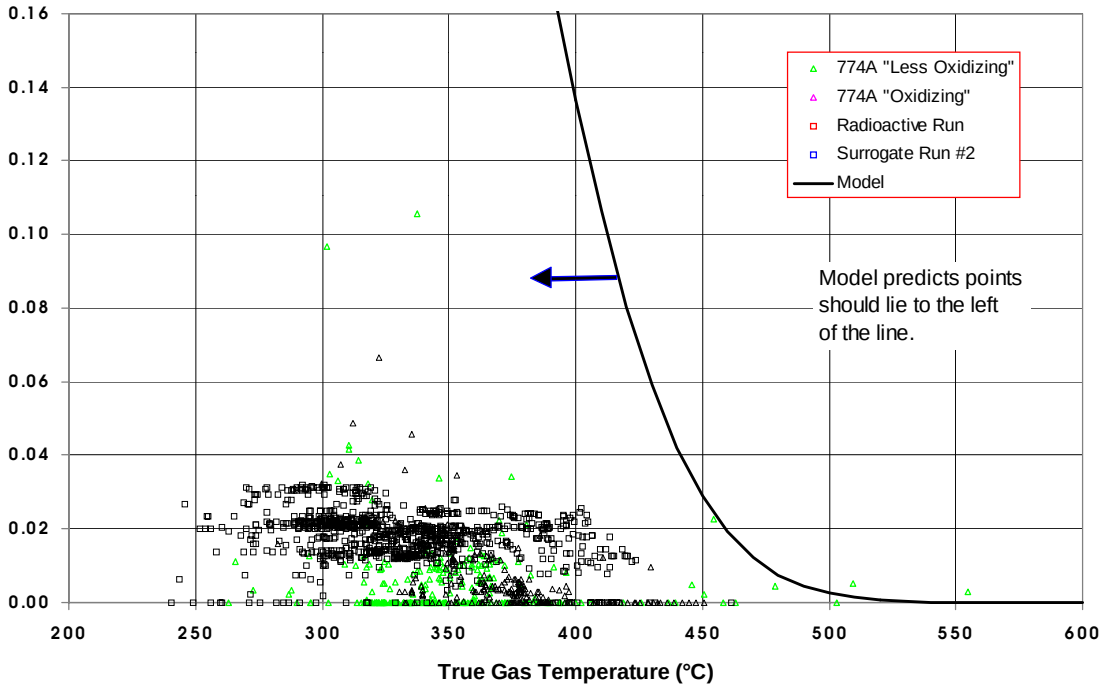


Figure 4.35 Carbon Monoxide Generation as a Function of Temperature – LC Melter and DWPF Minimelter Data

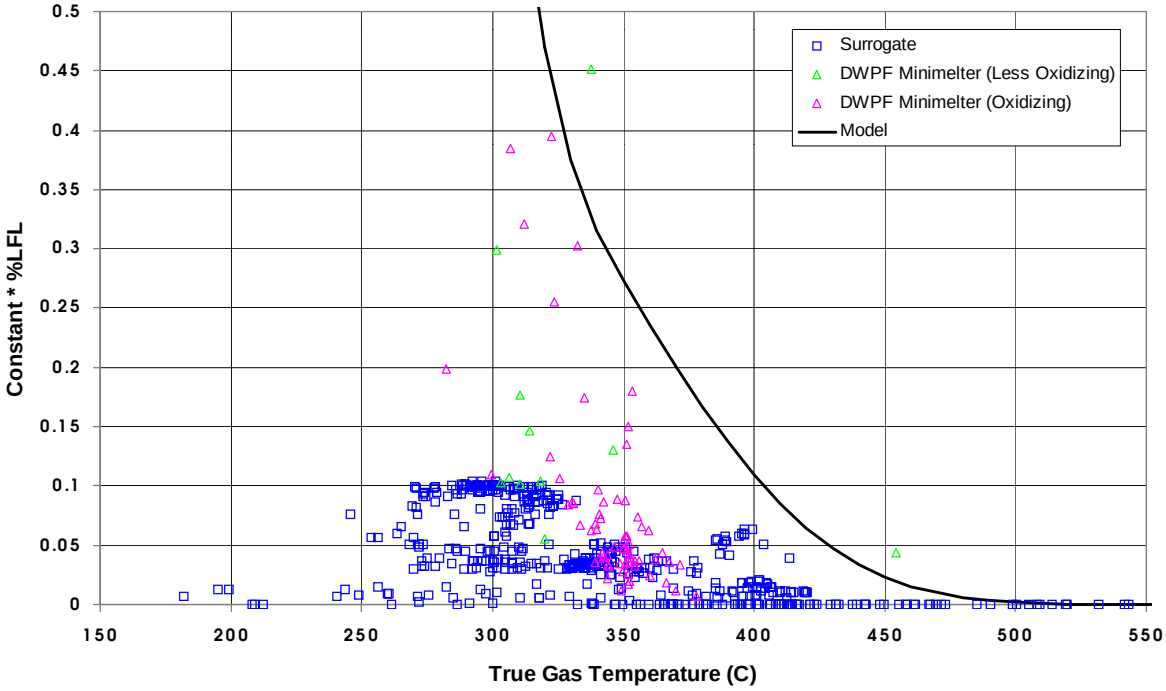


Figure 4.36 Scaled %LFL versus True Gas Temperature

4.3.6.1. Characterization of Offgas Organics Collected

After completion of the Large C Melter activities and glass and offgas sample collection, it was decided by the former RPP contractor to pursue limited analyses of both melter offgas condensate and melter offgas activated charcoal filters for volatile organic analytes (VOA) and semivolatile organic analytes (SVOA). The objective of this work, as commissioned by the previous contractor, was to provide qualitative data with respect to the type of organic species that could be produced in a radioactive LAW Melter system. The previous contractor was also concerned with the fate of organic analytes that could be recycled to the LAW Melter Feed Evaporator through the LAW Melter Offgas condensate system. Since this is the only planned radioactive melter demonstration using Envelope C waste, this information was intended by the previous contractor to be used qualitatively by RPP-WTP environmental modeling and risk assessment groups. This work was never intended to quantitatively assess emissions, but was intended to show the major types of organic species that could form in an actual radioactive melter system. These analyses were not planned in the original task planning for the Large C AN-102 melter project at SRTC. However, attempts to qualitatively analyze the condensates and charcoal filters were pursued to investigate the organics present in these samples.

The melter condensates were collected in 1-liter polybottles for residue returns to Hanford. After all melter scrub trains and modified method 60 trains had been disassembled and samples collected, a few of the polybottles containing melter condensates were collected for the organics analyses. Two separate bottles were collected, Condensate Sample 1 and Condensate Sample 2. A third condensate bottle was prepared (Condensate Sample 3) with deionized water that was acidified with nitric acid. Similar samples of the activated charcoal used in the melter tests were also collected in 1-liter polybottles. It should be noted that neither the condensates nor the charcoal samples were sampled and collected using typical EPA protocol such as zero-headspace certified glass bottles.

Melter condensate samples were analyzed for volatile organics by Gas Chromatography-Mass Spectrometry (GC-MS). Samples were concentrated using an OI Analytical model 4460A Dynamic Headspace concentrator (Purge and Trap). Separation was performed with a Hewlett Packard 5890 series II GC (60m x 0.75mm VOCOL glass capillary column with 3 um film thickness) and quantification was performed with a Hewlett Packard model 5971 quadrupole mass spectrometer. Internal standard and recovery surrogate compounds were added as specified in the Contract Laboratory Program (CLP) for volatile organics (SOW 7-93). Charcoal samples were analyzed for volatile organics as above after using methanol to extract the solid charcoal samples.

Melter condensate and charcoal samples were analyzed for semivolatile organics by extraction with methylene chloride and spiked with SVOC internal standard and then analyzed by GC/MS. Separation was performed with a Hewlett Packard 6890 GC (30

m DB-5 column with 0.25 mm diameter and 0.25 um film thickness) and quantification was performed with a Hewlett Packard model 5973 mass selective detector.

The condensates were also analyzed for soluble metals, soluble inorganic and organic carbon, anions and pH, as shown in Table 4.22. This table shows the results for the two replicate condensate samples collected from the melter testing (Condensate Sample 1 and 2) and the blank condensate sample equal to Condensate Sample 3. Results for the volatile organics and semivolatile organics analyses of the melter condensates are shown in Table 4.23. The condensates derived from melter operation were acidic upon collection due to dissolution of NOx gasses from melter operation. The blank condensate was acidified with concentrated nitric acid prior to submission for analyses. Table 4.23 indicates no volatile analytes were measured in the melter offgas condensates to the instrument detection levels of 50 μg/L. A listing of the group of volatile organics that are routinely analyzed for in the GC/MS VOA analyses are shown in Appendix 6.17. Various semivolatile organic-nitrile components were detected in the melter offgas condensates as shown in Table 4.23. The only detectable SVOA found in the blank water sample was diethyl phthalate that derives from the polybottle used to collect the samples. A list of other SVOA analytes not detected to the limit of 10 μg/L in the condensates is shown in Appendix 6.17. The list of SVOA's in Appendix 6.17 are the analytes routinely analyzed for in the GC/MS SVOA analyses.

Several VOA and SVOA analytes were detected in the solid charcoal samples at levels in the μg/g range as shown in Table 4.24. No analytes were detected in the blank charcoal sample and the sulfur detected in this sample possibly derives from sulfur carryover from analyses of the sample number 5 carbon that contained very high levels of semivolatile sulfur (2300 μg/g).

Table 4.22 Metals, Anions, Soluble Carbon, and pH Analyses for Melter Offgas Condensate Samples

		Condensate Sample 1	Condensate Sample 2	Condensate Sample 3 (blank)
		(mg/L)	(mg/L)	(mg/L)
Metals	Al	3.576	24.145	< 0.015
	B	146.246	245.101	< 0.003
	Ba	0.009	0.073	< 0.003
	Ca	4.734	42.862	< 0.018
	Cd	0.008	0.058	< 0.002
	Co	0.007	0.059	< 0.003
	Cr	4.181	10.661	< 0.009
	Cu	0.033	0.107	< 0.003
	Fe	7.864	37.027	< 0.004
	La	< 0.01	0.069	< 0.01
	Li	5.781	26.541	< 0.003
	Mg	0.081	0.607	< 0.001
	Mn	0.072	0.572	< 0.001
	Mo	0.26	0.825	< 0.003
	Na	150.716	583.02	0.028
	Ni	0.563	1.217	< 0.009
	P	1.201	1.475	< 0.035
	Pb	< 0.046	0.208	< 0.046
	Si	34.927	62.264	< 0.015
	Sn	0.031	0.067	< 0.016
	Sr	0.039	0.238	< 0.001
	Ti	1.607	8.758	< 0.001
	V	0.004	0.043	< 0.003
	Zn	11.667	50.936	< 0.003
	Zr	1.225	4.587	< 0.003
IC Anions	Fluoride	32	60	< 20
	Chloride	125	455	< 20
	Oxalate	< 100	< 100	< 100
	Phosphate	< 100	< 100	< 100
	Sulfate	57	253	< 50
	Formate	< 100	< 100	< 100
	Nitrate	19439	6255	13518
	Nitrite	< 100	< 100	< 100
Carbon	Total Organic Carbon	< 78	35	7
	Total Inorganic Carbon	< 1	< 1	< 1
	pH	< 1	1.3	< 1

Table 4.23 VOA and SVOA Analyses for Melter Offgas Condensate Samples

	Condensate Sample 1	Condensate Sample 2	Condensate Sample 3 (blank)
Volatile Organic Compounds			
	(µg/L)	(µg/L)	(µg/L)
See List of VOA Analytes in Appendix 6.17	< 50	< 50	< 50
Semi-Volatile Organic Compounds			
Pyridinecarbonitriles	520	390	< 10
But-2-enedinitrile	490	200	< 10
Diethyl Phthalate	300	280	180
1,3-Benzenedicarbonitrile	240	< 10	< 10
1,2-Benzenedicarbonitrile	< 10	94	< 10
Benzonitrile, 4-hydroxy	140	60	< 10
1-Propene, 1-chloro-, (E)-	49	< 10	< 10
Quinoline	42	< 10	< 10
Isoquinoline	< 10	15	< 10
Propanedinitrile, methylene-	34	< 10	< 10
Tributyl phosphate	30	< 10	< 10
Quinazoline	21	< 10	< 10
5-Cyano-2-picoline	14	< 10	< 10
Pyridine, 2-nitro-	13	< 10	< 10
3-Cyanobenzaldehyde	11	< 10	< 10
Pyridine, 2,6-dimethyl-	10	< 10	< 10
2-Ethylthiacyclohexane	< 10	11	< 10
See List of SVOA Analytes in Appendix 6.17	< 10	< 10	< 10

Table 4.24 VOA and SVOA Analytes in Melter Offgas Charcoal Samples

	Solid 1	Solid 2	Solid 3	Solid 4	Solid 5	Solid 6 (Blank)
Volatile Organic Compounds						
	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)
Methyl formate	26	< 1	27	25	< 1	< 1
Acetic acid, methyl ester	9.4	< 1	52	55	< 1	< 1
Formic acid	< 1	< 1	20	1	< 1	< 1
Hexanoic acid, methyl ester	< 1	< 1	7.5	6.4	< 1	< 1
Methane, dimethoxy-	< 1	< 1	5.1	7.7	< 1	< 1
Butanoic acid, methyl ester	< 1	< 1	< 1	4.1	7.4	< 1
See List of VOA Analytes in Appendix 6.17	< 1	< 1	< 1	< 1	< 1	< 1
Semi-Volatile Organic Compounds						
2-Propanol, 1-methoxy-2-methyl-	1.5	< 1	< 1	< 1	< 1	< 1
Unidentified	< 1	< 1	7.7	< 1	< 1	< 1
Propanal, 2,3-dichloro-2-methyl-	< 1	< 1	3.4	< 1	< 1	< 1
Ethane (dithioic) acid	< 1	< 1	2.8	3.9	< 1	< 1
Butanoic acid, 2,3-dichloro-, m.	< 1	< 1	2.6	< 1	< 1	< 1
Benzene, isocyano-	< 1	< 1	1.8	< 1	< 1	< 1
2-Pentene, 2-methyl-	< 1	< 1	1	< 1	< 1	< 1
Unidentified	< 1	< 1	1	< 1	< 1	< 1
Sulfur	< 1	< 1	< 1	1700	2300	810
Hexathiepane	< 1	< 1	< 1	2.9	2.9	< 1
3-Hexanol, 4-methyl-	< 1	< 1	< 1	< 1	5	< 1
2-Butyn-1-ol	< 1	< 1	< 1	< 1	2.3	< 1
Unidentified	< 1	< 1	< 1	< 1	1.3	< 1
Unidentified	< 1	< 1	< 1	< 1	1.1	< 1
See List of SVOA Analytes in Appendix 6.17	< 1	< 1	< 1	< 1	< 1	< 1

4.3.7. Radioactive Run Particulate & Volatile Metals Emissions – Modified EPA Method 0060

Three offgas samples were taken by modified EPA Method 60 (MM60) during the radioactive run. The total amounts of feed and the offgas sampled for each test are given in Table 4.25. All samples were taken while the melter was being fed.

The first sample (#1) was compromised by an offgas system vacuum problem that resulted in the impinger solutions being mixed together. This problem occurred right at the beginning of the sampling run and resulted in stopping feeding the melter. Therefore, the results from this train are of questionable value. The vacuum system problem was caused by a pluggage in the offgas line entering the MM60 sampling train. To remove this pluggage, this portion of the offgas line was reamed out and water was also used to dislodge some of the plug. The particulate results for this test showed very high amounts of particulate, as shown in Table 4.25, indicating that a large amount of the plug material was collected on the filter paper. Therefore, this sample is invalid, and is not included in the data tables in this section. (The results, are however, shown in Appendix 6.19.) Method 60 samples #2 and #3 were successfully taken.

Table 4.25 Method 60 Feed and Gas Sampled

		Sample #1	Sample #2	Sample #3
Volume of Gas Sampled	std. L	21.92	394.27	506.73
Total Mass of Particulate (Filter)	g	0.1653	0.0280	0.0170
Mass of Melter Feed	lb	~ 0	2.93	3.40
	ml	0	823	955

The MM60 samples taken were analyzed by EPA Method 60,[6] with modifications as described in Appendix 6.1. The analyses for elements and radionuclides are summarized in Appendix 6.19. The analytical data were used to determine the total amounts of each species collected in the sampling train. The total amount of each species fed was also determined for the time period of the sample. For EPA Method 60, "particulate" means any material collected on or before the filter paper, while "volatile" means any material collected after the filter (mainly in the impingers).

The offgas concentration data are summarized in Table 4.26. Values with < in red indicate that the concentration data from the analytical sample was below the detection limit, so the actual offgas concentration is less than the given value. The concentrations in the offgas were also calculated by subtracting the offgas sample blanks (greater of the field and reagent blanks) from the measured concentration of the analytical sample:

$$C_{\text{blank corrected}} = C_{\text{measured}} - C_{\text{blank correction}}$$

The blank corrected concentration was then used to calculate the concentration in the offgas. Values with < and *italics (in red)* indicate that the concentration values used were less than the blank values, so the resulting offgas concentration is again below the detection limit. The means and standard deviations of the concentration data from Table 4.26 are shown in Table 4.27. The standard deviations for most of the species are generally in the range from 50-100% of the mean value. This large spread results from the fact that the concentrations determined for sample #3 ranged from about 20-65% of the values for sample #2. The results from sample #2 may be high due to residual particulate on the offgas and sample lines that may have broken loose during the sample, but there is no way to know if this is true; additional sampling would have had to have been conducted.

Table 4.26 Mass per Offgas Volume of Elements & Radionuclides

	Sample #2 Particulate		Sample #3 Particulate		Sample #2 Volatiles		Sample #3 Volatiles	
	(not blank corrected)	(blank corrected)	(not blank corrected)	(blank corrected)	(not blank corrected)	(blank corrected)	(not blank corrected)	(blank corrected)
Total Particulate	0.0710 mg/L	-	0.0335 mg/L	-	-	-	-	-
ICPES				**(µg/L)**				
Ag	<0.0289	<0.0289	<0.0225	<0.0225	<0.0289	<0.0289	<0.0225	0
Al	**81.9**	**74.0**	**4.95**	**4.95**	**0.590**	**0.248**	**1.39**	**1.12**
B	**223**	**194**	**44.7**	**22.5**	**144**	**144**	**143**	**143**
Ba	0.0639	*<0.0639*	0.0148	*<0.0148*	0.0122	*<0.0122*	0.00947	*<0.00947*
Be	<0.00380	<0.00380	<0.00296	<0.00296	<0.00380	<0.00380	<0.00296	0
Ca	**4.88**	***4.88***	**1.98**	**1.98**	**2.72**	**0.797**	**1.90**	**0.408**
Cd	0.227	0.135	0.0598	0.0598	0.0129	0.00837	0.0101	0.00651
Co	0.325	0.198	0.0740	0.0740	0.0259	0.00304	0.0237	0.00592
Cr	1.96	1.89	1.29	1.23	0.0616	*<0.0616*	0.0385	*<0.0385*
Cu	0.162	*<0.162*	0.433	0.0835	1.75	0.458	0.105	*<0.105*
Fe	**12.5**	**12.0**	**8.44**	**8.09**	**1.17**	**0.535**	**0.976**	**0.480**
La	<0.0320	<0.0320	<0.0249	<0.0249	<0.0320	<0.0320	<0.0249	0
Li	**6.10**	**6.10**	**3.43**	**3.43**	**0.157**	**0.151**	**0.0124**	**0.00829**
Mg	**0.596**	**<0.596**	**0.118**	***<0.118***	**0.718**	**0.438**	**0.431**	**0.214**
Mn	0.228	0.202	0.0302	0.0101	0.0160	*<0.0160*	0.00829	*<0.00829*
Mo	0.366	0.295	0.155	0.0995	0.0259	0.0183	0.0189	0.0130
Na	**344**	**308**	**135**	**107**	**20.5**	**11.5**	**7.40**	**0.436**
Ni	0.278	0.119	0.107	0.107	0.193	*<0.193*	0.0527	*<0.0527*
P	0.683	0.511	0.344	0.210	0.176	0.0548	0.131	0.0373
Pb	1.24	0.629	0.271	*<0.271*	0.103	0.0441	0.0912	0.0450
Sb	1.02	0.614	0.234	*<0.234*	0.0502	0.0137	0.0497	0.0213
Si *	**2389**	**1362**	***615***	**615**	**26.3**	**17.9**	**43.4**	**36.9**
Sn	0.349	0.177	0.0924	0.0924	0.0951	0.0152	0.106	0.0438
Sr	0.0730	*<0.0730*	0.0296	*<0.0296*	<0.00457	*<0.00457*	0.00474	*<0.00474*
Ti	**2.31**	**2.10**	**1.47**	**1.30**	**0.0236**	**0.0122**	**0.0361**	**0.0272**
Tl	0.531	0.286	0.188	*<0.188*	0.193	0.0852	0.197	0.113
V	0.0266	0.00609	<0.0160	<0.0160	<0.0205	<0.0205	<0.0160	0
Zn	**9.25**	**9.10**	**6.81**	**6.69**	**1.64**	**1.44**	**0.734**	**0.578**
Zr	**2.34**	**2.21**	**0.652**	**0.547**	**<0.0198**	**<0.0198**	**0.0592**	**0.0438**
K	8.45	6.44	4.15	2.59	0.216	0.0399	0.276	0.139
As	<3.80	<3.80	<2.96	<2.96	<3.80	<1.33	<2.96	<1.04
Se	38.2	34.6	22.5	19.7	1.37	*<1.37*	1.86	0.266
Y	3.37E-02	2.69E-02	9.71E-03	4.44E-03	5.09E-04	4.63E-04	8.76E-04	8.41E-04
Rh	3.40E-03	3.34E-03	1.03E-03	9.74E-04	<3.38E-05	0	<2.63E-05	0
Pd	5.53E-03	3.93E-03	2.57E-03	1.33E-03	<3.80E-04	<3.47E-04	<2.26E-03	<2.24E-03
Ta	2.15E-04	0	1.14E-04	0	<2.90E-06	0	4.96E-05	4.73E-05
W	3.94E-01	3.92E-01	2.42E-01	2.40E-01	3.37E-04	3.19E-04	8.62E-04	8.48E-04
Pt	2.99E-04	2.70E-04	<2.23E-05	0	<1.43E-05	0	<1.12E-05	0

bold = major feed component

higher than expected

* Minor filter or blank impurities: Na, B, Ca, Al

("blank corrected" are the element weight minus the larger of the field and reagent blanks)

Table 4.26 (Continued)

	Sample #2 Particulate		Sample #3 Particulate		Sample #2 Volatiles		Sample #3 Volatiles	
	(not blank corrected)	(blank corrected)	(not blank corrected)	(blank corrected)	(not blank corrected)	(blank corrected)	(not blank corrected)	(blank corrected)
Radiochemical (ηCi/m^3)								
Co^{60}	<14	<12	<10	<8.5	<10.6	<9.28	<0.94	<0.94
Cs^{137}	1287	1280	579	574	<1.2	<1.2	1.46	0.165
Eu^{154}	<14.38	<12.4	<9	<7.57	<1	<1	<0.862	<0.862
Eu^{155}	<19.04	<15.5	<12	<8.79	<1.9	<1.9	<1.43	<1.43
Ra^{226}	<183.9	<148	<119	<90.6	<18.5	<1.03	<13	<13
Cs^{134}	<7.26	<5.4	<3.6	<2.17	<0.877	<0.877	<0.739	<0.175
Am^{241}	<37.7	<32	<23	<18.06	<2.88	<2.88	<1.94	<1.94
Eu^{152}	<35.6	<23	<4	<3.52	<5.99	<5.99	<4.81	<4.81
Ru^{103}	<14.07	<12.4	<8.8	<7.48	<0.873	<0.873	<0.63	<0.63
Ru^{106}/Rh^{106}	<90.7	<73	<63	<48.7	<9.88	<9.88	<6.81	<6.81
Sb^{125}	<45.5	<40	<29	<24.4	<2.35	<2.35	<0.618	<0.618
Ce^{144}	<50.7	<42	<29	<22.8	<4.16	<0.325	<2.96	<2.96
Sn^{113}	<16.81	<14.5	<10.2	<8.38	<1.11	<1.11	<0.791	<0.791
Zn^{65}	<14.18	<9	<10	<6.42	<1.99	<1.99	<1.71	0
Nb^{94}	<4.86	<3	<3.4	<1.9	<1.05	<1.05	<0.793	<0.793
Alpha Count	13.83	11.03	5.75	3.57	<0.894	<0.305	0.597	0.139
Beta Count	10923	10911	6794	6784	13.9	10.6	9.70	7.14
Sr^{90}	301	290	259	250	<5.34	<5.34	4.16	0
Tc^{99}	7807	7806	5009	5008	3.65	3.45	4.68	4.53
Pu^{238}	0.842	0.842	<0.188	<0.188	<0.171	<0.171	<0.131	<0.131
Pu^{239}/Pu^{240}	<0.39	<0.39	<0.208	<0.208	<0.224	<0.224	0.233	0.0413
Pu^{241}	<14.9	<1.88	<10.4	<0.266	<5.26	<5.26	<7.31	<3.08
Am^{241}	2.14	0.281	1.13	1.13	0.161	0.161	0.0870	0.0870
Cm^{244}	1.22	1.09	0.946	0.850	0.0813	0.0813	0.206	0.174
Cm^{242}	<0.049	<0.049	<0.037	<0.037	<0.00431	<0.00431	<0.00402	<0.000373
Se^{79}	24.1	16.6	<5.86	<5.86	<4.79	<4.79	<3.86	0
ICP-MS (μg/m^3)								
Tc^{99} (ηCi/m^3)	4240	4231	2699	2692	<5.73	<5.73	26.1	21.1
mass 230	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 231	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 232 (Th)	3.30	2.20	1.19	0.327	0.126	0.00949	0.543	0.452
mass 233	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 234 (U)	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 235 (U)	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 236 (U)	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 237 (Np)	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 238 (Pu & U)	4.27	1.33	1.57	1.57	2.54	0.708	0.462	0.462
mass 239 (Pu)	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 240 (Pu)	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 241 (Am & Pu)	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 242 (Pu)	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 243 (Am)	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 244 (Cm)	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 245 (Cm)	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0
mass 246	<0.116	<0.116	<0.0906	<0.0906	<0.116	<0.116	<0.0906	0

Table 4.27 Mean and Standard Deviation of Offgas Concentrations

	Particulate		Particulate (Blank Corrected)		Volatiles		Volatiles (Blank Corrected)	
ICPES (µg/L)	**Mean**	**St Dev**	**Mean**	**St Dev**	**Mean**	**St Dev**	**Mean**	**St Dev**
Ag	<0.0257	<0.00454	<0.0257	<0.00454	<0.0257	<0.00454	<0.0145	<0.0204
Al	**43.4**	**54.4**	**39.5**	**48.8**	**0.990**	**0.566**	**0.686**	**0.620**
B	**134**	**126**	**108**	**122**	**144**	**0.820**	**144**	**0.793**
Ba	0.0394	0.0347	*<0.0394*	*<0.0347*	0.0108	0.00191	*<0.0108*	*<0.00191*
Be	<3.38E-03	<5.97E-04	<3.38E-03	<5.97E-04	<3.38E-03	<5.97E-04	<1.90E-03	<2.69E-03
Ca	**3.43**	**2.05**	**3.43**	**2.05**	**2.31**	**0.577**	**0.602**	**0.275**
Cd	0.143	0.118	0.0976	0.0535	0.0115	0.00203	0.00744	0.00131
Co	0.199	0.177	0.136	0.0876	0.0248	0.00155	0.00448	0.00203
Cr	1.63	0.478	1.56	0.466	0.0501	0.0164	*<0.0501*	*<0.0164*
Cu	0.297	0.191	0.123	0.0556	0.929	1.17	0.281	0.250
Fe	**10.4**	**2.85**	**10.1**	**2.78**	**1.07**	**0.139**	**0.508**	**0.0387**
La	<0.0284	<0.00502	<0.0284	<0.00502	<0.0284	<0.00502	<0.0160	<0.0226
Li	**4.77**	**1.89**	**4.76**	**1.89**	**0.0846**	**0.102**	**0.0799**	**0.101**
Mg	**0.357**	**0.338**	***<0.357***	***<0.338***	**0.574**	**0.203**	***<0.326***	***<0.159***
Mn	0.129	0.140	0.106	0.135	0.0121	0.00544	0.0121	0.00544
Mo	0.260	0.150	0.197	0.138	0.0224	0.00490	0.0156	0.00370
Na	**239**	**148**	**207**	**142**	**13.9**	**9.24**	**5.98**	**7.83**
Ni	0.193	0.121	0.113	0.00867	0.123	0.0989	*<0.123*	*<0.0989*
P	0.514	0.240	0.360	0.213	0.154	0.0314	0.0460	0.0124
Pb	0.756	0.685	0.450	0.253	0.0973	0.00870	0.0446	0.000610
Sb	0.625	0.553	0.424	0.269	0.0500	3.46E-04	0.0175	0.00539
Si	1502	1255	988	528	34.9	12.1	27.4	13.5
Sn	0.221	0.182	0.134	0.0595	0.101	0.00768	0.0295	0.0202
Sr	0.0513	0.0307	*<0.0513*	*<0.0307*	4.65E-03	1.21E-04	*<4.65E-03*	*<1.21E-04*
Ti	**1.89**	**0.596**	**1.70**	**0.563**	**0.0299**	**0.00886**	**0.0197**	**0.0106**
Tl	0.359	0.243	0.237	0.0696	0.195	0.00286	0.0991	0.0197
V	0.0213	0.00753	0.0110	0.00700	<0.0183	<0.00322	<0.0103	<0.0145
Zn	**8.03**	**1.73**	**7.90**	**1.71**	**1.19**	**0.641**	**1.01**	**0.609**
Zr	**1.50**	**1.19**	**1.38**	**1.17**	**0.0395**	**0.0279**	**0.0318**	**0.0170**
K	6.30	3.04	4.51	2.73	0.246	0.0423	0.0894	0.0699
As	<3.38	<0.597	<3.38	<0.597	<3.38	<0.597	<1.18	<0.209
Se	30.4	11.1	27.2	10.5	1.62	*<0.350*	0.818	0.780
Total Particulate	0.0520	0.0265	-	-	-	-	-	-
	See Table 4.26 for key							

Table 4.27 (continued)

	Particulate		Particulate (Blank Corrected)		Volatiles		Volatiles (Blank Corrected)	
	Mean	**St Dev**	**Mean**	**St Dev**	**Mean**	**St Dev**	**Mean**	**St Dev**
Radiochemical (ηCi/m^3)								
Co^{60}	<12.1	<2.73	<10.2	<2.39	<5.76	<6.82	<5.11	<5.9
Cs^{137}	933	500	927	499	1.33	0.182	0.683	0.732
Eu^{154}	<11.7	<3.75	<10	<3.44	<0.933	<0.1	<0.933	<0.1
Eu^{155}	<15.3	<5.32	<12.2	<4.78	<1.66	<0.336	<1.66	<0.336
Ra^{226}	<151	<46.2	<119	<40.5	<15.7	<3.88	<7.01	<8.47
Cs^{134}	<5.45	<2.55	<3.76	<2.25	<0.808	<0.0971	<0.526	<0.496
Am^{241}	<30.2	<10.5	<24.8	<9.53	<2.41	<0.659	<2.41	<0.659
Eu^{152}	<19.6	<22.7	<13.4	<14	<5.4	<0.837	<5.4	<0.837
Ru^{103}	<11.4	<3.73	<9.93	<3.47	<0.752	<0.172	<0.752	<0.172
Ru^{106}/Rh^{106}	<76.7	<19.9	<60.8	<17.1	<8.34	<2.17	<8.34	<2.17
Sb^{125}	<37	<12	<32.4	<11.2	<1.48	<1.22	<1.48	<1.22
Ce^{144}	<40	<15.1	<32.5	<13.8	<3.56	<0.851	<1.64	<1.86
Sn^{113}	<13.5	<4.71	<11.5	<4.35	<0.952	<0.227	<0.952	<0.227
Zn^{65}	<12.2	<2.79	<7.85	<2.02	<1.85	<0.199	<0.993	<1.4
Nb^{94}	<4.12	<1.05	<2.43	<0.746	<0.921	<0.182	<0.921	<0.182
Alpha Count	9.79	5.71	7.30	5.27	0.745	0.210	0.222	0.118
Beta Count	8858	2920	8847	2918	11.8	2.97	8.88	2.46
Sr^{90}	280	29.7	270	28.0	4.75	0.838	2.67	3.78
Tc^{99}	6408	1979	6407	1979	4.16	0.728	3.99	0.758
Pu^{238}	0.515	0.462	0.515	0.462	<0.151	<0.0282	<0.151	<0.0282
Pu^{239}/Pu^{240}	0.299	0.129	0.299	0.129	0.229	0.00625	0.133	0.129
Pu^{241}	<12.7	<3.19	<1.07	<1.14	<6.28	<1.45	<4.17	<1.54
Am^{241}	1.64	0.713	0.708	0.604	0.124	0.0523	0.124	0.0523
Cm^{244}	1.08	0.191	0.971	0.171	0.144	0.0885	0.128	0.0656
Cm^{242}	<0.043	<0.00844	<0.043	<0.00844	<0.00417	<0.000206	<0.00234	<0.00279
Se^{79}	15.0	12.9	11.2	7.60	4.33	0.658	2.40	3.39
ICP-MS (μg/m^3)								
Tc^{99} (ηCi/m^3)	3470	1089	3462	1088	15.9	14.4	13.4	10.9
mass 230	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 231	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 232 (Th)	2.25	1.49	1.26	1.32	0.334	0.295	0.231	0.313
mass 233	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 234 (U)	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 235 (U)	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 236 (U)	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 237 (Np)	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 238 (Pu & U)	2.92	1.91	1.45	0.167	1.50	1.47	0.585	0.174
mass 239 (Pu)	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 240 (Pu)	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 241 (Am & Pu)	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 242 (Pu)	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 243 (Am)	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 244 (Cm)	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 245 (Cm)	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823
mass 246	<0.103	<0.0183	<0.103	<0.0183	<0.103	<0.0183	<0.0582	<0.0823

The bold highlighted elements in Table 4.26 are the ones that are most abundant in the feed. As expected, these are also then the most abundant in the offgas. Chromium in the particulate fraction is higher than expected, but previous experience[41] has shown that Cr, Fe, and Ni contamination from the piping can bias these elements high. The amount of potassium is high relative to its concentration in the feed, which is consistent with its higher volatility compared to the transition metals. Selenium, which is more volatile than other metals, shows behavior similar to potassium in that the amount evolved seems high; however, Se was not analyzed for in any of the feed samples, so the amount expected in the offgas cannot be estimated. The amount of volatile sodium relative to particulate was lower than expected given the volatility of sodium.

The value for sample #2 volatiles for copper is much higher than expected, and appears to be either an analytical error or a contamination problem. The Cu value for sample #3 is reasonable. The particulate values for silicon are very high. The filter paper used to collect the samples was quartz, so the background correction for Si can be subject to substantial error. For sample #2, significant Si above the blank was seen, but for sample #3, the amount was below the blank. The radionuclides detected generally showed volatiles to be 1-2 orders of magnitude less than the particulate. The only replicate radionuclide measurement was Tc^{99}. The particulate concentrations for Tc^{99} agree very well, while the volatile concentrations differ by up to an order of magnitude; however, the volatile concentrations are very small, so larger error is not surprising.

From the concentration data, the decontamination factor for each species was determined (decontamination factor [DF] is defined as the mass flow in ÷ mass flow out). The DF data are summarized in Table 4.28 along with the same data expressed as percent retained (in the glass). The highest DFs (~4,700-40,000, blank corrected) were found for Zr, Mg, Ca, Mn, Fe, Ti, Li, Zn, and Al. The DF for total particulate was 26720. Previous work with a DWPF pilot melter[42] gave a total particulate DF of about 2600, so the LC melter had an overall DF that was about 10X the DWPF pilot value. High DFs would also be expected for the other transition metals, and these ranged from ~250-2000. The DFs of these elements may be lower because they are present in smaller quantities, which result in larger percentage analytical errors. In Table 4.28, values with < in red had measurements below the detection limit of the analytical method. Values with *< in blue italics* had all measured values below either the field or reagent blank. Values in *green italics* (no <) had at least one measurement smaller than a blank.

Table 4.28 Decontamination Factors and Percents Retained for Elements & Radionuclides

Decontamination Factors and Percent Retained							
	Not Blank Corrected			Blank Corrected			Duratek Data
Elements	Mean DF	Percent Retained	Percent as Particulate	Mean DF	Percent Retained	Percent as Particulate	Percent Retained
Total Particulate	26720	-	-	-	-	-	-
Zr	**34416**	**99.997**	**95.4**	**40213**	**99.998**	**95.8**	**>99.99**
Mg	**20939**	**99.995**	**33.5**	**32088**	**99.997**	**46.6**	**>99.99**
Ca	**15354**	**99.993**	**57.6**	***23384***	***99.996***	***84.4***	**99.98**
Mn	9001	99.989	85.9	*17561*	*99.994*	*73.7*	99.95
Fe	**7290**	**99.986**	**90.5**	**7967**	**99.987**	**95.1**	**99.99**
La	<6459	<99.985	50	<9926	<99.99	75	
Ti	**6166**	**99.984**	**98.3**	**6902**	**99.986**	**98.7**	**99.97**
Li	**5474**	**99.982**	**98.6**	***<5485***	***<99.982***	***98.7***	**99.94**
Zn	**4928**	**99.980**	**87.6**	**5103**	**99.980**	**89.2**	**99.96**
Al	**4495**	**99.978**	**88.7**	**4716**	**99.979**	**90.6**	**99.99**
Sn	3666	99.973	62.6	6384	99.984	79.9	
Sr	3452	99.971	90.2	*<3452*	*<99.971*	*90.2*	
P	2442	99.959	75.9	4325	99.977	87.6	
V	<2349	<99.957	53.2	<4468	<99.978	61.4	
Ni	1980	99.949	63.1	*2256*	*99.956*	*52.7*	
Ba	1723	99.942	72.5	<1723	<99.942	72.5	
Pb	1506	99.934	83.6	*2021*	*99.951*	*89.6*	
Co	1213	99.918	84.2	*1632*	*99.939*	*95.5*	
Ag	<688	<99.855	50	<1058	<99.905	75	
Cd	675	99.852	90.1	*812*	*99.877*	*92.2*	
Na	**646**	**99.845**	**94.6**	**821**	**99.878**	**98.0**	**99.77**
Si	**351**	**99.715**	**96.2**	***414***	***99.759***	***96.5***	**99.99**
Mo	302	99.669	91.2	437	99.771	91.3	
Cr	235	99.574	97.0	245	99.592	96.9	99.23
B	**230**	**99.565**	**42.2**	**257**	**99.611**	**35.5**	**99.81**
Cu***	229	99.562	90.3	*319*	*99.687*	*72.2*	
K	227	99.560	95.6	345	99.711	97.1	98.97
Cu	64.0	98.438	44.5	*186*	*99.464*	*35.2*	
Be	NA	NA	50.0	NA	NA	75.0	
Sb	NA	NA	88.9	NA	NA	*94.7*	
Tl	NA	NA	61.1	NA	NA	*69.7*	
As	NA	NA	50.0	NA	NA	74.1	
Se	NA	NA	94.4	NA	NA	97.4	

<#: below detection limit NA = not available
measurement less than at least one blank ** without high volatility measurement (#2)
< all measurements less than blanks

Table 4.28 (continued)

Decontamination Factors and Percents Retained							
	Not Blank Corrected			Blank Corrected			Duratek Data
	Mean DF	Percent Retained	Percent as Particulate	Mean DF	Percent Retained	Percent as Particulate	Percent Retained
Radiochemical							
Co^{60}	<2750	<99.964	74.2	<3218	<99.969	73.1	
Cs^{137}	82	98.786	99.8	83	98.797	99.9	96.96 *
Eu^{154}	<2953	<99.966	92.4	<3440	<99.971	91.2	
Eu^{155}	<1316	<99.924	90.0	<1631	<99.939	87.6	
Am^{241}	<724	<99.862	92.5	<879	<99.886	91.0	
Alpha Count	9770	99.990	92.3	15428	99.994	96.8	
Beta Count	806	99.876	99.9	808	99.876	99.9	
Sr^{90}	2622	99.962	98.3	2735	99.963	99.1	
Tc^{99}	7.44	86.552	99.9	7.44	86.553	99.9	
These are NA:	Pu^{238} Pu^{239}/Pu^{240} Pu^{241} Am^{241} Cm^{244}	Ra^{226} Eu^{152} Ru^{106}/Rh^{106} Ce^{144} Zn^{65}	Cs^{134} Ru^{103} Sb^{125} Sn^{113} Nb^{94}	Cm^{242} Se^{79}			
ICP-MS							
Tc^{99}	6.73	85.13	99.7	6.74	85.17	99.8	
mass 230	<414	<99.759	50	<637	<99.843	75	
mass 231	<414	<99.759	50	<637	<99.843	75	
mass 232 (Th)	9562	99.990	82.5	18950	99.995	70.8	
mass 233	<414	<99.759	50	<637	<99.843	75	
mass 234 (U)	<414	<99.759	50	<637	<99.843	75	
mass 235 (U)	<918	<99.891	50	<1411	<99.929	75	
mass 236 (U)	<444	<99.775	50	<683	<99.854	75	
mass 237 (Np)	<706	<99.858	50	<1085	<99.908	75	
mass 238 (Pu & U)	10126	99.990	70.0	16013	99.994	71.3	
mass 239 (Pu)	<442	<99.774	50	<679	<99.853	75	
mass 240 (Pu)	<414	<99.759	50	<637	<99.843	75	
mass 241 (Am & Pu)	<417	<99.76	50	<641	<99.844	75	
mass 242 (Pu)	<414	<99.759	50	<637	<99.843	75	
mass 243 (Am)	<414	<99.759	50	<637	<99.843	75	
mass 244 (Cm)	<414	<99.759	50	<637	<99.843	75	
mass 245 (Cm)	<414	<99.759	50	<637	<99.843	75	
mass 246	<414	<99.759	50	<637	<99.843	75	

* non-radioactive Cs

As noted previously, the DF for silicon is lower than expected due to the difficulty in performing the blank correction for the quartz filter paper; Mg and Ca also had high blank concentrations. Most of the metals found in the offgas are probably due to entrainment of feed or glass particles, as evidenced by the prevalence of the glass formers and sodium. The particulate percentage of the offgas emissions of most of the transition metals are greater than 90%. The exceptions are the compounds that were present near their blank values (Cd, Co, Cu, Ni). A comparison of the percents retained between this work and from Duratek[43] shows similar trends, with K, B, Cr and Na having the lower values. An exception is Si, which had a low value in this work, as previously discussed.

Table 4.29 shows the DF defined as the amount in the feed divided by the amount collected in the volatiles (impinger) section of the offgas train. These data again show that, as expected, Li, Zr, Ti, Fe, Ca, Al, and Zn are not volatile. The total particulate DF is also very large. The high values for Mg and Na are again a surprise. This table dramatically shows the high volatility of boron. The most volatile elements, from Table 4.28 and Table 4.29, are B, Mg, Tl, Ca, Sn, and P. Copper is probably not as volatile as the data would indicate.

The DFs (Table 4.28) reported for Co^{60}, Eu^{154}, Eu^{155}, and Am^{241} are all based on values that were below the detection limits, and so are based on the detection limits. The DF for Sr^{90} (~2675) is close to that found for total Sr (~3450). The Cs DF was approximately 82, which is very close to the DF found for measurements of non-radioactive Cs in the DWPF pilot melter,[42,44] which was around 130. The percent retained measured in this work for Cs^{137} (99.79%) is much larger than that found for non-radioactive Cs by Duratek (96.96%)[43]. The Tc^{99} DF was very small at 6.7-7.4, which is expected due to the volatility of both $NaTc_2O_4$ and Tc_2O_7. The DFs for masses 232 and 238 and alpha counts were very high, as to be expected with the nonvolatile actinides. Most of the radionuclides were found predominately on the filter, except for masses 232 and 238. It seems unusual that these actinide metals (82.5 and 70.0 %, respectively) would have a smaller particulate fraction that more volatile elements such as Cs or Tc. These low measurements for these masses are supported by the low particulate percentage for alpha count (92.3).

Masses 232 and 238 (Th & U) were present in the zircon flour glass former, so masses 232, 238 and Zr would be expected to have similar DFs. The DF for Zr (34400 – 40200) is of similar magnitude to those of mass 232 Th (9562 – 18950) and mass 238 U (10130 – 16010).

The percents retained for Cs^{137} and Tc^{99} were 99.79% and 85.1-86.6, respectively. However, these same values, when calculated from the feed concentrations and the glass analyses, were found to be much lower. Table 4.30 compares the percents retained in the glass calculated by these two methods along with values determined elsewhere from other melter studies.

Table 4.29 Volatile Fraction Decontamination Factor (mass in feed ÷ mass in impingers)

Decontamination Factor					
Element	**Not Blank Corrected**	**Blank Corrected**	**Element**	**Not Blank Corrected**	**Blank Corrected**
Li	**1.02E+06**	**1.50E+06**	**Si**	**1.16E+04**	**1.58E+04**
Zr	**1.34E+06**	**1.45E+06**	La	<1.29E+04	<1.20E+04
Ti	**4.04E+05**	**6.91E+05**	Cd	6.60E+03	1.02E+04
Fe	**7.66E+04**	**1.62E+05**	Cr	7.93E+03	*<7.93E+03*
Na	**1.23E+04**	**1.55E+05**	Ba	<6.07E+03	<6.07E+03
Ca	**3.55E+04**	**1.46E+05**	Ni	5.69E+03	*<5.69E+03*
Al	**6.83E+04**	**1.41E+05**	Mo	3.36E+03	4.83E+03
Mg	**3.04E+04**	**5.67E+04**	V	<5.00E+03	<4.63E+03
Mn	*<5.60E+04*	*<5.60E+04*	Ag	<1.38E+03	<1.28E+03
Zn	**4.29E+04**	**5.26E+04**	Cu**	5.01E+02	5.01E+02
Co	7.70E+03	4.83E+04	**B**	**4.04E+02**	**4.05E+02**
Sn	1.03E+04	4.65E+04	Cu	2.67E+02	3.14E+02
Sr	3.61E+04	*<3.61E+04*	Be	NA	NA
P	1.00E+04	3.38E+04	Sb	NA	NA
K	5.63E+03	2.25E+04	Tl	NA	NA
Pb	9.11E+03	1.99E+04	** without high volatility measurement (#2)		

Table 4.30 Radionuclide Percents Retained in Glass

Analysis	Percent Retained (Glass / Feed)	Percent Retained Calculated from Offgas Measurements	Percent Retained, from:	Source
Radiochemical				
Co^{60}	95.45 ± 9.94	<99.96		
Cs^{137}	73.05 ± 10.97	99.79	96.96 102.14 ± 5.13 95.65	Duratek[43] DWPF Melter[45] SRTC Research Melter [45]
Eu^{154}	98.3 ± 15.7	<99.97		
Eu^{155}	108.7 ± 56.6	<99.92		
Am^{241}	36.95 ± 5.92	<99.86		
Sr^{90}	93.05 ± 19.5	99.98		
Tc^{99}	27.95 ± 0.64	86.55	99.13 69.09	DWPF Melter [45] SRTC Research Melter [45]
Total Alpha	37.61 ± 1.73	99.99		
Total Beta	66.96 ± 20.39	99.88		
Mass Spectrometry				
Tc^{99}	30.85 ± 4.08	85.15		
mass 232 (Th)	80.36 ± 68.63	99.995		
mass 235 (U)	73.01 ± 11.51	<99.93		
mass 237 (Np)	48.85 ± 3.17	<99.91		
mass 238 (Pu & U)	88.94 ± 56.24	99.994		

Note: ± uncertainties shown are one standard deviation.

The high values for Co^{60}, Eu^{154}, Eu^{155}, and Sr^{90} agree very well. However, note that the uncertainties for the glass/feed calculated values for Eu^{154} and Eu^{155} are very high. The amounts retained for masses 232 and 238 calculated from glass/feed are also low, but again the uncertainties are high. The glass/feed values for total alpha, total beta, Am^{241}, and masses 235 and 237 are also much lower than the offgas values. These low values were not expected and we can offer no explanation for them.

The percents retained for Cs^{137} and Tc^{99} from the two methods are consistent in that by either method they are lower than the other values, i.e., the major metals and nonvolatile radionuclide Sr^{90}, but the absolute values are much different. As shown by the data in Table 4.30 (from previous melter studies at SRTC), the volatility of Tc^{99} was much higher in the SRTC research melter which had a small cold cap versus the larger DWPF melter, which was operated with a significant (>90%) cold cap. About 31% of the Tc^{99} was lost in the research melter, while no loss was found for the DWPF melter. For these same conditions, very little Cs^{137} was lost from the research melter. These results were based on glass and feed measurements.

A hypothesis that could account for the actual losses of Tc^{99} and Cs^{137} is as follows. Feed of the LC melter comprised only a relatively small portion of the total time the system was operated; there was significant idling time with no cold cap. We can make the assumptions that both of these radionuclides were evolved during feeding at the DF values calculated from the offgas data during feeding, but at some unknown higher rates during idling. To estimate these unknown rates of volatilization, the addition of feed and volatilization were modeled for the entire run. The rate of volatilization was then determined to make the final concentrations in the glass equal to those measured. Figure 4.37 shows: the amount of glass produced throughout the run (as calculated from the feedrate); an indicator of can number; and the concentration of Tc^{99} in the glass. The final concentration was set to be 0.0065 μCi/g glass. The maximum possible Tc^{99} in the glass was 0.0216 μCi/g glass; this calculated amount accounts for the loss of Tc^{99} measured during feeding (from the measured DF). A similar graph for Cs^{137} is shown in Figure 4.38. Here the final concentration of Cs^{137} is 0.0255 μCi/g glass and the maximum is 0.0346 μCi/g glass.

This analysis was complicated by the way the glass sample was taken. Approximately 500 g of glass was taken from both can 5 and can 6. Each can's glass was crushed and mixed to get a somewhat representative sample of all the glass in the can. Each 500 g sample was then put through the reheat and cooldown cycle, wherein the glass was maintained at 1150°C for four hours. We assumed that Tc^{99} and Cs^{137} both volatilized during these reheats. After the reheats, the two 500 g samples were again crushed and mixed together. The final glass sample was from this mixture.

The addition to the melter was modeled as a simple stirred tank, while the volatilization was modeled as an exponential decay. The models are shown below and in more detail in Appendix 6.19.

Addition:

$$C_o = \frac{C_i(e^{k_A t} - e^{k_A t_o}) + C_{oi}e^{k_A t_o}}{e^{k_A t}}$$

where C_i = concentration of species in melter feed on an oxide basis, μCi/g glass
C_o = concentration of species in the glass in the melter, μCi/g glass
m = melter feedrate on oxide basis, g feed as oxide / min
M = mass of glass in melter, g
C_{oi} = initial concentration of species in the melter at $t = t_o$
k_A = m/M
Note: Ci adjusted for loss of species to offgas during feeding (DF)

Volatilization:

$$\frac{C_o}{C_{oi}} = e^{-k_V(t-t_o)}$$

where k_V is a constant. The variables and parameters from the above equations are shown in Table 4.31. The hypothesized volatility shown in the Figures does not seem unreasonable. It is realized that this analysis is based on limited data with possibly significant uncertainty, but the basic conclusion is still reasonable. It appears that the volatilities of both Cs^{137} and Tc^{99}, when compared on a rate basis, are more of a concern during idling of the melter than during feeding. Therefore, measurement of volatility during idling may be an important measurement that should be made.

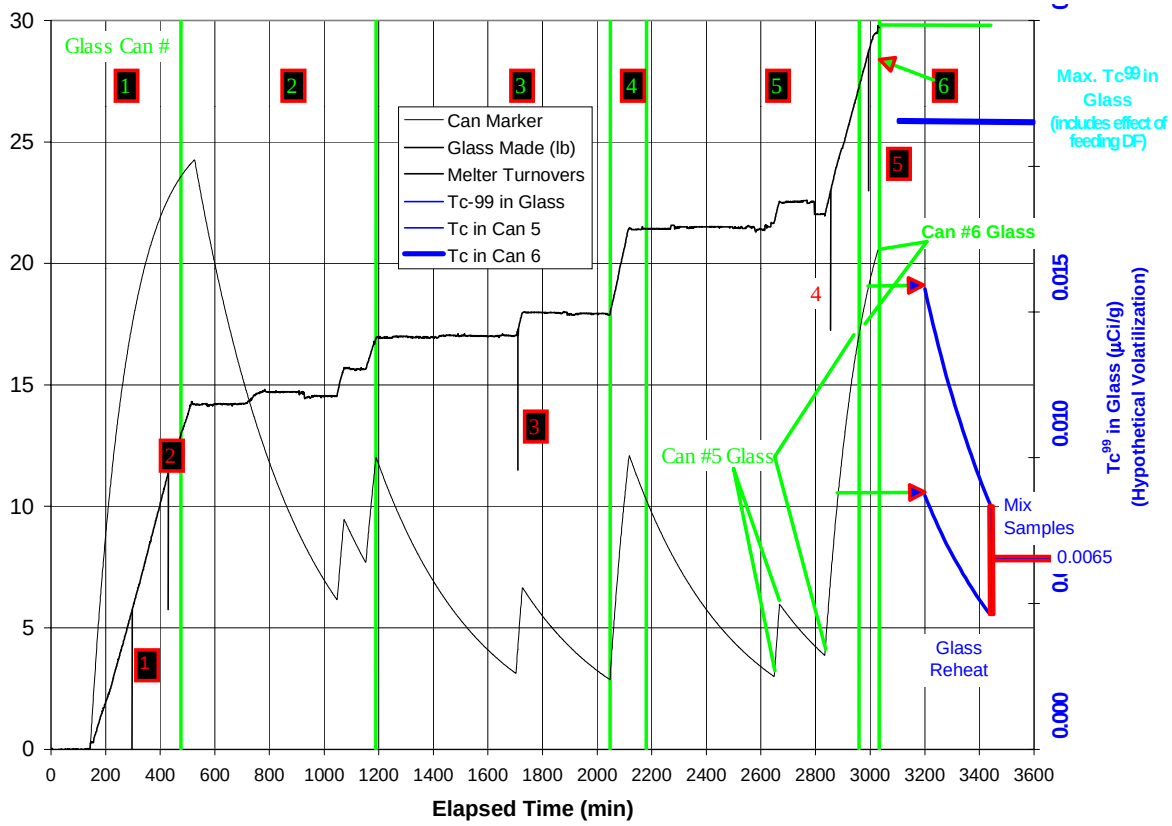


Figure 4.37 Hypothetical Volatilization of Tc^{99}.

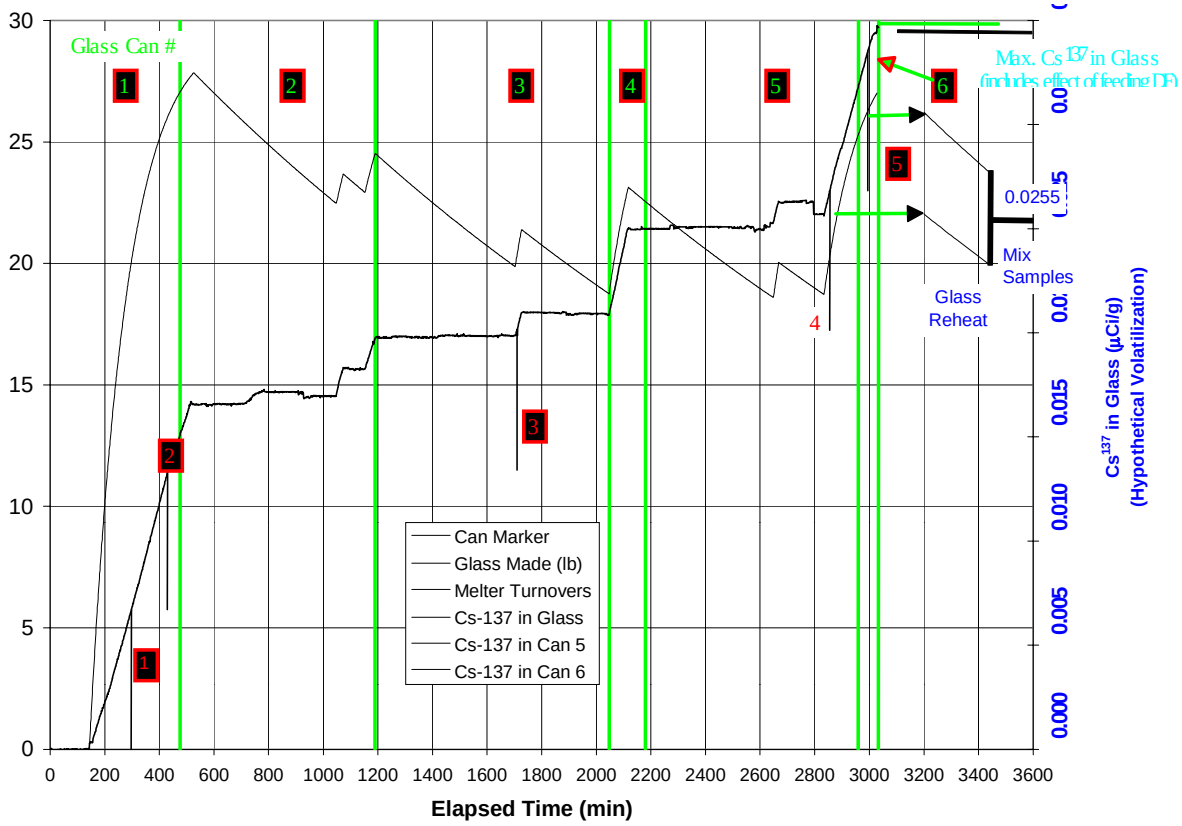


Figure 4.38 Hypothetical Volatilization of Cs^{137} .

Table 4.31 Variables in Equations for Tc^{99} and Cs^{137} Volatility.

Variable		Tc^{99}	Cs^{137}
C_i	µCi/g glass	0.0216	0.0346
k_A	min^{-1}	0.00733	
m	g/min	19.1	
M	g	2608	
k_V	min^{-1}	0.00263	0.000411

During treatment of the offgas samples for modified method 60 analyses, the filters containing particulate solids are dissolved by HF/HNO_3 digestion to dissolve the particulate solids for solution analyses. The filters that were digested for the radioactive runs 1-3 contained milligram quantities of undissolved solids after the acid digestion step. These trace solids were retained from further treatment and were submitted for crystalline phase characterization using X-ray diffraction analyses.

Figure 4.39-Figure 4.41 below show these solids to be zircon ($ZrSiO_4$), graphite (C), talc ($Mg_3Si_4O_{10}(OH)_2$) and colquirite ($LiCaAlF_6$).

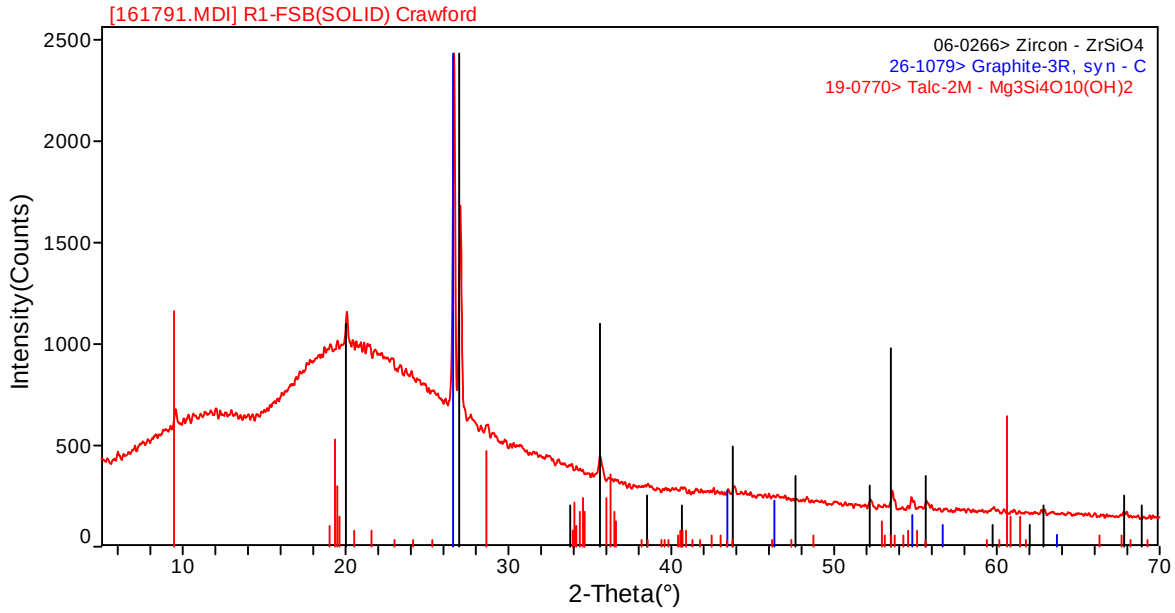


Figure 4.39 XRD Spectra from Analyses of Radioactive #1 Filter Particulate Solids

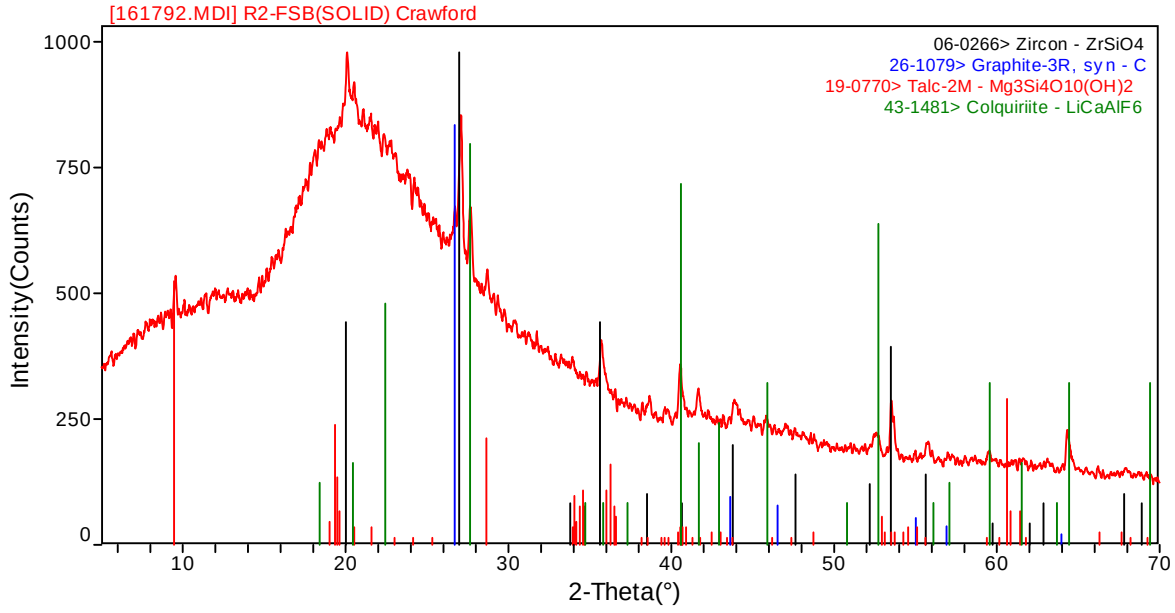


Figure 4.40 XRD Spectra from Analyses of Radioactive #2 Filter Particulate Solids

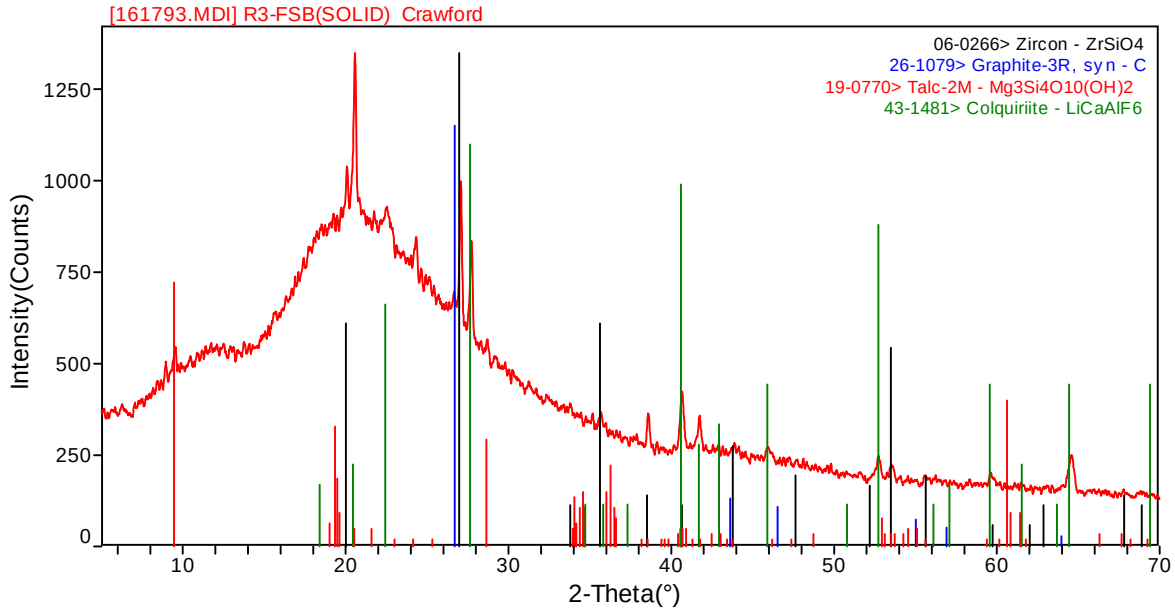


Figure 4.41 XRD Spectra from Analyses of Radioactive #3 Filter Particulate Solids

4.3.7.1. SEM, EDAX, and XRD Analysis of Radioactive Run Particulate from Filter Samples

A filter paper with solids derived from an idling period on 12/5/00 was submitted for characterization using x-ray diffraction, scanning electron microscopy and energy dispersive x-ray analysis. The purpose in these analyses of the surrogate filter solids was to investigate the types of solid particulate matter that are retained by the filter paper in typical melter operation. The X-ray diffraction pattern of the surrogate solid particulates retained on the filter paper is presented in Figure 4.42. Four separate crystalline species were identified as halite (NaCl), magnetite ($Fe^{2+}/Fe^{3+}O_4$), hematite (Fe_2O_3) and lithium sodium sulfate ($LiNa(SO_4)$).

SEM microscopic images and EDAX patterns of the filter solid particulates are shown in Figure 4.43-Figure 4.47. Figure 4.43 shows the 200X magnification of the filter solids. Individual particles on photo # 0967 were analyzed by EDAX. Figure 4.44-Figure 4.47 show the EDAX patterns for spots A-D, respectively. The elements identified in these EDAX spectra agree with the individual crystalline species identified in the XRD patterns, i.e., presence of Cl, Fe and S. Other elements identified in Figure 4.44-Figure 4.47 derive from the glass former minerals used in the melter feed, i.e., Al, Zn, Zr, Ti, K and Ca.

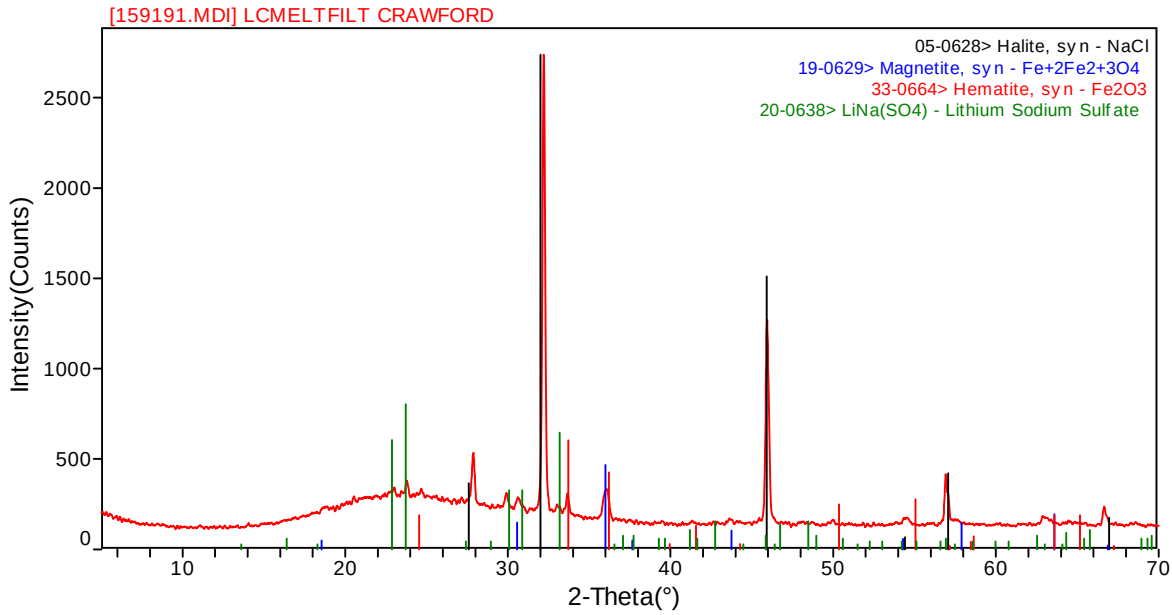


Figure 4.42 XRD Pattern from Analysis of Surrogate Filter Solid Particulates

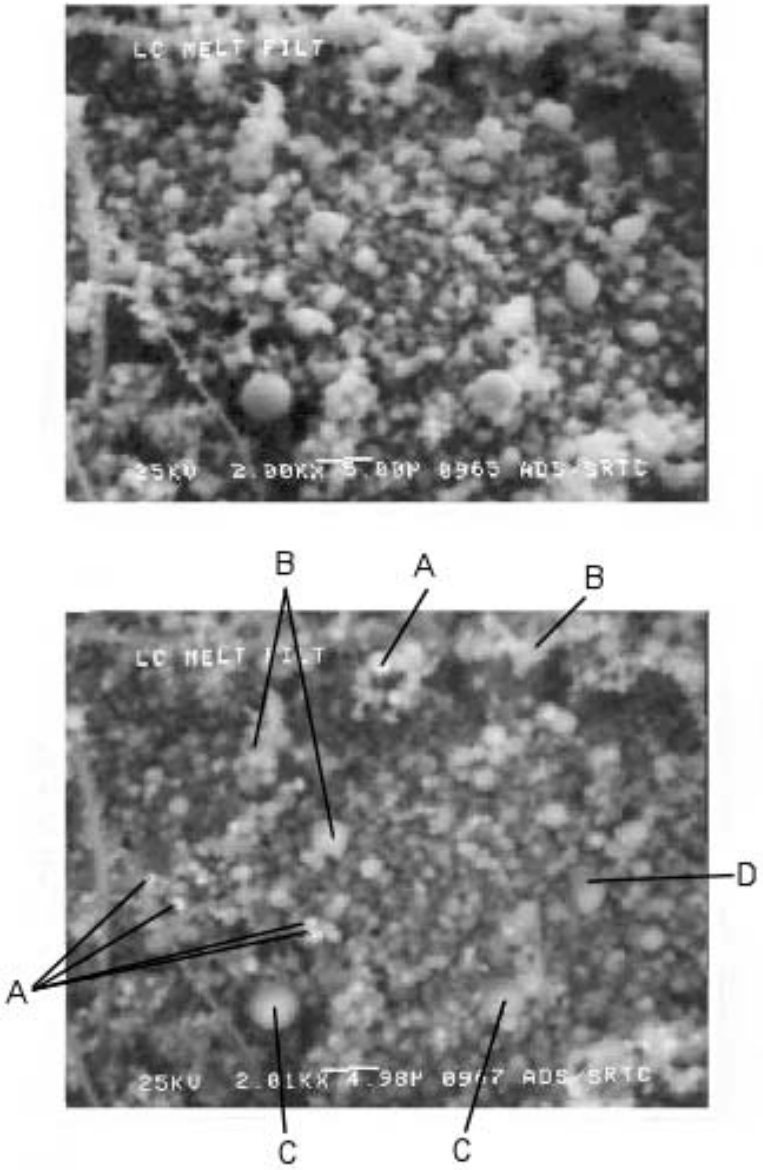


Figure 4.43 SEM Image of Photo # 0965 and # 0967

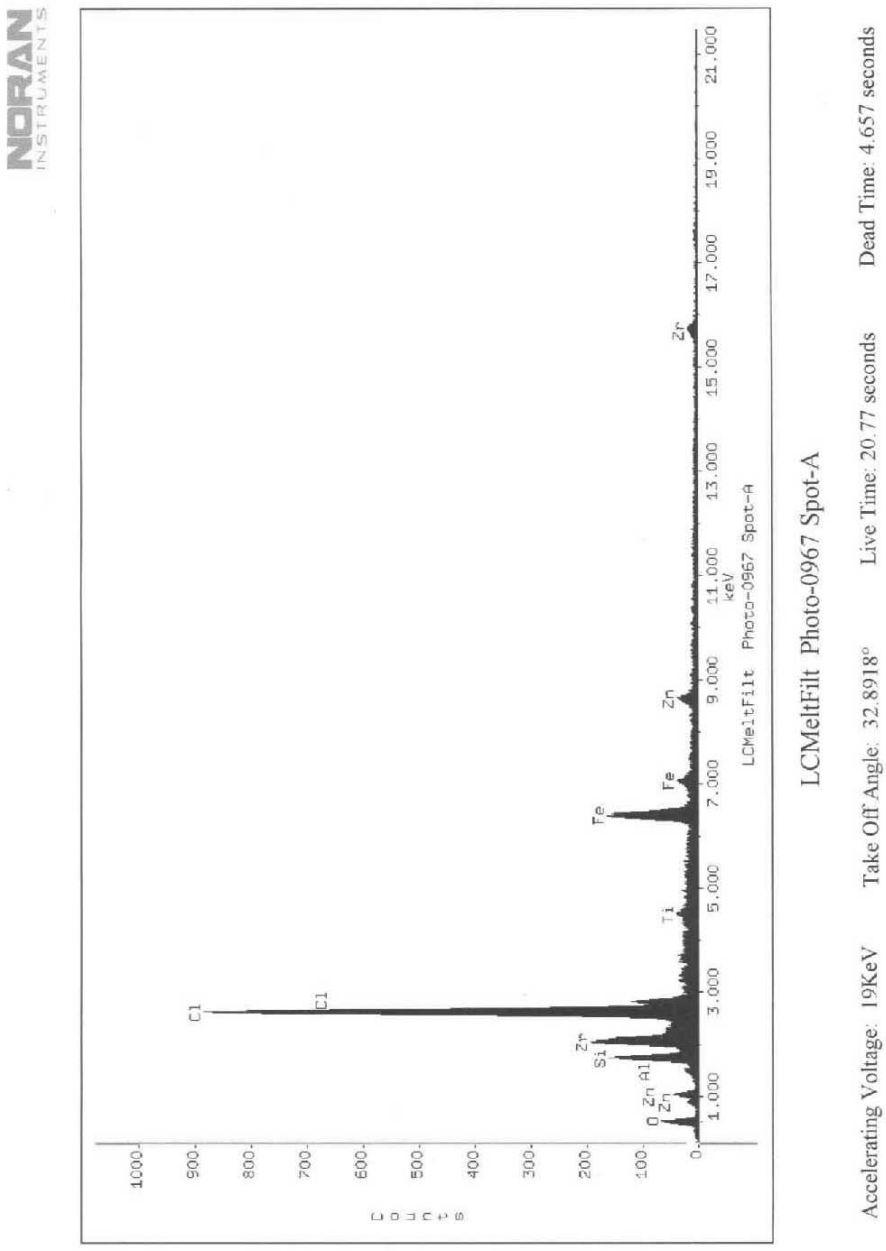


Figure 4.44 EDAX Pattern from Spot A Shown in SEM Image 0967

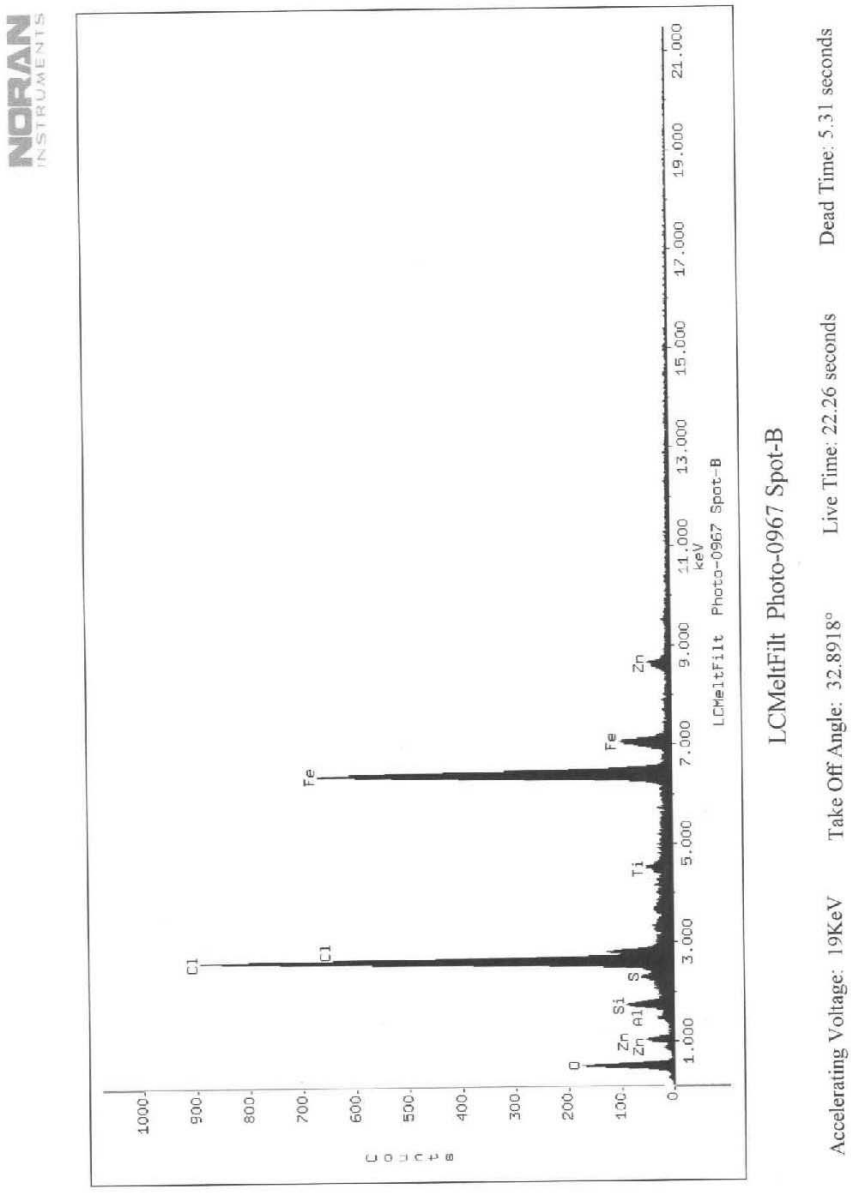


Figure 4.45 EDAX Pattern from Spot B Shown in SEM Image 0967.

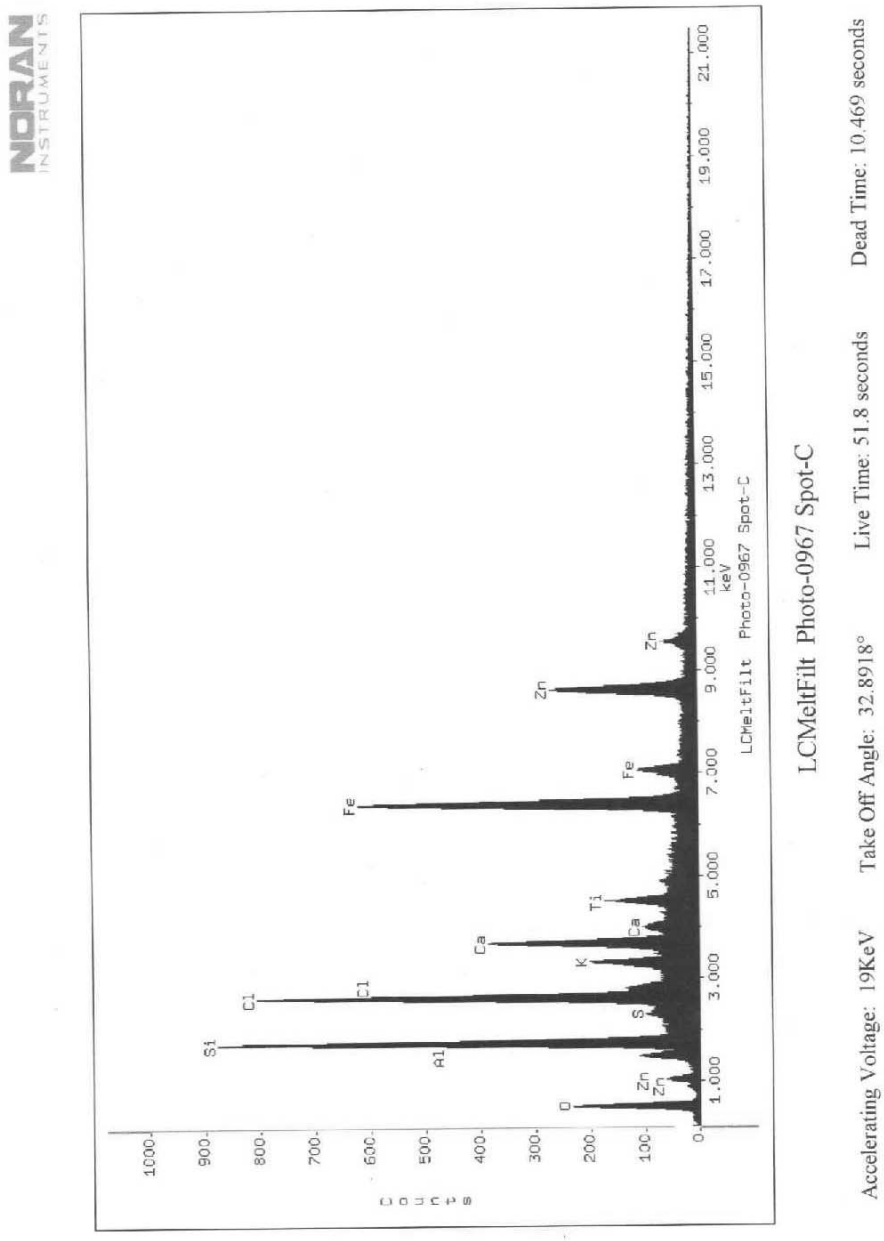


Figure 4.46 EDAX Pattern from Spot C Shown in SEM Image 0967

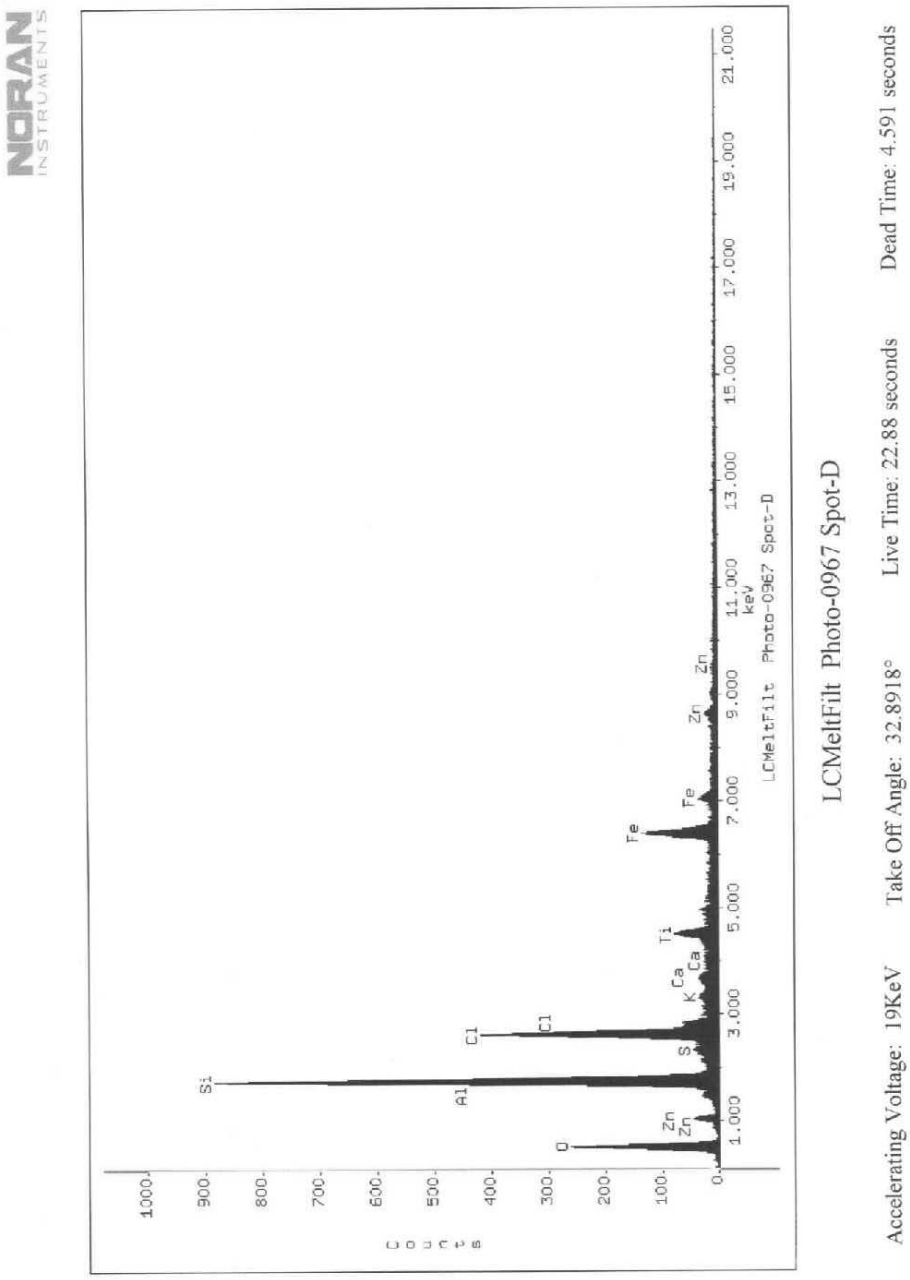


Figure 4.47 EDAX Pattern from Spot D Shown in SEM Image 0967

4.3.8. Radioactive Run Glass Preparation and Analysis

4.3.8.1. Glass Sample Treatment - Crucible Vitrification with Simulated Canister Cooling

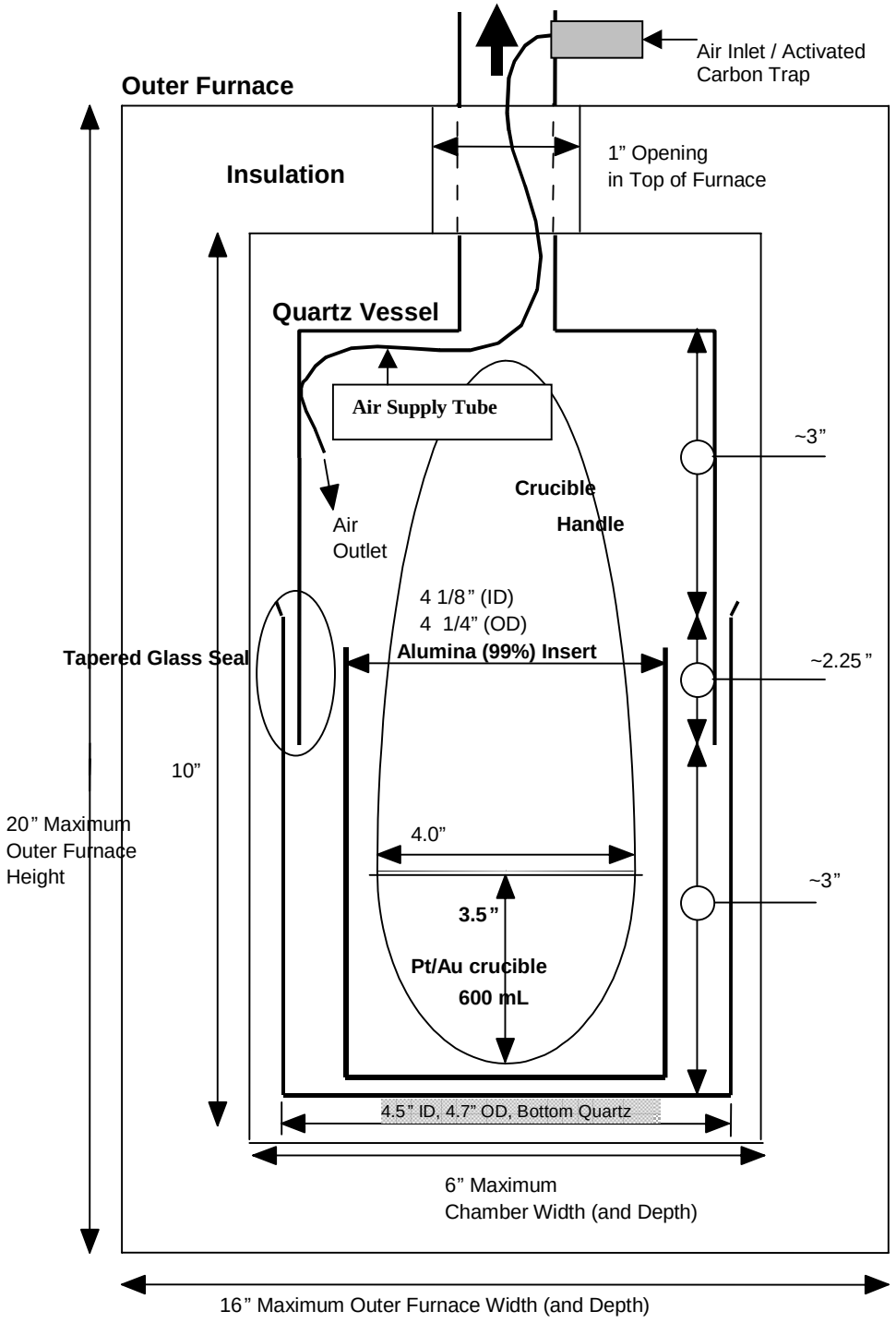
The goal of the crucible vitrification phase was to re-melt 1,000 grams each of the melter product surrogate #2 glass and the melter product radioactive AN-102 glass in platinum/gold crucibles, followed by simulated canister cooling of the glasses. This task was performed in a separate furnace described below after all of the Large C melter testing was completed. All subsequent glass testing described in this report was performed with the product glasses resulting from these remelt and controlled cooling tasks that were performed in a small furnace. This decision was agreed upon by the previous customer BNFL, Inc. and the interim customer CH2M Hill Hanford Group. The ~ 1,000 grams of glass from the discharge collection cans from the melter were remelted and cooled in a controlled manner to produce enough glass for all subsequent testing including chemical and radionuclide content, crystalline phase identification, durability testing and regulatory analyses. This was done to ensure that all of these above tests would be performed on glasses that would be representative (see discussion below on modeled cooling curve used in these tests) of actual melter glasses made in a full scale vitrification plant, i.e., it was impossible to control cool all of the actual melter discharge glass/cans from the Large C melter tasks so only a relatively small amount, ~ 1,000 grams, was used.

The target melt temperature for all active crucible scale vitrifications was 1150°C. These re-melt and controlled cooling tests were performed with ~ 500 grams of crushed melter product glass in 600-mL Pt/Au crucibles. The AN-102 waste stream is a Resource Conservation and Recovery Act (RCRA) listed waste. Even though this waste stream had been run through the Large C melter as described previously in this report, it was decided that these remelt and control cool tasks would still use an offgas system for vitrification testing to maintain certain listed waste component effluent levels below the allowable limits within SRTC lab facilities.[13] No experimental testing was performed relative to this small furnace vitrification offgas system for remelting and control cooling. After re-melting, the glasses were cooled according to a prescribed cooling schedule provided by VSL/RPP-WTP. A detailed diagram of the furnace as configured for these studies is presented in Figure 4.48. The furnace used for these studies is a DelTech Model DT-29-TL-610 Top Loading Laboratory Furnace capable of 1200°C with a programmable setpoint temperature control. The furnace was initially ‘baked out’ and calibration-tested before use according to recommended procedures by the vendor. Thermocouples and digital readouts used for calibration of the furnace were calibrated by the SRTC standards lab with NIST-traceable standards.

An offgas collection glassware apparatus was attached to the quartz glass system within the furnace. The offgas system contained a primary water-cooled condenser, a dry ice bath and two activated carbon beds in series. As shown in Figure 4.48, ambient air flowed into a quartz tube through an inlet carbon filter. The quartz vessel inside of the furnace contained an alumina insert that held the vitrification crucible. Incoming air

was swept through the quartz tube carrying offgas from inside the sealed quartz vessel system to the offgas system (condenser, cold trap and carbon filters). The central offgas tube exits the furnace through a 1" diameter opening cut out of the top of the furnace. All loading of equipment and samples into the furnace was performed through a top-located circular furnace door of 6" diameter (not shown in Figure 4.48).

The final carbon filter in the offgas system was connected to vacuum. A vacuum of nominally 2-3 inches of water was maintained on the crucible throughout the entire vitrification process. The vacuum was monitored periodically by connecting a water manometer to the air inlet. Vacuum was supplied by SRTC facility-supplied vacuum through a connection within the radiochemical hood. As mentioned above, no samples were collected from the crucible furnace offgas system during the remelt and control cooling tasks.



(Offgas exits to: (1) water condenser, (2) dry ice bath, (3) carbon filters in series)

Figure 4.48 Furnace Diagram

After the melting period in the crucible melts of the surrogate #2 glasses and the radioactive AN-102 glasses, the molten glass was cooled inside of the furnace according to the LAW cooling schedule provided by VSL/RPP-WTP.[46] The glass cooling profile was intended to simulate the temperature cooling profile of glass in containers planned for the RPP-WTP. The temperature range for the controlled cooling was 1100°C to 400°C. This cooling profile is shown in Figure 4.49. After the furnace program reached the lower temperature of the cooling schedule, heating of the furnace was discontinued and the system was allowed to cool to ambient temperature. The glass and offgas system were handled after the furnace vitrification system was at ambient temperature. An actual plot of the furnace setpoint and recorded temperatures along with the furnace output level is shown in Figure 4.50. The setpoint and actual temperature traces are shown in purple and green and the furnace output percentage is shown in blue. The initial portion of the re-melt involved rapidly heating the melter glass up to 1150°C. The glass was held at 1150°C for ~ 4 hours. The glass was then cooled for ~ 50-hr controlled cooling period. The final stage involved turning the furnace off (setpoint trace goes to 'zero') while the re-melted glasses cooled.

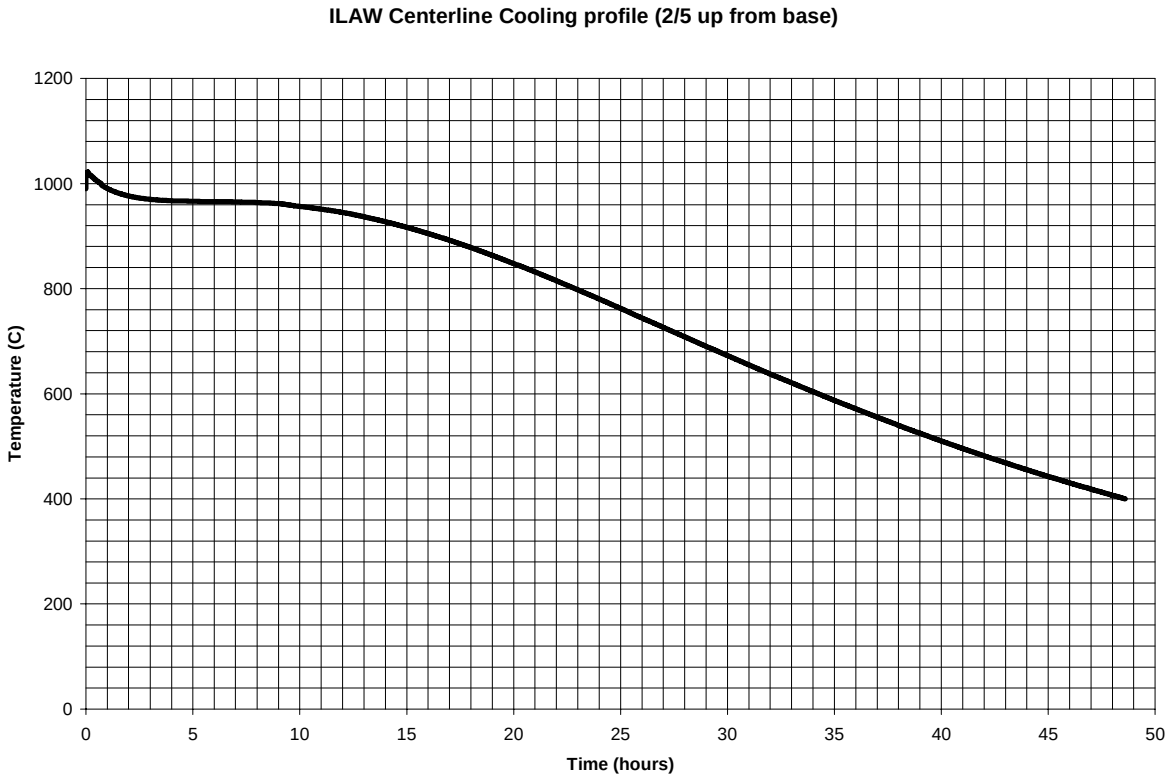


Figure 4.49 Cooling Curve for AN-102 Vitrification

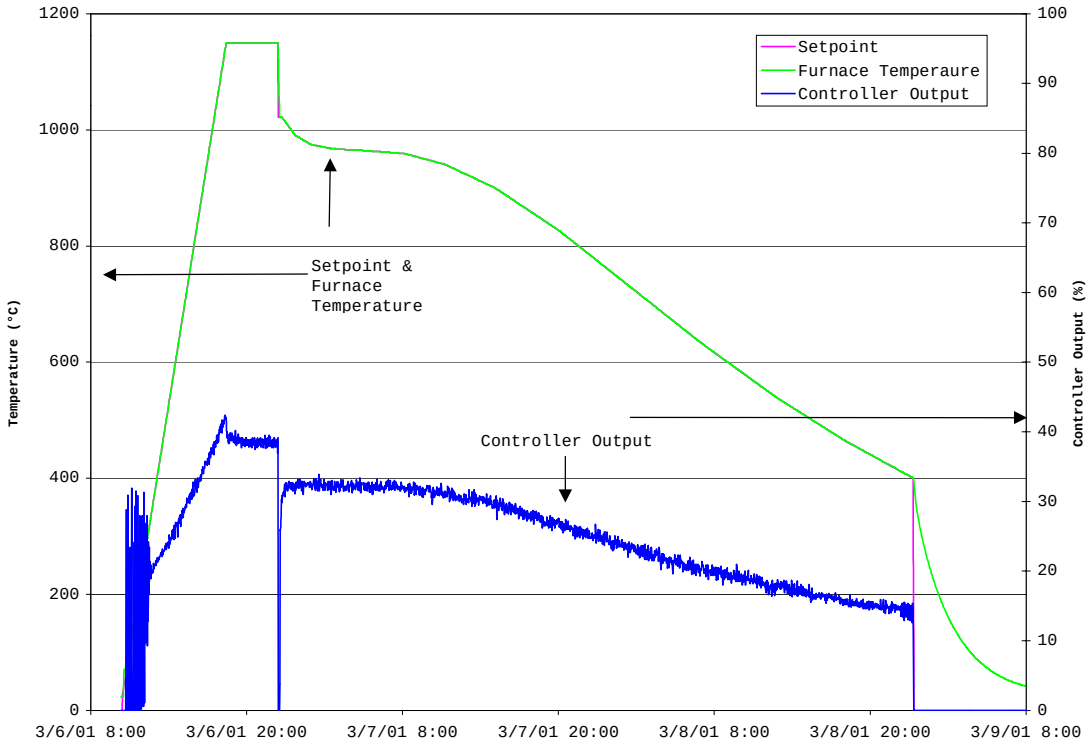


Figure 4.50 Temperature vs. Time for AN-102 Radioactive and Surrogate #2 Glass Re-melt Vitrification Tests.

4.3.8.2. Glass Dissolution and Analyses

Product glasses resulting from the above re-melt and simulated canister cooling activities (for both the surrogate #2 glass and the active AN-102 glass) were initially size-reduced by manually grinding the glass pieces using an agate mortar and pestle. The resulting glasses (1,000 grams of remelted and canister-cooled surrogate #2 glass and 1,000 grams of remelted and canister-cooled active AN-102 glass) were then used for all subsequent testing described in this report, i.e., chemical composition, radionuclide content, crystalline phase analysis and waste form testing by PCT. After manual grinding with the mortar and pestle, the glass was then further pulverized to a (-) 200 mesh size using a Mixer Mill with agate cups and agate grinding ball. Samples of the standard Low Activity Reference Material (LRM) glass[47,48] were also ground in the Mixer Mill. Resulting glass powders were verified to be (-) 200 mesh by passing through an ASTM-certified brass sieve. These powdered glass samples were then dissolved using versions of ASTM glass dissolution procedures involving Na_2O_2/NaOH fusion with acid uptake (ASTM C 1317-95), and acid dissolution (ASTM C 1412-99).

The peroxide fusion method used nominally 1.25 gram powdered glass samples added to 6 grams of Na_2O_2 and 4 grams of NaOH in Ni-crucibles. The resulting mixture was heated in a Thermolyne furnace at 700°C for 15 minutes. The resulting mixture was then cooled and transferred to a 250-mL volumetric plastic flask. A volume of 25 mL

of concentrated 15.7 Molar nitric acid was used to rinse the crucible and also added to the flask. The sample was then diluted to the 250-ml mark of the volumetric flask.

The acid dissolution method used nominally 1.25 gram powdered glass samples added to a wide mouth plastic bottle. Then 10 mL of 50% (~ 29 Molar) HF and 10 mL of concentrated 15.7 Molar HNO_3 were added. The bottle was capped and the mixture was heated in an oven at 105°C for 2 hours. The mixture was then cooled, 70 mL of 0.6M boric acid was added and the plastic bottle re-sealed and heated for an additional hour. After cooling, the solution was diluted to 250 ml in a volumetric flask with deionized water.

4.3.8.3. Product Consistency Test

The Product Consistency Test (PCT) was performed at 90°C on the LAW glasses resulting from remelt and controlled cooling. The durability was measured using the ASTM C-1285 standard nuclear waste glass durability test commonly referred to as the Product Consistency Test (PCT).[49] This is a crushed glass leach test at 90°C for 7 days using deionized water as leachate. The ground glass samples used for the PCT were prepared by grinding in a rotary blade grinder. This grinder contains a tungsten carbide blade and a stainless steel chamber. Triplicate tests were performed in sealed stainless steel vessels. The active AN-102 glass, the surrogate #2 glass and Low Activity Reference standard LRM glasses were tested at 90°C±2°C. Final leachate pHs were measured and final elemental concentrations of the filtered, acidified leachates were measured by ICP-ES. Purified ASTM Type I water obtained from a MilliQ water purification system was used as leachate in all tests. Ultrapure nitric acid was used to acidify the leachates prior to analysis.

4.3.9. Glass Characterization

4.3.9.1. Elemental Analyses

Radioactive AN-102, Surrogate #2 and the LRM glasses prepared for dissolution for analytical characterization were prepared using an agate ball/mill grinder. As mentioned above, glass from the remelt and controlled cooling tasks was used for these dissolutions. Dissolved glasses were analyzed by ICP-ES, AA(K) and Total Uranium methods to determine the inorganic components present in the glass matrix. Results are discussed below for the radioactive AN-102 glass, the Surrogate #2 glass and the LRM glass, respectively.

Table 4.32 shows the analytical results for the elemental analyses of the radioactive AN-102 glass by the sodium peroxide fusion and microwave acid dissolution methods. Note that B cannot be measured by the acid method, whereas Na, Ni, and K cannot be measured by the peroxide method. Results for the peroxide method for Mn are also unreliable. The elemental analyses have been converted to an oxide basis assuming the oxides shown in the table. The values used for Cl, F, and SO_3 are the values predicted

from the material balance rather than actual measured values; these elements were not measured.

These data appear to show that the Na loading in the radioactive AN-102 glass was only about 9.3 wt%. However, the fact that the total oxide for the acid dissolution totals to only 90 wt% indicates that the acid dissolution values should be normalized upward. We know that there are no significant elements that were not accounted for, so the majority of the "missing" amount is due to systematic error wherein all of the elements concentrations are 10% low. SRTC experience has shown that this is generally true for the acid dissolution versus the peroxide dissolution. Note that most of the significant oxides are smaller in the acid dissolution than in the peroxide dissolution. A notable exception is Zr, which is dissolved more readily in the acid dissolution than in the peroxide dissolution.

These data were normalized as presented in Table 4.33 in the following manner. It was assumed, for example, that the correct Na concentration was the value that results from normalizing the acid dissolution data to a total of 100 wt%. Similarly, the normalized B from the peroxide fusion was used as the B value in the acid dissolution. The results of cross-substituting values for Na, B, Mn, K, and Ni, are shown in the third and fourth 'normalized' columns of Table 4.33. Note that the data for neither dissolution can be summed to 100% due to the restriction that the cross-substituted values had to be equal for each dissolution. The results of this normalization are concentration values that are much closer (e.g., Li_2O: 2.83, 2.41 to 2.88, 2.68 wt%). Therefore, the Na concentration in the glass was actually about 10.2 to 10.4 wt% versus an original target of 11.8 wt%.

Table 4.33 also shows the average measured (and normalized) oxide concentrations, the target oxide concentrations from the VSL glass formulation spreadsheet, and the target oxide concentrations from the material balance. The material balance values are those derived from the measurements of the actual amounts of materials added the melter feed tank. The only significant elements in the waste feed were sodium (6.85-7.63 M) and aluminum (~8400 mg/L). The last column of Table 4.33 shows that the radioactive AN-102 glass was low in waste components (<1) relative to glass formers (>1, with exceptions Al, Ca, B and Mg). The material balance calculations and the glass formulation were performed using the Na measurement for the waste from the ICPES analysis only (7.63 M); the value from atomic absorption (AA) (6.85) was not used.

Table 4.34 shows a comparison of the actual radioactive AN-102 glass composition and the composition that would have been predicted from the material balance had the Na value from AA only been used. When this value is used, the Na content predicted is 10.29 wt%, which is exactly the same as the measured normalized value. Apparently, the Na value from the AA measurement was more accurate than the ICPES value.

Table 4.32 Elemental and Oxide Composition of Radioactive AN-102 Glass-Un-Normalized Data

(Most abundant oxides shown in boldface.)

Element	Peroxide Fusion %Elemental	Acid %Elemental	Oxide	Peroxide Fusion % Oxide	Acid % Oxide	Target % Oxide
Al	**3.03**	**2.50**	**Al_2O_3**	**5.73**	**4.72**	**6.15**
B	**3.00**	**(1)**	**B_2O_3**	**9.66**	**(1)**	**10.1**
Ba	0.00339	0.0757	BaO	0.00378	0.0846	(3)
Ca	**4.19**	**3.60**	**CaO**	**5.86**	**5.03**	**6.43**
Cd	0.00938	0.00389	CdO	0.0107	0.00444	0.00188
Co	0.0616	0.00395	CoO	0.0784	0.00502	1.78E-04
Cr	0.0586	0.0624	Cr_2O_3	0.0857	0.0912	0.0171
Cu	0.0318	0.0239	CuO	0.0398	0.0299	3.51E-04
Fe	**4.29**	**4.27**	**Fe_2O_3**	**6.13**	**6.11**	**6.50**
K (AA)	(2)	0.0673	K_2O	(2)	0.0811	0.0741
La	0.00480	0.00585	La_2O_3	0.00563	0.00686	3.64E-04
Li	**1.31**	**1.12**	**Li_2O**	**2.83**	**2.41**	**2.75**
Mg	**0.853**	**0.802**	**MgO**	**1.41**	**1.33**	**1.52**
Mn	(5)	0.0231	MnO_2	(5)	0.0366	1.01E-04
Mo	0.00416	0.00479	MoO_3	0.00625	0.00719	0.00260
Na	**(2)**	**6.80**	**Na_2O**	**(2)**	**9.17**	**11.8**
Na (AA)	**(2)**	**6.93**	**Na_2O**	**(2)**	**9.34**	
Ni	(2)	0.0307	NiO	(2)	0.0390	0.0127
P	0.0661	0.0999	P_2O_5	0.0841	0.127	0.0811
Pb	0.0570	0.0211	PbO	0.0613	0.0228	0.00429
Si	**22.7**	**19.9**	**SiO_2**	**48.6**	**42.7**	**46.8**
Sn	0.0167	0.0185	SnO_2	0.0211	0.0235	0.00155
Sr	0.0132	0.00918	SrO	0.0156	0.0109	0.0120
Ti	**0.775**	**0.821**	**TiO_2**	**1.29**	**1.37**	**1.13**
V	0.00599	0.00466	V_2O_5	0.0107	0.00832	(3)
Zn	**2.61**	**2.53**	**ZnO**	**3.25**	**3.15**	**3.04**
Zr	**2.14**	**2.40**	**ZrO_2**	**2.89**	**3.24**	**3.04**
U	0.000182	0.00110	UO_2	0.00124	0.000206	(3)
Cl (4)			Cl	0.0886	0.0886	0.0930
F (4)			F	0.0505	0.0505	0.0530
S (4)			SO_3	0.0360	0.0360	0.316
			Totals (7):	97.98	90.02	99.97

Notes:

(1) Boric acid used to dilute to mark in acid dissolved glass.
(2) Sodium used in NaOH/Na_2O_2 fusion in Ni-crucibles. K present as contaminant.
(3) These analytes not calculated in glass formulation.
(4) These and other elements not measured in AN-102 glasses analyzed at SRTC. See Regulatory Analyses Technical Report for analyzed values.[50] Target oxide values for these elements included in oxide Totals.
(5) Mn unreliable from Na_2O_2 fusion.
(6) Minor components not shown.
(7) Total oxide wt% values for Peroxide Fusion data calculated using Na, Ni, K, and Mn values from Acid data. Total oxide wt% values for Acid Dissolution method calculated using B value from Peroxide Fusion data.

Table 4.33 Elemental and Oxide Composition of Radioactive AN-102 Glass-Normalized Data

(Most abundant oxides shown in boldface.)

Oxide	Peroxide Fusion % Oxide	Acid % Oxide	Normalized Peroxide Fusion % Oxide	Normalized Acid % Oxide	Normalized Average % Oxide	Target (1) % Oxide (Formulation)	Target (2) % Oxide (Material Balance)	Material Balance / Formulation	Average / Target (Mat. Bal.)
Al_2O_3	**5.73**	**4.72**	**5.84**	**5.24**	**5.54**	**6.15**	**6.53**	**1.06**	**0.85**
B_2O_3	**9.66**		**9.85**	**9.85**	**9.85**	**10.1**	**10.3**	**1.02**	**0.96**
BaO	0.00378	0.0846	0.00385	0.0940	0.0489		1.05E-05		
CaO	**5.86**	**5.03**	**5.97**	**5.59**	**5.78**	**6.43**	**6.46**	**1.00**	**0.89**
CdO	0.0107	0.00444	0.0109	0.00494	0.00793	0.00188	0.00179	0.95	
CoO	0.0784	0.00502	0.0799	0.00558	0.0427	1.78E-04	0		
Cr_2O_3	0.0857	0.0912	0.0874	0.101	0.0944	0.0171	0.0145	0.85	
CuO	0.0398	0.0299	0.0406	0.0333	0.0369	3.51E-04	3.34E-04	0.95	
Fe_2O_3	**6.13**	**6.11**	**6.25**	**6.79**	**6.52**	**6.50**	**6.51**	**1.00**	**1.00**
K_2O		0.0811	0.00574	0.00763	0.00668	0.0741	0.0808		
La_2O_3	0.00563	0.00686	0.0901	0.0901	0.0901	3.64E-04	3.46E-04		
Li_2O	**2.83**	**2.41**	**2.88**	**2.68**	**2.78**	**2.75**	**2.77**	**1.01**	**1.00**
MgO	**1.41**	**1.33**	**1.44**	**1.48**	**1.46**	**1.52**	**1.55**	**1.02**	**0.94**
MnO_2		0.0366	0.0407	0.0407	0.0407	1.01E-04	0.0167		
MoO_3	0.00625	0.00719	0.00637	0.00799	0.00718	0.00260	0.00248	0.95	
Na_2O		**9.17**	**10.19**	**10.19**	**10.29**	**11.80**	**11.31**	**0.96**	**0.91**
Na_2O		**9.34**	**10.39**	**10.39**			**10.16**		
NiO		0.0390	0.0434	0.0434	0.0434	0.0127	0.0239	1.88	
P_2O_5	0.0841	0.127	0.0858	0.141	0.114	0.0811	0.115	1.42	
PbO	0.0613	0.0228	0.0625	0.0253	0.0439	0.00429	0.00408	0.95	
SiO_2	**48.6**	**42.7**	**49.5**	**47.4**	**48.5**	**46.8**	**46.5**	**0.99**	**1.04**
SnO_2	0.0211	0.0235	0.0216	0.0262	0.0239	0.00155	0.00132	0.85	
SrO	0.0156	0.0109	0.0159	0.0121	0.0140	0.0120	0.0114	0.95	
TiO_2	**1.29**	**1.37**	**1.32**	**1.52**	**1.42**	**1.13**	**1.21**	**1.07**	**1.17**
V_2O_5	0.0107	0.00832	0.0109	0.00925	0.0101		4.51E-05		
ZnO	**3.25**	**3.15**	**3.31**	**3.51**	**3.41**	**3.04**	**3.03**	**1.00**	**1.12**
ZrO_2	**2.89**	**3.24**	**2.95**	**3.60**	**3.27**	**3.04**	**3.11**	**1.02**	**1.05**
UO_2	0.00124	0.000206							
Cl (3)	0.0886	0.0886	0.0886	0.0886	0.0886	0.0930	0.0886	0.95	
F (3)	0.0505	0.0505	0.0505	0.0505	0.0505	0.0530	0.0505	0.95	
SO_3 (3)	0.360	0.360	0.360	0.360	0.360	0.316	0.360	1.14	
Totals:	98.22	89.98	100.25	98.61	99.93	99.97	98.93 (4)		

Notes:
(1) Target % Oxides from VSL formulation.
(2) Target % Oxides from material balance based on actual additions.
(3) Values are from material balance except for Formulation Target.
(4) Total is not 100% because Na from ICP value only used in material balance. Total uses average Na.

Table 4.34 Comparison of Measured Glass Composition with Material Balance Predictions

Oxide	Average % Oxide Measured	Target % Oxide (Mat. Bal., Initial Na = 7.63 M)	Target % Oxide (Mat. Bal., Initial Na = 6.85 M)
Al_2O_3	**5.54**	**6.53**	**6.61**
B_2O_3	**9.85**	**10.3**	**10.4**
BaO	0.0489	1.05E-05	1.06E-05
CaO	**5.78**	**6.46**	**6.53**
CdO	0.00793	0.00179	0.00181
CoO	0.0427	0	
Cr_2O_3	0.0944	0.0145	0.0147
CuO	0.0369	3.34E-04	3.38E-04
Fe_2O_3	**6.52**	**6.51**	**6.58**
K_2O	0.00668	3.46E-04	0.0817
La_2O_3	0.0901	0.0808	3.50E-04
Li_2O	**2.78**	**2.77**	**2.80**
MgO	**1.46**	**1.55**	**1.56**
MnO_2	0.0407	0.0167	0.0169
MoO_3	0.00718	0.00248	0.00251
Na_2O	**10.29**	**11.31**	**10.29**
Na_2O		**10.16**	
NiO	0.0434	0.0239	0.0241
P_2O_5	0.114	0.115	0.116
PbO	0.0439	0.00408	0.00413
SiO_2	**48.5**	**46.5**	**47.0**
SnO_2	0.0239	0.00132	0.00133
SrO	0.0140	0.0114	0.0116
TiO_2	**1.42**	**1.21**	**1.22**
V_2O_5	0.0101	4.51E-05	4.56E-05
ZnO	**3.41**	**3.03**	**3.06**
ZrO_2	**3.27**	**3.11**	**3.14**
UO_2			
Cl (3)	0.0886	0.0886	0.0896
F (3)	0.0505	0.0505	0.0511
SO_3 (3)	0.360	0.360	0.364
Totals:	99.93	98.93 (4)	99.49

Table 4.35 shows elemental weight percent of all analyzed components in the Surrogate #2 AN-102 glass. The elemental values were converted to their oxide components by multiplying by an oxide conversion factor. The target oxide composition shown in Table 4.35 is taken from the VSL glass recipe shown in Table 6.2 in Appendix 6.6. The peroxide fusion data and the acid dissolution data are compared to the target composition in the last two columns for those analytes in the glass at > 0.1 wt%. This comparison of analyzed oxide to target values is nominally within the 10% analytical uncertainty of the measurements used to

determine the various components in the glass. Elemental analysis was not performed for chlorine, fluorine and sulfur in the glass analyzed in SRTC. Values shown in Table 4.35 for these elements represent the maximum amounts that could be present from waste feed concentrations.

Table 4.36 shows similar data for the standard LRM glass. The target oxide composition shown in Table 4.36 is taken from averaging all of the reported round-robin analytical data reported by Ebert and Wolf.[47] The peroxide fusion data and the acid dissolution data are compared to the target composition in the last two columns for those analytes in the glass at > 0.1 wt%. This comparison of analyzed oxide to target values is nominally within the 10% analytical uncertainty of the measurements used to determine the various components in the glass. Elemental analysis was not performed for chlorine, fluorine and sulfur in the glass analyzed in SRTC. Values shown in Table 4.36 for these elements represent the maximum amounts that could be present from waste feed concentrations.

Table 4.35 Elemental and Oxide Composition of Surrogate #2 AN-102 Glass

AN102 Surrogate #2 Glass									
Element		Peroxide Fusion %Elemental		Acid %Elemental	Oxide Oxide	Peroxide Fusion % Oxide	Acid % Oxide	Target % Oxide	% of Target Peroxide	% of Target Acid
Al		3.43		3.17	Al_2O_3	6.48	5.98	6.14	105.55	97.36
B		3.04		(1)	B_2O_3	9.78	(1)	10.14	96.44	(1)
Ba	<	0.00		0.08	BaO	0.00	0.09	<0.00		
Ca		3.93		3.79	CaO	5.49	5.30	6.42	85.58	82.52
Cd		0.00		0.00	CdO	0.01	0.00	0.00		
Co		0.03		0.00	CoO	0.04	0.01	(3)		
Cr		0.05		0.06	Cr_2O_3	0.07	0.08	0.02		
Cu		0.02		0.03	CuO	0.03	0.04	<0.00		
Fe		4.20		4.38	Fe_2O_3	6.01	6.26	6.50	92.40	96.32
K (AA)		0.13		0.06	K_2O	0.16	0.08	0.10		
La	<	0.01		0.01	La_2O_3	0.01	0.01	(3)		
Li		1.17		1.09	Li_2O	2.52	2.35	2.75	91.86	85.45
Mg		0.86		0.86	MgO	1.43	1.43	1.52	94.42	94.36
Mn		0.09		0.03	MnO_2	0.14	0.04	<0.00		
Mo		0.00		0.00	MoO_3	0.01	0.01	<0.00		
Na		(2)		8.35	Na_2O	(2)	11.26	11.80	(2)	95.39
Na (AA)		(2)		8.66	Na_2O	(2)	11.67	11.80	(2)	98.92
Ni		(2)		0.03	NiO	(2)	0.04	0.01	(2)	
P		0.05		0.08	P_2O_5	0.07	0.11	(3)		
Pb	<	0.03		0.02	PbO	0.04	0.02	<0.00		
Si		22.62		20.72	SiO_2	48.40	44.33	46.77	103.49	94.78
Sn	<	0.02		0.02	SnO_2	0.02	0.03	(3)		
Sr		0.01		0.01	SrO	0.02	0.01	(3)		
Ti		0.86		0.90	TiO_2	1.44	1.50	1.13	127.57	133.10
V		0.00		0.00	V_2O_5	0.01	0.01	(3)		
Zn		2.56		2.54	ZnO	3.19	3.16	3.03	105.15	104.29
Zr		2.07		2.28	ZrO_2	2.79	3.08	3.03	92.07	101.77
U	<	0.00	<	0.00	UO_2	0.00	0.00	(3)		
Cl (4)					Cl	0.21	0.21	0.21		
F (4)					F	0.06	0.06	0.06		
S (4)					SO_3	0.29	0.29	0.29		
					Totals:*	100.19	95.76	99.91		

Notes:

(1) Boric acid used to dilute to mark in acid dissolved glass.

(2) Sodium used in $NaOH/Na_2O_2$ fusion in Ni-crucibles.

(3) These analytes not calculated in glass formulation.

(4) These and other elements not measured in AN-102 glasses analyzed at SRTC. See Regulatory Analyses Technical Report for analyzed values. [50] Target oxide values for these elements included in oxide Totals.

* Total oxide wt% values for Peroxide Fusion method calculated by adding sodium values from Acid method, and nickel values from Acid Dissolution data. Total oxide wt% values for Acid Dissolution method calculated by adding boron value from Peroxide Fusion data.

Table 4.36 Elemental and Oxide Composition of LRM Standard Glass

LRM Standard Glass									
Element		Peroxide Fusion %Elemental		Acid %Elemental	Oxide Oxide	Peroxide Fusion % Oxide	Acid % Oxide	Target % Oxide	% of Target Peroxide	% of Target Acid
Al		5.09		5.12	Al_2O_3	9.61	9.67	9.54	100.71	101.38
B		2.34		(1)	B_2O_3	7.55	(1)	7.90	95.55	-
Ba		0.00		0.01	BaO	0.00	0.01	<0.01		
Ca		0.47		0.37	CaO	0.66	0.52	0.54	121.51	96.57
Cd		0.14		0.15	CdO	0.16	0.18	0.16	101.03	110.11
Co		0.03		0.00	CoO	0.03	0.00	(3)		
Cr		0.13		0.15	Cr_2O_3	0.19	0.21	0.19	101.32	112.44
Cu		0.07		0.07	CuO	0.09	0.09	(3)		
Fe		0.99		1.04	Fe_2O_3	1.42	1.49	1.42	99.91	105.06
K (AA)		1.24		1.27	K_2O	1.49	1.53	1.48	100.83	103.37
La	<	0.01		0.01	La_2O_3	0.01	0.01	0.02		
Li		0.05		0.05	Li_2O	0.10	0.10	0.11	91.99	91.60
Mg		0.07		0.07	MgO	0.11	0.11	0.10	110.51	114.45
Mn		0.12		0.06	MnO_2	0.18	0.10	0.08		
Mo		0.07		0.08	MoO_3	0.10	0.11	0.10	97.91	113.65
Na		(2)		15.50	Na_2O	(2)	20.90	20.03	-	104.33
Na (AA)		(2)		14.26	Na_2O	(2)	19.22	20.03	-	95.94
Ni		(2)		0.16	NiO	(2)	0.20	0.19	-	104.77
P		0.20		0.30	P_2O_5	0.26	0.38	0.53	49.02	71.53
Pb		0.12		0.11	PbO	0.12	0.12	0.10	124.28	115.29
Si		22.62		24.41	SiO_2	48.39	52.21	54.26	89.19	96.22
Sn	<	0.01		0.02	SnO_2	0.01	0.02	0.03		
Sr		0.00		0.00	SrO	0.01	0.00	(3)		
Ti		0.09		0.09	TiO_2	0.14	0.14	0.11	131.67	129.49
V		0.00		0.00	V_2O_5	0.00	0.00	(3)		
Zn		0.10		0.01	ZnO	0.12	0.02	(3)		
Zr		0.65		0.79	ZrO_2	0.88	1.07	0.93	95.03	115.28
U	<	0.00	<	0.00	UO_2	0.00	0.00	(3)		
Cl (4)					Cl	0.07	0.07	0.07		
F (4)					F	0.86	0.86	0.86		
S (4)					SO_3	0.30	0.30	0.30		
					Totals:*	93.15	97.15	99.05		

Notes:

(1) Boric acid used to dilute to mark in acid dissolved glass.

(2) Sodium used in $NaOH/Na_2O_2$ fusion in Ni-crucibles.

(3) These analytes not calculated in glass formulation.

(4) These and other elements not measured in AN-102 glasses analyzed at SRTC. See Regulatory Analyses Technical Report for analyzed values. [50] Target oxide values for these elements included in oxide Totals.

* Total oxide wt% values for Peroxide Fusion method calculated by adding sodium values from Acid method, and nickel values from Acid Dissolution data. Total oxide wt% values for Acid Dissolution method calculated by adding boron value from Peroxide Fusion data.

4.3.9.2. Radiochemical Analyses

Dissolved glasses resulting from remelting and controlled cooling were analyzed by various radiochemical methods. All reported analytical data is shown in Table 4.37 for the glasses dissolved by peroxide fusion. Similar data is shown in Table 4.38 for glasses dissolved by acid dissolution. All results were reported in either units of dpm/mL or dpm/g for these dissolved glass samples. These values were converted to specific activities of radionuclides in the glasses (μCi/g glass) using Equation 4.2 below:

Equation 4.2:

dpm/mL x (mL/grams glass) x (1 min/60 s) x (1Ci/3.7E+10 dps) x 1E+06 μCi/1Ci

dpm/g x (grams glass) x (1 min/60 s) x (1Ci/3.7E+10 dps) x 1E+06 μCi/1Ci

The exact amounts of each glass weighed out in the dissolution process to produce the 200-mL or 250-mL solutions are noted at the bottom of Table 4.37 and Table 4.38. All radionuclide values reported in Table 4.37 and Table 4.38 were analyzed directly except for Y^{90} and Ba^{137m}. $Yttrium^{90}$ (half-life = 2.671 days) is a decay product of Sr^{90} (half-life = 28.5 years) and is in secular equilibrium with Sr^{90}. Thus the concentration of this short-lived Y^{90} daughter-product is equal to Sr^{90}. $Barium^{137m}$ is a metastable decay product of Cs^{137} and is in secular equilibrium with Cs^{137}. The activity of Ba^{137m} is 95% of that for Cs^{137} since 5% of the Cs^{137} decays directly to stable Ba^{137}.

Table 4.37 and Table 4.38 indicate that Sr^{90} and Y^{90} are the predominant radionuclides in the active AN-102 glass at about 1 μCi/g levels. Cs^{137} and Ba^{137m} and Tc^{99} are present at nominally much lower specific activities (~0.02 to ~0.03 μCi/g) in the active AN-102 glass. Conversion of the tabulated radionuclide values from units of μCi/g glass to Ci/m^3 can be calculated using the measured density of both the Envelope C glass = 2.87 g/cm^3 and LRM glass = 2.52 g/cm^3 per Equation 4.3 below.[47,48,50]

Equation 4.3:

Envelope C glass:

1 μCi/g x 2.87 g/cm^3 x 1 Ci/ 1E+06 μCi x (100 cm/1 m) ^{3} = 2.87 Ci/m^3

LRM glass:

1 μCi/g x 2.52 g/cm^3 x 1 Ci/ 1E+06 μCi x (100 cm/1 m) ^{3} = 2.52 Ci/m^3

Section C, Specification 2.2.2.8 of the RPP-WTP-DOE/ORP contract indicates that average radionuclide concentration limitations shall be less than 3 Ci/m^3 for Cs^{137}, <20 Ci/m^3 for Sr^{90} and < 0.1 Ci/m^3 for Tc^{99} for the ILAW glasses.[51]

Conversion of the units shown in Table 4.37 as μCi/g to units of ηCi/g indicates that the transuranic (TRU) content of the AN-102 glass samples is ~ 21 ηCi/g measured total alpha (0.021 μCi/g), or ~ 8 ηCi/g (0.008 μCi/g) from summation of the Pu^{238}, Pu^{239} and Pu^{240}, Am^{241} and Cm^{244} isotope alpha-emitters. These values are at least 4X lower than the DOE/ORP contract limit of 100 nCi/g.[51] Similarly, Table 4.38 shows that the TRU content of the AN-102 glass sample is ~ 16 ηCi/g measured total alpha, or ~ 6 ηCi/g from summation of the Pu/Am/Cm alpha-emitters. According to the Code of Federal Regulations (CRF) (10 CFR 61.56, Waste Classification, Table 1), a limit of 3,500 ηCi/g is provided for the beta-emitter radioisotope Pu^{241}. Both Table 4.37 and Table 4.38 indicate that Pu^{241} was not detected in dissolved AN-102 glass to the detection level of < 1.1 ηCi/g for peroxide fusion and was detected in the acid dissolved glass at 1.8 ηCi/g for acid dissolved glass. Overall agreement between various radionuclides analyzed by peroxide fusion (Table 4.37) and acid dissolution (Table 4.38) is very good.

Mass spectrometry values for Tc^{99} measured in the dissolved glasses in units of μg/L in Table 4.37 and Table 4.38 were converted to specific activity values in units of μCi/g via Equation 4.4.

Equation 4.4:

$a = 3.5778E+05 \times (g / (t_Y \times M))$

Where:
a = activity in Curies (Ci)
3.5778E+05 = constant (Ci*years/g)
g = mass-99 in grams
t_Y = ½ life of Tc^{99} in years = 2.13E+05 years
M = mass number of Tc^{99} = 99

Using the mass spectral value for Tc^{99} from analyses of the acid dissolved radioactive Large C AN102 glass as 1.86E-6 mg/L and solving Equation 4.4 above, one calculates an average specific activity for Tc^{99} in the radioactive AN-102 glass to be 6.35 E-02 μCi/g glass, via:

$a(Ci/L) = 3.5778E+05 \times (1.86E-6\ g/L / (2.13E+05 \times 99))$

$a(Ci/L) = 3.16E-8\ Ci/L$

$a(Ci/g\ glass) = 3.16E-8\ Ci/L \times (0.250L/1.2424\ g\ glass)$

$a(\mu Ci/g\ glass) = 6.35E-9\ Ci/g$, or $6.35E-3\ \mu Ci/g$

There is good agreement from comparison of the Tc^{99} values shown in Table 4.37 and Table 4.38 when the radiochemical values are compared to those calculated from mass spectrometry data.

Table 4.37 Radionuclide Analyses for Peroxide Fusion Dissolved Glasses

Method	Component	3-162018			3-162019		3-162020		3-162021	
		LCRAD-PF			LCSUR-PF		LCSTD-PF		LC REAGBLNK	
		dpm/mL	uCi/g	Ci/m^3	dpm/mL	uCi/g	dpm/mL	uCi/g	dpm/mL	uCi/mL
Gamma Scan	Co^{60}	2.56E+02	2.10E-02	6.03E-02	< 1.45E+01	1.30E-03	< 4.71E+000	3.78E-04	< 1.68E+01	7.57E-06
	Cs^{137}*	3.11E+02	2.55E-02	7.33E-02	< 1.30E+01	1.16E-03	< 1.52E+001	1.22E-03	< 1.30E+01	5.86E-06
	Eu^{154}	2.36E+02	1.93E-02	5.55E-02	< 1.13E+01	1.01E-03	< 1.24E+001	9.95E-04	< 1.60E+01	7.21E-06
	Eu^{155}	1.75E+02	1.44E-02	4.13E-02	< 2.58E+01	2.31E-03	< 2.06E+001	1.65E-03	< 2.27E+01	1.02E-05
Total Alpha		2.57E+02	2.11E-02	6.05E-02	< 3.08E+01	2.76E-03	< 2.67E+01	2.14E-03	< 2.13E+01	9.59E-06
Total Beta		3.48E+04	2.85E+00	8.19E+00	9.70E+01	8.69E-03	< 9.50E+01	7.62E-03	< 9.50E+01	4.28E-05
		dpm/g			dpm/g		dpm/g			
Separation Counting	Sr^{90}*	1.32E+06	5.95E-01	1.71E+00	1.15E+04	5.18E-03	< 6.12E+03	2.76E-03	< 3.44E+01	1.55E-05
		dpm/mL			dpm/mL		dpm/mL			
Separation Counting	Tc^{99}*	8.02E+01	6.58E-03	1.89E-02	< 4.37E+00	3.92E-04	4.29E+00	3.44E-04	6.44E+00	2.90E-06
		ug/L								
ICP Mass Spec		< 2.48E+00	< 7.66E-03	< 2.20E-02						
		dpm/g			dpm/g		dpm/g			
Separation Counting	Pu^{238}	1.37E+03	6.17E-04	1.77E-03	1.53E+02	6.89E-05	< 9.58E+01	4.32E-05	< 2.09E+00	9.41E-07
Separation Counting	Pu$^{239/240}$	8.21E+01	3.70E-05	1.06E-04	< 2.03E+02	9.14E-05	< 8.86E+01	3.99E-05	< 1.04E+00	4.68E-07
Separation Counting	Pu^{241}	< 2.52E+03	1.14E-03	3.26E-03	< 7.67E+03	3.45E-03	< 6.36E+03	2.86E-03	< 2.97E+01	1.34E-05
Separation Counting	Am^{241}	9.95E+03	4.48E-03	1.29E-02	< 7.20E+02	3.24E-04	< 7.84E+02	3.53E-04	< 1.28E+03	5.77E-04
Separation Counting	Cm^{244}	5.58E+03	2.51E-03	7.21E-03	< 3.29E+01	1.48E-05	< 4.41E+01	1.99E-05	< 4.95E+01	2.23E-05
AN102 Radioactive Glass = ADS#018 = 1.0988 grams in 0.2 L										
AN102 Surrogate Glass = ADS#019 = 1.2568 grams in 0.250 L										
LRM Standard Glass = ADS#020 = 1.1232 grams in 0.2 L										

* Specification limits (Reference 51): < 3 Ci/m^3 for Cs^{137}, < 20 Ci/m^3 for Sr^{90} and < 0.1 Ci/m^3 for Tc^{99}; Densities used for Env. C glass (2.87 g/cm^3) and LRM glass (2.52 g/cm^3) from References 50 and 47b, respectively.

Table 4.38 Radionuclide Analyses for Acid Dissolved Glasses

Method	Component	3-162006			3-162007		3-162008		3-162009	
		LCRAD-AC			LCSUR-AC		LCSTD-AC		LC REAGBLNK	
		dpm/mL	uCi/g	Ci/m^3	dpm/mL	uCi/g	dpm/mL	uCi/g	dpm/mL	uCi/mL
Gamma Scan	Co^{60}	2.28E+02	2.07E-02	5.93E-02	< 4.71E+00	4.18E-04	< 1.62E+01	1.46E-03	< 1.62E+01	7.30E-06
	Cs^{137}*	2.81E+02	2.54E-02	7.30E-02	< 1.16E+01	1.03E-03	< 1.71E+01	1.54E-03	< 2.03E+01	9.14E-06
	Ba^{137m}	2.67E+02	2.42E-02	6.95E-02	< 1.10E+01	1.00E-03	< 1.63E+01	1.47E-03	< 1.93E+01	8.71E-06
	Eu^{154}	1.79E+02	1.62E-02	4.66E-02	< 9.35E+00	8.30E-04	< 1.39E+01	1.25E-03	< 1.24E+01	5.59E-06
	Eu^{155}	8.47E+01	7.67E-03	2.20E-02	< 2.01E+01	1.79E-03	< 1.86E+01	1.67E-03	< 2.14E+01	9.64E-06
Total Alpha		1.87E+02	1.69E-02	4.86E-02	< 2.70E+01	2.40E-03	< 2.36E+01	2.12E-03	< 2.17E+01	9.77E-06
Total Beta		2.66E+04	2.41E+00	6.92E+00	< 1.02E+02	9.06E-03	< 1.02E+02	9.18E-03	< 9.50E+01	4.28E-05
		dpm/g			dpm/g		dpm/g			
Separation Counting	Sr^{90}*	1.78E+06	8.02E-01	2.30E+00	< 4.56E+03	2.05E-03	< 4.62E+03	2.08E-03	< 2.31E+01	1.04E-05
	Y^{90}	1.78E+06	8.02E-01	2.30E+00	< 4.56E+03	2.05E-03	< 4.62E+03	2.08E-03	< 2.31E+01	1.04E-05
		dpm/mL			dpm/mL		dpm/mL			
Separation Counting	Tc^{99}*	7.09E+01	6.43E-03	1.84E-02	< 5.83E-01	5.18E-05	< 5.38E-01	4.84E-05	< 6.06E-01	2.73E-07
		ug/L								
ICP Mass Spec		1.86E+00	6.35E-03	1.82E-02						
		dpm/g			dpm/g		dpm/g			
Separation Counting	Pu^{238}	1.06E+03	4.77E-04	1.37E-03	2.01E+02	9.05E-05	< 3.58E-02	1.61E-08	< 1.68E+00	7.57E-07
Separation Counting	$Pu^{239/240}$	1.41E+03	6.35E-04	1.82E-03	1.16E+02	5.23E-05	< 1.37E-02	6.17E-09	< 1.53E+00	6.89E-07
Separation Counting	Pu^{241}	4.07E+03	1.83E-03	5.26E-03	< 8.28E+03	3.73E-03	< 5.10E-03	2.30E-09	< 3.71E+01	1.67E-05
Separation Counting	Am^{241}	8.29E+03	3.73E-03	1.07E-02	< 1.39E+03	6.26E-04	< 5.34E+02	2.41E-04	< 1.26E+03	5.68E-04
Separation Counting	Cm^{244}	4.50E+03	2.03E-03	5.82E-03	< 6.86E+01	3.09E-05	< 4.83E+01	2.18E-05	< 6.99E+01	3.15E-05
AN102 Radioactive Glass = ADS#006 = 1.2424 grams in 0.25 L										
AN102 Surrogate Glass = ADS#007 = 1.2679 grams in 0.250 L										
LRM Standard Glass = ADS#008 = 1.2516 grams in 0.25 L										

***** Specification limits (Reference 51): < 3 Ci/m3 for Cs^{137}, < 20 Ci/m3 for Sr^{90} and < 0.1 Ci/m3 for Tc^{99}; Densities used for Env. C glass (2.87 g/cm3) and LRM glass (2.52 g/cm3) from References 50 and 47b, respectively.

4.3.9.3. Results of 'Association of Standards and Test Methods' (ASTM) Test C 1285 – 97 Leach Test 'Product Consistency Test' (PCT) on AN-102 ILAW Glass

The two tables in this section show the results of the standard ASTM C 1285-97 test on the radioactive AN-102 glass and on the surrogate #2 glass. Both of these glasses tested were produced in the remelting and controlled cooling tasks described above. This standard test is commonly called the Product Consistency Test (PCT) and is performed at 90°C.[49] The procedure for PCT-A of the ASTM C 1285-97 was strictly followed for this test. Quadruplicate samples of the AN-102 glass surrogate #2 were used and, as prescribed by the procedure, triplicate blanks. The standard glasses, Low Activity Reference Material (LRM)[47,48] and Analytical Reference Material (ARM)[52] were also leached in the test with the AN-102 and the surrogate # 2 glass.

In the contract, SRTC was required to subject the AN-102 and the surrogate glass to the PCT and report the results for B, Si, and Na. Section 2.2.2.17.2 of Mod. No. M013 of the contract specifies that in the PCT, the glass shall have a normalized mass loss less than 2 g/m^2 (2 grams of glass per square meter of exposed surface area of glass tested in a 90°C PCT) based on each of the elements B, Si, and Na. The LRM[47,48], and the standard (ARM) glass[52] were also tested with the AN-102 glass to confirm that the test conditions for the PCT were properly controlled. Table 4.39 gives the average concentrations in ppm of B, Si, and Na, in the final leachates after the tests. The averages of the final pH values of the leachates are also presented. The concentrations have been corrected for the acidification dilutions of the leachates as required by the ASTM procedure. The raw data that is the bases of these averages are in Appendix 6.18. The last row of the table presents the consensus results of the PCT of a round robin on the LRM glass involving six different laboratories.[47,48] As can be seen, the concentrations measured in this test for LRM glass were very close to the consensus concentrations.

Table 4.39 Average Concentrations (ppm) of B, Si, and Na, and the Final pH from the 90°C PCT.

Sample ID	B	Si	Na	pH (b)
Blanks (a)	0.013	0.035	0.222	6.48
ARM (a)	19.2	68.7	39.6	10.2
AN-102 RAD (c)	12.6	50.5	35.7	9.90
AN-102 SUR (c)	13.4	51.9	43.7	10.0
LRM (a)	30.6	87.1	178.9	10.6
LRM (d)	26.7	82.0	159.7	11.7

(a) Based on triplicate tests.
(b) Initial pH of the leach water was 6.57
(c) Based on quadruplicate tests.
(d) Published consensus values for LRM glass. [47,48]

The results for the blanks indicate that contamination of the leachates from possible impurities in the water or on the stainless steel vessels was negligible. The results for the standard ARM-1 glass were compared to a control chart based on results for previous Product Consistency Tests on this standard glass.[53] This comparison is part of the ASTM procedure. The results for the ARM-1 glass were between the lower and upper control limits (See Appendix 6.18 for PCT data sheet on ARM glass) indicating that all the test conditions were properly controlled. Standard solutions containing B, Si, and Na were submitted for analysis with the leachates. The measured results agreed within 10% of the known values (see Appendix 6.18) indicating that the analyses were sufficiently accurate. Thus the results of the PCT are acceptable.

The final pH is an approximate indication of the durability of the glass in a PCT. The higher the final pH, the lower the durability. The measured concentrations are a much more accurate indication. Based on the results in Table 4.39 the AN-102 glass appears slightly more durable that the LRM glass.

Normalized mass losses are the best indication of the durability of a glass in a PCT. Normalization accounts for the concentration of an element in the glass. The normalized release is a measure of the total mass of glass leached in a PCT based on a specific element in the glass. The specification for ILAW glass is that the normalized mass losses based on B, Si, and Na, shall each be <2 grams of glass per square meter of exposed surface area of glass tested in a 90°C PCT for 7 days.[51] In the PCT, the glass is carefully sieved through standard mesh size sieves so that the surface area of the glass is reproducible from test to test. The exposed surface area of the glass in a PCT has been estimated by assuming that the particles are spherical and that the distribution of particle sizes is Gaussian.[54] The size of the holes in the 100 and 200 mesh sieves are 0.149 mm and 0.074 mm, respectively. Thus the diameter of the spheres range between these two values with an average value of $1.12X10^{-4}$ m. Based on these assumptions the exposed surface area has been calculated to be 0.02 m^2 per gram of sieved glass.

The normalized mass loss in terms of grams of glass leached is calculated using the following equation

$NR_i = (C_i/C_{ig})/0.02E3$

Where NR_i is normalized release based on element i, in grams of glass leached per square meter of glass exposed in the PCT. C_i is the concentration of element i in ppm in the leachate and C_{ig} is the weight percent of element i in the glass. The PCT procedure prescribes that for every gram of glass, there is exactly 10 mL of leachate; thus there is 0.02 m^2 of glass surface area per 10 mL of leachate. The factor of 1000 in the denominator results from C_i being in ppm, C_{ig} in weight percent, and the test condition of 10 mL per 0.02 m^2 of glass.

Table 4.40 presents the normalized releases calculated from the PCT data and the measured composition of the radioactive AN-102 glass (Table 4.32) and the surrogate glass (Table 4.35). Table 4.40 presents the averages and standard deviations based on triplicate tests. The normalized releases for all three elements are less than the upper limit of 2 g glass/m^2 specified in section 2.2.2.17.2 of the Section C, Statement of Work.[51] Thus the glass meets this specification. Table 4.40 also shows similar normalized results for the LRM glass calculated from the PCT data and the measured composition of the LRM glass (Table 4.36).

Table 4.40 Normalized Mass Losses (g glass/m^2) Based on B, Si, and Na, for AN-102 Glass in a 90°C PCT.

	AN-102 Glass	AN-102 Surrogate Glass	LRM Glass
Element	**Normalized Release[a]**	**Normalized Release[a]**	**Normalized Release[b]**
B	0.209±0.004	0.220±0.002	0.654±0.021
Si	0.111±0.003	0.115±0.001	0.193±0.001
Na	0.262±0.009	0.261±0.003	0.261±0.003

(a) Based on quadruplicate Product Consistency Tests.
(b) Based on triplicate Product Consistency Tests.

4.3.9.4. X-Ray Diffraction and Scanning Electron Microscopy Analyses

The X-ray diffraction pattern of the radioactive AN-102 glass is presented in Figure 4.51. Two possible crystalline structures are identified as quartz and chromium/iron/nickel. The quartz peak likely derives from trace SiO2 quartz contaminates that develop during re-melt and simulated canister cooling of the melter glasses. The Cr/Fe/Ni is likely due to trace steel particles in the glass powders that were prepared from grinding the AN-102 active glass in a tungsten blade grinder with steel compartment. The overall XRD spectrum combined with the scanning electron microscopy data presented below indicates no significant presence of crystals in the AN-102 glass above the XRD instrument detection limits of nominally 0.5 vol%.

Table 4.41 contains summary information on the SEM microscopic images and EDAX patterns of the powdered glass samples derived from grinding the AN-102 radioactive

glass. These glass powders were obtained during preparation of the glass for PCT durability tests using a Techmar tungsten blade grinder with stainless steel grinding compartment. Images obtained from secondary electron and backscattered electron microscopy were obtained at magnifications of 200X to 2000X. Generally the SEM technique uses backscattered electrons (BSE), or incident electrons, to indicate potential density differences in the image particles. Use of secondary electron (SE) imaging that involves actual electrons from the matrix material provides topography images of the matrix. Microscopy images shown in Figure 4.52 and Figure 4.53 show the (–)100 to (+)200 mesh ground glass that was used in the PCT. Figure 4.52 images show no visible crystalline structure on the glass particles. Energy dispersive X-ray analyses were obtained for the matrix particles shown in SEM image Figure 4.53. The EDAX patterns shown in Figure 4.54 show this material to be comprised of the elemental components of the glass matrix, including Na, Mg, Al, Si, Zr, K, Ca, Ti, Fe and Zn. SEM Figure 4.53 shows images of the bulk glass matrix particles and relatively smaller particles with apparent different densities than the bulk matrix (see spots C, D and E). These lighter shaded particles were examined with EDAX to produce the patterns shown in Figure 4.55-Figure 4.56. This EDAX pattern indicates presence of Cr, Fe and Ni that is indicative of trace stainless steel particles derived from grinding of the glass. These apparent steel trace contaminants in these analyzed powdered glasses do not interfere with the PCT durability testing since the PCT is conducted in stainless steel containers. Also, is should be noted that separate powdered glass samples obtained from agate ball/mill grinding were analyzed for glass characterization.

Table 4.41 Summary Information on Microscopy Data

Figure	SEM Image	Technique	Magnification	EDAX
Figure 4.52 TOP	021	SE	200-X	
Figure 4.52 MIDDLE	022	BSE	200-X	Figure 4.54
Figure 4.52 BOTTOM	023	BSE	100-X	
Figure 4.53 TOP	024	BSE	2000-X	
Figure 4.53 MIDDLE	025	BSE	400-X	Figure 4.55
Figure 4.53 BOTTOM	026	BSE	400-X	Figure 4.56

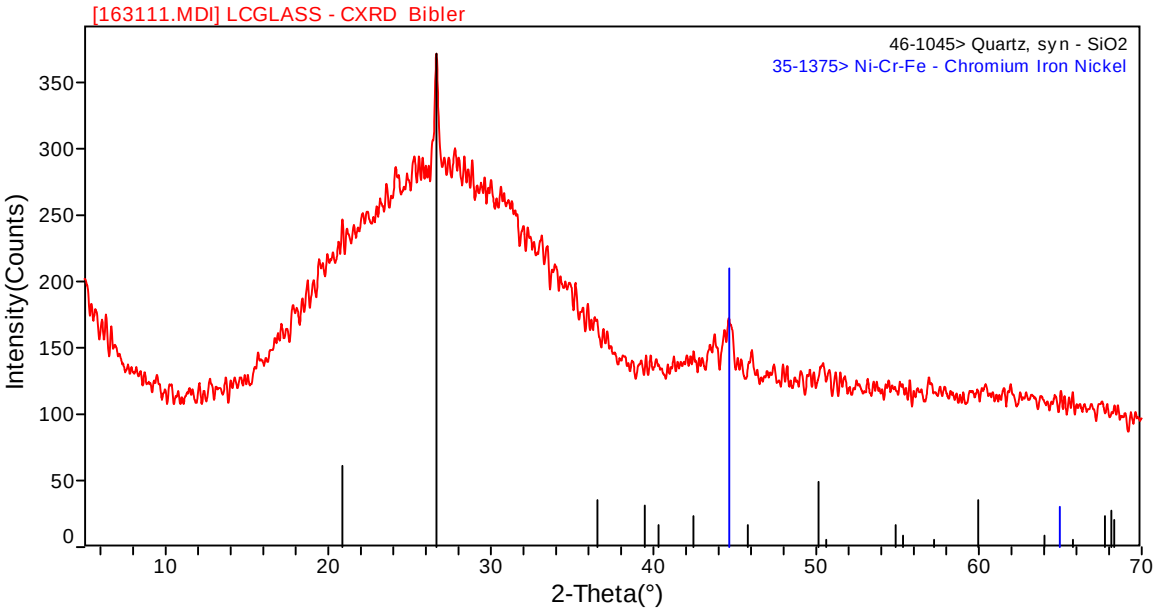


Figure 4.51 XRD Pattern from Analysis of AN-102 Active Glass

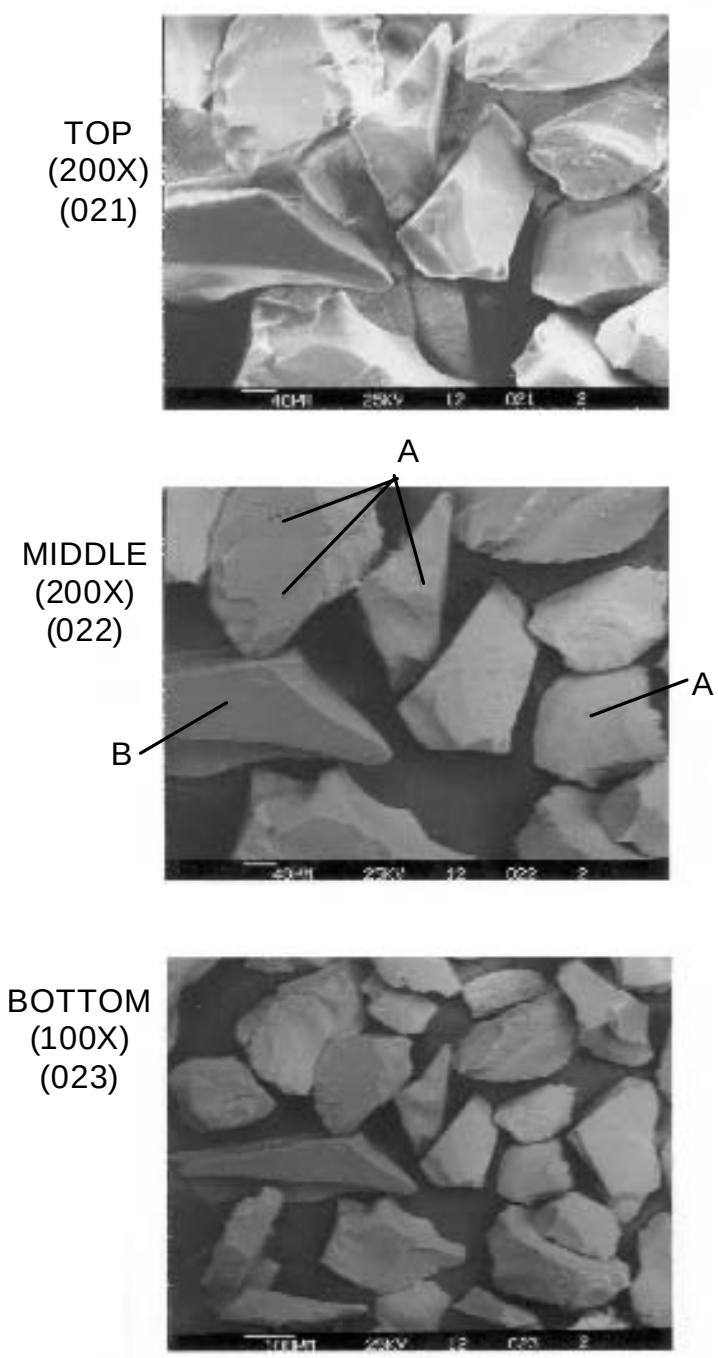


Figure 4.52 SEM Image of 021, 022 and 023

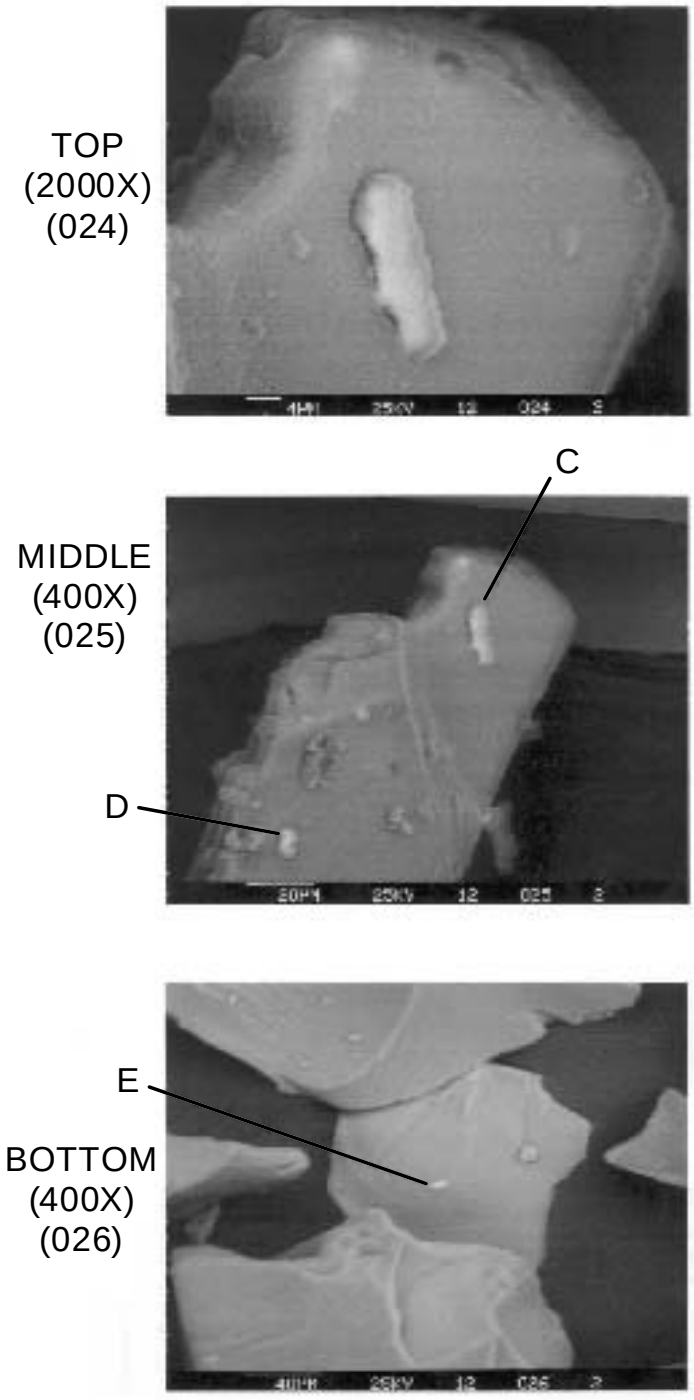
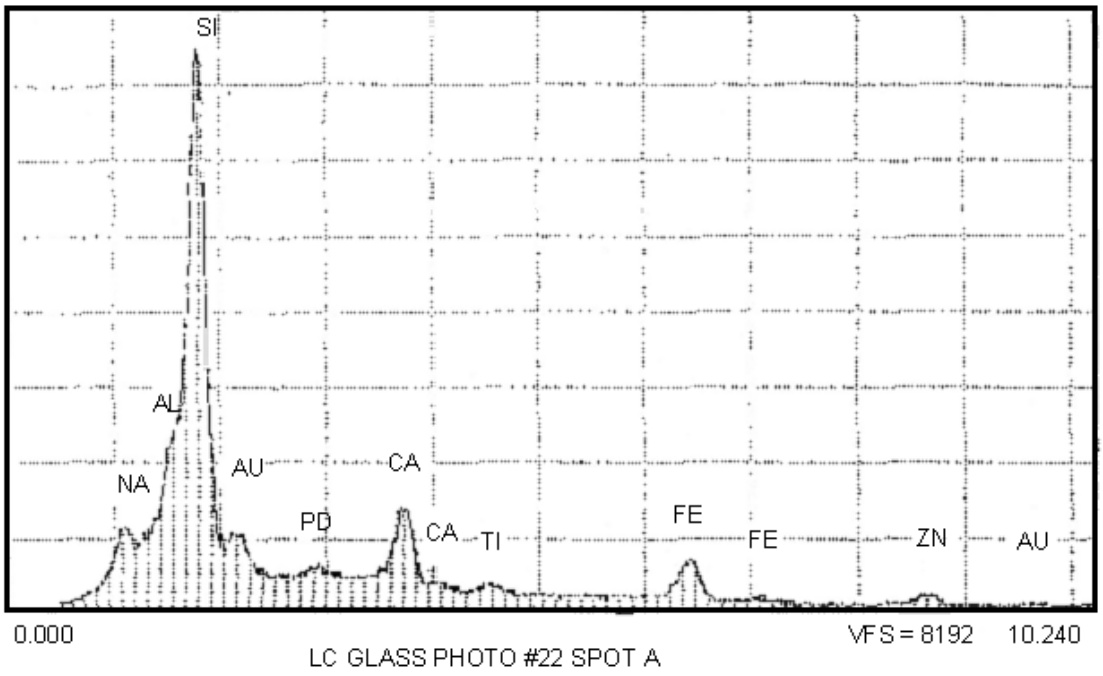


Figure 4.53 SEM Images of 024, 025, 026.



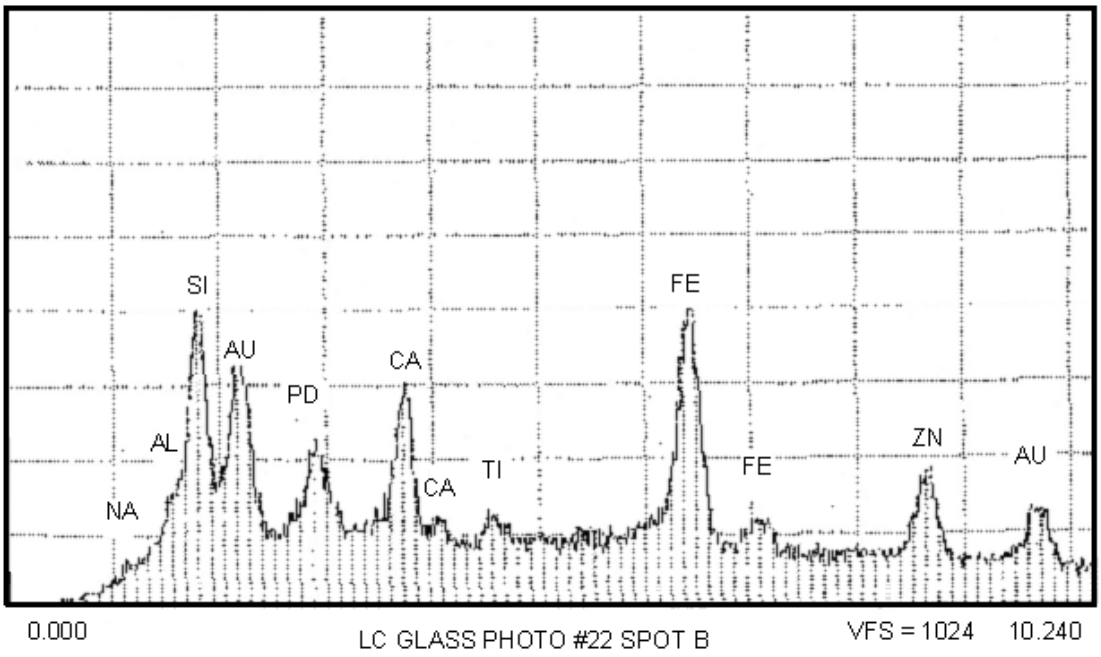
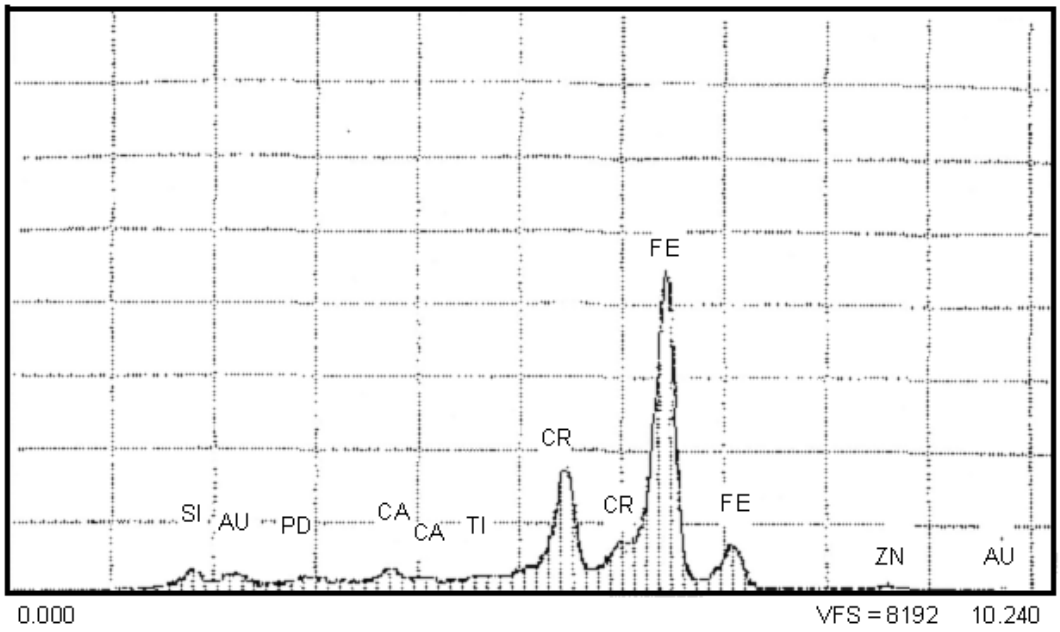


Figure 4.54a-b EDAX Pattern from Particles Shown in SEM Image 022



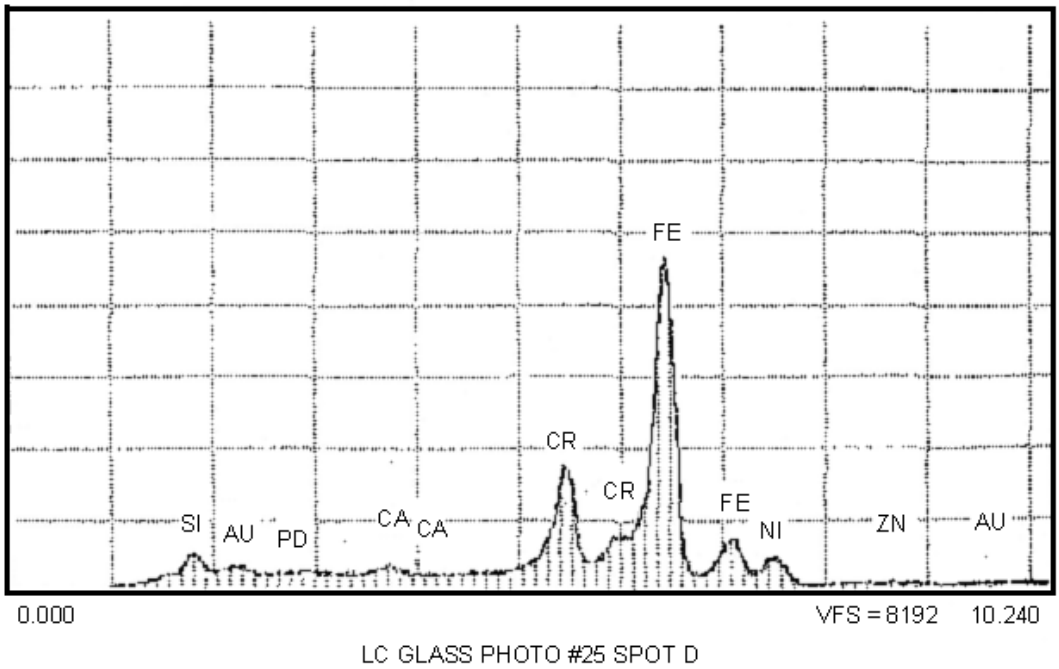


Figure 4.55a-b EDAX Pattern from Particles Shown in SEM Image 025

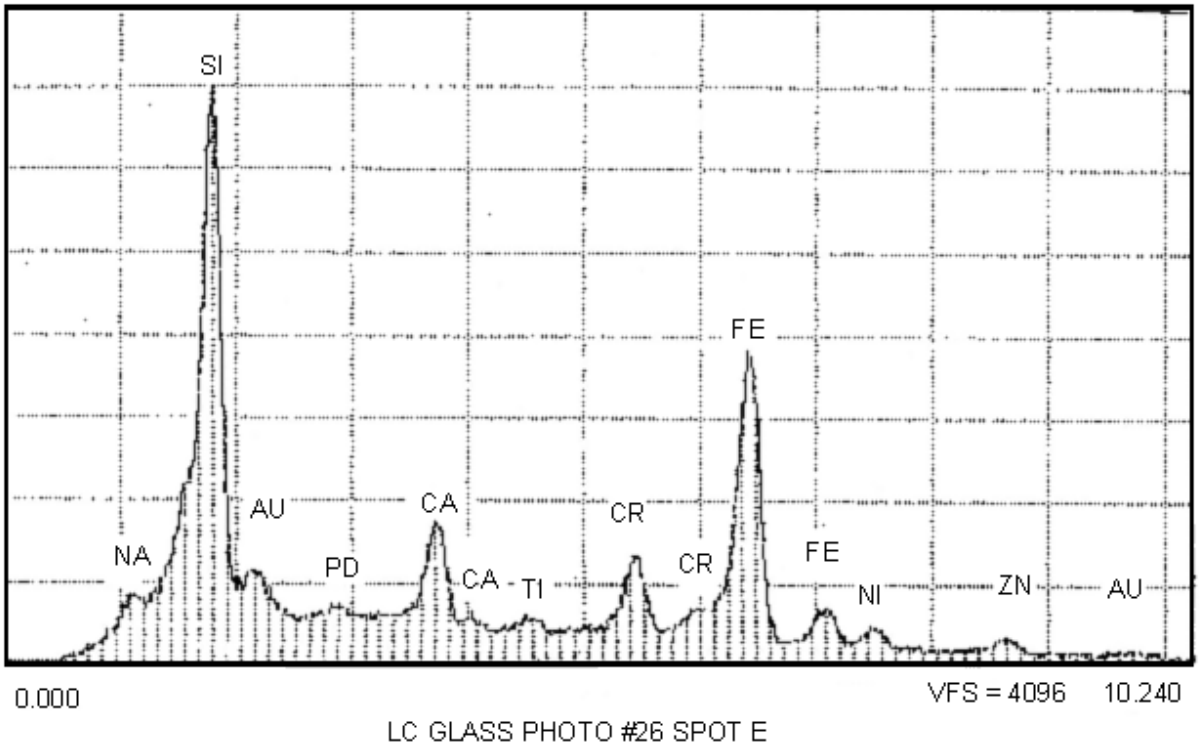


Figure 4.56 EDAX Pattern from Particles Shown in SEM Image 026

4.4. Rheological Characterization of Melter Feed Streams

The main results of the rheology work are summarized first. The surrogate and radioactive supernate solutions following separation from the Sr/TRU precipitate behaved like Newtonian liquids in spite of the presence of small amounts of entrained solids and crystals. Viscosity increased with increasing sodium molar concentration and decreased with increasing temperature, as expected. Pretreated LAW radioactive and surrogate supernate results were very comparable. The 7.1M and 6M radioactive supernates contained more insoluble starting solids than the corresponding surrogate supernates. The rheological properties of both surrogate-based and radioactive-based AN102 LAW melter feeds were very strong functions of the starting sodium molarity of the supernate. The apparent viscosity of the melter feeds increased by about a factor of five over a wide range of shear rates going from 5M to 6M, and again going from 6M to 7.1M sodium starting supernates. The radioactive melter feeds were more viscous than their surrogate counterparts. The amount of insoluble solids in the radioactive supernates could be a contributor to these differences in rheology.

4.4.1. Discussion of Principle Rheology Results

Rheological properties should be viewed from an applications perspective. In fully turbulent pipeline flow of Newtonian liquids, a factor of five increase in viscosity would produce only a slight increase in friction factor. A transfer pump designed for one set of conditions would very likely function satisfactorily at the other set. Conversely, in a stirred tank containing a yield stress fluid, a factor of two increase in the yield stress could lead to large stagnant regions. So it would seem that the ability to determine an accurate yield stress is quite important. Unfortunately, accurate prediction of the shear stress field within a mixed tank containing a non-Newtonian fluid remains problematic. This is partly due to difficulties in accurately modeling the fluid properties over a large shear rate range and partly due to difficulties in solving the fluid dynamics problem.

4.4.2. Supernate Results

Table 4.42 gives results for pretreated AN-102 LAW waste supernate samples and viscosity standards fit to the Newtonian fluid equation. The error bars are derived from the capabilities of the instrument assuming a nearly linear data set with a good zero point setting.

Table 4.42 Supernate Viscosities with Associated Standard Viscosities

Sample	Viscosity, Pa·s	Temperature, °C	R^2
Canon S20, 29.0 cP standard	0.0295±0.001	25	0.9991
7.1M AN102 surrogate supernate	0.0050±0.001	25	0.9988
6M AN102 surrogate supernate	0.0034±0.001	25	0.9985
5M AN102 surrogate supernate	0.0026±0.001	25	0.9989
Canon S20, 29.0 cP standard	0.0296±0.001	25	0.9987
Canon S20, 29.0 cP standard	0.0299±0.001	25	0.9992
7.1M AN102 radioactive supernate	0.0051±0.001	25	0.9958
6M AN102 radioactive supernate	0.0040±0.001	25	0.9978
5M AN102 radioactive supernate	0.0029±0.001	25	0.9988
7.1M AN102 radioactive supernate	0.0035±0.001	40	0.9975
6M AN102 radioactive supernate	0.0028±0.001	40	0.9951
5M AN102 radioactive supernate	0.0022±0.001	40	0.9989

The radioactive supernate flow curve data generation sequence was 7.1M at 25°C then 40°C, 6M at 40°C then 25°C, and finally 5M at 25°C then 40°C. This sequence required just three temperature steps on the sample jacket. A small bias may have been introduced through evaporative losses that correlate to time in the rheometer beaker. The above sequencing may have biased the second viscosity result for each sodium molarity. The 6M supernate at 25°C had been in the rheometer considerably longer (upwards of 30 minutes) than the 7.1M and 5M supernates at 25°C. The 6M supernate also appears to be slightly more viscous then expected based on earlier results. There were at least duplicate measurements for all of the data at 25°C. The data at 40°C came from single measurements. A discussion of the

variability seen in replicate measurements is given later in Section 4.4.4. One other observation was that the radioactive supernate did form a froth or foam layer when shaken vigorously. The foam layer life was not long, but its presence was unexpected.

4.4.3. Melter Feed Results

The main finding of the AN-102 melter feed rheology work was the rheological properties that varied widely between the 5M and 7.1M sodium melter feeds. This is readily apparent from the raw data for the radioactive melter feeds shown in

Figure 6.11 of Appendix 6.16. An ideal operating region probably exists between 5M and 6M sodium. A potentially emerging issue will be the ability to accurately measure and control the sodium molarity within perhaps as little as ±0.1M variation to keep rheological properties within design limits (postulated upper and lower bounds on fluid properties).

The data obtained by the RV20/M5 rheometer at low shear rates and shear stresses is the least accurate data obtained in generating a flow curve. This impacted the supernate viscosity data, and also had implications for yield stress determinations. The RV20/M5 rheometer also has uncompensated inertial errors, issues with the stepping motor rotating the inner cylinder, etc. which tend to corrupt the data to various degrees that are sample dependent and are not quantified. Consequently, when flow curve data was fit to a rheological equation of state containing a yield stress, the yield stress parameter became an extrapolation of the flow curve data back to zero shear rate. Depending on the application for the data, this can be either a major or a minor problem. The essential concepts are model-dependence and extrapolation. The tables below present the results from three different model fits to the same data. Regressed yield stress varies considerably from model to model for the reasons outlined above. Typical regressions are shown in Figure 6.12 and Figure 6.13 of Appendix 6.16 for the Bingham Plastic and Casson equations of state, respectively.

The melter feed results in Table 4.43 were based on the first flow curve obtained for a given sample (least impacted by drying, settling, etc.). The data were fit to a Bingham Plastic model. This melter feed data was taken at 25°C. In all cases more than one flow curve was obtained per sample. This often involved reusing some of the same melter feed in the subsequent measurements. In the Table 4.43, the 7.1M and 6M results come from the SV1 rotor, while the 5M results come from the MV1 rotor. A discussion of the results of duplicate trials and of the reproducibility of the data will be given in Section 4.4.4. Data was also obtained for the 6M melter feed with the MV1 rotor to allow comparisons between 5M and 6M without issues about the rotor geometry. VSL[27] obtained a yield stress for high-sulfate AN-102 surrogate melter feeds using a controlled stress vane method to obtain their yield stress. Their yield stress determination (previously shown in Table 4.7 is given in Table 4.43 for comparison purposes only. VSL states that these measurements were made within “one week of mixing”, which from a time perspective, most likely was not close to the 24-hour measurements taken in this study. This time factor could be an issue, especially at the higher sodium molarity.

Table 4.43 Bingham Fluid 25°C Flow Curve Regressions for AN-102 Melter Feeds

Sample	Up Curve			Down Curve			VSL
	$\tau_{o,B}$, Pa	η_B, Pa·s	R^2	$\tau_{o,B}$, Pa	η_B, Pa·s	R^2	$\tau_{o,B}$, Pa
7.1M-Rad	108	0.878	0.981	105	0.810	0.991	-
7.1M-Sim	21	0.392	0.986	0.9	0.333	0.995	500
6M-Rad	30	0.326	0.972	25	0.314	0.997	-
6M-Sim	13	0.258	0.992	1.9	0.252	0.998	18
5M-Rad	2.6	0.0438	0.993	0.3	0.0444	0.998	-
5M-Sim	2.6	0.0372	0.989	0.0	0.0357	0.984	1

There was good agreement between the radioactive and SRTC surrogate melter feed Bingham fluid parameters at 5M, fair agreement at 6M, and poor agreement at 7.1M. Moisture loss was not an issue, since it was well controlled and understood going into the first flow curve measurement. In all cases, the radioactive samples were always more viscous than their SRTC surrogate counterparts.

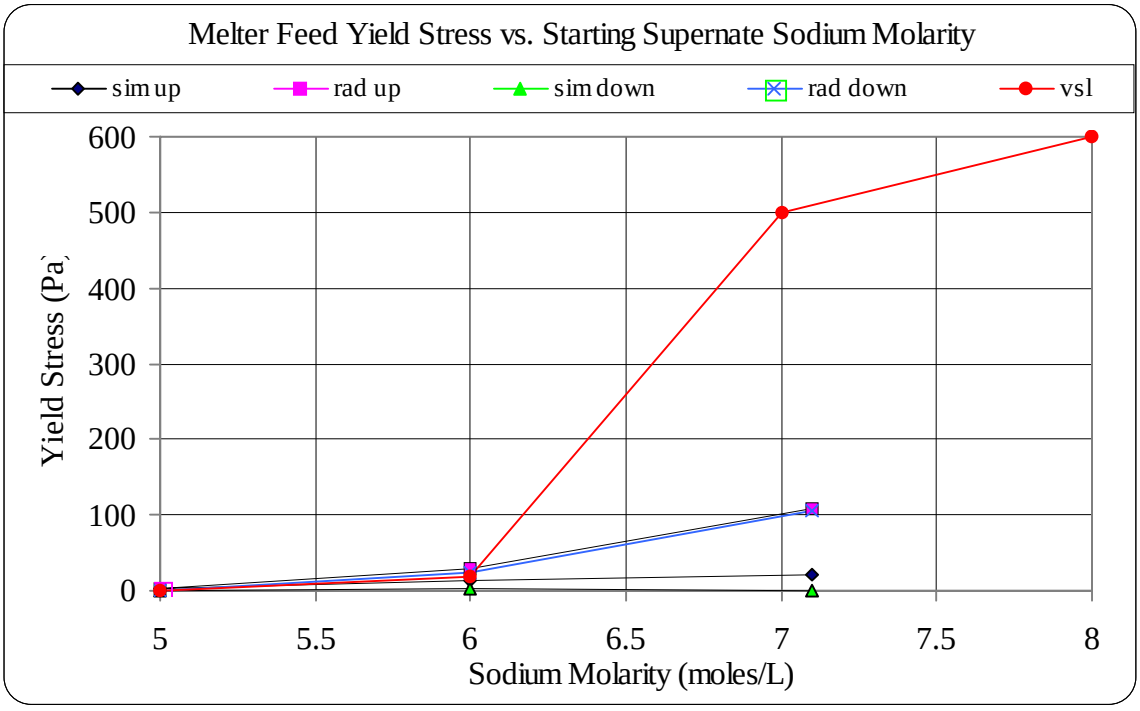


Figure 4.57 Melter Feed Yield Stress Versus Starting Sodium Molarity

The VSL[27] vane yield stress results shown in Table 4.43 are generally similar to the flow curve fitted Bingham Plastic yield stresses. In the VSL report[27], Figure 13 shows the up flow curve for the 5M and 6M AN-102 melter feeds. Curve fitting the data between 80 to 200 sec^{-1} using a ruler yielded a yield stress of 2.5 Pa and a consistency of 0.0175 Pa-sec for the 5M AN-102 melter feed. For the 6M AN-102 melter feed, the yield stress was 150 Pa and the consistency was 0.75 Pa-sec. VSL's 5M AN-102 feed is similar in behavior to that reported

by SRTC for their simulant and radioactive AN-102 melter feed. This is not true for the 6M melter feed, where VSL's melter feed is much thicker than what was reported by SRTC.

VSL 7M yield stress shown in Table 4.43 is much different than that reported by SRTC, for either their simulant or real radioactive melter feeds. VSL also tested an 8M melter feed and determined a yield stress of 600 Pa. Their result at 7M does not seem consistent with their results at 6M and 8M as clearly shown in Figure 4.57. Typically, as the weight percent total solids (or sodium molarity as shown in Figure 4.57) increases, the yields stress increase exponentially. This was not evident in Figure 4.57. The vane method VSL used to measure the yield stress could have been very time consuming, allowing the slurry to settle. The vane can then become immersed into the compacted settled zone. If this were the case, these higher yield stress values would be easily explainable. VSL's Figure 18a[27] provides apparent viscosities for 6M and 7M AN-102 melter feeds, which were about 15 and 20 Poise respectively at a shear rate of 200 sec^{-1}. The shear stresses at these shear rates are 300 and 400 Pa for the 6M and 7M AN-102 melter feeds respectively. The vane yield stress measurement or the flow curve (with a lot of slippage) that was used to obtain the 7M apparent viscosity are in disagreement.

The probable cause of the divergence between radioactive and surrogate LAW melter feeds with increasing sodium molarity was the presence of precipitated crystals in the 7.1M radioactive supernate used in this testing. The 7.1M supernate was heated to 50°C and the crystals dissolved. The crystals formed again as the sample was cooled back to room temperature. The decision was made to leave them in the supernate. It was observed that when an aliquot of the 7.1M supernate was taken, it had the normal fraction of crystals, but when it was diluted to 6M about half of the crystals redissolved. Similarly, when the 5M supernate was prepared by diluting the 7.1M supernate, nearly all of the crystals redissolved. Consequently, the 6M and 7.1M radioactive melter feeds have a higher insoluble solids content than the corresponding surrogate melter feeds. This is a well-known cause of higher apparent viscosities.

Table 4.44 Casson Fluid Flow Curve Regressions for AN-102 Slurries

Sample	Up Curve			Down Curve		
	$\tau_{o,C}$, Pa	η_C, Pa·s	R^2	$\tau_{o,C}$, Pa	η_C, Pa·s	R^2
7.1M-Rad	48	0.516	0.969	52	0.441	0.991
7.1M-Sim	4.3	0.319	0.992	0.32	0.296	0.994
6M-Rad	9.7	0.233	0.980	10	0.202	0.997
6M-Sim	2.8	0.208	0.995	0.47	0.218	0.993
5M-Rad	0.64	0.034	0.993	0.08	0.039	0.992
5M-Sim	0.58	0.030	0.992	0.0	0.035	0.986

Table 4.44 gives the results for the Casson fluid model for the same raw data used in Table 4.43. A similar pattern was seen in the agreement between the radioactive and surrogate results to what was seen with the Bingham plastic model – good agreement at 5M to poor agreement at 7.1M. Casson fluid model yield stress values were lower by at least 50% in all

cases when compared to the Bingham plastic model. This was an inevitable consequence of the combined linear-square root dependence of the Casson model shear stress on the shear rate.

Table 4.45 gives the corresponding regression results for the Herschel-Bulkley model for the same raw data used in Table 4.43 and Table 4.44. R^2 is omitted from the table since R^2 was greater than 0.99 for all results listed from this study. The R^2 values using the Herschel-Bulkley model were closer to one when compared to the Bingham plastic and Casson fluid models. The Bingham plastic and Casson fluid models yielded about the same R^2 values. VSL[27] reported results for 6M and 5M melter feeds "within 24 hours of preparation" fit to the Herschel-Bulkley model. These are included in Table 4.45 under the 'Up Curve' results for comparison purposes only.

Table 4.45 Herschel-Bulkley Fluid Flow Curve Regressions for AN-102 Melter Feeds

Sample	Up Curve			Down Curve		
	$\tau_{o,H}$, Pa	A, Pa·s^n	n	$\tau_{o,H}$, Pa	a, Pa·s^n	n
7.1M-Rad	58	5.47	0.712	78	2.67	0.811
7.1M-Sim	0	22.36	0.726	8.5	0.107	1.183
6M-Rad	4.14	3.04	0.655	17.9	0.717	0.869
6M-Sim	3.5	0.841	0.816	6.4	0.107	1.137
6M-VSL	9.3-22.6	2.4-11.6	0.6-1.1	-	-	-
5M-Rad	0.76	0.163	0.796	1.12	0.020	1.127
5M-Sim	0.20	0.200	0.747	1.20	0.004	1.365
5M-VSL	-0.002	0.095	0.786	-	-	-

The pattern seen in Table 4.43 and Table 4.44 for surrogate versus radioactive melter feeds was repeated in Table 4.45. Fairly good agreement was obtained at 5M, while there was little agreement at 7.1M. The shear rate index on shear rate (power law contributor) in the Herschel-Bulkley model permitted regressions that nearly eliminated the model yield stress in some cases. This was the case for the 7.1M surrogate up curve, which was quite bowed and shear thinning. The elimination of the yield stress resulted in a power law fluid model for this melter feed. The 5M radioactive and surrogate up curves had a negligible yield stress by regression, although it was clearly indicated by the raw data. VSL results for the 5M melter feed matched closely, i.e. negligible yield stress and similar curvature (reflected in the shear rate index). The 6M melter feed VSL results were given in ranges that were similar to some of the up curve and some of the down curve data obtained in this study. The 6M melter feed VSL results seem to indicate that their material was more viscous than either the radioactive or surrogate sample tested here and is supported by Figure 13 in the VSL[27] document. Based on visual observations, the melter feeds tested here would have produced higher flow curves, i.e. more viscous flow curves, if they had been run before the soluble glass former chemicals had fully dissolved. The effects of glass former chemicals in higher sodium molarity melter feeds reported by Hansen[25] indicated that the yield stress was the most effected. The effect of time on the rheological properties should be studied further.

Up curves were at a higher shear stress than down curves over most of the shear rate range for all of the melter feeds tested in this study. Up curves were generally more bowed (shear thinning) than down curves. This was reflected in the smaller n values of the up curves compared to the down curves. There are some values of n greater than one for the down curves. This was not indicative of shear-thickening behavior in any of the above instances. All flow curves were indicative of shear thinning behavior, i.e. the apparent viscosity decreased with increasing shear rate. The down curve yield stresses were large enough to give shear thinning behavior for the (a, n) pairs above. Instead, the n values greater than one seemed to derive from data immediately following the hold portion of the flow curve program. In this period shear stress seemed to be falling both as a result of decreasing shear rate and as a result of continuing shear thinning. This lasted for perhaps the first minute of the down flow curve segment (total down curve time of four minutes). This is probably indicative of some residual thixotropy in the samples. Settling of solids over the duration of the flow curve measurement was deemed a non-factor based on the settling test data.

4.4.4. Graphical Comparisons and Reproducibility of Rheology Results

4.4.4.1. Supernate Comparisons

The viscosity of pretreated AN-102 surrogate and radioactive waste supernates was measured at 25°C for three molarities of dissolved sodium. Measurements were made with the NV double-gap concentric cylinder geometry as described in the method section, 3.3. Samples were run in duplicate. Some additional data was available on surrogate supernates from scoping tests run prior to the surrogate mock-up run of the radioactive work. Both radioactive and surrogate supernates were Newtonian liquids for all practical purposes. This was true even though all of the supernate samples contained small amounts of entrained solids. The LAW waste supernates were only a few times more viscous than water. The shear stress data was obtained near the low end of the torque sensitivity range for the RV20/M5 rheometer. Figure 4.58 is a composite plot of the rheograms for the three surrogate supernate molarities.

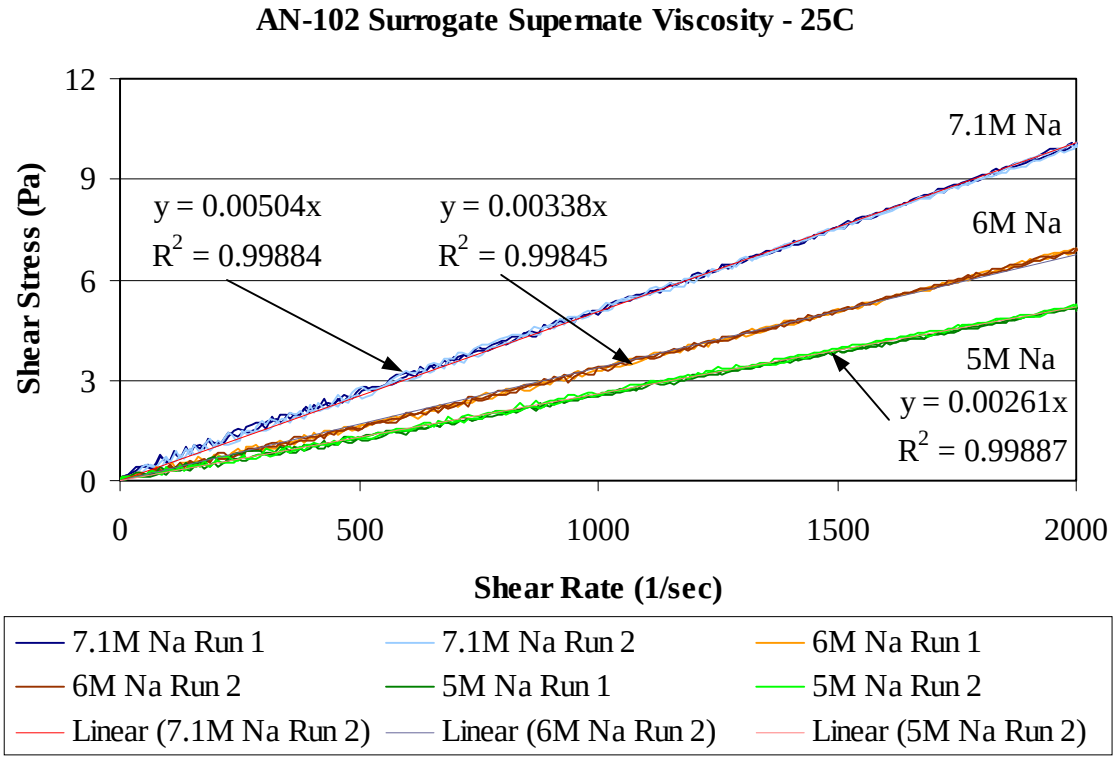


Figure 4.58 Surrogate Supernate Viscosity at 25°C

The pretreated LAW supernate data was noisy at low shear rates. None of the samples pulled as much as 6% of the maximum torque at the shear rate of 2000 sec^{-1}. The low shear rate data was typically less than 1% of the maximum torque. The regression results reported in Table 4.42 all came from the second flow curve for a given sample. Samples of the type being measured here test the lower viscosity limits of the RV20/M5 system. The instrument manufacturer, ThermoHaake, has claimed ±0.5% of maximum torque accuracy for any torque measurement. This translated to about ±0.89 Pa for the NV rotor. Thus regressed viscosity values were inherently uncertain by at least ±0.0005 Pa·s (±0.5 cP) over the shear rate range used. This is the smallest expected uncertainty for a Newtonian fluid model when the raw shear stress-shear rate data is highly linear, and the instrument zero point is properly set. Issues such as sample preparation reproducibility, uncertainty in temperature control, etc compounded error. Rheogram reproducibility was high indicating precision and reproducibility, but was not an indication of absolute accuracy.

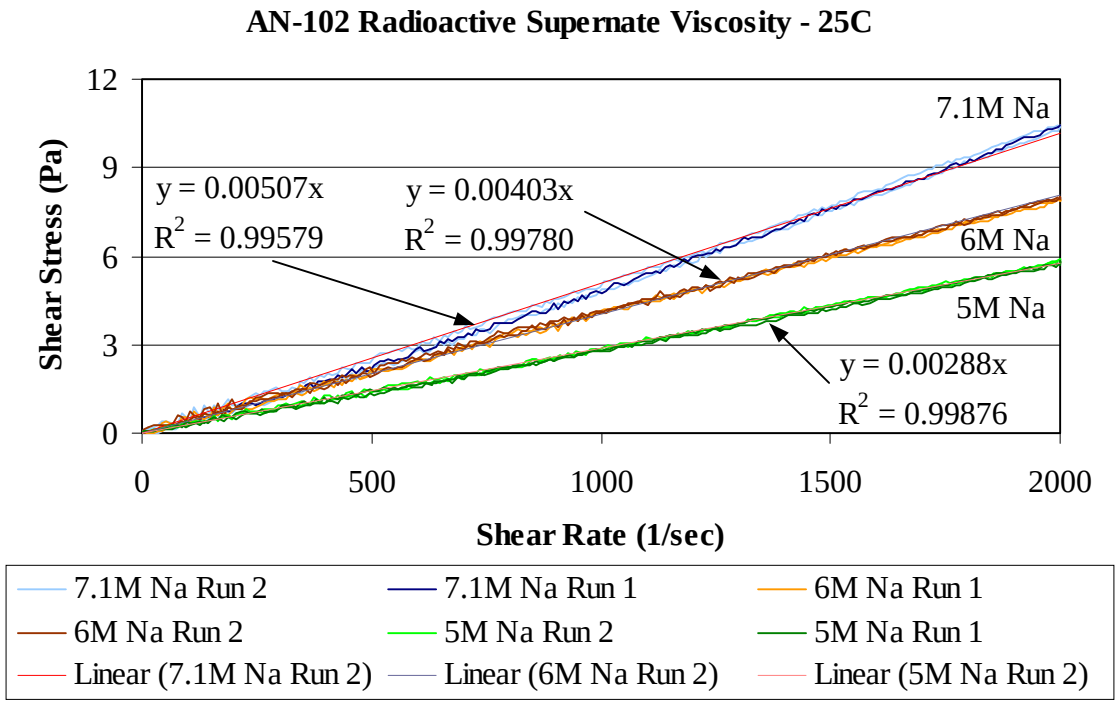


Figure 4.59 Radioactive Supernate Viscosity at 25°C

Figure 4.59 gives a corresponding set of data for the radioactive supernate samples. Zero drift was a concern during supernate analyses, because the torque drawn was relatively small. Consequently, a non-trivial zero drift would noticeably impact the calculated viscosity for a supernate sample. The first run with 7.1M supernate returned to zero shear rate with a noticeable offset (instrument zero drift), but the span from maximum torque to final torque was identical to that for the second run. The ASCII data file for the first run was found to lack all of the up curve data when it was opened. The down curve data for this one data set was corrected for zero drift by incrementing the torque to offset the zero drift for all data points. Generally, second runs had small zero drift. Sometimes first runs had small zero drifts and sometimes not. Oil standards were run and rerun before actual samples were tested to warm up the instrument. This only served to partially mitigate the zero drift issue.

Regressions were made on the second run in all cases. Differences between first and second run regressions were generally trivial. As seen in Figure 4.58 and Figure 4.59, the data for the first and second runs generally were superimposed. The second run was regressed to give the values in Table 4.42. A regression of the first run would have given a number that was indistinguishable from those in Table 4.42 given the uncertainties in the instrument. Larger zero drifts were tolerated in the melter feed results below, because the magnitude of the zero drift was trivial relative to measured shear stress.

Table 4.46 summarizes some additional viscosity results obtained during scoping work on pretreated AN-102 LAW waste supernates. One rheogram was obtained using the Haake RS150 rheometer and its double gap cylinder geometry. The RS150 rheometer is a more modern instrument than the RV20/M5 used in this study.

Table 4.46 Additional Surrogate Supernate Viscosity Data Obtained

Sample	Viscosity, Pa·s	Temperature, °C	Instrument
7.1M	0.0048	25	RS150
7.1M	0.0048	25	RV20/M5
7.1M	0.0046	25	RV20/M5
7.1M	0.0046	25	RV20/M5
6M	0.0036	25	RV20/M5
6M	0.0036	25	RV20/M5
6M	0.0038	25	RV20/M5
5M	0.0029	25	RV20/M5
5M	0.0029	25	RV20/M5

Comparisons of the data in Table 4.46 to that in Table 4.42 showed variations of less than 12%. These differences are fairly trivial in a practical sense. They can be attributed to slight differences in temperature jacket performance, to small differences in dilution control, etc. Generally, the supernate viscosity data was reproducible within the limits of the hardware.

A proposed duplicate study of supernate and melter feed rheological properties at a higher temperature was not pursued. The limited volume of radioactive sample would not have permitted the preparation of a second series of melter feed samples at elevated temperature. (It was agreed that the glass former chemical addition and mixing period should all occur at elevated temperature if this were attempted. Similarly, it was felt that heating a sample prepared at 25°C to elevated temperature just to get another rheogram would not be obtaining representative or realistic data on the system.) Nevertheless, the viscosity of the three radioactive supernates was measured at 40°C to check for any issues with making this measurement in the radioactive hood. There was a prohibitive zero drift on the first attempt at 6M supernate, and this sample was rerun with better results. The first runs with 7.1M and 5M supernates both had small zero drifts, and these samples were not rerun. The rheograms at 40°C are shown in Figure 6.6, Appendix 6.16.

Earlier work at SRTC did not study AN-102 supernate viscosity, however other surrogate supernate viscosities have been studied[25]. These include surrogates for AN-105, AN-107, and AZ-101. Figure 4.60 compares data obtained for radioactive and surrogate AN-102 supernate in this study to early work done at SRTC as a function of sodium molarity.

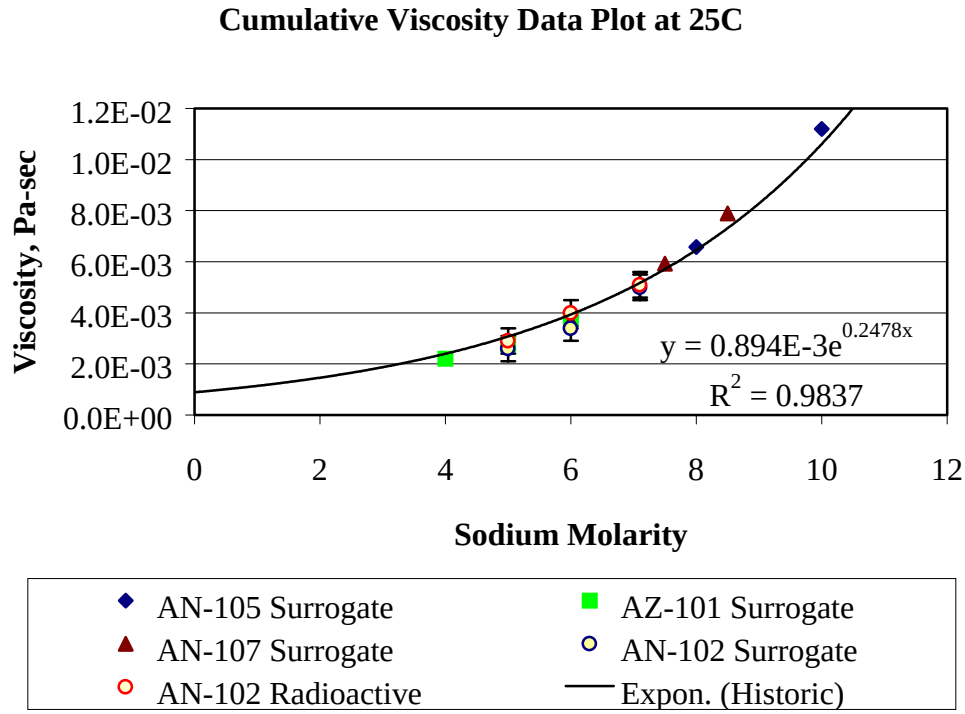


Figure 4.60 Comparison of Viscosities of Various Supernates

The supernate data in this study was very similar to past surrogate supernate data. Given the inherent uncertainty in the measurement equipment, there appear to be only trivial differences between the three envelope surrogates (A, B, and C), the AN-102 data, and the model. The historical data was fit to an exponential dependence on sodium molarity with a single adjustable parameter as shown Figure 4.60. The pre-exponential factor in the model was fixed to the viscosity of water, 0.8904E-03 Pa-sec, at 25°C. A high R^2 value was obtained in spite of the simple model used. The AN-102 viscosities determined in this study were very close to the regressed historical data as shown in Figure 4.60.

4.4.4.2. 5M Melter Feed Comparisons

SRTC researchers have studied simulated AN-102 supernate plus melter feeds for over a year. Early surrogate melter feed used a low sulfate recipe. Later surrogate melter feeds were based on a high sulfate recipe. Glass former requirements per mole of sodium have evolved during this time. The glass former batching recipes in effect for the low sulfate surrogate required only 136 grams of glass formers per mole of sodium. The glass former batching recipes in effect for both the 2000 and 2001 high sulfate surrogate required about 262 grams of glass formers per mole of sodium. Current glass former requirements for high sulfate surrogate supernate and for radioactive supernate are nearly identical (see Table 6.8 and Table 6.9 in Appendix 6.15). There is a small,

nontrivial difference in the mass of sugar added. There was about a three-fold higher sugar addition in the surrogate recipe to offset a lower organic content. This report will try to put the data obtained to date into a common context. VSL[27] results cited in this report are for high-sulfate AN-102 surrogates only.

The 5M sodium melter feeds are the best place to start comparing melter feed data. Issues with undissolved solids in the supernate were almost nonexistent at 5M. All SRTC data on the 5M melter feed, both past and present, was obtained with the MV1 rotor on the RV20 rheometer. The 5M melter feed was free flowing and readily transferred between containers. Figure 4.61 shows how the surrogate and radioactive melter feeds were easily poured from the preparation jar into the rheometer beaker.

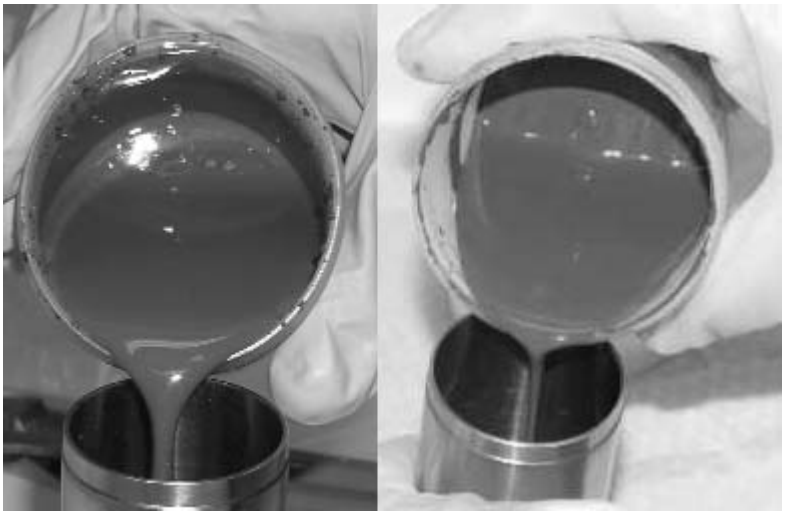


Figure 4.61 Fluidity of 5M Surrogate and Radioactive Melter Feeds

The 5M melter feeds behaved much like Newtonian fluids with viscosities of about 0.040 Pa-sec. Figure 4.62 compares the up curve rheograms for the current radioactive and surrogate melter feeds to the data obtained in October 2000 with the first high-sulfate surrogate and to the SRTC data obtained in July 2000 with the original low sulfate surrogate. All data was taken 24 hours after adding the glass former chemicals. The results being compared are from the initial rheograms. None of this data was from a rerun, or second run, sample.

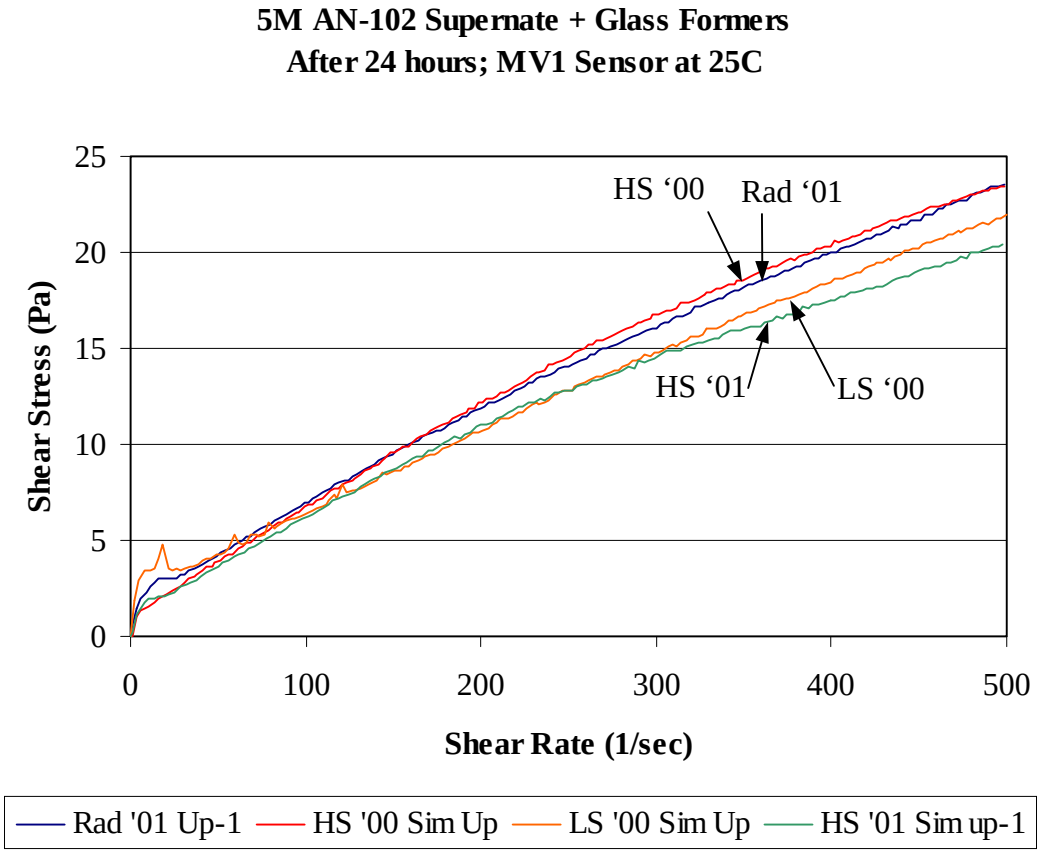


Figure 4.62 5M Melter Feed Up Curve Comparison

There were minor differences between the four up flow curves. At high shear rates, 400-500 sec^{-1}, the curves showed variations in shear stress of up to 15%. This is relatively small considering the almost factor of two difference in glass former content of the high and low sulfate surrogates. Visually the flow curves were much closer together than some of the regressed model parameters given in Table 4.43 seem to suggest. At low shear rates, 0-30 sec^{-1}, the curves for the radioactive sample and the low sulfate sample showed signs of additional structural breakdown and possible signs of wall slip that were not readily apparent in the curves for the high sulfate surrogate melter feeds. Nevertheless, it appears likely that any of the four samples would be acceptable for pipeline pressure drop calculations.

Figure 6.7, Appendix 6.16, compares the results for three flow curves of the 5M radioactive melter feeds taken one after another. The procedure followed was to fill the MV1 beaker, run a flow curve, recover the melter feed into the slurry mix jar, wash the rotor and beaker, hand mix the melter feed, refill the MV1 beaker, run a second flow curve, etc. Not much gross settling occurred on the time scale of washing and reloading, see settling discussion in Section 4.4.5. Because of down time issues, the second rheogram was generated about 30-35 minutes after the first, and the third rheogram was generated about 45 minutes after the second. The MV1 flow curve for

the 6M radioactive melter feed was included to give perspective and a sense of scale to the drift seen in the 5M data versus time.

The shear stress at 500 sec^{-1} increased by about 50% from the first measurement to the third. This represents only a small step, however, toward becoming as viscous as the 6M melter feed. A loss of one gram of water to evaporation in this melter feed corresponds to an increase in apparent supernate starting molarity of about 0.2M sodium. Evaporative loss rates of 0.5-1.0 g/hour were observed when the slurry jars were poorly sealed (typical evaporation losses were 0.5-1.0 grams/24 hours in semi-sealed jars). The shear stress at 500 sec^{-1} from the third flow curve moved about 10% of the difference between the initial 5M and 6M flow curve numbers. It seems reasonable to attribute this drift to a small evaporation loss. In working with 5M surrogate melter feed, a second run was made less than 25 minutes after the first and under more favorable conditions for control of sample (more sample was available). The results from those two flow curves were nearly identical. It seems very unlikely that the act of performing the rheological measurements built additional structure into the sample that manifested as a more viscous flow curve. Based on this sequence of rheograms, the accuracy of the first 5M melter feed is probably no better than ±20% (assuming half of 50% shift above for three trials would have overstated what could have happened prior to measuring the first sample). Larger working volumes would be needed to reduce this uncertainty.

4.4.4.3. 6M Melter Feed Comparisons

Issues that were minor for the 5M melter feeds became more significant for the 6M melter feeds. Due to the presence of precipitated crystals in the radioactive supernate, more insoluble solids were in the radioactive melter feed than in the surrogate melter feed. Figure 4.63 shows that the 6M radioactive melter feed was barely free-flowing unlike the 5M melter feeds.

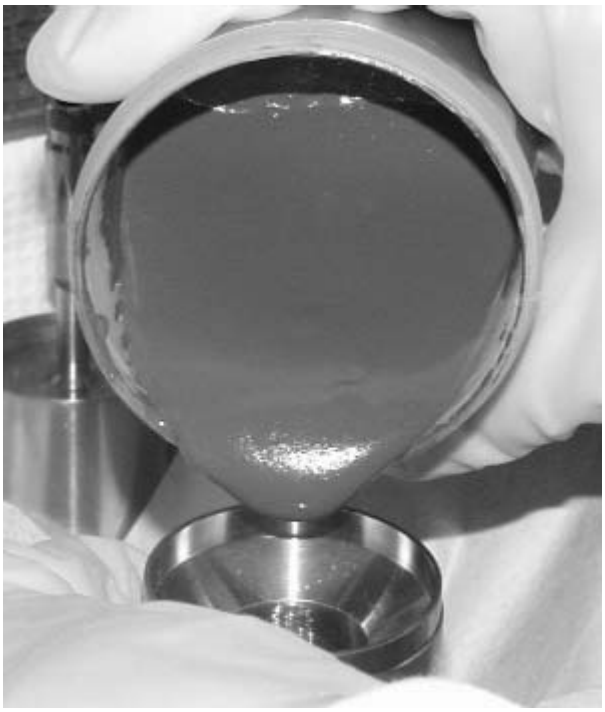


Figure 4.63 Transfer of 6M Radioactive Melter Feed

Figure 4.64 compares results from this study with Hansen's 2000 work[25] for melter feeds after 24 hours of mixing measured with the MV1 rotor at 25°C. The current surrogate melter feed ran about 20 Pa below the radioactive melter feed over most of the shear rate range. The Bingham plastic consistencies were about 0.24 Pa·s and 0.26 Pa·s for the surrogate and radioactive melter feeds in MV1 respectively. Both Hansen's high and low sulfate melter feeds had appreciably lower flow curves than this work. Conversely, Hansen's 5M high sulfate melter feed had a slightly higher flow curve than the 5M curve from this study. This lack of consistency within and between data sets may point to issues in sample preparation, type of glass formers used, and sample handling that may or may not have been identified as of this study.

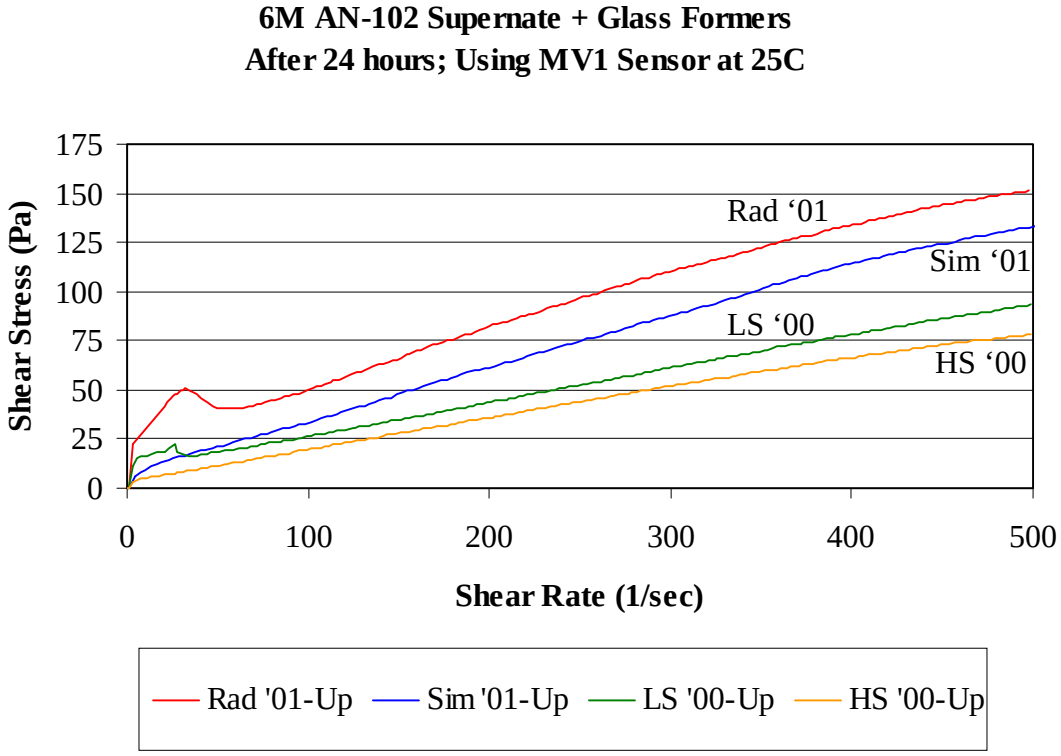


Figure 4.64 6M Data Comparison for MV1

The radioactive and low sulfate surrogate melter feeds both underwent more changes at low shear rates than did either of the high sulfate surrogate melter feeds. This observation was identical to what was seen at 5M.

Figure 4.65 is a composite plot showing all 6M data obtained in this study using the SV1 sensor. Two separate preparations of 6M surrogate melter feed are shown ("Sim 1" is from the surrogate demonstration preceding the radioactive work. "Sim 2" and "Sim 3" came from earlier scoping study work). "Rad 1" was the initial run with the radioactive melter feed. It was then recovered and used to generate the MV1 6M data, then recovered again and used to generate a second SV1 flow curve, "Rad 2".

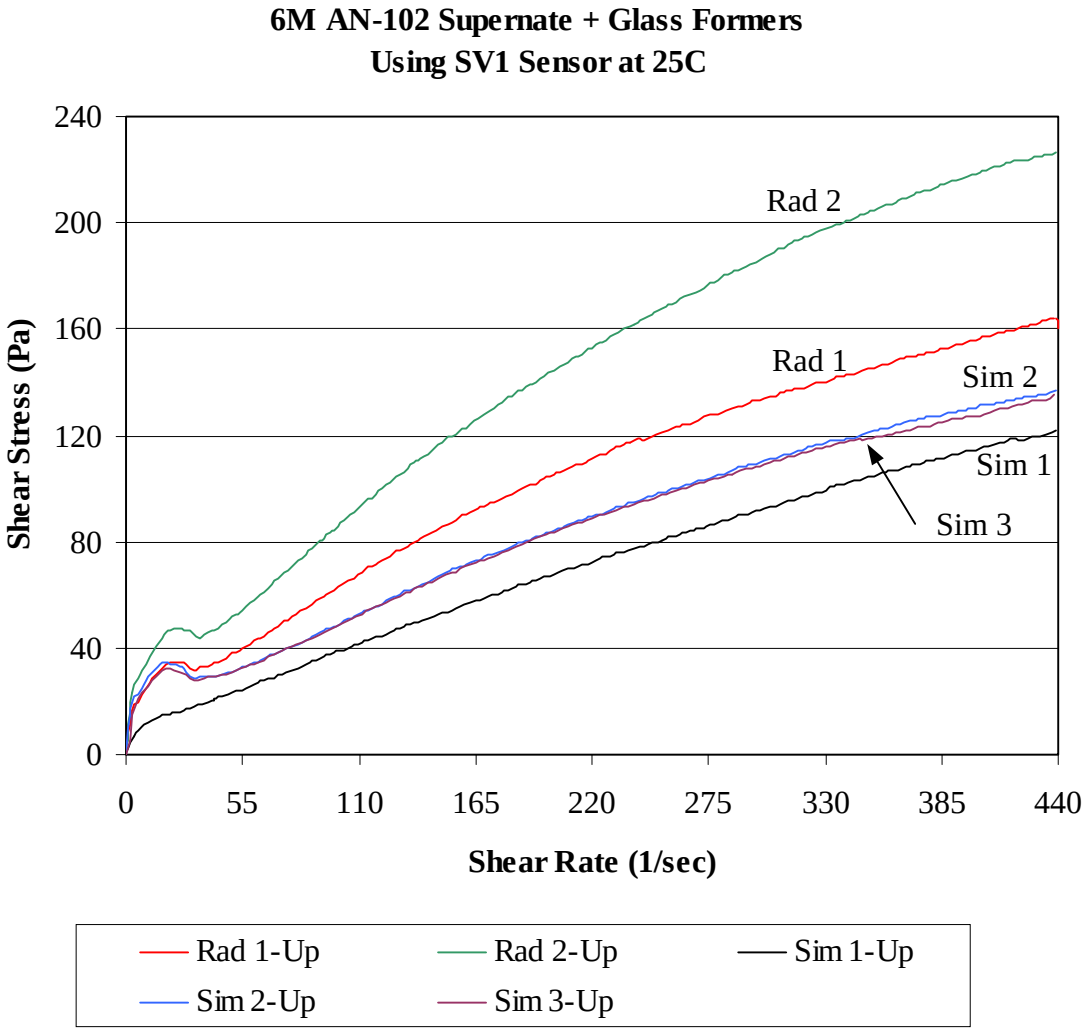


Figure 4.65 6M Data Comparison for SV1

The shear stresses for the surrogates were obviously lower than for the radioactive melter feeds, throughout the flow curve as shown in Figure 4.65. “Sim 2” and “Sim 3” were nearly identical, but ran about 15 Pa higher than “Sim 1”. A ~25% larger sample mass was prepared for “Sim 2/3” relative to “Sim 1”. Mass loss after 24 hours for “Sim 2/3” was also about 25% larger than for “Sim 1”. Consequently, it is difficult to explain the difference between the three surrogate flow curves using moisture loss arguments. The mixer rpm were also slightly higher for “Sim 2/3” than for “Sim 1”, so the power input per unit mass was probably comparable. The difference in the rheological results could be due to different addition rates of the glass formers to the supernate-sugar solution (see 7.1M discussion section 4.4.4.4). Alternately, the difference could reflect the fundamental sensitivity of this material to small variations in unidentified processing conditions.

The differences in the results for "Rad 2" relative to "Rad 1" were probably due to moisture loss. There were some problems getting the MV1 result quickly after obtaining the "Rad 1" SV1 result. The "Rad 2" SV1 result was not obtained until an hour-and-a-half after "Rad 1". The upward shift in the "Rad 2" flow curve was not trivial, but still falls well below the 7.1M radioactive melter feed data.

Another comparison that should be made is between results obtained with MV1 and SV1 for the 6M melter feeds. Both sensors possess a concentric cylinder geometry, but the dimensions are different, see Appendix 6.15. In surrogate work the MV beaker and SV beaker were filled simultaneously following the completion of the 24 hour mixing step. The initial rheograms were generated with only about five minutes of downtime between them. The results are shown in Figure 6.8, Appendix 6.15. Also included on this figure are three rheograms from the preliminary scoping studies. These represent two completely separate preparation cycles starting with dilution of 7.1M supernate, continuing through addition of sugar, glass formers, and mixing overnight.

Essentially interchangeable up-curve data was obtained from the MV1 and SV1 sensors for a given starting melter feed. The SV1 and MV1 up curves are nearly superimposed for a given preparation. In addition the SV1 and MV1 surrogate up curves are very closely grouped for all preparations. The down curve data from MV1 was generally lower than that for SV1, but the MV1 flow curves were run out to 600 sec^{-1} shear rates, while the SV1 samples could only be taken to 440 sec^{-1}. Thus, the down curves of the two sensors had a greater shear history difference than the corresponding up curves. This indicates that these melter feeds are mildly thixotropic.

There was a more noticeable difference between the results for the 6M radioactive melter feed as seen in Figure 6.9, Appendix 6.16. The lower result for the MV1 rheogram was unexpected. Since the MV1 rheogram was obtained after the SV1 rheogram, the lower MV1 result was not likely due to moisture loss. Moisture loss should have moved the data in the opposite direction. This unusual behavior shows up clearly on the plot of log apparent viscosity versus shear rate in Figure 4.66. Since the flow curves were not corrected for non-Newtonian behavior, this could be another factor influencing comparisons between the SV1 and MV1 sensor data.

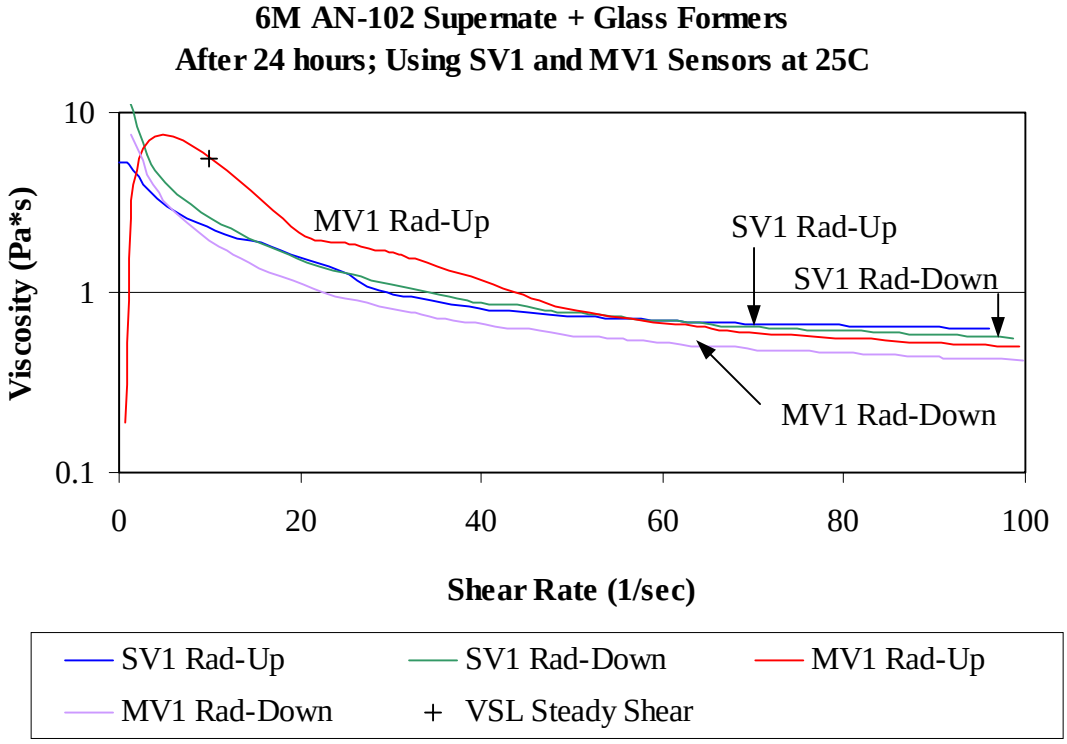


Figure 4.66 Apparent Viscosity of Radioactive 6M Melter Feed in SV1 and MV1

The MV1 sample was a composite of unused sample plus material recovered from the initial SV1 test. It may well be that the MV1 rheogram suffered from wall slip, i.e. the formation of a relatively low viscosity boundary layer at the shearing surface. This layer may have formed early and went through several transitions at about 20 sec^{-1} and 50 sec^{-1}, then persisted in some form throughout the flow curve. The up curve for the MV1 data shows a lot of unusual structure at low shear rates. The expected shape is a smooth decay to an approximately constant value at the high shear rates of the instrument. If slip is present, then the data being analyzed understate the viscosity of the sample, i.e. it is not an error in a conservative direction. The apparent viscosities were quite similar, i.e. within a factor of two, above shear rates of 60 sec^{-1}. The result of a flow curve measurement by VSL[27] at a shear rate of 10 sec^{-1} is marked as a "+" on the plot and is taken from Table 20 of their document.

4.4.4.4. 7.1M Melter Feed Comparisons

Analysis of the 7.1M melter feed presented several challenges. It was noted early in the surrogate scoping work that this melter feed could be transformed into a clay-like solid by several mechanisms, see the left side of Figure 4.67. Also shown in Figure 4.67 is the 7.1M radioactive melter feed following the 24 hour mixing period. The 7.1M melter feeds are not free-flowing, as evidenced by the material adhering to the walls of the mixing jar and the uneven free surface. A considerable quantity of the melter feed adhered to the agitator blades when the mixer was raised out of the slurry. This melter

feed was scraped back into the jar of melter feed prior to the transfer between radioactive hoods that preceded the rheological measurements. Recovering the melter feed on the agitator blades, after the 24 hour mixing period was complete, was standard practice during this work.

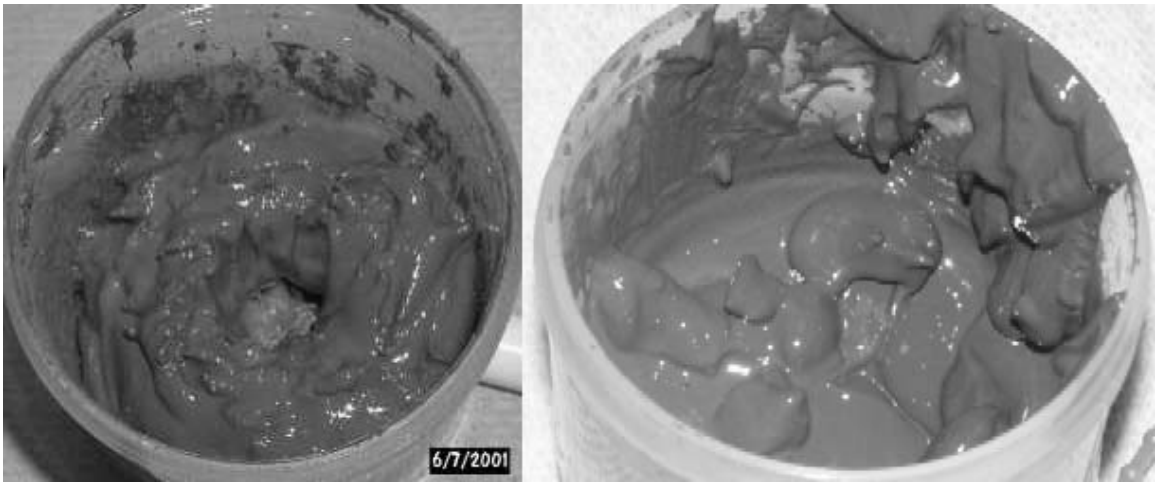


Figure 4.67 Clay-like Solid 7.1M Surrogate Mass and 7.1M Radioactive melter feed

The melter feeds shown in Figure 4.67 could almost be molded like clay, and in fact was shaped with a spatula to show the bottom of the jar. The mass showed a negligible inclination to flow under its own weight.

Three mechanisms have been identified that promoted the clay-like state of the melter feeds at 7.1M. These included:

1. Overly rapid addition of the glass formers to the melter feed.
2. Excessive evaporation loss during mixing.
3. The presence of insoluble solids above a certain concentration in the starting supernate.

Adding the glass former chemicals in less than three minutes was too fast while adding the same glass formers over 30 minutes seemed to be adequate for incorporating the glass formers into a fine paste (no clumping). Losing one gram of water from a starting supernate mass of about 40 grams did not lead to clay formation, but losing four grams of water did lead to clay formation. The presence of less than 1% insoluble solids did not impact the capacity of the surrogate supernate to incorporate the 7.1M glass former mass, but the presence of 3-4% very nearly did interfere with the capacity of the radioactive LAW supernate to incorporate the glass formers. Only minuscule water losses could be tolerated in the 7.1M radioactive case.

Transfer of the 7.1M melter feed between the jar and measuring beakers was difficult for both the radioactive and the surrogate melter feeds. Figure 4.68 shows transfers being made for both systems into the two different rheometer beakers. The photo on the left is from an early attempt to run the surrogate melter feed using MV1 beaker.

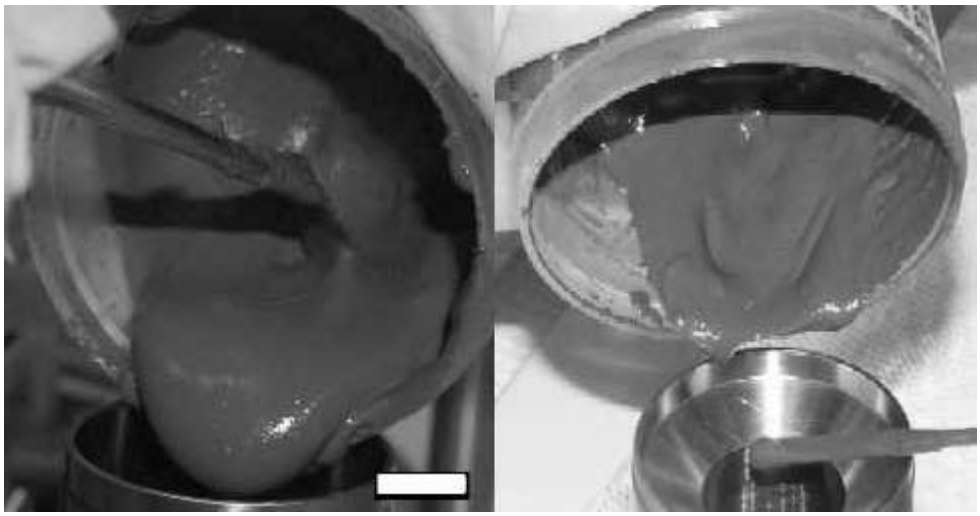


Figure 4.68 7.1M Melter Feed Melter Feed Transfer

There was a wide range in the rheological data obtained for 7.1M melter feeds. The previously discussed factors were considered responsible for much of the variation. Figure 4.69 shows four flow curves for the surrogate and radioactive melter feeds.

In Figure 4.69, the surrogate (Sim) flow curves were from the demonstration run that preceded the radioactive testing. In both cases the run labeled "1" was the first rheogram after the 24-hour mixing was concluded. The run labeled "2" came after run labeled "1" once the SV1 rotor had been cleaned, dried, and reassembled. During surrogate melter feed preparation, water loss was kept to a minimum, glass formers were slowly added over a thirty-minute period, and there were only trace amounts of insoluble solids in the starting supernate. For the radioactive supernate, glass formers were added slowly over about a forty-minute period. Water loss was observed at an intermediate stage during the 24-hour mixing period for this melter feed. This was corrected twice by small additions of de-ionized water. Note that the 7.1M radioactive supernate had the highest starting concentration of insoluble solids

The rheology data in Figure 4.69 derived from two preparations that went about as well as could be reasonably expected. There was a large difference between the rheological properties of the surrogate and radioactive melter feeds. This was attributed to the presence of the insoluble solids in the radioactive supernate.

Not all surrogate melter feed preparations went equally well, as seen previously in Figure 4.67. In the worst cases no rheological measurements were made. In some cases additional drying occurred which led to higher apparent viscosities.

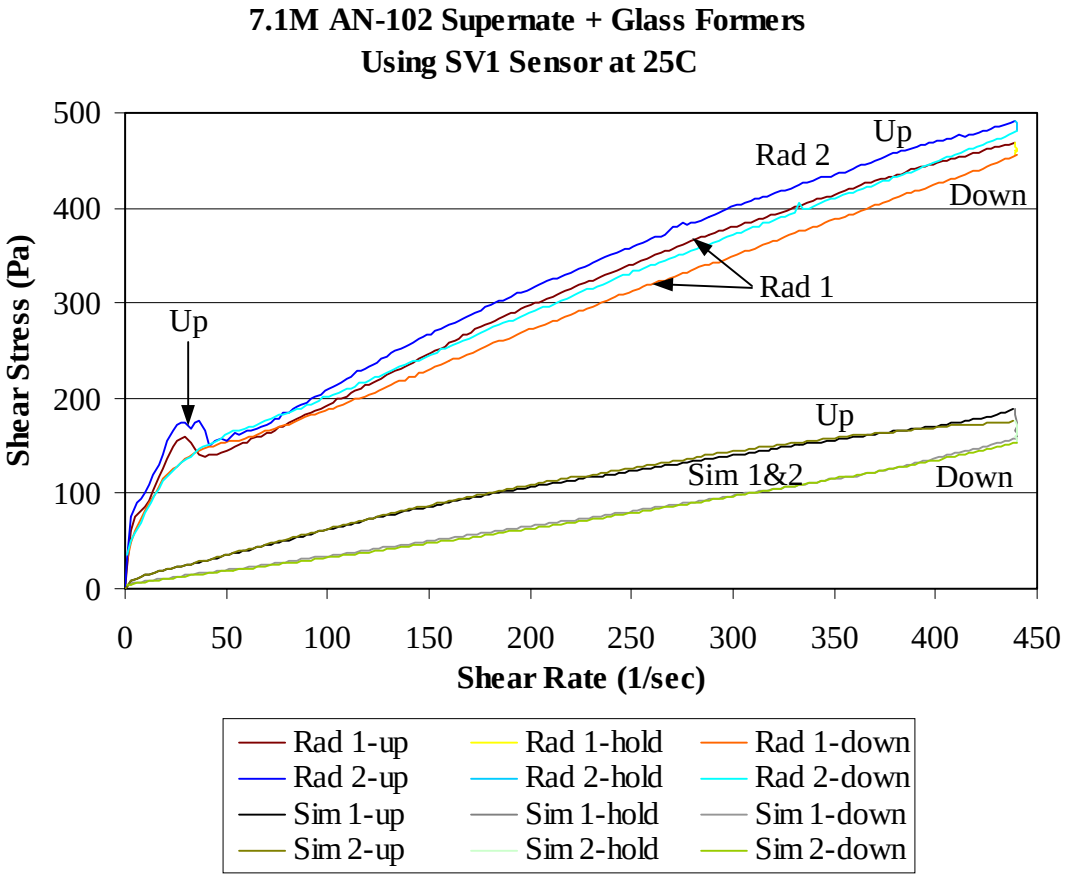


Figure 4.69 7.1M Rheological Results

Figure 4.70 shows some additional data compared to the first radioactive and surrogate melter feed up flow curves from Figure 4.69. The two highest surrogate curves came from a run where the glass former chemicals were added too fast. This interfered with dissolution of some of the soluble compounds. Mixing never looked more than marginally adequate during the 24 hours, even though this sample was mixed at 900 rpm vs. the nominal 350 rpm. Also shown in Figure 4.70 is a curve from Hansen's report[25] for high-sulfate 7M surrogate that was mixed for 48 hours, "Sim MV1 '00 (48hr)". (There was no data point for 24 hours of mixing in his work. The low sulfate surrogate study covered 4M, 5M, and 6M only.)

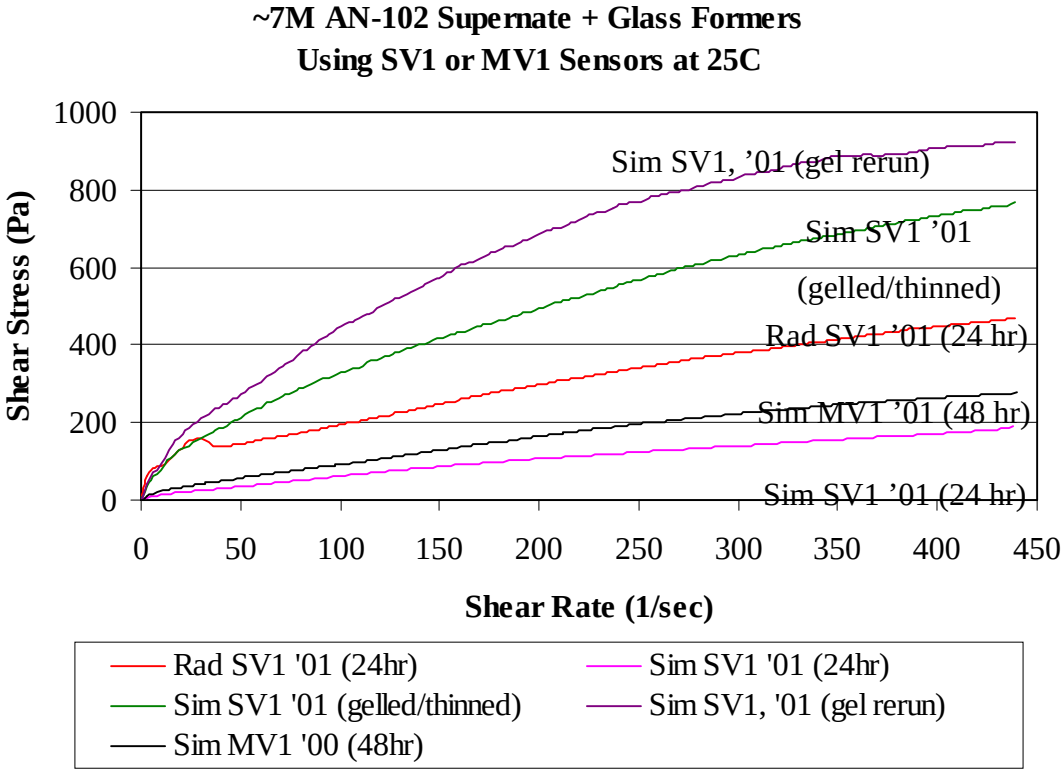


Figure 4.70 Additional 7.1M Data for Comparison

The rheological data for the radioactive melter feed falls in the middle of the various surrogate flow curves shown in Figure 4.70. This adds support to the premise that much of the observed increase in apparent viscosity shown earlier in Figure 4.66 could be due to a net higher weight per cent insoluble solids in the radioactive melter feed.

The radioactive melter feed sample in Figure 4.70 followed the thick surrogate melter feed curves at low shear rates. Then at a shear rate between 20-30 sec^{-1}, it appeared that there may have been a period of slip in the up flow curve for the radioactive melter feed. If slip persisted through the shear rate ramp up period, then it was not obvious. At the higher shear rates, if slip were an issue, a non-periodic jagged flow curve would result. This was not seen in any of the flow curve measurements. This low shear rate behavior, also seen in the 6M radioactive melter feed, may have coincided with the destruction of some sort of structure in the melter feed.

4.4.5. Settling Tests and Other Melter Feed Data

Six settling tests were conducted as described in the experimental method section. The tests were run on the three surrogate melter feeds from the demonstration run and the three radioactive melter feeds. The tests were a better measure of clarification than of settling, since the observed variable was the position of an interface between clear

supernate and opaque slurry. Segregation of solids within the opaque slurry was not observable. The first goal was to obtain long time settling properties. Some additional data obtained tracked the rate of formation of the clear layer for the 5M radioactive melter feed. Table 4.47 summarizes the long term, or greater than one week, settling results for all the melter feeds tested.

Table 4.47 Clarified Volume Relative to Total Volume of Melter Feeds

Sample	Volume % Clear Supernate
5M surrogate melter feed	15
6M surrogate melter feed	6
7.1M surrogate melter feed	2
5M radioactive melter feed	9
6M radioactive melter feed	≈1
7.1M radioactive melter feed	<1

Figure 4.71 is a composite photo showing the surrogate melter feeds at long times, i.e. after over 200 hours.

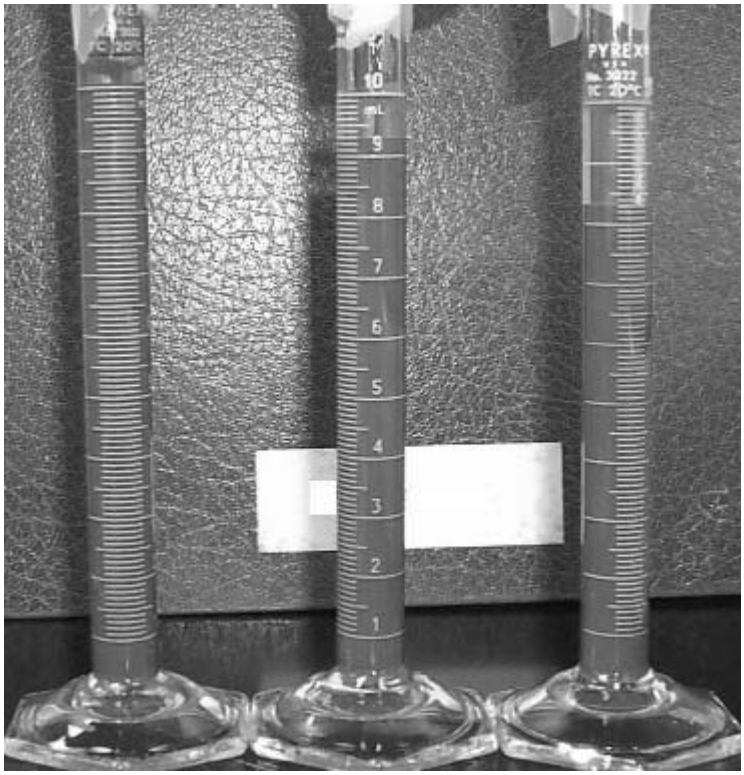


Figure 4.71 Surrogate Settling Test Steady State

The surrogate melter feeds settled without obtaining good settled volume versus time data. The 7.1M and 6M graduated cylinders were loaded at the same time, and all

detectable settling was completed within 3 days. The 5M melter feed fully settled within 1 day.

The radioactive melter feeds at 6M and 7.1M were very thick following the rheological work. It was extremely difficult to get them into the 10-ml graduated cylinder and impossible to get the materials in cleanly. The walls remained coated with solids. The expected breakthrough of a clear supernate was observed as expected, but it did not form as quickly as the surrogate melter feeds. There may have been more clear liquid present than could be seen. Figure 4.72 shows the final settled states of the three radioactive melter feed tests.

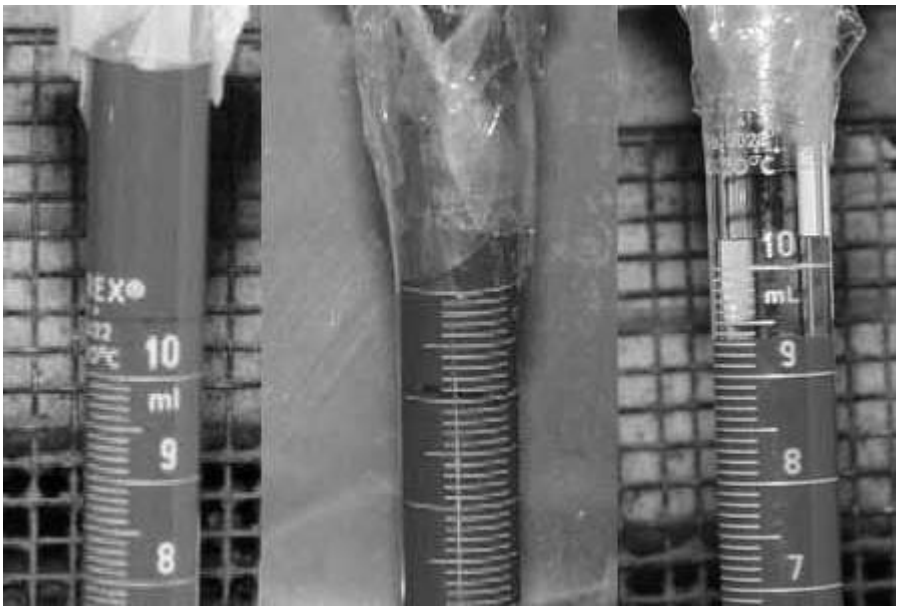


Figure 4.72 Radioactive Settling Test Steady State

The 7.1M interface formed at about 10.4 ml, i.e. above the marked graduations. The 6M interface formed at about 9-9.1 ml. Attempts to use time-lapse photography to track the settling were hampered by the samples themselves and issues associated with the computer architecture. Data was obtained for the 5M radioactive melter feed with better time resolution. The 5M radioactive melter feed results are shown in Figure 4.73.

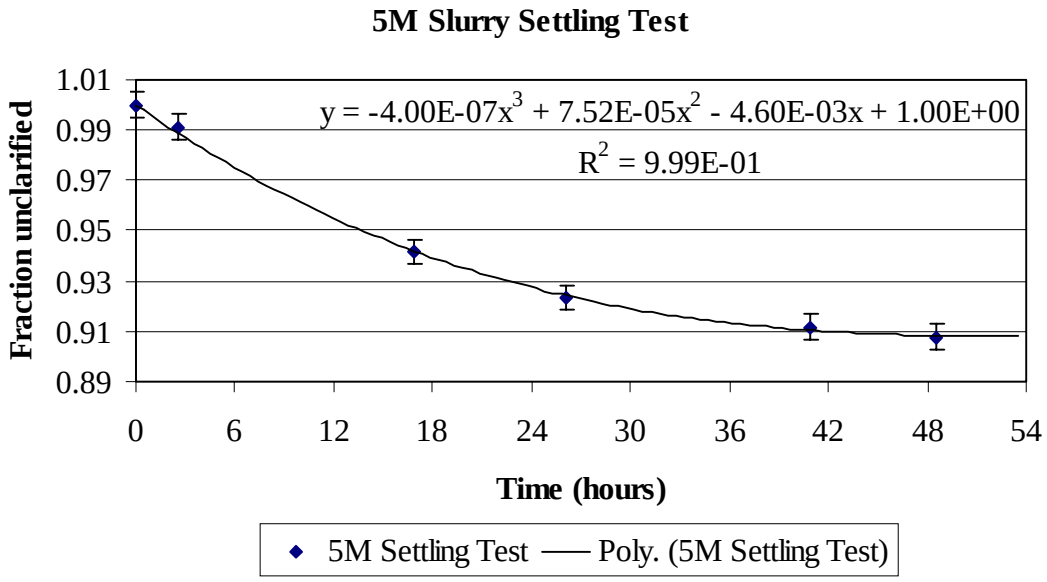


Figure 4.73 5M Radioactive Melter Feed Settling Test

The interface data was fit to a cubic polynomial with a forced y-axis intercept of unity. The polynomial equation should not be used outside the range of the data. Other issues such as hindered settling and wall effects on the settling rate have not been considered. Note that this curve is that of the slowest settling particles that generate the interface, hence the reason for using these results for decanting purposes only. The settling rate of the 5M radioactive melter feed was slower than that for the 5M surrogate melter feed. Settling occurred over about a 48 hour period with the radioactive melter feed versus no more than 24 hours for the surrogate melter feed.

A slender rod was used to probe the settled solids after the settling tests were complete. It was noted that a thicker, more dense/packed region of solids existed below the supernate/solids interface. These solids are most likely the heavier particles that settled much quicker than the rate at which the interface data was generated. An issue related to this thicker settled material is agitator restart.

Additional data was obtained during this testing. Several density determinations were made on the 7.1M surrogate supernate. The average result was about 1.32 grams per cubic centimeter. The average density of the 7.1M radioactive supernate was also 1.32 grams per cubic centimeter (both with and without the precipitated solids). VSL[27] reported a density of 1.34 g/ml for high-sulfate LAW AN-102 surrogate at 7M sodium. The pH of the surrogate melter feeds was measured. The pH probe was kept in the more fluid portion of the mass in the sample jar to get a stable reading. VSL reported some pH values for 7M, 6M, and 5M AN102 melter feed.[27] Table 4.48 summarizes these results.

Table 4.48 The pH of Surrogate Melter Feed

Sample	pH	pH – VSL
7-7.1M Surrogate Melter Feed	9.1	8.36
6M Surrogate Melter Feed	8.9	8.93
5M Surrogate Melter Feed	8.8	8.59

These pH values are quite a bit lower than the starting supernate, pH > 12. It should be noted that melter feed rheology is often strongly influenced by pH. The tendency is to have a maximum apparent viscosity at intermediate pH values with lower apparent viscosities at low and high pH values. Just what constitutes low, intermediate, and high is usually a function of the surface properties of the insoluble solids.

5. Conclusions

The Large C Melter tests were successfully completed, meeting all of the experimental objectives. Waste-containing glass was produced in kilogram quantities and characterization of the metals and radionuclides present was performed. Additional glass samples were submitted to another task for regulatory characterization.

The work presented in this technical report supports use of the technology being proposed by RPP-WTP personnel for pretreatment and immobilization of pretreated Hanford tank 241-AN-102 waste. The AN-102 active waste stream was immobilized into a durable LAW waste glass that meets the applicable LAW product requirement specifications set forth in Reference 51 pertaining to waste loading, chemical composition, crystalline phase identification, radionuclide concentration limits and waste form durability testing from PCT. Sodium oxide loading in the LAW Envelope C glass is greater than 10 wt% as shown by the normalized characterization data. This demonstration was successful at producing an active AN-102 glass based on formulations provided by VSL. Resulting glass compositions were very similar to the target compositions for the three glasses (radioactive AN-102, surrogate #2 AN-102 and standard LRM) examined. Analyzed activities from radioactive AN-102 glass for Cs^{137}, Sr^{90} and Tc^{99} indicate these radionuclides are present below the average target values in the Hanford RPP contract specifications. The transuranic concentrations of the AN-102 glass are well below the contract specification limit for TRU-containing waste. X-ray diffraction and microscopy analyses of active AN-102 glass show this waste form to be amorphous with no evidence for the presence of crystals.

The ASTM standard Product Consistency Test (PCT) performed at 90°C on the AN-102 radioactive glass and the Low Activity Reference standard LRM glass showed similar measured releases for the B, Si, Na components. The PCT results indicate that normalized released for B, Si, and Na are well below the specification limit of 2 g glass/m^2.

Successful sampling of the melter offgas for volatile and particulate emissions was performed. Quantification of fixed gas emissions was also accomplished. The volatile and particulate emissions were performed by a modified EPA Method 60. The results showed that the relative emission rates for most of the non-radioactive elements were in the ranges expected. The particulate collected tended to mimic the composition of the feed, indicating the expected entrainment as the mechanism of emission. The volatile sampling showed that the most volatile element was boron, as expected. Mg, Tl, Ca, Sn, and P also showed more volatility than the other metals. The least volatile were Li, Zr, Ti, Fe, Ca, Al, and Zn. The overall particulate DF was found to be about 2.7E4 and the more abundant metals ranged from 4.7E3 to 4.0E4. The DFs for Cs^{137} and Tc^{99} were about 82 and 7, respectively. The Cs^{137} DF is in good agreement with previous studies using the DWPF pilot melter and non-radioactive Cs. The DFs for alpha count, Sr^{90}, mass 238, and mass 232 were over 10^3, which indicates these components were retained in the glass at >99.9%. Beta count was retained at 99.88%.

Comparison of DFs measured during feeding for Cs^{137} and Tc^{99} suggests that much more of these volatile radionuclides were retained in the glass versus measured dissolved glass/feed

ratios. These data have been explained by consideration of the overall idle times vs. feed times of the melter and by the additional 4-hr melt and cooling that was performed on the analyzed melter glass. Estimated volatilization rates for both Cs^{137} and Tc^{99} were determined from modeling of the system using a simple stirred tank model for the melter and an exponential decay for the Cs and Tc volatilization.

The overall material balances from the evaporator feed to the production of glass closed very well, indicating that the quality of the analytical data was good. Three melter feed samples were taken, and apart from different water contents, had virtually the same measured composition.

Offgas composition measurements by gas chromatography showed the main offgas component from the feed was CO_2. NO_x was also present, as seen visually in the offgas glassware, but these compounds were not quantified. Small quantities of H_2 and CO were also found during feeding. Both of these peaked at about 0.03 mol per mol of organic carbon in the feed during surrogate run #2. For the radioactive run the CO:TOC ratio was again about 0.03, but the H_2:TOC ratio was only 0.01. All of these values are very small. Scaled to the LAW melter, the offgas % Lower Flammable Limit would be about 2%. In addition to the gases above, trace quantities of what was probably N_2O, and possibly ethane, propane, and isobutane were also found several times during the run. The quality of the offgas measurements was shown by the agreement between redundant CO_2 measurements and closure of the carbon material balance to within about 5% for both the radioactive and surrogate #2 runs.

Additional tasks that were completed were to qualitatively analyze the offgas condensate and charcoal filters for organics and to perform rheological measurement on both radioactive and surrogate feed. The following is a summary and issues related to these tasks.

<u>Qualitative Analyses of Condensate and Charcoal:</u>

- Qualitative organic analyses indicate no detectable volatile organics in the condensates and presence of six different volatile organic components in the charcoal samples.

- Qualitative organic analyses indicate detectable semivolatile organic-nitriles in the condensates and presence of about ten different semivolatile organic components in the charcoal samples that were found to be present at very near the instrument detection limit of 1 µg/g.

<u>Rheological Measurements on Radioactive and Surrogate Feed</u>

- Rheological and settling rate data suggest that the optimal operational point lies between 5M and 6M sodium for the melter feeds.

- There were post precipitation issues with the radioactive LAW supernate. Crystals had formed in the supernate at 25°C. These crystals had no effect on the supernate rheology but drastically effected the rheology of the resulting melter feeds, especially as the sodium molarity increased.

- Evaporative losses impacted the reproducibility of rheology results for both the surrogate and the radioactive samples. These evaporative losses can impact the design basis of a unit operation, especially if operating near the upper limits of the design basis.

- The method of adding, such as rate and order of glass former chemicals and the intensity of mixing the glass former chemicals with the supernate can increase the risk of producing a melter feed with unexpected physical properties.

- Shaking the radioactive LAW supernate produced a slight froth layer that was not evident in the surrogate. The life of the froth was short lived.

- The surrogate and radioactive supernates are Newtonian fluids and their viscosities were essentially identical on the range of 5 to 7.1M sodium.

- The rheological properties of the melter feeds were different between the surrogate and the radioactive samples. The radioactive samples were more viscous for any given sodium molarity. The differences became larger as the sodium molarity increased. This could have been due to the insoluble solids in the radioactive sample being greater than that of the surrogate at 25°C.

- The properties of the 7.1M sodium melter feeds would present a formidable challenge to conventional processing equipment. The properties of the 5M sodium melter feed were nearly those of a 0.040 Pa-sec liquid, which could present problems for segregation (settling) of solids from the slurry. An indeterminate intermediate region would probably be best for processing this was stream.

- Settling tests of the melter feed revealed a dense/compacted solids zone beneath the interface produced by the supernate and settled solids. Yield stress of compacted material was not characterized. This can be an agitator restart issue. The settling rate of the radioactive melter feed was slower than that of the surrogate melter feed.

- The ability to measure the sodium concentration was an issue. This could lead to being to lean or excessive in the amount of glass formers added to a given batch.

- The delivery/blending/mixing of glass formers with supernate was not prototypic of the present methodology of the RPP-WTP process.

- Rheological measurements of melter feeds at elevated temperatures (50°C) should not be done with melter feeds made at 25°C. Melter feeds should be made and measured at approximately the same temperature. The resulting melter feed will have then been subjected to process conditions (temperature and time).

- Based on the limited data available and comparison that was performed, the VSL's AN-102 high sulfate melter feed was comparable to SRTC's simulant and actual melter feeds at 5M sodium. This was not the case at the 6M or 7M sodium melter feeds, where the VSL simulant being much thicker than those of SRTC's.

6. Appendices

6.1. Exceptions to EPA Methods 60 and 5 and Technical Justification

The modified EPA Method 60 document is maintained in the SRTC L13-1, GTOP-3-123 procedure file.[55]

Justification of exceptions is given below. Following the section number, an explanation of the exception is given. Refer to the attached modified Method 60 and the attached published Method 60.

Bold indicates text added to the method, other than explanations of text removed.

Method 60

2.1 The sampling system IS the offgas system, so no sample needs to be withdrawn and there is no probe. The system is by default isokinetic.

2.1 These are for sampling for mercury, so this does not apply.

2.1 **Empty, NaOH, and empty impingers are inserted between the last nitric acid and the desiccant impingers. An activated carbon impinger is added after the desiccant.**

The NaOH impinger is added to scrub out some of the acid gases that will be generated to protect downstream equipment. The empty impinger is added to protect the desiccant impinger. The activated carbon impinger is added to collect volatile organics. None of these affects the ability of the upstream impingers to remove metals. The method is modified in later steps to account for the weight gains of these additional impingers as necessary for the method.

2.3 Analysis for mercury will not be performed.

4.1.1 A probe is not used for sampling the Large C melter.

4.1.2 A pitot tube and differential pressure gauge is not needed since there is no duct velocity to be measured.

4.1.6.1 This step applies to mercury sampling, which will not be done.

4.1.7 The metering system is necessarily different since it comprises the entire offgas system. Alternate metering systems will be used:

1. A dry gas meter, per Method 5 will be used for total volume measurement and also as a secondary volumetric flowmeter by measuring the rate of revolution of

this meter. This meter will be calibrated versus a known standard meter or other calibrated meter.

2. A thermal flowmeter shall also be used for instantaneous flow estimates. This meter is known to read incorrectly if the composition of the gas measured differs from dry air.

3. A helium tracer gas method shall be used to measure the volumetric flowrate. Method Alt-102, "An Alternate Procedure for Stack Gas Volumetric Flow Rate Determination (Tracer Gas)" shall be used with the following exceptions:

   a. The linearity, calibration error, span drift, and resolution shall be determined during testing.

   b. The tracer gas to be used will be helium rather than sulfur hexafluoride or sulfur dioxide since SF6 cannot be measured by the gas chromatograph and measurement of SO2 in the sample is desired.

Note: All gas meters shall be calibrated per SRTC procedures and be logged in the SRTC-ITS M&TE database.

Gas density will be determined by gas chromatographic analysis and material balance calculations.

5.9 HCl is used for mercury sample recovery, so is not needed.

5.11-12 Potassium permanganate is used for mercury sampling, so is not needed.

5.13 Sulfuric acid is used for mercury sampling, so is not needed.

5.14 **Drierite™ (4-10 mesh) may be used in place of silica gel. Activated carbon (~ 8 mesh or 4-10 mesh) is also required.**

5.15 Hydrofluoric acid is not needed for sampling; it is needed by ADS for sample analysis.

6.1.2 Calibration of the probe nozzle, pitot tube, and probe heater is not applicable since these components are not used.

The metering system and temperature indicators are calibrated per the SRTC-ITS M&TE system.

6.1.4.1, 6.1.4.3, 6.1.4.4 References to potassium permanganate not applicable.

6.1.5 **Leak check procedures given in this procedure and in GTOP-3-121 are equivalent to those specified (Method 5).**

6.1.6 Reference to sampling mercury is not applicable.

7.1 **Sample train disassembly procedure is described in this procedure and incorporates all applicable and necessary steps of Method 60. Additional handling steps are required to handle the radiological samples.**

7.1.1-7.1.3 These steps do not apply as they refer to sample train components that are not used.

7.1.4 **Transfer of sampling train equipment is described in this procedure.**

7.1.5.2.1-3 References to probe not applicable. Reagent water will not be used for washing; acetone will be used.

7.1.5.3 References to probe not applicable.

7.1.5.5 References to permanganate solutions not applicable.

7.1.5.5.1 **Change "precedes the two permanganate impingers" to "precedes the NaOH impinger".**

Steps in this procedure address the NaOH impinger and the empty impinger that follows. (Called 7.1.5.5.1B in modified M60)

Steps referring to permanganate impinger not applicable.

7.1.5.5.2 References to permanganate solutions not applicable.

7.1.5.6 **Add steps for handling the activated carbon impinger. (Called 7.1.5.6B in modified M60)**

7.1.5.11 Container No. 10 is not used since it pertains to mercury sampling.

7.1.5.12 Container No. 10 is not used since it pertains to mercury sampling.

7.5.2-8.2.3 The applicability of these sections is not covered by this procedure.

Method 5

Method 60 specifically refers to a number of sections in Section 4.1 and 4.3 of Method 5. Some of these are implemented as described in Method 5, some are implemented in alternative ways in this procedure, and some are not implemented.

4.1.2 The preliminary determinations only apply to a sampling system with a sample probe inserted into a stack.

4.1.3 Portions of this step that apply are reproduced in this procedure. Steps that do not apply refer to the sample probe.

4.1.4.1 Alternative, but equivalent, pretest leak check procedures are given in this procedure and GTOP-3-121 because the experimental setup differs from the standard M60 equipment.

4.1.4.2 Leak checks during the sampling run are not anticipated and would be difficult to implement in the radiological hood.

4.1.4.3 Alternative, but equivalent, post-test leak check procedures are given in this procedure and GTOP-3-121 because the experimental setup differs from the standard M60 equipment.

4.1.5 Particulate train operation (M60 train) is described in this procedure and in GTOP-3-121 due to the significant differences in the equipment.

Calibrations are specified in Section 5 of Method 5.

5.3.1 Calibration prior to use:

All applicable sampling train components have been calibrated as part of the ITS M&TE system.

5.3.2 Calibration after use:

Calibration of the dry gas meters and mass flowmeters after use is not possible due to the radiological conditions in the hood.

Calibration after use of the gas chromatographs, used to measure flow (Method alt-012), shall be performed.

Method 60 Analytical

Exceptions to the specific details for sample analyses prescribed in Method 60 are given below. The material below is reproduced from an SRTC memorandum.[56]

Differences Between EPA Method 60 and Current ADS Methods

The following letter is provided to list the differences between ADS methods and modified method 60 protocol provided by Jack Zamecnik.

The analytical portion of method 60 can be broken into four sections: digestion and sample preparation, Atomic Absorption (AA) analysis, Inductively Coupled Plasma Emission Spectroscopy (ICP-ES) and analysis of radioactive components i.e. radiochemistry and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Since the radioactive elements and actinides are not listed under method 60 elements in the task plan document WSRC-TR-2000-00397, radiochemistry and ICP-MS will be performed under existing ADS methods without consideration of SW-846 methods. Modifications and notations for the first three sections will be detailed in the following paragraphs.

Section 1: Digestion and Sample Preparation

Most of the sample collection procedures will be performed outside of ADS and are therefore the responsibility of the customer. Solutions 1-5, 7-9 and 12 as described in section 7.1 of the modified method 60 will be provided to ADS. The method will be followed with the following adjustments. 1) Samples will be weighed to only ±1 mg (described as ±0.1 mg in section 7.2.2) due to the availability of radiological contained balances in ADS. 2) In the sections where multiple digestion techniques are available to ADS, ADS will use the Parr Bomb method under manufacturers' recommended conditions. 3) In sections 7.2.3.1 and 7.2.4 of Method 60, solutions are reduced to 20 ml and digested. ADS will use 10 ml sample volumes due to the size of in-house Parr Bombs. 4) ADS is concerned about the loss of volatile radioactive isotopes for the H_2O_2 hot plate digestion in section 7.2.4. ADS plans to a Parr Bomb digestion by combining 10 ml evaporated sample with 10 ml concentrated HNO3 and heating to 140°C. The nitric acid digestion should be vigorous enough to destroy any residual organic material. The resulting solution will then be diluted to 150 ml.

Section 2: Atomic Absorption (AA) analysis

Arsenic and selenium are currently measured by hydride collection using ADS method 1557. This method is very similar to SW-846 methods 7062 (As) and 7742 (Se). There is only one area of discrepancy between the ADS method and SW-846 methods: QA/QC methodology. In particular, ADS does not routinely perform spiked samples, standards or reagent blanks or analyze duplicate or replicate samples in a routine analysis. However, these adjustments can be made with the following caveats: 1) extra charges will be applied based on the amount of extra work performed and 2) AA Task Supervisor must be notified of the need for method 60. Also, changes in sample size described in SW-846 may be necessary due to the radiological concerns.

Section 3: Inductively Coupled Plasma Emission Spectroscopy (ICP-ES)

Method 60 points to method 6010 for ICP-ES analysis. Currently ADS performs ADS methods 1509 and 1559 for radiological ICP-ES analysis and data work-up. Based on this ICP-ES system and the limited capabilities of the software, there are several discrepancies between these methods and method 6010. First, while the current contained ICP-ES torch configuration is HF resistant, the spray chamber-nebulizer set-up is not HF resistant. ADS does have a new set-up on order, which we will use if the RPP schedule permits. Second, ADS does not perform background correction on the contained ICP-ES (described in sections 2.2, 3.1.1, 3.1.2, 3.1.7 and 4.1.1 of method 6010). ADS has found the instrument to work well for trace level analysis as exemplified by the excellent performance in the Mixed Analyte Performance Evaluation Program (MAPEP). Third, ADS will often perform manual inter-element interference corrections (IEC) based on common spectral overlaps on the ICP-ES. However, these overlaps are not documented to the extent required by method 6010 (section 3.1.4-3.1.10). Also, ADS does not routinely perform an IEC check solution to verify the accuracy of the correction routine. ADS can perform this check with the same caveats described for AA analysis of reagent blanks, duplicates and replicate samples. Further, to prepare an adequate IEC check solution, ADS will need a good idea of the matrix submitted

for each sample under method 60. Fourth, ADS does not routinely analyze matrix spiked and duplicate samples (section 8.4). These tasks can be accommodated at additional cost and with Task supervisor notification.

6.2. Engineering Drawings List

Drawing Numbers

EES-22710-R3 -017, Rev. A
EES-22710-R4 -018, Rev. A
EES-22710-R3 -019, Rev. A
EES-22710-JC -004, Rev. A
EES-22710-R1 -001, Rev. A
EES-22710-L5 -006, Rev. B
EES-22710-JC -003, Rev. A
EES-22710-L6 -008, Rev. C
EES-22710-L6 -012, Rev. C
EES-22710-L6 -011, Rev. C
EES-22710-L6 -010, Rev. C
EES-22710-L6 -009, Rev. C
EES-22710-L5 -005, Rev. B
EES-22710-L5 -007, Rev. B
EES-22710-L6 -029, Rev. C
EES-22710-L6 -030, Rev. B
EES-22710-L6 -031, Rev. B
EES-22710-L6 -032, Rev. B
EES-22710-R2 -027, Rev. B
EES-22710-R1 -024, Rev. B
EES-22710-R2 -028, Rev. B
EES-22710-R2 -026, Rev. B
EES-22710-R2 -025, Rev. B
EES-22710-R1 -033, Rev. B
EES-22710-R2 -034, Rev. C
EES-22710-R3 -035, Rev. A
EES-22710-R3 -036, Rev. A

6.3. Approved Checkout & Operating Procedures

System	Procedure Number	Revision	Title
Checkout			
Instrumentation & Controls	(EES) Field Procedure FP-835	1	Calibration and Verification of Control and Instrument Loops for BNFL LC Melter
Offgas	GTOP-3-116	0	LC Melter Offgas System Checkout
Control & Heating	GTOP-3-117	1	LC Melter Control And Heating Checkout
Feed System	GTOP-3-119	0	BNFL Large C Melter Feed System/Chiller Checkout
Operating			
Melter & Controls	GTOP-3-118	1	LC Melter & Control System Operation
Feeding & Pouring	GTOP-3-120	1	BNFL Large C Melter Feeding/Glass Pouring Operation
Offgas	GTOP-3-121	3	LC Melter Offgas System Operation
Offgas Analyzer	GTOP-3-122	1	BNFL Large C Melter Offgas Analyzer Operation
Offgas Sampling	GTOP-3-123	0	LC Melter Offgas System Sampling
	Also reference SRT-RPP-2000-00042, rev. 0		Sampling of the Large C Melter Offgas using Appropriate Portions of EPA Methods
Alarms	GTOP-3-124	0	BNFL Large C Alarm Responses

6.4. ISMS Reference Documents

Implementation of the ISMS in SRTC involves use of the SRTC Conduct of R&D Manual, which prescribes the steps and actions necessary to assure safe operation of experimental equipment. This process was followed and documented as given below.

1. T. K. Snyder, *Conduct of R&D Summary for the BNFL Large C Melter Operation*, **SRT-PTD-2000-00029**, June 27, 2000.

2. J. R. Zamecnik, *R&D Hazards Screening Checklist for BNFL Large C Melter System*, **BNF-003-98-181, Rev. 0**, November 1, 1999.

3. A. L. Fishburne, *Notice of NEPA Approval for EEC No. TC-A-98-017, BNFL Part B*, **TSD-WRS-98-028**, June 4, 1998.

4. *Screening Process Hazards Review Report for BNFL Large C Melter Project*, **BNF-003-98-183, Rev. 0**, November 3, 1999.

5. J. R. Zamecnik, *Supporting Information for SPHR BNF-003-98-183*, **BNF-003-98-183 (Attachment)**, November 3, 1999.

6. R. F. Schumacher, *Process Hazards Review – Melter for Large Low Activity Waste (C) Vitrification*, **E-PHR-A-00041**, February 29, 2000.

7. A. S. Choi, *Off-Gas Flammability During BNFL's Large C Melter Run*, **SRT-PCC-2000-00006**, February 22, 2000.

8. D. M. Ferrara, *Vitrification of Low-Activity Radioactive Waste (LAW) Samples Using a Research Melter in Building 773-A, Laboratory B-126*, **SRT-USQ-00-0033**, March 22, 2000.

9. *SRS Final Acceptance Inspection – BNFL Large C Melter System*, May 4, 2000.

10. J. R. Zamecnik, *Offgas Flammability Control Interlocks for the BNFL Large C Melter*, **SRT-GFM-2000-008, Rev. 3**, April 14, 2000.

11. J. R. Zamecnik, *Offgas Flammability Control Strategy for the BNFL Large C Melter*, **SRT-GFM-2000-002, Rev. 2**, April 14, 2000.

12. J. R. Zamecnik, *Disposition of Action Items and Recommendations for the Melter for Large Low Activity Waste Vitrification (BNFL LC Melter) Process Hazards Review (E-PHR-A-00041, Rev. 0)*, **SRT-GFM-2000-015, Rev. 0**, July 5, 2000.

13. A. L. Fishburne, *Notice of NEPA Approval for EEC No. TC-A-2000-033, Rev. 0, BNFL Part B1 Sample LC Evaporator and Melter Off Gas System Cleaning*, **TSD-WRS-2000-033**, July 17, 2000.

14. D. M. Ferrara, *Radiological Safety Review for the 773-A B-126/130 RPP Melter Study*, electronic mail to H. F. Sturm, et al., December 7, 2000.

15. *Job Hazard Analysis for BNFL LC Melter Glass Can Handling*, **BNF-003-98-0298**, July 11, 2000.

16. *Job Hazard Analysis for BNFL LC Melter Feed Tube Removal*, **BNF-003-98-0299**, July 11, 2000.

17. *Job Hazard Analysis for Hanford RPP LC Melter Impinger Box Removal*, **SRT-RPP-2000-00039**, October 17, 2000.

18. *Job Hazard Analysis for RPP LC Melter Feed Tube Rodding*, **SRT-RPP-2000-00057**, December 9, 2000.

6.5. Details of Melter Sizing Calculations

Values:

		LAW Melter	LC Melter
Cylindrical Diameter (d)	in	140.48	4.026
Glass Height	in	30.00	4.026
Melt Surface Area	m^2	10	0.0077
	ft^2	107.6	0.083
Surface Area Scale Factor to Full-Scale Melter			1296.6
Glass Volume	liter	7620	0.840
Mass of Glass in Melter	kg	20955	2.31
Glass Sp Gr		2.75	2.75
Melter Feed Total Solids	wt %	62.3	62.3
Glass Production Flux (glass/hr/melt surface area)	$kg/hr/m^2$	41.67	41.67
Glass Production Flux (glass/hr/melt surface area)	$lb/hr/ft^2$	8.52	8.52
Glass Production Rate	Mt/d	10.00	
Glass Production Rate	kg/hr	416.7	0.32
Glass Production Rate	lb/hr	916.7	0.71
Glass Mass/Feed Volume	kg/liter	0.817	0.82
Melter Feed Wet Calcine (mass glass/mass feed)		0.476	0.476
Melter Feed Dry Calcine (mass glass/mass dry feed)		0.765	0.765
Feedrate	liter/hr	510.0	0.39
Feedrate	ml/min		6.55
Feedrate	kg/hr	874.5	0.674
Feedrate	lb/hr	1923.8	1.48
Volume of Feed per Melter Volume	liter	25649	2.83
Volume of Feed for 3 Melter Volumes	liter	76948	8.48
Total Volume of Feed	liter		14.08
Melter Volumes Produced from 7.5 liters of Initial LC		-	4.98
Mass of Glass Produced from7.5 liters of Initial LC	kg	-	11.51
Total Time for 7.5 liters of Initial LC	hr	-	35.8

		LAW Melter	LC Melter
Glass Surface Area/Vapor Space Volume	m^{-1}	0.538	0.538
Melter Vapor Space Volume	m^3	18.58	0.0143
Melter Vapor Space Volume	ft^3	656	0.506
Melter Vapor Space Volume	liter	18580	14.33
Feedrate/Surface Area	liter/hr/m^2	51.0	51.0
Vapor Space Volume / Glass Volume		2.44	17.06
Plenum Gas Temperature	C	600	600
Offgas Flow (from Feed only)	kg/hr	457.8	0.353
Molecular Weight (from MEB)	g/mol	22.34	22.34
Offgas Flow (from Feed only)	Nm^3/hr	459.3	0.354
Offgas Flow (from Feed only)	m^3/hr	1468.3	1.132
Offgas Flow (from Feed only)	scfm	270.4	0.208
Offgas Flow (from Feed only)	cfm	864.2	0.666
Offgas Flow (from Feed only)	slpm		5.9
Offgas Flow (from Feed only)	lpm		18.9
Offgas Flux from Feed	kg/hr/m^2	45.8	45.8
Offgas Residence Time (excludes air inleakage and bubbler)	sec	45.6	45.6
Bubbler Air	Nm^3/hr	125.0	0.096
Bubbler Air	scfm	73.6	0.0567
Bubbler Air	slpm		1.61
Air Inleakage (estimated- 100 scfm, 485 lb/hr)	Nm^3/hr	170.0	0.131
		100.1	0.077
			2.19
Air Flow (Bubbler + Inleakage @ Plenum T)	m^3/hr	943.0	0.727
Air Flow (Bubbler + Inleakage)	Nm^3/hr	295.0	0.228
Air Flow (Bubbler + Inleakage)	scfm	173.6	0.134
Air Flow (Bubbler + Inleakage)	slpm		3.79
Total Offgas Flow	Nm^3/hr	754.3	0.582
Total Offgas Flow	m^3/hr	2411	1.859
Total Offgas Flow	scfm	444.0	0.342
Total Offgas Flow	cfm	1419.2	1.094
Total Offgas Flow	slpm		9.70
Total Offgas Flow	lpm		30.99
Total Offgas Residence Time	sec	27.7	27.7
Bubbler Air	scfm	73.57	0.0567

	A	B	S	T
1			LAW Melter	LC Melter
4	Cylindrical Diameter (d)	in	=SQRT(4*S6^2/PI())	4.026
5	Glass Height	in	30	=T4
10	Melt Surface Area	m^2	10	=T11*0.3048^2
11		ft^2	=PI()*(S4/12)^2/4	=T8-T9
12	Surface Area Scale Factor to Full-Scale Melter			=$S11/T11
13	Glass Volume	liter	=S11*S5/12*0.3048^3*1000	=T8*T5/12*0.3048^3*1000
14	Mass of Glass in Melter	kg	=S13*S15	=T13*T15
15	Glass Sp Gr		=$C15	=$C15
16	Melter Feed Total Solids	wt %	='Makeup Feed-LC-5M'!W54	=S16
21	Glass Production Flux (glass/hr/melt surface area)	$kg/hr/m^2$	=S24/S10	=S21
22	Glass Production Flux (glass/hr/melt surface area)	$lb/hr/ft^2$	=2.2*S21*0.3048^2	=2.2*T21*0.3048^2
23	Glass Production Rate	Mt/d	10	
24	Glass Production Rate	kg/hr	=S23/24*1000	=T21*T10
25	Glass Production Rate	lb/hr	=S24*2.2	=T24*2.2
26	Glass Mass/Feed Volume	kg/liter	=S24/S32	=S26
29	Melter Feed Wet Calcine (mass glass/mass feed)		=S24/S34	=S29
30	Melter Feed Dry Calcine (mass glass/mass dry feed)		=$D30	=$D30
32	Feedrate	liter/hr	510	=T24/T26
33	Feedrate	ml/min		=T32*1000/60
34	Feedrate	kg/hr	=S32*S19	=T32*T19
38	Feedrate	lb/hr	=S34*2.2	=T34*2.2
40	Volume of Feed per Melter Volume	liter	=S14/S26	=T14/T26
41	Volume of Feed for 3 Melter Volumes	liter	=3*S40	=3*T40
42	Total Volume of Feed	liter		=T44/3*T41
44	Melter Volumes Produced from 7.5 liters of Initial LC		-	=T45/T14
45	Mass of Glass Produced from7.5 liters of Initial LC	kg	-	='Makeup Feed-LC-5M'!$V46/1000
47	Total Time for 7.5 liters of Initial LC	hr	-	=T45/T24

	A	B	S	T
51			LAW Melter	LC Melter
52	Glass Surface Area/Vapor Space Volume	m^{-1}	=S10/S53	=S52
53	Melter Vapor Space Volume	m^3	18.58	=T10/T52
54	Melter Vapor Space Volume	ft^3	=S53/(0.3048^3)	=T53/(0.3048^3)
55	Melter Vapor Space Volume	liter	=S53*1000	=T53*1000
60	Feedrate/Surface Area	liter/hr/m^2	=S32/S10	=T32/T10
61	Vapor Space Volume / Glass Volume		=S55/S13	=T55/T13
64	Plenum Gas Temperature	C	600	600
65	Offgas Flow (from Feed only)	kg/hr	=S34*(1-S29)	=T34*(1-T29)
66	Molecular Weight (from MEB)	g/mol	22.34	=S66
67	Offgas Flow (from Feed only)	Nm^3/hr	=S65/S66*0.08206*273.16	=T65/T66*0.08206*273.16
68	Offgas Flow (from Feed only)	m^3/hr	=S65/S66*0.08206*(273.16+S64)	=T65/T66*0.08206*(273.16+T64)
69	Offgas Flow (from Feed only)	scfm	=S70/(273.16+S64)*273.16	=T70/(273.16+T64)*273.16
70	Offgas Flow (from Feed only)	cfm	=S68/(0.3048^3)/60	=T68/(0.3048^3)/60
71	Offgas Flow (from Feed only)	slpm		=T69*28.32
72	Offgas Flow (from Feed only)	lpm		=T70*28.32
73	Offgas Flux from Feed	kg/hr/m^2	=S65/S10	=T65/T10
74	Offgas Residence Time (excludes air inleakage and bubbler)	sec	=S53/S68*3600	=T53/T68*3600
82	Bubbler Air	Nm^3/hr	125	=S82/T12
83	Bubbler Air	scfm	=S82/(0.3048^3)/60	=T82/(0.3048^3)/60
84	Bubbler Air	slpm		=T83*28.32
85	Air Inleakage (estimated- 100 scfm, 485 lb/hr)	Nm^3/hr	170	=S85/T12
86			=S85/(0.3048^3)/60	=T85/(0.3048^3)/60
87				=T86*28.32
88	Air Flow (Bubbler + Inleakage @ Plenum T)	m^3/hr	=(S82+S85)*(S64+273.16)/273.16	=(T82+T85)*(T64+273.16)/273.16
89	Air Flow (Bubbler + Inleakage)	Nm^3/hr	=S88/((S64+273.16)/273.16)	=T88/((T64+273.16)/273.16)
90	Air Flow (Bubbler + Inleakage)	scfm	=S89/(0.3048^3)/60	=T89/(0.3048^3)/60
91	Air Flow (Bubbler + Inleakage)	slpm		=T90*28.32
92	Total Offgas Flow	Nm^3/hr	=S82+S85+S68*273.16/(273.16+S64)	=T82+T85+T68*273.16/(273.16+T64)
93	Total Offgas Flow	m^3/hr	=S92*(S64+273.16)/273.16	=T92*(T64+273.16)/273.16
94	Total Offgas Flow	scfm	=S99+S102+S70*273.16/(S64+273.16)	=T99+T102+T70*273.16/(T64+273.16)
95	Total Offgas Flow	cfm	=S94/273.16*(S64+273.16)	=T94/273.16*(T64+273.16)
96	Total Offgas Flow	slpm		=T94*28.32
97	Total Offgas Flow	lpm		=T95*28.32
98	Total Offgas Residence Time	sec	=S53/(S68+S88)*3600	=T53/(T68+T88)*3600
99	Bubbler Air	scfm	=S82/(0.3048^3)/60	=T82/(0.3048^3)/60

6.6. Vitreous State Laboratory Glass Formulation Spreadsheets

Table 6.1 Glass Former Recipe for Low Sulfate Simulant (Surrogate #1) from VSL Spreadsheet "LAWAN102 with Sulfate for SRTC: LAWAN102 Low Sulfate Surrogate"

											Recipe for glass LAWC21 using Low sulfate Simulant AN102					23-May-00	
Mol. Wt.	Envelope Constituents	calculated M	Low sulfate AN-102 mg/L 5/1500 email	GLASS Oxides Loading	Conversion to wt% "Oxides"	AN102 surr. wt% As glass 100%	AN102 wt% in glass @ 11.8% Na2O 13.29%	Glass Former Mix 100%	LAWC21 this target for AN102 0.1329	Additives this sample 86.71%	Source in Additives	Assay	Ratio	Target Weight (g) Additives	other oxides present % Fe2O3	%SiO2	Vendor Inormation
107.87	Ag			Ag2O	0.00	0.00	0.0000		0.0000								
26.98	Al	0.42	**11400**	Al2O3	3.87	7.10	0.943	6.00	6.1457	5.203	**Kyanite (Al2SiO5) 325 Mesh**	0.990	0.540	**319.39**	1.16%	43.70%	Kyanite Mining
10.81	B		**59.9**	B2O3	0.03	0.06	0.0084	11.70	10.1540	10.146	**H3BO3 (Technical Granular)**	0.986	0.563	**599.79**			US Borax
137.33	Ba			BaO	0.00	0.00	0.0000		0.0000								
40.08	Ca		**412**	CaO	0.10	0.19	0.0252	7.40	6.4421	6.417	**Wollanstonite NYAD 325 Mesh**	0.993	0.475	**446.47**	0.40%	51.00%	NYCO Minerals
112.41	Cd		**0.0**	CdO	0.00	0.00	0.0000		0.0000								
58.93	Co		**0.0**	CoO	0.00	0.00	0.0000		0.0000								
52.00	Cr		**142.0**	Cr2O3	0.07	0.14	0.0182		0.0182								
63.55	Cu		**22.7**	CuO	0.01	0.01	0.0012		0.0012								
55.85	Fe		**25.0**	Fe2O3	0.01	0.01	0.0016	7.50	6.5052	6.504	**Fe2O3 (Iron III oxide, -325 Mesh)**	0.998	1.000	**200.16**			Alfa Aesar-Johnson Matthey
39.10	K	0.08	**3060**	K2O	0.66	1.21	0.161		0.1613								
138.91	La			La2O3	0.00	0.00	0.0000		0.0000								
6.94	Li		**1**	Li2O	0.00	0.00	0.0001	3.17	2.7489	2.749	**Li2CO3 (Chemetall Foote Co. Tech. gr.)**	0.99	0.404	**225.55**			Cyprus Foote Mineral Co.
24.30	Mg		**21**	MgO	0.01	0.01	0.0015	1.75	1.5190	1.518	**Olivine (Mg2SiO4) 325 Mesh (#180)**	0.990	0.480	**104.80**	7.68%	42.52%	UNIMIN Corp.
54.94	Mn		**12**	MnO2	0.00	0.01	0.0008		0.0008								
95.94	Mo		**41.5**	MoO3	0.01	0.02	0.0027		0.0027								
22.99	Na	8.70	**200000**	Na2O	48.43	88.82	**11.80**		11.8000								
58.69	Ni		**315**	NiO	0.07	0.13	0.0175		0.0175								
207.20	Pb		**111.0**	PbO	0.02	0.04	0.0052		0.0052								
118.71	Sn			SnO2	0.00	0.00	0.0000		0.0000								
28.09	Si		**14**	SiO2	0.01	0.01	0.0013	54.18	46.9832	46.982	**SiO2 (Sil-co-Sil 75)**	0.997	1.000	**1086.64**			US SILICA
87.62	Sr		**0**	SrO	0.00	0.00	0.0000		0.0000								
47.90	Ti		**0**	TiO2	0.00	0.00	0.0000	1.30	1.1273	1.127	**TiO2 (Rutile Airfloated)**	0.954	1.000	**38.78**	0.71%	0.91%	Chemalloy
183.85	W		**0**	WO3	0.00	0.00	0.0000		0.0000								
65.39	Zn		**3.2**	ZnO	0.00	0.00	0.0002	3.50	3.0352	3.035	**ZnO (Kadox-920)**	0.997	1.000	**99.90**			Zinc Corp. of America
91.22	Zr		**6**	ZrO2	0.00	0.00	0.0003	3.50	3.0353	3.035	**Zircon ZrSiO4 (Flour) Mesh 325**	0.990	0.651	**154.54**		33.00%	American Mineral
79.90	Br		**0**	Br	0.00	0.00	0.0000		0.0000								
35.45	Cl		**3090**	Cl	0.56	1.02	0.1352		0.1352								
19.00	F		**1230**	F	0.22	0.41	0.0538		0.0538								
94.97	PO4		**968**	P2O5	0.13	0.24	0.0317		0.0317		**Total Sodium Moles**			12.50	**moles**		
96.06	SO4	0.02	**2090**	SO3	0.31	0.57	0.0762		0.0762		**Expected Glass yield**			**3282**	**g**		
46.00	NO2	1.41	**64800**	NO2	11.64						**Sum of Additives (g)**			**3276**	**g**		
62.00	NO3	2.55	**158000**	NO3	28.38						**Sugar as added reductant**			**59.7**	**g**		
17.00	OH			OH	0.00												
60.00	CO3	0.49	**29300**	CO3	5.26												
89.04	oxalate		**1000**	C	0.18												
45.03	formate			C	0.00												
	SUM			SUM	100.00	100.00	13.29	100.00	100.00	86.715							
	NO2+NO3	3.96	M#	VSL uses 12 moles Carbon (1 mole sucrose/342.3g) per 16 Moles NOx in order to mitigate foaming													
12.00	TOC		**18149.0**			This feed requires		84.66	g/L or	9.731	g. of sucrose per Mole Na						
										0.8996	if 5 times higher, LAWC21 would be better						
		This sample already includes				2.173	moles C, and sucrose has be lowered by			-61.99	g sucrose						

Table 6.2 Glass Former Recipe for High Sulfate Simulant (Surrogate #2) from VSL Spreadsheet "LAWAN102 with Sulfate for SRTC: LAWAN102-HS 2nd SRTC Surrogate"

											Recipe for glass LAWC21 using 2nd Surrogate HS					22-Aug-01	
Mol. Wt.	Envelope Constituent	calculated M	Evapor. feed AN-102 active mg/L	GLASS Oxides	Conversion to wt% "Oxides"	AN102 wt%	AN102 wt% in glass @	Glass Former	LAWC21 this target	Additives this	Source in Additives	Assay	Ratio	Target Weight	other oxides present		
			6/1500 email	Loading		As glass	11.8% Na2O	Mix	for AN102	sample				(g) Additives	% Fe2O3	%SiO2	Vendor Inormation
107.87	Ag			Ag2O	0.00	0.00	0.0000		0.0000								
26.98	Al	0.24	**6349**	Al2O3	3.13	5.68	0.758	6.22	6.1439	5.386	**Kyanite (Al2SiO5) 325 Mesh**	0.990	0.540	**396.73**	1.16%	43.70%	Kyanite Mining
10.81	B		**25.0**	B2O3	0.02	0.04	0.0051	11.70	10.1437	10.139	**H3BO3 (Technical Granular)**	0.986	0.563	**719.26**			US Borax
137.33	Ba			BaO	0.00	0.00	0.0000		0.0000								
40.08	Ca		**96**	CaO	0.03	0.06	0.0085	7.40	6.4210	6.412	**Wollanstonite NYAD 325 Mesh**	0.993	0.475	**535.39**	0.40%	51.00%	NYCO Minerals
112.41	Cd		**0.04**	CdO	0.00	0.00	0.0000		0.0000								
58.93	Co		**0.0**	CoO	0.00	0.00	0.0000		0.0000								
52.00	Cr		**86.1**	Cr2O3	0.07	0.12	0.0159		0.0159								
63.55	Cu		**9.9**	CuO	0.00	0.01	0.0008		0.0008								
55.85	Fe		**1.9**	Fe2O3	0.00	0.00	0.0002	7.50	6.4993	6.499	**Fe2O3 (Iron III oxide, -325 Mesh)**	0.998	1.000	**239.87**			Alfa Aesar-Johnson Matthey
39.10	K	0.03	**1260**	K2O	0.40	0.72	0.096		0.0959								
138.91	La		**0**	La2O3	0.00	0.00	0.0000		0.0000								
6.94	Li		**5**	Li2O	0.00	0.00	0.0006	3.17	2.7476	2.747	**Li2CO3 (Chemetall Foote Co. Tech.**	0.99	0.404	**270.48**			Cyprus Foote Mineral Co.
24.30	Mg		**0.14**	MgO	0.00	0.00	0.0000	1.75	1.5165	1.516	**Olivine (Mg2SiO4) 325 Mesh (#180)**	0.990	0.480	**125.67**	7.68%	42.52%	UNIMIN Corp.
54.94	Mn		**35**	MnO2	0.01	0.03	0.0035		0.0035								
95.94	Mo		**24.1**	MoO3	0.01	0.02	0.0023		0.0023								
22.99	Na	6.02	**139500**	Na2O	48.69	88.42	**11.80**		11.8000								
58.69	Ni		**142**	NiO	0.05	0.09	0.0114		0.0114								
207.20	Pb		**52.1**	PbO	0.01	0.03	0.0035		0.0035								
118.71	Sn		**0**	SnO2	0.00	0.00	0.0000		0.0000								
28.09	Si		**19**	SiO2	0.01	0.02	0.0026	53.97	46.7661	46.763	**SiO2 (Sil-co-Sil 75)**	0.997	1.000	**1289.77**			US SILICA
87.62	Sr		**0**	SrO	0.00	0.00	0.0000		0.0000								
47.90	Ti		**0.01**	TiO2	0.00	0.00	0.0000	1.30	1.1265	1.127	**TiO2 (Rutile Airfloated)**	0.954	1.000	**46.50**	0.71%	0.91%	Chemalloy
183.85	W		**0**	WO3	0.00	0.00	0.0000		0.0000								
65.39	Zn		**0.9**	ZnO	0.00	0.00	0.0001	3.50	3.0330	3.033	**ZnO (Kadox-920)**	0.997	1.000	**119.80**			Zinc Corp. of America
91.22	Zr		**0.2**	ZrO2	0.00	0.00	0.0000	3.50	3.0330	3.033	**Zircon ZrSiO4 (Flour) Mesh 325**	0.990	0.651	**185.33**		33.00%	American Mineral
79.90	Br		**0**	Br	0.00	0.00	0.0000		0.0000								
35.45	Cl		**3315**	Cl	0.86	1.57	0.2095		0.2095								
19.00	F		**1008**	F	0.26	0.48	0.0637		0.0637								
94.97	PO4		**1515**	P2O5	0.30	0.54	0.0716		0.0716		**Total Sodium Moles**			15.00	**moles**		
96.06	SO4	0.06	**5530**	SO3	1.20	2.18	0.2913		0.2913		**Expected Glass yield**			**3938**	**g**		
46.00	NO2	0.79	**36550**	NO2	9.53						**Sum of Additives (g)**			**3929**	**g**		
62.00	NO3	1.44	**89000**	NO3	23.21						**Sugar as added reductant (decreased for TOC)**			**67**	**g**		
17.00	OH			OH	0.00												
60.00	CO3	0.67	**40115**	CO3	10.46												
89.04	oxalate		**1170**	C	0.31												
45.03	formate		**5445**	C	1.42												
	SUM			SUM	100.00	100.00	13.34	100.00	100.00	86.655							
	NO2+NO3	2.23	MI	VSL uses 12 moles Carbon (1 mole sucrose/342.3g) per 16 Moles NOx in order to mitigate foaming.													
12.00	TOC		**8682.0**	mg/L		This feed requires		47.71	g/L or		7.919 g. of sucrose per Mole Na						
									3.4374								

Table 6.3 Glass Former Recipe for High Sulfate Active (Radioactive) from VSL Spreadsheet "LAWAN102 with Sulfate for SRTC: LAWAN102 High Sulfate Active"

											Recipe for glass LAWC21 using High Sulfate Active sample					23-May-00	
Envelope Constituents	calculated M	Evapor. feed AN-102 active mg/L 5/15/00 email	Tank AN102 Ox.Wt	GLASS Oxides Loading	Conversion to wt% "Oxides"	AN102 wt% As glass 100%	AN102 wt% in glass @ 11.8% Na2O 13.29%	Glass Former Mix 100%	LAWC21 this target for AN102 0.1329	Additives this sample 86.71%	Source in Additives	Assay	Ratio	Target Weight (g) Additives	other oxides present % Fe2O3	%SiO2	Vendor Inormation
Ag			0.00	Ag2O	0.00	0.00	0.0000		0.0000								
Al	0.31	8390	15.85	Al2O3	3.35	5.97	0.793	6.18	6.1519	5.359	**Kyanite (Al2SiO5) 325 Mesh**	0.990	0.540	**131.59**	1.16%	43.70%	Kyanite Mining
B		22.2	0.07	B2O3	0.02	0.03	0.0036	11.70	10.1490	10.145	**H3BO3 (Technical Granular)**	0.986	0.563	**239.91**			US Borax
Ba		0	0.00	BaO	0.00	0.00	0.0000		0.0000								
Ca		176	0.25	CaO	0.05	0.09	0.0123	7.40	6.4291	6.417	**Wollanstonite NYAD 325 Mesh**	0.993	0.475	**178.58**	0.40%	51.00%	NYCO Minerals
Cd		32.9	0.04	CdO	0.01	0.01	0.0019		0.0019								
Co		2.8	0.00	CoO	0.00	0.00	0.0002		0.0002								
Cr		117.0	0.34	Cr2O3	0.07	0.13	0.0171		0.0171								
Cu		5.6	0.01	CuO	0.00	0.00	0.0004		0.0004								
Fe		3.5	0.01	Fe2O3	0.00	0.00	0.0003	7.50	6.5037	6.503	**Fe2O3 (Iron III oxide, -325 Mesh)**	0.998	1.000	**80.02**			Alfa Aesar-Johnson Matthey
K	0.03	1230	1.48	K2O	0.31	0.56	0.074		0.0741								
La		6	0.01	La2O3	0.00	0.00	0.0004		0.0004								
Li		0	0.00	Li2O	0.00	0.00	0.0000	3.17	2.7488	2.749	**Li2CO3 (Chemetall Foote Co. Tech. gr.)**	0.99	0.404	**90.22**			Cyprus Foote Mineral Co.
Mg		0	0.00	MgO	0.00	0.00	0.0000	1.75	1.5175	1.517	**Olivine (Mg2SiO4) 325 Mesh (#180)**	0.990	0.480	**41.92**	7.68%	42.52%	UNIMIN Corp.
Mn		1	0.00	MnO2	0.00	0.00	0.0001		0.0001								
Mo		34.7	0.05	MoO3	0.01	0.02	0.0026		0.0026								
Na	7.61	175000	235.90	Na2O	49.84	88.81	11.80		11.8000								
Ni		200	0.25	NiO	0.05	0.10	0.0127		0.0127								
Pb		79.6	0.09	PbO	0.02	0.03	0.0043		0.0043								
Sn		24	0.03	SnO2	0.01	0.01	0.0015		0.0015								
Si		71	0.15	SiO2	0.03	0.06	0.0076	54.00	46.8326	46.825	**SiO2 (Sil-co-Sil 75)**	0.997	1.000	**430.93**			US SILICA
Sr		203	0.24	SrO	0.05	0.09	0.0120		0.0120								
Ti		0	0.00	TiO2	0.00	0.00	0.0000	1.30	1.1273	1.127	**TiO2 (Rutile Airfloated)**	0.954	1.000	**15.51**	0.71%	0.91%	Chemalloy
W		0	0.00	WO3	0.00	0.00	0.0000		0.0000								
Zn		1.9	0.00	ZnO	0.00	0.00	0.0001	3.50	3.0351	3.035	**ZnO (Kadox-920)**	0.997	1.000	**39.96**			Zinc Corp. of America
Zr		1	0.00	ZrO2	0.00	0.00	0.0001	3.50	3.0350	3.035	**Zircon ZrSiO4 (Flour) Mesh 325**	0.990	0.651	**61.82**		33.00%	American Mineral
Br		0	0.00	Br	0.00	0.00	0.0000		0.0000								
Cl		1860	1.86	Cl	0.39	0.70	0.0930		0.0930								
F		1060	1.06	F	0.22	0.40	0.0530		0.0530								
PO4		2170	1.62	P2O5	0.34	0.61	0.0811		0.0811		**Total Sodium Moles**			5.00 **moles**			
SO4	0.08	7570	6.31	SO3	1.33	2.38	0.3156		0.3156		**Expected Glass yield**			**1313 g**			
NO2	1.01	46600	46.60	NO2	9.84						**Sum of Additives (g)**			**1310 g**			
NO3	1.94	120000	120.00	NO3	25.35						**Sugar as added reductant (decreased for TOC)**			**8 g**			
OH			0.00	OH	0.00												
CO3	0.67	40115	40.12	CO3	8.47												
oxalate		1010	1.01	C	0.21												
formate			0.00	C	0.00												
SUM			473.35	SUM	100.00	100.00	13.29	100.00	100.00	86.713							
NO2+NO3	2.95	MI		VSL uses 12 moles Carbon (1 mole sucrose/342.3g) per 16 Moles NOx in order to mitigate foaming													
TOC		21500.0		mg/L		This feed requires		63.08	g/L or	8.287	g of sucrose per Mole Na						
									3.7240								
	This sample already includes					1.177 moles C, and sucrose has be lowered by					-33.57 g sucrose						

6.7. Corrections to Melter Feed Tank Scale Readings

The spreadsheet used to determine the appropriate corrections to the melter feed tank scale readings are shown below. The addition of known amounts of the Large C radioactive supernate, the glass formers, and a calibration check with calibrated weights were used to generate the correction factor.

The correction resulting from this analysis was:

Corrected Weight = 1.031 × Measured Weight (reading)

Table 6.4 Feed Tank Scale Correction Factor Determination

		Expected	Measured from Run	Measured from Cal Check	Measured All	Difference		Ratio: expected/ measured	Predicted Expected based on Slope from Curvefit	Predicted - Expected	%Error Difference/ Expected x 100
Empty		0.00	0.00		0.00	0.00			0.00	0.00	NA
Supernate added	lb	19.01	18.19		18.19	0.82		1.0453	18.76	-0.26	-1.36
Weight after agitator turned on	lb	19.64	18.82		18.82		0.63	1.0438	19.40	-0.24	-1.22
(from cal check)	lb	30.00		29.13	29.13			1.0300	30.04	0.03	0.10
Weight of glass formers added	lb	30.97	29.73		29.73	1.24		1.0417	30.65	-0.32	-1.02
Weight after glass formers added	lb	50.61	48.55		48.55	2.06		1.0425	50.06	-0.56	-1.10
(from cal check)	lb	60.11		59.03	59.03			1.0183	60.86	0.76	1.26
								1.0369			
Slope from Curvefit:		1.031082									
Calibration Check:											

		Expected	Measured Low *	Measured Low Adjusted for Zero	Difference	Ratio: expected/ measured	Predicted from Curvefit Slope	Predicted - Expected	%Error Difference/ Expected x 100		
Empty (w/ secondary container, frame, motor)		0.000	-8.93	0.00							
Weight #1		30.004	20.20	29.13	0.87	1.0300	30.04	0.03	0.10		
Weight #1 + #2		60.108	50.10	59.03	1.08	1.0183	60.86	0.76	1.26		
		Expected	Measured High *	Measured High Adjusted for Zero	Difference	Ratio: expected/ measured					
		0.000	-8.93	0.00							
		30.004	20.55	29.48	0.52	1.0178	30.40	0.39	1.31		
		60.108	50.50	59.43	0.68	1.0114	61.28	1.17	1.95		
Weight #1	kg	13.6098	30.004	lb							
Weight #2	kg	13.6552	30.104	lb							
* Measured values fluctuated within the range from Low to High											
Calibration check weight data recorded in Laboratory Notebook WSRC-NB-2000-00256.											
Other data recorded in this same notebook or on the data acquisition system.											

		Expected	Measured from Run	Measured from Cal Check	Measured All
Empty		0	0		=D2
Supernate added	lb	=6.7*1.29*2.2	18.19		=D3
Weight after agitator turned on	lb	=C3+H4	18.82		=D4
(from cal check)	lb	=C15		=E15	=E5
Weight of glass formers added	lb	30.97	=D7-D4		=D6
Weight after glass formers added	lb	=C6+C4	48.55		=D7
(from cal check)	lb	=C16		=E16	=E8
Slope from Curvefit:		1.03108246			
Calibration Check:					

		Expected	Measured Low *	Measured Low Adjusted for Zero	Difference
Empty (w/ secondary container, frame, motor)		0	-8.93	=D14+8.93	
Weight #1		=D23	20.2	=D15+8.93	=C15-E15
Weight #1 + #2		=C15+D24	50.1	=D16+8.93	=C16-E16
		Expected	Measured High *	Measured High Adjusted for Zero	Difference
		0	-8.93	=D19+8.93	
		=D23	20.55	=D20+8.93	=C20-E20
		=D24+D23	50.5	=D21+8.93	=C21-E21
Weight #1	kg	13.6098	=C23*1000/453.6	lb	
Weight #2	kg	13.6552	=C24*1000/453.6	lb	
* Measured values fluctuated within the range from Low to High					
Calibration check weight data recorded in Laboratory Notebook WSRC-NB-2000-00256.					
Other data recorded in this same notebook or on the data acquisition system.					

Table 6.4 (continued)

Difference		Ratio: expected/ measured	Predicted Expected based on Slope from Curvefit	Predicted - Expected	%Error Difference/ Expected x 100
=C2-D2			=D2*C$10	=J2-C2	NA
=C3-D3		=C3/D3	=D3*C$10	=J3-C3	=K3/C3*100
=D4-D3		=C4/D4	=D4*C$10	=J4-C4	=K4/C4*100
		=C5/E5	=E5*C$10	=J5-C5	=K5/C5*100
=C6-D6		=C6/D6	=D6*C$10	=J6-C6	=K6/C6*100
=C7-D7		=C7/D7	=D7*C$10	=J7-C7	=K7/C7*100
		=C8/E8	=E8*C$10	=J8-C8	=K8/C8*100
		=AVERAGE(I3:I8)			

Ratio: expected/ measured	Predicted from Curvefit Slope	Predicted - Expected	%Error Difference/ Expected x 100
=C15/E15	=E15*C$10	=H15-C15	=I15/C15*100
=C16/E16	=E16*C$10	=H16-C16	=I16/C16*100

Ratio: expected/ measured			
=C20/E20	=E20*C$10	=H20-C20	=I20/C20*100
=C21/E21	=E21*C$10	=H21-C21	=I21/C21*100

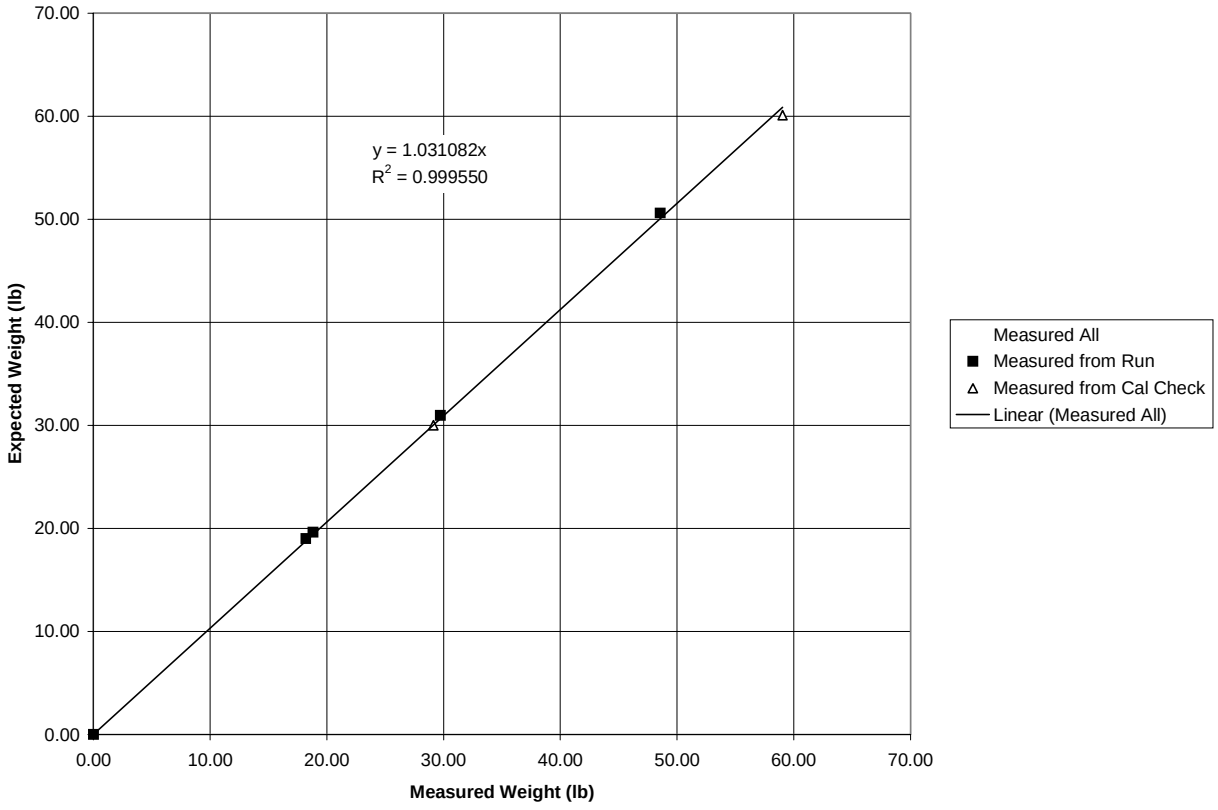


Figure 6.1 Correction of Feed Tank Scale Weight

6.8. Supernate and Slurry Density Correlation

The following table gives the data used to determine the correlation between the density and total solids for supernates and slurries used in this and similar work.

Table 6.5 Total Solids and Density Data

Supernate	Total Solids (wt %)	Density (kg/L)	Reference
Water	0.00	0.997	-
Surrogate #2	31.64	1.257	this work
Large C Evaporator Concentrate (rad)	40.28	1.297	4
	40.30	1.291	"
Large C Evaporator Feed (rad)	30.98	1.226	"
	30.58	1.228	"
	32.04	1.229	"
	32.43	1.232	"
Diluted & Filtered AN-102 Supernate (rad)	37.70	1.330	57
AN-102 Supernate as received (rad)	50.30	1.470	"
AN-107 Surrogate	36.92	1.300	25
C Simulant (AN-107)	42.88	1.360	"
	46.49	1.390	"
	46.67	1.396	"
	47.32	1.422	"
A Simulant	33.11	1.294	"
	40.85	1.371	"
	47.49	1.464	"
B Simulant	25.44	1.198	"
	30.27	1.253	"
	32.23	1.299	"

Melter Feed Slurry				Reference: 25	
	Total Solids (wt %)	Density (kg/L)		Total Solids (wt %)	Density (kg/L)
C Simulant (AN-107)	58.99	1.624	A Simulant	70.10	1.799
"	64.73	1.722	"	70.44	1.820
"	64.93	1.727	"	70.68	1.764
"	65.20	1.693	"	70.10	1.819
"	65.69	1.749	"	73.23	1.721
"	66.15	1.743	"	71.79	1.785
"	65.37	1.721	B Simulant	61.94	1.671
"	68.10	1.831	"	66.97	1.747
"	68.62	1.769	"	67.10	1.777
"	69.06	1.813	"	67.14	1.586
"	68.26	1.793	"	67.74	1.783
"	68.37	1.825	"	67.49	1.768
"	68.29	1.883	"	67.78	1.758
A Simulant	57.87	1.547	"	71.30	1.839
"	65.27	1.685	"	72.41	1.868
"	64.32	1.696	"	72.57	1.787
"	64.19	1.656	"	71.67	1.828
"	63.31	1.662	"	73.63	1.905
"	67.33	1.693	"	72.01	1.865
"	65.06	1.705			

The correlation found for these data was:

$$\text{Density (kg/L)} = 9.6049\times10^{-5}\,S^2 + 4.6881\times10^{-3}\,S + 0.9971$$

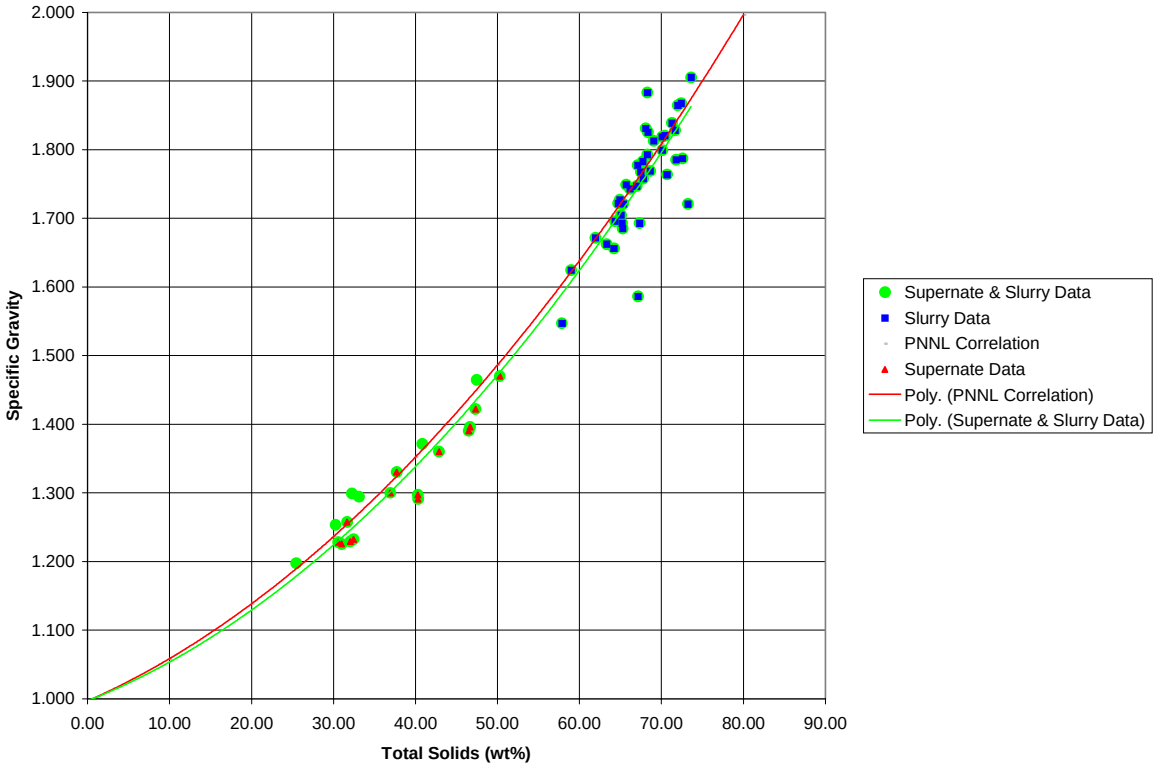
where S = Total Solids (wt %)
$R^2 = 0.9856$

A similar correlation has been reported by PNNL:

$$\text{Density (kg/L)} = 9.\times10^{-5}\,S^2 + 5.3\times10^{-3}\,S + 0.9963$$

The data are plotted with the fitted curve and the PNNL correlation curve in Figure 6.2.

Figure 6.2 Density versus Total Solids Correlation



6.9. Surrogate Run #2 Material Balance Calculations- Actual Additions

		Surrogate Feed			
Na Molarity	M	6.02			
Volume	liter	7.50			
		M	mg/liter	mol	g
NO3-		1.44	89000	1.0765E+01	668
NO2-		0.79	36550	5.9585E+00	274
SO4=		0.0576	5530	4.3175E-01	41.5
Cl		0.0935	3315	7.0128E-01	24.9
F		0.0530	1008	3.9773E-01	7.6
OH-		0.00		0.0000E+00	0
CO3=		0.134	8023	1.0027E+00	60
TOC (sugar in glassformers)		0.72	8682	5.4258E+00	65
Al		0.235	6349	1.7648E+00	47.6
B		0.0023	25	1.7343E-02	0.19
Ca		0.0024	95.9	1.7945E-02	0.72
Cd		0.0000	0.04	2.6690E-06	0.00
Cr		0.0017	86.1	1.2419E-02	0.65
Cu		0.0002	9.9	1.1686E-03	0.074
Fe		0.00003	1.88	2.5248E-04	0.014
Li		0.00	4.71	5.0908E-03	0.035
Mg		0.00	0	4.2417E-05	0
Mn		0.0006	35.15	4.7986E-03	0.26
Mo		0.0003	24.10	1.8840E-03	0.18
Na		6.02	138500	4.5183E+01	1039
Ni		0.0024	142.00	1.8140E-02	1.07
P		0.0160	494.10	1.1964E-01	3.7
Pb		0.0003	52.10	1.8860E-03	0.39
Si		0.0007	19.15	5.1138E-03	0.144
Sn		0.00000		0.0000E+00	0.00
Sr		0.0000		0.0000E+00	0.00
Ti		0.00	0.01	1.5658E-06	0
Zn		0.00	0.85	9.7981E-05	0
Zr		0.00000	0.23	1.8993E-05	0.002
K		0.0322	1260.00	2.4168E-01	9.5
Additional solids (oxides) mass					702.2
check					
Total Sample	g		20.529	9311.9	9311.9
Solids in Sample	g			2946.3	2946.3
Water	g		2244.1	6365.6	6365.6
Total Sample (lb)					
Sample w/o Glassformers:			delta total:	0.0	
Total Solids in Sample	%	31.64			31.64
Measured Density	kg/liter	1.244	to solve MB	1.257	meas.
Estimated Density**	kg/liter	1.242	calculated		
Volume Check	liter				

		Surrogate Feed + Sugar			
Na Molarity	M	5.93			
Volume	liter	7.62			
		M	mg/liter	mol	g
NO3-				1.0765E+01	668
NO2-				5.9585E+00	274
SO4=				4.3175E-01	41.5
Cl				7.0128E-01	24.9
F				3.9773E-01	7.6
OH-		0.00	0	0.0000E+00	0
CO3=		0.132	7900	1.0027E+00	60
TOC (sugar in glassformers)		0.85	10189	6.4669E+00	78
Al		0.232	6251.6	1.7648E+00	47.6
B		0.0023	24.62	1.7343E-02	0.19
Ca		0.0024	94.43	1.7945E-02	0.72
Cd		0.0000	0.04	2.6690E-06	0.00
Cr		0.0016	84.78	1.2419E-02	0.65
Cu		0.0002	9.748	1.1686E-03	0.074
Fe		0.00003	1.851	2.5248E-04	0.014
Li		0.00067	4.638	5.0908E-03	0.035
Mg		0	0	4.2417E-05	0
Mn		0.0006	34.61	4.7986E-03	0.26
Mo		0.0002	23.73	1.8840E-03	0.18
Na		5.93	136375	4.5183E+01	1039
Ni		0.0024	139.82	1.8140E-02	1.07
P		0.0157	486.5	1.1964E-01	3.7
Pb		0.0002	51.30	1.8860E-03	0.39
Si		0.0007	18.856	5.1138E-03	0.144
Sn		0.00000	0.00	0.0000E+00	0.00
Sr		0.0000	0.00	0.0000E+00	0.00
Ti		0	0	1.5658E-06	0
Zn		0	1	9.7981E-05	0
Zr		0.00000	0	1.8993E-05	0.002
K		0.0317	1240.7	2.4168E-01	9.5
Additional solids (oxides) mass					1046.1
check					3302.7
Total Sample	g		21.315	9668.3	9668.3
Solids in Sample	g				3302.7
Water	g		2256.6		6365.6
Total Sample (lb)					
Sample w/o Glassformers:			delta:	0.0	
Total Solids in Sample	%	34.16			34.16
Measured Density	kg/liter				
Estimated Density**	kg/liter	1.269			
Volume Check	liter				

		Surrogate Feed Diluted to 5 M			
		Water Added	1.38	liter	
		Water Added	0.18	liter/liter original	
Na Molarity	M	5.00			
Volume	liter	9.04			
		M	mg/liter	mol	g
NO3-		1.19	73866	1.0765E+01	667.50
NO2-		0.66	30335	5.9585E+00	274.13
SO4=		0.0478	4589.7	4.3175E-01	41.48
Cl		0.0776	2751.3	7.0128E-01	24.86
F		0.0440	836.2	3.9773E-01	7.56
OH-		0.00	0	0.0000E+00	0.00
CO3=		0.111	6659	1.0027E+00	60.173
TOC (sugar in glassformers)		0.72	8588	6.4669E+00	77.609
Al		0.195	5269.4	1.7648E+00	47.618
B		0.0019	20.75	1.7343E-02	0.188
Ca		0.0020	79.59	1.7945E-02	0.719
Cd		0.0000	0.03	2.6690E-06	0.000
Cr		0.0014	71.46	1.2419E-02	0.646
Cu		0.0001	8.217	1.1686E-03	0.074
Fe		0.00003	1.560	2.5248E-04	0.014
Li		0.00056	3.909	5.0908E-03	0.035
Mg		0	0	4.2417E-05	0.001
Mn		0.0005	29.17	4.7986E-03	0.264
Mo		0.0002	20.00	1.8840E-03	0.181
Na		5.00	114949	4.5183E+01	1038.750
Ni		0.0020	117.85	1.8140E-02	1.065
P		0.0132	410.1	1.1964E-01	3.706
Pb		0.0002	43.24	1.8860E-03	0.391
Si		0.0006	15.894	5.1138E-03	0.144
Sn		0.00000	0.00	0.0000E+00	0.000
Sr		0.0000	0.00	0.0000E+00	0.000
Ti		0	0	1.5658E-06	0.000
Zn		0	1	9.7981E-05	0.006
Zr		0.00000	0	1.8993E-05	0.002
K		0.0267	1045.7	2.4168E-01	9.450
Additional solids (oxides) mass					1046.098
check					3302.7
Total Sample	g				11051.6
Solids in Sample	g				3302.7
Water	g				7748.9
Total Sample (lb)					
Sample w/o Glassformers:					
Total Solids in Sample	%				29.88
Measured Density	kg/liter				NA
Estimated Density**	kg/liter				1.223
Volume Check	liter				9.04
				delta	0.000004

		Glass Formers for 1 liter of 5 M		Glass Formers for Actual Volume 5 M		
					9.04	
Na Molarity	M					
Volume	liter					
		mol	g	mol	g	wt %
NO3-						
NO2-						
SO4=						
Cl						
F						
OH-						
CO3=						
TOC (sugar in glassformers)				0.00	0.00	0.00
Al		1.59	42.92	14.37	387.83	3.29
B		3.81	41.16	34.41	371.98	3.16
Ca		1.51	60.65	13.67	548.09	4.65
Cd						
Cr						
Cu						
Fe		1.06	59.43	9.62	537.04	4.56
Li		2.41	16.70	21.74	150.88	1.28
Mg		0.54	13.18	4.90	119.08	1.01
Mn						
Mo						
Na						
Ni						
P						
Pb						
Si		10.02	281.39	90.54	2542.81	21.57
Sn						
Sr						
Ti		0.18	8.69	1.64	78.50	0.67
Zn		0.49	31.86	4.40	287.86	2.44
Zr		0.33	30.31	3.00	273.91	2.32
K						
Additional solids (oxides) mass			718.00	40	6488.25	55.05
check						
Total Sample	g		1304.3	25.984	11786.2	
Solids in Sample	g			25.984	meas.	
Water	g					
Total Sample (lb)						
Sample w/o Glassformers:						
Total Solids in Sample	%					
Measured Density	kg/liter					
Estimated Density**	kg/liter					
Volume Check	liter					

		Surrogate Feed (Un)Diluted to 5.93 M			
			Water Added	0.00	liter
			Water Added	-0.18	liter/liter original
			Total Water Added	0.00	liter /liter original
Na Molarity	M	5.93			
Volume	liter	7.62			
		M	mg/liter	mol	g
NO3-		1.41	87634	1.0765E+01	667.50
NO2-		0.78	35989	5.9585E+00	274.13
SO4=		0.0567	5445.2	4.3175E-01	41.48
Cl		0.0921	3264.1	7.0128E-01	24.86
F		0.0522	992.0	3.9773E-01	7.56
OH-		0.00	0	0.0000E+00	0.00
CO3=		0.132	7900	1.0027E+00	60.17
TOC (sugar in glassformers)		0.85	10189	6.4669E+00	77.61
Al		0.232	6251.6	1.7648E+00	47.62
B		0.0023	24.62	1.7343E-02	0.19
Ca		0.0024	94.43	1.7945E-02	0.72
Cd		0.0000	0.04	2.6690E-06	0.00
Cr		0.0016	84.78	1.2419E-02	0.65
Cu		0.0002	9.748	1.1686E-03	0.07
Fe		0.00003	1.851	2.5248E-04	0.01
Li		0.00067	4.638	5.0908E-03	0.04
Mg		0	0	4.2417E-05	0.00
Mn		0.0006	34.61	4.7986E-03	0.26
Mo		0.0002	23.73	1.8840E-03	0.18
Na		5.93	136375	4.5183E+01	1039
Ni		0.0024	139.82	1.8140E-02	1.07
P		0.0157	486.5	1.1964E-01	3.71
Pb		0.0002	51.30	1.8860E-03	0.39
Si		0.0007	18.856	5.1138E-03	0.14
Sn		0.00000	0.00	0.0000E+00	0.00
Sr		0.0000	0.00	0.0000E+00	0.00
Ti		0	0	1.5658E-06	0.00
Zn		0	1	9.7981E-05	0.01
Zr		0.00000	0	1.8993E-05	0.00
K		0.0317	1240.7	2.4168E-01	9.45
Additional solids (oxides) mass					1046.10
check					3302.7
Total Sample	g				9668.3
Solids in Sample	g				3302.7
Water	g				6365.6
Total Sample (lb)					
Sample w/o Glassformers:					
Total Solids in Sample	%				34.16
Measured Density	kg/liter				NA
Estimated Density**	kg/liter				1.269
Volume Check	liter				7.62
				delta	0.00

		Feed: Waste + Glass Formers					
Na Molarity	M	3.79					
Volume	liter	11.91					
		M	mg/liter	mol	g	wt% dry	
NO3-		0.90	56061	10.8	668	3.11	
NO2-		0.500	23023	6.0	274	1.28	
SO4=		0.0363	3483	0.432	41.5	0.19	
Cl		0.0589	2088	0.701	24.9	0.12	
F		0.0334	635	0.398	7.6	0.035	
OH-		0.00	0	0.0	0	0.00	
CO3=		0.084	5054	1.00	60	0.28	
TOC (sugar in glassformers)		0.54	6518	6.5	78	0.36	
Al		1.36	36572	16.1	435	2.03	
B		2.89	31257	34.4	372	1.73	
Ca		1.150	46093	13.69	549	2.56	
Cd		0.0000	0	0.0000	0.00	0.0000014	
Cr		0.0010	54	0.0124	0.65	0.0030	
Cu		0.00010	6	0.00117	0.074	0.00035	
Fe		0.808	45106	9.62	537	2.5	
Li		1.827	12675	21.75	151	0.70	
Mg		0.411	10001	4.90	119.1	0.56	
Mn		0.000	22	0.005	0.26	0.0012	
Mo		0.0002	15	0.0019	0.18	0.0008	
Na		3.79	87241	45.2	1039	4.8	
Ni		0.0015	89	0.0181	1.07	0.0050	
P		0.0100	311	0.120	3.7	0.017	
Pb		0.0002	33	0.0019	0.39	0.0018	
Si		7.60	213575	90.5	2543	11.9	
Sn		0.0000	0	0.0000	0.00	0	
Sr		0.0000	0	0.000	0.00	0	
Ti		0.138	6593	1.64	78.50	0.37	
Zn		0.370	24177	4.40	287.87	1.34	
Zr		0.252	23005	3.00	273.91	1.28	
K		0.0203	794	0.242	9.5	0.044	
Additional solids (oxides) mass					7534	35.1	
check					15088.9	70.3	
Total Sample	g		47.299	21454.6	21454.5	-0.1	Amounts
Solids in Sample	g			15089.0	15088.9	-0.1	<-Missing
Water	g		7554.5	6365.6	6365.6	0.0	
Total Sample (lb)					47.298		
Sample w/o Glassformers:						Data	
Total Solids in Sample	%				70.33	62.00	
Measured Density	kg/liter				NA		
Estimated Density**	kg/liter				1.802	1.66	
Volume Check	liter				11.91		
				delta	0.00		

		Oxide	Glass Produced			
			5.64	Melter volumes		
			1.31	kg/liter 5 M surrogate		
Na Molarity	M					
Volume	liter		4.73			
			Mass Oxide (g)	Mass Element (g)	Wt% Oxide	Wt% Element
NO3-		none				
NO2-		none				
SO4=		none				
Cl		Cl	24.9	24.9	0.21	0.39
F		F	7.6	7.6	0.06	0.12
OH-		none				
CO3=		none				
TOC (sugar in glassformers)		none				
Al		Al2O3	823	435	7.0	6.8
B		B2O3	1198	372	10.13	5.78
Ca		CaO	768	549	6.49	8.53
Cd		CdO	0.00	0.00	0.0000	0.0000
Cr		Cr2O3	0.94	0.65	0.008	0.010
Cu		CuO	0.09	0.07	0.00079	0.00115
Fe		Fe2O3	768	537	6.49	8.35
Li		Li2O	325	151	2.75	2.35
Mg		MgO	197.4	119.1	1.67	1.85
Mn		MnO2	0.42	0.26	0.004	0.00
Mo		MoO3	0.27	0.18	0.0023	0.0028
Na		Na2O	1400	1039	11.8	16.1
Ni		NiO	1.36	1.07	0.011	0.017
P		P2O5	8.5	3.7	0.07	0.06
Pb		PbO	0.42	0.39	0.004	0.006
Si		SiO2	5440	2543	46.0	39.5
Sn		SnO	0.00	0.00	0.0000	0.0000
Sr		SrO	0.00	0.00	0.000	0.000
Ti		TiO2	131	78	1.11	1.22
Zn		ZnO	358	288	3.03	4.47
Zr		ZrO2	370	274	3.13	4.26
K		K2O	11.4	9.5	0.10	0.15
Additional solids (oxides) mass		none				
check				%:	100.00	100.00
Total Sample	g					
Solids in Sample	g		11834.6	6433.6		
Water	g					
Total Sample (lb)						
Sample w/o Glassformers:						
Total Solids in Sample	%					
Measured Density	kg/liter		2.50			
Estimated Density**	kg/liter					
Volume Check	liter					

6.10. Surrogate Run #2 Material Balance Calculations- Adjust Water to Give Correct Total Solids and Density.

		Surrogate Feed			
Na Molarity	M	6.02			
Volume	liter	7.50			
		M	mg/liter	mol	g
NO3-		1.44	89000	1.0765E+01	668
NO2-		0.79	36550	5.9585E+00	274
SO4=		0.0576	5530	4.3175E-01	41.5
Cl		0.0935	3315	7.0128E-01	24.9
F		0.0530	1008	3.9773E-01	7.6
OH-		0.00		0.0000E+00	0
CO3=		0.134	8023	1.0027E+00	60
TOC (sugar in glassformers)		0.72	8682	5.4258E+00	65
Al		0.235	6349	1.7648E+00	47.6
B		0.0023	25	1.7343E-02	0.19
Ca		0.0024	95.9	1.7945E-02	0.72
Cd		0.0000	0.04	2.6690E-06	0.00
Cr		0.0017	86.1	1.2419E-02	0.65
Cu		0.0002	9.9	1.1686E-03	0.074
Fe		0.00003	1.88	2.5248E-04	0.014
Li		0.00	4.71	5.0908E-03	0.035
Mg		0.00	0	4.2417E-05	0
Mn		0.0006	35.15	4.7986E-03	0.26
Mo		0.0003	24.10	1.8840E-03	0.18
Na		6.02	138500	4.5183E+01	1039
Ni		0.0024	142.00	1.8140E-02	1.07
P		0.0160	494.10	1.1964E-01	3.7
Pb		0.0003	52.10	1.8860E-03	0.39
Si		0.0007	19.15	5.1138E-03	0.144
Sn		0.00000		0.0000E+00	0.00
Sr		0.0000		0.0000E+00	0.00
Ti		0.00	0.01	1.5658E-06	0
Zn		0.00	0.85	9.7981E-05	0
Zr		0.00000	0.23	1.8993E-05	0.002
K		0.0322	1260.00	2.4168E-01	9.5
Additional solids (oxides) mass					702.2
check			Actual lb	Actual g	
Total Sample	g		20.529	9311.9	9311.9
Solids in Sample	g			2946.3	2946.3
Water	g			6365.6	6365.6
Sucrose	g				
Total Sample (lb)					
Sample w/o Glassformers:			delta total:	0.0	
Total Solids in Sample	%	31.64			31.64
Measured Density	kg/liter	1.244	to solve MB	1.257	meas.
Estimated Density**	kg/liter	1.242	calculated		
Volume Check	liter				

		Surrogate Feed + Sugar			
Na Molarity	M	5.93			
Volume	liter	7.62			
		M	mg/liter	mol	g
NO3-				1.0765E+01	668
NO2-				5.9585E+00	274
SO4=				4.3175E-01	41.5
Cl				7.0128E-01	24.9
F				3.9773E-01	7.6
OH-		0.00	0	0.0000E+00	0
CO3=		0.132	7900	1.0027E+00	60
TOC (sugar in glassformers)		0.85	10189	6.4669E+00	78
Al		0.232	6251.6	1.7648E+00	47.6
B		0.0023	24.62	1.7343E-02	0.19
Ca		0.0024	94.43	1.7945E-02	0.72
Cd		0.0000	0.04	2.6690E-06	0.00
Cr		0.0016	84.78	1.2419E-02	0.65
Cu		0.0002	9.748	1.1686E-03	0.074
Fe		0.00003	1.851	2.5248E-04	0.014
Li		0.00067	4.638	5.0908E-03	0.035
Mg		0	0	4.2417E-05	0
Mn		0.0006	34.61	4.7986E-03	0.26
Mo		0.0002	23.73	1.8840E-03	0.18
Na		5.93	136375	4.5183E+01	1039
Ni		0.0024	139.82	1.8140E-02	1.07
P		0.0157	486.5	1.1964E-01	3.7
Pb		0.0002	51.30	1.8860E-03	0.39
Si		0.0007	18.856	5.1138E-03	0.144
Sn		0.00000	0.00	0.0000E+00	0.00
Sr		0.0000	0.00	0.0000E+00	0.00
Ti		0	0	1.5658E-06	0
Zn		0	1	9.7981E-05	0
Zr		0.00000	0	1.8993E-05	0.002
K		0.0317	1240.7	2.4168E-01	9.5
Additional solids (oxides) mass					1046.1
check					3302.7
Total Sample	g		21.315	9668.3	9668.3
Solids in Sample	g				3302.7
Water	g				6365.6
Sucrose	g				
Total Sample (lb)					
Sample w/o Glassformers:			delta solids	0.0	
Total Solids in Sample	%	34.16			34.16
Measured Density	kg/liter				
Estimated Density**	kg/liter	1.269			
Volume Check	liter				

		Surrogate Feed Diluted to 5 M			
		Water Added	1.38	liter	
		Water Added	0.18	liter/liter original	
Na Molarity	M	5.00			
Volume	liter	9.04			
		M	mg/liter	mol	g
NO3-		1.19	73866	1.0765E+01	667.50
NO2-		0.66	30335	5.9585E+00	274.13
SO4=		0.0478	4589.7	4.3175E-01	41.48
Cl		0.0776	2751.3	7.0128E-01	24.86
F		0.0440	836.2	3.9773E-01	7.56
OH-		0.00	0	0.0000E+00	0.00
CO3=		0.111	6659	1.0027E+00	60.173
TOC (sugar in glassformers)		0.72	8588	6.4669E+00	77.609
Al		0.195	5269.4	1.7648E+00	47.618
B		0.0019	20.75	1.7343E-02	0.188
Ca		0.0020	79.59	1.7945E-02	0.719
Cd		0.0000	0.03	2.6690E-06	0.000
Cr		0.0014	71.46	1.2419E-02	0.646
Cu		0.0001	8.217	1.1686E-03	0.074
Fe		0.00003	1.560	2.5248E-04	0.014
Li		0.00056	3.909	5.0908E-03	0.035
Mg		0	0	4.2417E-05	0.001
Mn		0.0005	29.17	4.7986E-03	0.264
Mo		0.0002	20.00	1.8840E-03	0.181
Na		5.00	114949	4.5183E+01	1038.750
Ni		0.0020	117.85	1.8140E-02	1.065
P		0.0132	410.1	1.1964E-01	3.706
Pb		0.0002	43.24	1.8860E-03	0.391
Si		0.0006	15.894	5.1138E-03	0.144
Sn		0.00000	0.00	0.0000E+00	0.000
Sr		0.0000	0.00	0.0000E+00	0.000
Ti		0	0	1.5658E-06	0.000
Zn		0	1	9.7981E-05	0.006
Zr		0.00000	0	1.8993E-05	0.002
K		0.0267	1045.7	2.4168E-01	9.450
Additional solids (oxides) mass					1046.098
check					3302.7
Total Sample	g				11051.6
Solids in Sample	g				3302.7
Water	g				7748.9
Sucrose	g				
Total Sample (lb)					
Sample w/o Glassformers:					
Total Solids in Sample	%				29.88
Measured Density	kg/liter				NA
Estimated Density**	kg/liter				1.223
Volume Check	liter				9.04
				delta	0.000004

		Glass Formers for 1 liter of 5 M		Glass Formers for Actual Volume 5 M		
					9.04	
Na Molarity	M					
Volume	liter					
		mol	g	mol	g	wt %
NO3-						
NO2-						
SO4=						
Cl						
F						
OH-						
CO3=						
TOC (sugar in glassformers)				0.00	0.00	0.00
Al		1.59	42.92	14.37	387.83	3.29
B		3.81	41.16	34.41	371.98	3.16
Ca		1.51	60.65	13.67	548.09	4.65
Cd						
Cr						
Cu						
Fe		1.06	59.43	9.62	537.04	4.56
Li		2.41	16.70	21.74	150.88	1.28
Mg		0.54	13.18	4.90	119.08	1.01
Mn						
Mo						
Na						
Ni						
P						
Pb						
Si		10.02	281.39	90.54	2542.81	21.57
Sn						
Sr						
Ti		0.18	8.69	1.64	78.50	0.67
Zn		0.49	31.86	4.40	287.86	2.44
Zr		0.33	30.31	3.00	273.91	2.32
K						
Additional solids (oxides) mass			718.00	40	6488.25	55.05
check				lb		
Total Sample	g		1304.3	25.984	11786.2	
Solids in Sample	g			25.984	meas.	
Water	g					
Sucrose	g		0.0		0.00	
Total Sample (lb)						
Sample w/o Glassformers:						
Total Solids in Sample	%					
Measured Density	kg/liter					
Estimated Density**	kg/liter					
Volume Check	liter					

		Surrogate Feed (Un)Diluted to 4.3 M			
			Water Added	2.82	liter
			Water Added	0.19	liter/liter original
			Total Water Added	0.38	liter /liter original
Na Molarity	M	4.30			
Volume	liter	10.51			
		M	mg/liter	mol	g
NO3-		1.02	63525	1.0765E+01	667.50
NO2-		0.57	26088	5.9585E+00	274.13
SO4=		0.0411	3947.1	4.3175E-01	41.48
Cl		0.0667	2366.1	7.0128E-01	24.86
F		0.0379	719.1	3.9773E-01	7.56
OH-		0.00	0	0.0000E+00	0.00
CO3=		0.095	5727	1.0027E+00	60.17
TOC (sugar in glassformers)		0.62	7386	6.4669E+00	77.61
Al		0.168	4531.7	1.7648E+00	47.62
B		0.0017	17.84	1.7343E-02	0.19
Ca		0.0017	68.45	1.7945E-02	0.72
Cd		0.0000	0.03	2.6690E-06	0.00
Cr		0.0012	61.45	1.2419E-02	0.65
Cu		0.0001	7.066	1.1686E-03	0.07
Fe		0.00002	1.342	2.5248E-04	0.01
Li		0.00048	3.362	5.0908E-03	0.04
Mg		0	0	4.2417E-05	0.00
Mn		0.0005	25.09	4.7986E-03	0.26
Mo		0.0002	17.20	1.8840E-03	0.18
Na		4.30	98856	4.5183E+01	1039
Ni		0.0017	101.35	1.8140E-02	1.07
P		0.0114	352.7	1.1964E-01	3.71
Pb		0.0002	37.19	1.8860E-03	0.39
Si		0.0005	13.669	5.1138E-03	0.14
Sn		0.00000	0.00	0.0000E+00	0.00
Sr		0.0000	0.00	0.0000E+00	0.00
Ti		0	0	1.5658E-06	0.00
Zn		0	1	9.7981E-05	0.01
Zr		0.00000	0	1.8993E-05	0.00
K		0.0230	899.3	2.4168E-01	9.45
Additional solids (oxides) mass					1046.10
check					3302.7
Total Sample	g				12486.3
Solids in Sample	g				3302.7
Water	g				9183.6
Sucrose	g				
Total Sample (lb)					
Sample w/o Glassformers:					
Total Solids in Sample	%				26.45
Measured Density	kg/liter				1.00
Estimated Density**	kg/liter				1.188
Volume Check	liter				10.51
				delta	0.00

		Feed: Waste + Glass Formers					
Na Molarity	M	3.09					
Volume	liter	14.62					
		M	mg/liter	mol	g	wt% dry	
NO3-		0.74	45642	10.8	668	2.75	
NO2-		0.407	18744	6.0	274	1.13	
SO4=		0.0295	2836	0.432	41.5	0.17	
Cl		0.0480	1700	0.701	24.9	0.10	
F		0.0272	517	0.398	7.6	0.031	
OH-		0.00	0	0.0	0	0.00	
CO3=		0.069	4114	1.00	60	0.25	
TOC (sugar in glassformers)		0.44	5307	6.5	78	0.32	
Al		1.10	29775	16.1	435	1.79	
B		2.35	25448	34.4	372	1.53	
Ca		0.936	37527	13.69	549	2.26	
Cd		0.0000	0	0.0000	0.00	0.0000012	
Cr		0.0008	44	0.0124	0.65	0.0027	
Cu		0.00008	5	0.00117	0.074	0.00031	
Fe		0.658	36723	9.62	537	2.2	
Li		1.487	10319	21.75	151	0.62	
Mg		0.335	8142	4.90	119.1	0.49	
Mn		0.000	18	0.005	0.26	0.0011	
Mo		0.0001	12	0.0019	0.18	0.0007	
Na		3.09	71028	45.2	1039	4.3	
Ni		0.0012	73	0.0181	1.07	0.0044	
P		0.0082	253	0.120	3.7	0.015	
Pb		0.0001	27	0.0019	0.39	0.0016	
Si		6.19	173882	90.5	2543	10.5	
Sn		0.0000	0	0.0000	0.00	0	
Sr		0.0000	0	0.000	0.00	0	
Ti		0.112	5367	1.64	78.50	0.32	
Zn		0.301	19684	4.40	287.87	1.19	
Zr		0.205	18729	3.00	273.91	1.13	
K		0.0165	646	0.242	9.5	0.039	
Additional solids (oxides) mass					7534	31.0	
check					15088.9	62.2	
Total Sample	g		47.299	21454.6	24272.5	2817.9	<-Missing
Solids in Sample	g			13337.1	15088.9	1751.7	
Water	g			8117.5	9183.6	1066.2	
Sucrose	g				0.0		
Total Sample (lb)					53.511		
Sample w/o Glassformers:						Data	
Total Solids in Sample	%				62.16	62.00	
Measured Density	kg/liter				NA		
Estimated Density**	kg/liter				1.660	1.66	
Volume Check	liter				14.62		
				delta	0.00		

		Oxide	Glass Produced			
			5.64	Melter volumes		
			1.31	kg/liter 5 M surrogate		
Na Molarity	M					
Volume	liter		4.73			
			Mass Oxide (g)	Mass Element (g)	Wt% Oxide	Wt% Element
NO3-		none				
NO2-		none				
SO4=		none				
Cl		Cl	24.9	24.9	0.21	0.39
F		F	7.6	7.6	0.06	0.12
OH-		none				
CO3=		none				
TOC (sugar in glassformers)		none				
Al		Al2O3	823	435	7.0	6.8
B		B2O3	1198	372	10.13	5.78
Ca		CaO	768	549	6.49	8.53
Cd		CdO	0.00	0.00	0.0000	0.0000
Cr		Cr2O3	0.94	0.65	0.008	0.010
Cu		CuO	0.09	0.07	0.00079	0.00115
Fe		Fe2O3	768	537	6.49	8.35
Li		Li2O	325	151	2.75	2.35
Mg		MgO	197.4	119.1	1.67	1.85
Mn		MnO2	0.42	0.26	0.004	0.00
Mo		MoO3	0.27	0.18	0.0023	0.0028
Na		Na2O	1400	1039	11.8	16.1
Ni		NiO	1.36	1.07	0.011	0.017
P		P2O5	8.5	3.7	0.07	0.06
Pb		PbO	0.42	0.39	0.004	0.006
Si		SiO2	5440	2543	46.0	39.5
Sn		SnO	0.00	0.00	0.0000	0.0000
Sr		SrO	0.00	0.00	0.000	0.000
Ti		TiO2	131	78	1.11	1.22
Zn		ZnO	358	288	3.03	4.47
Zr		ZrO2	370	274	3.13	4.26
K		K2O	11.4	9.5	0.10	0.15
Additional solids (oxides) mass		none				
check				%:	100.00	100.00
Total Sample	g					
Solids in Sample	g		11834.6	6433.6		
Water	g					
Sucrose	g					
Total Sample (lb)						
Sample w/o Glassformers:						
Total Solids in Sample	%					
Measured Density	kg/liter		2.50			
Estimated Density**	kg/liter					
Volume Check	liter					

6.11. Radioactive Run – Material Balance Calculations

This sheet uses density fixed at measured value, calculates Total Solids. The calc'd TS is much higher than measured. (Note no additional water added).	MW or AW		Radioactive Feed- From Evaporator Concentrate- 7 bottles				Radioactive Feed Diluted to 7.63 M				Glass Formers for 1 liter of original feed (7.63 M)		Total Glass Adde
Tank weight adjusted							FEED WAS NOT ACTUALLY DILUTED PRIOR TO INITIAL SAMPLE						Addition was assumed feed 7 liter
							Water Added	0.00	liter				
							Water Added	0.00	liter/liter original				
				This volume gives the best mass									Glassformers a
				balance on feed addition and is									added corresp
Na Molarity		M	7.63	consistent with observed bottle			7.63						liters of feed
Volume		liter	6.68	volumes			6.68						
			M	mg/liter	mol	g	M	mg/liter	mol	g	mol	g	mol
NO3-	62.0049		1.93	119684	1.2903E+01	800	1.93	119684	1.2903E+01	800.02			
NO2-	46.0055		1.01	46619	6.7735E+00	312	1.01	46619	6.7735E+00	311.62			
SO4=	96.0616		0.0788	7567	5.2652E-01	50.6	0.0788	7566.6	5.2652E-01	50.58			
Cl	35.453		0.0525	1861	3.5084E-01	12.4	0.0525	1860.8	3.5084E-01	12.44			
F	18.9984		0.0559	1061	3.7338E-01	7.1	0.0559	1061.2	3.7338E-01	7.09			
OH-	17.00737		1.46	24820	9.7593E+00	166	1.46	24831	9.7593E+00	165.98			
CO3= (from TIC)	60.0093		0.913	54807	6.1050E+00	366	0.913	54807	6.1050E+00	366.36	1.86	111.34	12.99
TOC (sugar in glassformers)	12.001		1.79	21500	1.1975E+01	144	1.79	21500	1.1975E+01	143.72	0.420	5.03	2.94
Ag	107.87		0.000	0.592	3.6685E-05	0	0.00	0.592	3.6685E-05	0.00			
Al	26.9815		0.311	8388	2.0782E+00	56.1	0.311	8388.5	2.0782E+00	56.07	2.27	61.32	15.91
B	10.811		0.0021	22.2	1.3751E-02	0.15	0.0021	22.24	1.3751E-02	0.15	5.91	63.86	41.35
Ba	137.34		0.0000	0.197	9.5881E-06	0.00	0.00	0.197	9.5881E-06	0.00			
Ca	40.08		0.0044	176	2.9393E-02	1.18	0.0044	176.24	2.9393E-02	1.18	2.31	92.38	16.14
Cd	112.4		0.0003	32.9	1.9570E-03	0.22	0.0003	32.91	1.9570E-03	0.22			
Co	58.9332												
Cr	51.996		0.0022	117	1.5015E-02	0.78	0.0022	116.80	1.5015E-02	0.78	0.002	0.09	0.01
Cu	63.54		0.0001	5.60	5.8935E-04	0.037	0.0001	5.602	5.8935E-04	0.04			
Fe	55.85		0.00006	3.53	4.2299E-04	0.024	0.00006	3.534	4.2299E-04	0.02	1.63	91.27	11.44
La	138.91		0.00004	6.20	2.9835E-04	0.041	0.00	6	2.9835E-04	0.04			
Li	6.94		0.00	0.197	1.8977E-04	0.001	0.00003	0.197	1.8977E-04	0.00	3.72	25.80	26.03
Mg	24.31		0.00	0.104	2.8498E-05	0	0	0.104	2.8498E-05	0.00	0.77	18.69	5.38
Mn	54.938		0.0000	1.28	1.5554E-04	0.01	0.0000	1.28	1.5554E-04	0.01	0.004	0.21	0.03
Mo	95.94		0.0004	34.7	2.4183E-03	0.23	0.0004	34.71	2.4183E-03	0.23			
Na ICP	22.9898	ICP	7.63	175396	5.0998E+01	1172	7.63	175396	5.0998E+01	1172.43	0.04	0.85	0.26
Na AA		AA	6.85	157571									
Ni	58.71		0.0034	199.51	2.2715E-02	1.33	0.0034	199.51	2.2715E-02	1.33	0.003	0.19	0.02
P	30.9738		0.0341	1054.74	2.2762E-01	7.1	0.0341	1054.7	2.2762E-01	7.05			
Pb	207.19		0.0004	79.64	2.5694E-03	0.53	0.0004	79.64	2.5694E-03	0.53			
Si	28.086		0.0025	71.05	1.6910E-02	0.475	0.0025	71.051	1.6910E-02	0.47	15.52	435.91	108.64
Sn	118.69		0.00021	24.42	1.3754E-03	0.16	0.00021	24.42	1.3754E-03	0.16			
Sr	87.62		0.0023	202.97	1.5484E-02	1.36	0.0023	202.97	1.5484E-02	1.36			
Ti	47.90		0.00	0.197	2.7491E-05	0	0.000	0.197	2.7491E-05	0.00	0.30	14.55	2.13
V	50.94		0.00	0.58	7.6368E-05	0	0.00	0.58	7.6368E-05	0.00			
Zn	65.37		0.00	1.91	1.9532E-04	0	0	1.91	1.9532E-04	0.01	0.75	48.77	5.22
Zr	91.22		0.00001	1.22	8.9337E-05	0.008	0.00001	1.22	8.9337E-05	0.01	0.51	46.14	3.54
K	39.102	AA	0.0316	1234.7	2.1107E-01	8.3	0.0316	1234.7	2.1107E-01	8.25	0.004	0.17	0.03
Oxides, O (except CO3=), H, impurities						341.0				341.01		990.32	
check										3449.2			
Calculated Values:													
Total Sample		g				8622.9				8622.9		2006.9	
Total Sample (lb)		lb				19.01				19.01		4.42	
Solids in Sample		g				3449.2				3449.2			
Water		g				5173.8				5173.8			
Sucrose	342.3	g									0.035	11.96	0.24
Measured Values:													
otal Sample (by weight gain in tank)		g		From actual tank weight:		8622.9							From actuals:
					delta weight:	0.0							
Total Sample (by weight measured before addition)		g											
													delta:
Sample w/o Glassformers:													
Total Solids in Sample		wt%	40.00	from composite analysis						40.00			

This sheet uses density fixed at measured value, calculates Total Solids. The calc'd TS is much higher than measured. (Note no additional water added).	MW or AW		Feed: Waste + Glass Formers										
Tank weight adjusted			This calculation makes the total mass of feed measured match the calculated amount				MELTER FEED SAMPLE #1 - DRY BASIS						
			The calculated Volume is very close to the approximate measured amount				value not used						
							less than value shown						Dry bas
Na Molarity		M	4.21										
Volume		liter	12.19	Compare to ~12.3 "eyeballed"			156305a; peroxide	156306a; peroxide	156305b; peroxide	156306b; peroxide	156303; MW	156304; MW	Meas. St Dev
			M	mg/liter	mol	g	wt %	wt %	wt %	wt %	wt %	wt %	wt %
NO3-	62.0049		1.0586	65635.4751	12.9025	800.0190	3.876	3.806					0.050
NO2-	46.0055		0.5557	25566.0365	6.7735	311.6198	1.352	1.301					0.036
SO4=	96.0616		0.0432	4149.5912	0.5265	50.5786	0.248	0.221					0.019
Cl	35.453		0.0288	1020.4807	0.3508	12.4385	0.225	0.246					0.014
F	18.9984		0.0306	581.9712	0.3734	7.0935	0.225	0.246					0.014
OH-	17.00737		0.8007	13617.3873	9.7593	165.9799							
CO3= (from TIC)	60.0093		1.5664	93997.7182	19.0924	1145.7213							
TOC (sugar in glassformers)	12.001		1.2234	14682.2471	14.9120	178.9593							
Ag	107.87		0.0000	0.3247	0.0000	0.0040							
Al	26.9815		1.4758	39818.5837	17.9879	485.3416	2.585	2.595	2.540	2.540	0.795	0.763	0.029
B	10.811		3.3933	36685.1500	41.3605	447.1487	3.087	2.886	3.010	2.810			0.124
Ba	137.34		0.0000	0.1080	0.0000	0.0013	0.0030	0.0031	0.003	0.003	0.0042	0.0036	0.001
Ca	40.08		1.3262	53153.0126	16.1645	647.8725	3.822	3.872	3.670	3.710	3.782	3.894	0.089
Cd	112.4		0.0002	18.0465	0.0020	0.2200	0.007	0.006	0.005	0.003	0.005	0.003	0.002
Co	58.9332						0.026	0.023	0.013	0.018	0.005	0.005	0.005
Cr	51.996		0.0022	114.2737	0.0268	1.3929	0.031	0.035	0.026	0.028	0.016	0.013	0.009
Cu	63.54		0.0000	3.0723	0.0006	0.0374	0.007	0.007	0.005	0.003	0.002	0.002	0.002
Fe	55.85		0.9386	52420.5479	11.4410	638.9446	3.928	4.024	3.700	3.760	3.877	3.977	0.126
La	138.91		0.0000	3.4001	0.0003	0.0414	0.113	0.113	0.013	0.013	0.011	0.011	0.052
Li	6.94		2.1352	14816.3365	26.0259	180.5937	1.166	1.034	1.210	1.080	1.200	1.077	0.074
Mg	24.31		0.4416	10735.4148	5.3822	130.8520	0.762	0.807	0.690	0.730	0.726	0.788	0.043
Mn	54.938		0.0022	121.6082	0.0270	1.4823	0.062	0.058	0.060	0.050	0.019	0.020	0.020
Mo	95.94		0.0002	19.0345	0.0024	0.2320	0.008	0.008	0.003	0.003	0.006	0.006	0.002
Na ICP	22.9898	ICP	4.2052	96676.6950	51.2564	1178.3749					8.681	7.488	0.844
Na AA		AA									9.040	7.373	1.179
Ni	58.71		0.0037	215.9726	0.0448	2.6325					0.027	0.026	0.001
P	30.9738		0.0187	578.4285	0.2276	7.0504	0.128	0.123	0.049	0.049	0.066	0.064	0.036
Pb	207.19		0.0002	43.6748	0.0026	0.5323	0.248	0.248	0.030	0.029	0.033	0.027	0.003
Si	28.086		8.9148	250382.3826	108.6615	3051.8659	16.924	18.624	16.700	18.500	17.504	20.015	1.248
Sn	118.69		0.0001	13.3935	0.0014	0.1633	0.458	0.458	0.017	0.017	0.015	0.014	0.001
Sr	87.62		0.0013	111.3078	0.0155	1.3567	0.006	0.006	0.006	0.005	0.011	0.010	0.003
Ti	47.90		0.1744	8353.2853	2.1256	101.8167	0.704	0.722	0.660	0.670	0.648	0.661	0.029
V	50.94		0.0000	0.3192	0.0001	0.0039	0.011	0.011	0.003	0.003	0.003	0.003	0.004
Zn	65.37		0.4285	28009.6791	5.2227	341.4049	2.273	2.234	2.160	2.100	2.191	2.114	0.067
Zr	91.22		0.2905	26497.8115	3.5406	322.9771			1.860	1.870	0.200	0.178	0.007
K	39.102	AA	0.0198	772.4232	0.2408	9.4149	0.129	0.123			0.074	0.064	0.008
Oxides, O (except CO3=), H, impurities						7273							
check						17497.4							
Calculated Values:													
Total Sample		g				22671.2	22671.2	sum elems	7551.8			Elements (wt%):	
Total Sample (lb)		lb				49.98		sum ions	2493.5				TOC:
Solids in Sample		g				17497.4		TOC	179.0				Ions (wt%):
Water		g				5173.8		water	5173.8	Oxides, O (except CO3=), H, impurities			
Sucrose	342.3	g				83.7		solids	7273.3			Water (wt%):	
									22671.2			TOTAL:	
Measured Values:													
otal Sample (by weight gain in tank)		g				22553.0							
Total Sample (by weight measured before addition)		g											
Sample w/o Glassformers:													
Total Solids in Sample		wt%			calculated:	77.18	70.15	70.27	70.21				

This sheet uses density fixed at measured value, calculates Total Solids. The calc'd TS is much higher than measured. (Note no additional water added).	Calculated Glass Produced		Elem/ Oxide					SECOND MELTER FEED SAMPLE- FEED DILUTED BY WATER				
								Sample taken on 12/15 at 18:15				
Tank weight adjusted												
								Water Added	6.95	lb	Water added calculated from	
				6.66	Melter volumes that could be made			Water Added	3.15	liter	actual tank weights	
								Water Added	3152.52	g	Uses calculated total solids	
				2.09	kg glass/liter feed							
Na Molarity								3.21				159179-159182
Volume				5.18	Volume of glass that could be made			15.99				Measured
	Oxide	Oxide Wt		Mass Oxide (g)	Mass Element (g)	Wt% Oxide	Wt% Element	M	mg/liter	mol	g	mg/L or wt% wet
NO3-	none							0.81	50033	12.9	800.0190	40869
NO2-	none							0.424	19489	6.8	311.6198	14290
SO4=	none							0.0329	3163	0.527	50.5786	3428
Cl	Cl	35.45	1	12.4	12.4	0.09	0.16	0.0219	778	0.351	12.4385	2562
F	F	19.00	1	7.1	7.1	0.05	0.09	0.0234	444	0.373	7.0935	2779
OH-	none							0.61	10380	9.8	165.9799	NA
CO3= (from TIC)	none							1.194	71653	19.09	1145.7213	NA
TOC (sugar in glassformers)	none							0.93	11192	14.9	178.9593	NA
Ag	Ag2O	231.74	2	0.00425	0.00396	0.00003	0.00005	0.0000	0.2475	0.0000	0.0040	NA
Al	Al2O3	101.96	2	917	485	6.6	6.4	1.1250	30352.9642	17.9879	485.3416	1.4654
B	B2O3	69.62	2	1440	447	10.29	5.91	2.5867	27964.4062	41.3605	447.1487	1.5495
Ba	BaO	153.34	1	0.001470	0.001317	0.000011	0.000017	0.0000	0.0824	0.0000	0.0013	0.0038
Ca	CaO	56.08	1	906	648	6.48	8.56	1.0109	40517.5509	16.1645	647.8725	2.2492
Cd	CdO	128.40	1	0.25	0.22	0.0018	0.0029	0.0001	13.7565	0.0020	0.2200	0.0032
Co	CoO	74.93	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0074
Cr	Cr2O3	151.99	2	2.04	1.39	0.015	0.018	0.0017	87.1087	0.0268	1.3929	0.0126
Cu	CuO	79.54	1	0.05	0.04	0.00034	0.00049	0.0000	2.3419	0.0006	0.0374	0.0025
Fe	Fe2O3	159.69	2	914	639	6.53	8.44	0.7155	39959.2067	11.4410	638.9446	2.3570
La	La2O3	325.82	2	0.04860	0.04144	0.00035	0.00055	0.0000	2.5919	0.0003	0.0414	0.0073
Li	Li2O	29.88	2	389	181	2.78	2.39	1.6276	11294.2172	26.0259	180.5937	0.6598
Mg	MgO	40.31	1	217.0	130.9	1.55	1.73	0.3366	8183.4066	5.3822	130.8520	0.4708
Mn	MnO2	86.94	1	2.35	1.48	0.017	0.02	0.0017	92.6997	0.0270	1.4823	0.0244
Mo	MoO3	143.94	1	0.35	0.23	0.0025	0.0031	0.0002	14.5096	0.0024	0.2320	0.0028
Na ICP	Na2O	61.98	2	1588	1178	11.4	15.6	3.2055	73694.8428	51.2564	1178.3749	4.4907
Na AA												4.7489
Ni	NiO	74.71	1	3.35	2.63	0.024	0.035	0.0028	164.6319	0.0448	2.6325	0.0154
P	P2O5	141.94	2	16.2	7.1	0.12	0.09	0.0142	440.9253	0.2276	7.0504	0.0574
Pb	PbO	223.19	1	0.57	0.53	0.004	0.007	0.0002	33.2925	0.0026	0.5323	0.0234
Si	SiO2	60.08	1	6529	3052	46.7	40.3	6.7956	190861.8238	108.6615	3051.8659	11.0919
Sn	SnO	134.69	1	0.19	0.16	0.0013	0.0022	0.0001	10.2096	0.0014	0.1633	0.0120
Sr	SrO	103.62	1	1.60	1.36	0.011	0.018	0.0010	84.8478	0.0155	1.3567	0.0048
Ti	TiO2	79.90	1	170	102	1.21	1.34	0.1329	6367.5537	2.1256	101.8167	0.2404
V	VO2	82.94	1	0.006334	0.003890	0.000045	0.000051	0.0000	0.2433	0.0001	0.0039	0.0041
Zn	ZnO	81.37	1	425	341	3.04	4.51	0.3266	21351.2564	5.2227	341.4049	1.2582
Zr	ZrO2	123.22	1	436	323	3.12	4.27	0.2214	20198.7879	3.5406	322.9771	1.0582
K	K2O	94.20	2	11.3	9.4	0.08	0.12	0.0151	588.8038	0.2408	9.4149	0.0394
Oxides, O (except CO3=), H, impurities	none										7273	
check					%:	100.00	100.00				17497.4	
Calculated Values:												
Total Sample											25823.7	
Total Sample (lb)											56.93	
Solids in Sample				13988.8	7571.3						17497.4	
Water											8326.3	
Sucrose											83.7	
Measured Values:												
otal Sample (by weight gain in tank)											25705.5	
Total Sample (by weight measured before addition)												
Sample w/o Glassformers:												
Total Solids in Sample										calculated:	67.76	61.37

This sheet uses density fixed at measured value, calculates Total Solids. The calc'd TS is much higher than measured. (Note no additional water added).	CONVERT ANALYSIS 1 TO OXIDES							THIRD MELTER FEED SAMPLE						
Tank weight adjusted														
								Water removed:	2.92	L				
									2921.31	g				
Na Molarity												(159184-159187)		
Volume								12.25				Measured	Calculated	
	wt%							M	mg/liter	mol	g	mg/L or wt% wet	mg/L or wt% wet	% difference (meas-calc)/ [(meas+calc)/2]
NO3-	3.841	NO3-	62.0049				3.841	1.0535	65322.1776	12.9025	800.0190	58622	65322	10.81
NO2-	1.327	NO2-	46.0055				1.327	0.5531	25444.0023	6.7735	311.6198	21109	25444	18.62
SO4=	0.234	SO4=	96.0616				0.234	0.0430	4129.7840	0.5265	50.5786	3662	4130	12.00
Cl	0.235	Cl	35.453				0.235	0.0286	1015.6096	0.3508	12.4385	3409	1016	
F	0.235	F	18.9984				0.235	0.0305	579.1933	0.3734	7.0935	3409	579	
OH-		OH-						0.7969	13552.3875	9.7593	165.9799	NA	13552	
CO3= (from TIC)		CO3=						1.5589	93549.0394	19.0924	1145.7213	NA	93549	
TOC (sugar in glassformers)		TOC						1.2176	14612.1644	14.9120	178.9593	NA	14612	
Ag		Ag2O		Ag				0.0000	0.3231	0.0000	0.0040	0.0025	0.000017	-197.20
Al	2.565	Al(OH)3	78.00361	Al	26.9815	1	7.416	1.4687	39628.5179	17.9879	485.3416	2.0670	2.1192	2.50
B	2.948	H3BO3	61.83311	B	10.811	1	16.863	3.3771	36510.0410	41.3605	447.1487	2.2345	1.9524	-13.47
Ba	0.003	BaO	153.34	Ba	137.34	1	0.004	0.0000	0.1075	0.0000	0.0013	0.0023	0.0000	-198.98
Ca	3.792	CaO	56.0794	Ca	40.08	1	5.305	1.3198	52899.2976	16.1645	647.8725	3.0332	2.8288	-6.97
Cd	0.005	CdO	128.3994	Cd	112.4	1	0.006	0.0002	17.9603	0.0020	0.2200	0.0023	0.0010	-82.17
Co	0.020	CoO	74.9324	Co	58.933	1	0.026	0.0000	0.0000	0.0000	0.0000	0.0032	0.0000	-200.00
Cr	0.025	Cr2O3	151.9902	Cr	51.996	2	0.036	0.0022	113.7282	0.0268	1.3929	0.0143	0.0061	-80.79
Cu	0.004	CuO	79.54	Cu	63.54	1	0.005	0.0000	3.0576	0.0006	0.0374	0.0016	0.0002	-161.83
Fe	3.878	Fe2O3	159.69	Fe	55.847	2	5.544	0.9342	52170.3292	11.4410	638.9446	3.1235	2.7899	-11.29
La	0.046			La	138.91			0.0000	3.3839	0.0003	0.0414	0.0080	0.0002	-191.10
Li	1.128	Li2CO3	73.8873	Li	6.939	2	6.004	2.1250	14745.6138	26.0259	180.5937	1.0821	0.7885	-31.38
Mg	0.750	MgO	40.3114	Mg	24.312	1	1.244	0.4395	10684.1715	5.3822	130.8520	0.6568	0.5713	-13.91
Mn	0.045	MnO2	86.94	Mn	54.938	1	0.071	0.0022	121.0277	0.0270	1.4823	0.0192	0.0065	-99.16
Mo	0.006	MoO3	143.94	Mo	95.94	1	0.008	0.0002	18.9436	0.0024	0.2320	0.0021	0.0010	-67.71
Na ICP	8.085	Na		Na	22.9898	1	8.085	4.1851	96215.2286	51.2564	1178.3749	5.6271	5.1452	-8.95
Na AA												4.9330		4.21
Ni	0.027	NiO	74.7094	Ni	58.71	1	0.034	0.0037	214.9417	0.0448	2.6325	0.0189	0.0115	-48.73
P	0.080	P2O5	141.9446	P	30.9738	2	0.183	0.0186	575.6675	0.2276	7.0504	0.0571	0.0308	-59.81
Pb	0.030	PbO	223.1894	Pb	207.19	1	0.032	0.0002	43.4663	0.0026	0.5323	0.0732	0.0023	-187.69
Si	18.044	SiO2	60.0848	Si	28.086	1	38.603	8.8723	249187.2337	108.6615	3051.8659	12.9876	13.3255	2.57
Sn	0.016	SnO	134.6894	Sn	118.69	1	0.018	0.0001	13.3296	0.0014	0.1633	0.1182	0.0007	-197.60
Sr	0.007	SrO	103.6194	Sr	87.62	1	0.008	0.0013	110.7765	0.0155	1.3567	0.0068	0.0059	-13.77
Ti	0.677	TiO2	79.8988	Ti	47.9	1	1.130	0.1736	8313.4126	2.1256	101.8167	0.3703	0.4446	18.22
V	0.006			V	50.942			0.0000	0.3176	0.0001	0.0039	0.0038	0.000017	-198.23
Zn	2.179	ZnO	81.3694	Zn	65.37	1	2.712	0.4264	27875.9807	5.2227	341.4049	1.6656	1.4907	-11.08
Zr	1.865	ZrO2	123.2188	Zr	91.22	1	2.519	0.2891	26371.3297	3.5406	322.9771	1.4198	1.4102	-0.68
K	0.069	K		K	39.102	1	0.069	0.0197	768.7362	0.2408	9.4149	0.0525	0.0411	-24.34
Oxides, O (except CO3=), H, impurities											7273			
check							101.798				17497.4			
Calculated Values:														
Total Sample											22902.4			
Total Sample (lb)											50.49			
Solids in Sample											17497.4			
Water											5405.0			
Sucrose											83.7			
Measured Values:														
otal Sample (by weight gain in tank)														
Total Sample (by weight measured before addition)														
Sample w/o Glassformers:														mean
Total Solids in Sample										calculated:	76.40	77.60	75.20	76.40

This sheet uses density fixed at measured value, calculates Total Solids. The calc'd TS is much higher than measured. (Note no additional water added).	Glass- average of predicted and from the 3 melter feed measurements									
Tank weight adjusted										
Na Molarity										
Volume		calc	1	2	3					
		Element g	Element g	Element g	Element g	Mean	wt% elem/total elem		wt oxide g	wt% elem or oxide/ total oxide
NO3-	none									
NO2-	none									
SO4=	none									
Cl	Cl	12.4	41.2	41.0	41.7	12.4	0.163	Cl	12.4	0.0882
F	F	7.09	41.2	44.4	41.7	7.09	0.0927	F	7.09	0.0503
OH-	none									
CO3= (from TIC)	none									
TOC (sugar in glassformers)	none									
Ag	Ag	0.00396			0.561	0.561	0.00733	Ag2O	0.603	0.00427
Al	Al	485	449	378	473	446	5.84	Al2O3	844	5.98
B	B	447	516	400	512	469	6.13	B2O3	1509	10.7
Ba	Ba	0.00132	0.608	0.975	0.515	0.608	0.00795	BaO	0.679	0.00481
Ca	Ca	648	663	581	695	647	8.45	CaO	905	6.42
Cd	Cd	0.220	0.843	0.833	0.527	0.606	0.00791	CdO	0.692	0.00491
Co	Co	0	3.53	1.90	0.721	2.72	0.0355	CoO	3.45	0.0245
Cr	Cr	1.39	4.33	3.25	3.28	3.06	0.0401	Cr2O3	4.48	0.0318
Cu	Cu	0.0374	0.747	0.646	0.355	0.0374	4.89E-04	CuO	0.0469	3.32E-04
Fe	Fe	639	678	609	715	660	8.63	Fe2O3	944	6.70
La	La	0.0414	7.97	1.89	1.82	0.0414	5.42E-04	La2O3	0.0486	3.45E-04
Li	Li	181	197	170	248	199	2.60	Li2O	428	3.04
Mg	Mg	131	131	122	150	134	1.75	MgO	221	1.57
Mn	Mn	1.48	7.85	6.31	4.40	5.01	0.0655	MnO2	7.93	0.0562
Mo	Mo	0.232	0.965	0.723	0.469	0.232	0.00303	MoO3	0.348	0.00247
Na ICP	Na ICP	1178	1415	1160	1289	1260	16.5	Na2O	1699	12.0
Na AA	Na AA		1436	1226	1130	1264	16.5		1704	12.1
Ni	Ni	2.63	4.69	3.98	4.33	3.91	0.0511	NiO	4.97	0.0353
P	P	7.05	14.0	14.8	13.1	12.2	0.160	P2O5	28.0	0.199
Pb	Pb	0.532	5.21	6.04	16.8	0.532	0.00696	PbO	0.573	0.00407
Si	Si	3052	3157	2864	2974	3012	39.4	SiO2	6444	45.7
Sn	Sn	0.163	2.74	3.09	27.1	0.163	0.00213	SnO	0.185	0.00131
Sr	Sr	1.36	1.25	1.25	1.56	1.35	0.0177	SrO	1.60	0.0113
Ti	Ti	102	119	62.1	84.8	91.8	1.20	TiO2	153	1.09
V	V	0.00389	0.989	1.05	0.876	0.00389	5.08E-05	VO2	0.00633	4.49E-05
Zn	Zn	341	381	325	381	357	4.67	ZnO	445	3.15
Zr	Zr	323	326	273	325	312	4.08	ZrO2	421	2.99
K	K	9.41	12.1	10.2	12.0	10.9	0.143	K2O	13.1	0.0932
Oxides, O (except CO3=), H, impurities		7571	8194	7120	7940	7652			14102	
check										
Calculated Values:										
Total Sample										
Total Sample (lb)										
Solids in Sample										
Water										
Sucrose										
Measured Values:										
otal Sample (by weight gain in tank)										
Total Sample (by weight measured before addition)										
Sample w/o Glassformers:										
Total Solids in Sample										

This sheet uses density fixed at measured value, calculates Total Solids. The calc'd TS is much higher than measured. (Note no additional water added).	MW or AW		Radioactive Feed- From Evaporator Concentrate- 7 bottles				Radioactive Feed Diluted to 7.63 M				Glass Formers for 1 liter of original feed (7.63 M)		Total Glass Adde
Tank weight adjusted							FEED WAS NOT ACTUALLY DILUTED PRIOR TO INITIAL SAMPLE						Addition was assumed feed 7 liter
							Water Added	0.00	liter				
							Water Added	0.00	liter/liter original				
				This volume gives the best mass									Glassformers a
				balance on feed addition and is									added corresp
Na Molarity		M	7.63	consistent with observed bottle			7.63						liters of feed
Volume		liter	6.68	volumes			6.68						
			M	mg/liter	mol	g	M	mg/liter	mol	g	mol	g	mol
Radiochemical (µCi/ml)				µCi/mL	µCi								
Co-60				0.0496	331.7127								
Cs-134													
Cs-137				0.0724	484.2569								
Eu-154				0.0445	297.5815								
Eu-155				0.0300	200.2471								
Am-241				0.0285	190.2846								
Sr-90				1.7942	11993.4130								
Tc-99				0.0554	370.0571								
Total Alpha			from evap	0.1040	695.1824								
Total Beta			feed	6.8500	45788.4586								
ICP-Mass Spectroscopy				mg/liter	mg								
mass 99				3.1986	21.3809								
Tc-99 (uCi/ml)				0.0543	362.7658								
mass 230				0.0062	0.0416								
mass 231				0.0062	0.0416								
mass 232 (Th)				1.7144	11.4595								
mass 233				0.0062	0.0416								
mass 234 (U)				0.0062	0.0416								
mass 235 (U)				0.0113	0.0752								
mass 236 (U)				0.0062	0.0416								
mass 237 (Np)				0.0853	0.5701								
mass 238 (Pu & U)				1.0688	7.1440								
mass 239 (Pu)				0.0169	0.1128								
mass 240 (Pu)				0.0062	0.0416								
mass 241 (Am & Pu)				0.0088	0.0587								
mass 242 (Pu)				0.0062	0.0416								
mass 243 (Am)				0.0062	0.0416								
mass 244 (Cm)				0.0062	0.0416								
mass 245 (Cm)				0.0062	0.0416								
mass 246				0.0062	0.0416								

This sheet uses density fixed at measured value, calculates Total Solids. The calc'd TS is much higher than measured. (Note no additional water added).	MW or AW		Feed: Waste + Glass Formers											
Tank weight adjusted			This calculation makes the total mass of feed measured match the calculated amount				MELTER FEED SAMPLE #1 - DRY BASIS							
			The calculated Volume is very close to the approximate measured amount				value not used							
							less than value shown							Dry bas
Na Molarity		M	4.21											
Volume		liter	12.19	Compare to ~12.3 "eyeballed"			156305a; peroxide	156306a; peroxide	156305b; peroxide	156306b; peroxide	156303; MW	156304; MW	Meas. St Dev	
			M	mg/liter	mol	g	wt %	wt %	wt %	wt %	wt %	wt %	wt %	
Radiochemical (µCi/ml)					µCi		µCi/mL	µCi/mL			µCi/mL	µCi/mL		
Co-60					331.7127		0.0356	0.0386			0.0305	0.0286		
Cs-134							0.0000	0.0000			0.0000	0.0000		
Cs-137					484.2569		0.0452	0.0413			0.0711	0.0463		
Eu-154					297.5815		0.0000	0.0000			0.0000	0.0000		
Eu-155					200.2471		0.0000	0.0000			0.0000	0.0000		
Am-241					190.2846		0.0000	0.0000			0.0000	0.0000		
Sr-90					11993.4130									
Tc-99					370.0571									
Total Alpha					695.1824		0.0328	0.0386			0.0409	0.0331		
Total Beta					45788.4586		5.1057	4.7742			5.3819	4.7039		
ICP-Mass Spectroscopy					mg		mg/liter	mg/liter			mg/liter	mg/liter		
mass 99					21.3809									
Tc-99 (uCi/ml)					362.7658									
mass 230					0.0416	0.000042								
mass 231					0.0416	0.000042								
mass 232 (Th)					11.4595	0.180349								
mass 233					0.0416	0.000042								
mass 234 (U)					0.0416	0.000042								
mass 235 (U)					0.0752	0.000075								
mass 236 (U)					0.0416	0.000042								
mass 237 (Np)					0.5701	0.000570								
mass 238 (Pu & U)					7.1440	0.248438								
mass 239 (Pu)					0.1128	0.000113								
mass 240 (Pu)					0.0416	0.000042								
mass 241 (Am & Pu)					0.0587	0.000059								
mass 242 (Pu)					0.0416	0.000042								
mass 243 (Am)					0.0416	0.000042								
mass 244 (Cm)					0.0416	0.000042								
mass 245 (Cm)					0.0416	0.000042								
mass 246					0.0416	0.000042								

This sheet uses density fixed at measured value, calculates Total Solids. The calc'd TS is much higher than measured. (Note no additional water added).	Calculated Glass Produced			Elem/ Oxide				**SECOND MELTER FEED SAMPLE- FEED DILUTED BY WATER**				
Tank weight adjusted								Sample taken on 12/15 at 18:15				
								Water Added	6.95	lb	Water added calculated from	
				6.66	Melter volumes that could be made			Water Added	3.15	liter	actual tank weights	
								Water Added	3152.52	g	Uses calculated total solids	
				2.09	kg glass/liter feed							
Na Molarity								3.21				159179-159182
Volume				5.18	Volume of glass that could be made			15.99				Measured
	Oxide	Oxide Wt		Mass Oxide (g)	Mass Element (g)	Wt% Oxide	Wt% Element	M	mg/liter	mol	g	mg/L or wt% wet
				Calculated from average measurements								
Radiochemical (µCi/ml)					µCi	µCi/g	µCi/g			µCi		µCi/mL
Co-60					349.2609	0.0250	0.0461			331.7127		0.0189
Cs-134												
Cs-137					547.8611	0.0392	0.0724			484.2569		0.0340
Eu-154					249.9731	0.0179	0.0330			297.5815		0.0076
Eu-155					152.1781	0.0109	0.0201			200.2471		0.0037
Am-241					181.7711	0.0130	0.0240			190.2846		
Sr-90					11993.4130	0.8574	1.5841			11993.4130		
Tc-99					370.0571	0.0265	0.0489			370.0571		
Total Alpha					717.4076	0.0513	0.0948			695.1824		0.0161
Total Beta					55717.4209	3.9830	7.3590			45788.4586		2.2638
ICP-Mass Spectroscopy												mg/liter
mass 99					21.381	0.0002	2.824E-04			21.3809		
Tc-99 (uCi/ml)					362.766	0.026	4.791E-02			362.766		
					mg	wt%	wt%					
mass 230					0.0416	2.972E-07	5.491E-07			0.0416		0.08
mass 231					0.0416	2.972E-07	5.491E-07			0.0416		0.08
mass 232 (Th)					180.3372	1.289E-03	2.382E-03			180.3489		11.75
mass 233					0.0416	2.972E-07	5.491E-07			0.0416		0.08
mass 234 (U)					0.0416	2.972E-07	5.491E-07			0.0416		0.08
mass 235 (U)					0.1314	9.391E-07	1.735E-06			0.0752		0.15
mass 236 (U)					0.0333	2.377E-07	4.393E-07			0.0416		0.08
mass 237 (Np)					1.1411	8.158E-06	1.507E-05			0.5701		0.08
mass 238 (Pu & U)					229.8058	1.643E-03	3.035E-03			248.4379		24.27
mass 239 (Pu)					0.5438	3.888E-06	7.183E-06			0.1128		0.08
mass 240 (Pu)					0.0416	2.972E-07	5.491E-07			0.0416		0.08
mass 241 (Am & Pu)					0.0587	4.198E-07	7.757E-07			0.0587		0.08
mass 242 (Pu)					0.0416	2.972E-07	5.491E-07			0.0416		0.08
mass 243 (Am)					0.0416	2.972E-07	5.491E-07			0.0416		0.08
mass 244 (Cm)					0.0416	2.972E-07	5.491E-07			0.0416		0.08
mass 245 (Cm)					0.0416	2.972E-07	5.491E-07			0.0416		0.08
mass 246					0.0416	2.972E-07	5.491E-07			0.0416		0.08

This sheet uses density fixed at measured value, calculates Total Solids. The calc'd TS is much higher than measured. (Note no additional water added).	What supernate would have been if water had been added before glass formers				CONVERT ANALYSIS 1 TO OXIDES							THIRD MELTER FEED SAMPLE		
Tank weight adjusted														
												Water removed:	2.92	L
													2921.31	g
Na Molarity	5.21													
Volume	9.79											12.25		
	M	mg/liter	mol	g	wt%							M	mg/liter	mol
Radiochemical (µCi/ml)														
Co-60														
Cs-134														
Cs-137														
Eu-154														
Eu-155														
Am-241														
Sr-90														
Tc-99														
Total Alpha														
Total Beta														
ICP-Mass Spectroscopy														
mass 99														
Tc-99 (uCi/ml)														
mass 230														
mass 231														
mass 232 (Th)														
mass 233														
mass 234 (U)														
mass 235 (U)														
mass 236 (U)														
mass 237 (Np)														
mass 238 (Pu & U)														
mass 239 (Pu)														
mass 240 (Pu)														
mass 241 (Am & Pu)														
mass 242 (Pu)														
mass 243 (Am)														
mass 244 (Cm)														
mass 245 (Cm)														
mass 246														

This sheet uses density fixed at measured value, calculates Total Solids. The calc'd TS is much higher than measured. (Note no additional water added).	Glass- average of predicted and from the 3 melter feed measurements									
Tank weight adjusted										
Na Molarity										
Volume		calc	1	2	3					
		Element g	Element g	Element g	Element g	Mean	wt% elem/total elem		wt oxide g	wt% elem or oxide/ total oxide
Radiochemical (µCi/ml)			uCi	uCi	uCi	uCi	uCi/g			
Co-60		349.3	406	302	357	354	0.0462			0.0251
Cs-134										
Cs-137		547.9	621	544	542	564	0.0737			0.0400
Eu-154		250.0		122	330	234	0.0306			0.0166
Eu-155		152.2		58.6	198	136	0.0178			0.00965
Am-241		181.8			173	178	0.0232			0.01259
Sr-90		11993.4				11993	1.5674			0.850
Tc-99		370.1				370.1	0.0484			0.02624
							ppb			
Total Alpha		717.4	443	257	1475	723	94.4859			0.0513
Total Beta		55717.4	60840	36198	80043	58200	7.6063			4.13
ICP-Mass Spectroscopy										
mass 99	mg	21.381				21.381	2.7943			1.52
Tc-99 (uCi/ml)		362.766				363	0.0474			0.0257
		mg	mg	mg	mg	mg	ppb			ppb
mass 230		0.042	0.201	1.30	1.21	0.687	0.0898			0.0487
mass 231		0.042	0.201	1.30	1.21	0.687	0.0898			0.0487
mass 232 (Th)		180.337	206.753	187.83	153.8979	182	23.8127			12.9
mass 233		0.042	0.201	1.30	1.21	0.687	0.0898			0.0487
mass 234 (U)		0.042	0.201	1.30	1.21	0.687	0.0898			0.0487
mass 235 (U)		0.131	1.712	2.36	1.9847	1.55	0.2023			0.110
mass 236 (U)		0.033	0.405	1.30	1.21	0.736	0.0961			0.0522
mass 237 (Np)		1.141	1.419	1.30	1.4338	1.33	0.1740			0.0944
mass 238 (Pu & U)		229.806	230.927	388.15	191.4206	260	33.9901			18.4
mass 239 (Pu)		0.544	0.283	1.30	1.2359	0.688	0.0899			0.0488
mass 240 (Pu)		0.042	0.201	1.30	1.21	0.687	0.0898			0.0487
mass 241 (Am & Pu)		0.059	0.201	1.30	1.21	0.0587	0.0077			0.00416
mass 242 (Pu)		0.042	0.201	1.30	1.21	0.687	0.0898			0.0487
mass 243 (Am)		0.042	0.201	1.30	1.21	0.687	0.0898			0.0487
mass 244 (Cm)		0.042	0.201	1.30	1.21	0.687	0.0898			0.0487
mass 245 (Cm)		0.042	0.201	1.30	1.21	0.687	0.0898			0.0487
mass 246		0.042	0.201	1.30	1.21	0.687	0.0898			0.0487

6.12. Determination of Melter Feedrate – Example for the Radioactive Run

The melter feed tank weight is shown below. The red line shows the same weights versus time with idle periods removed so that only weight changes during feeding are shown. These data were fitted to a linear equation, resulting in an average feedrate of 0.0678 lb/min, or 19.0 ml/min. The fit of the data is very good.

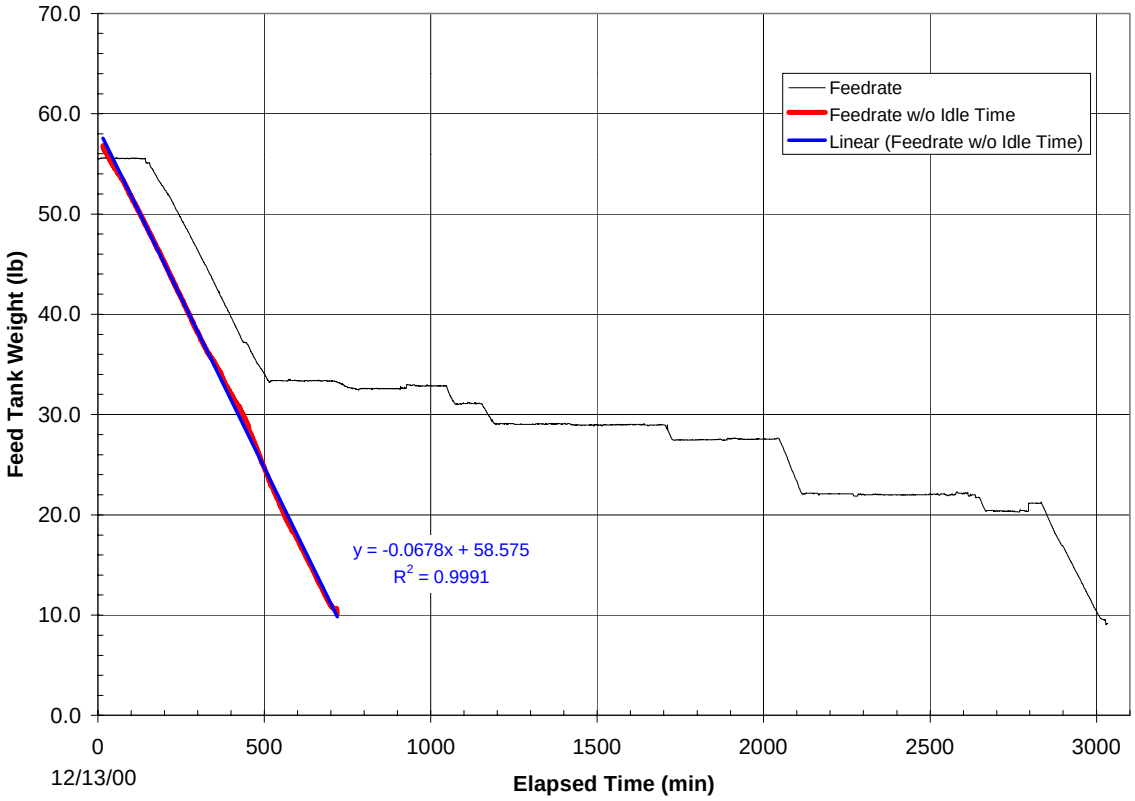


Figure 6.3 Melter Feed Tank Weight and Flowrate Determination

6.13. Offgas Flowrate Accuracy – Example from Surrogate Run #2

The offgas flowrates measured by the dry gas meter and the helium tracer method are shown below. The DGM readings were averaged over 6 readings to remove some of the variation. The variations shown by the DGM are real, but to compare them to the He tracer readings (from the GC data), these data need to be smoothed; the tracer readings change only on a frequency of 2.5 minutes versus every minute for the DGM. Also, the tracer readings can be additionally dampened by back mixing in the offgas train and sampling system.

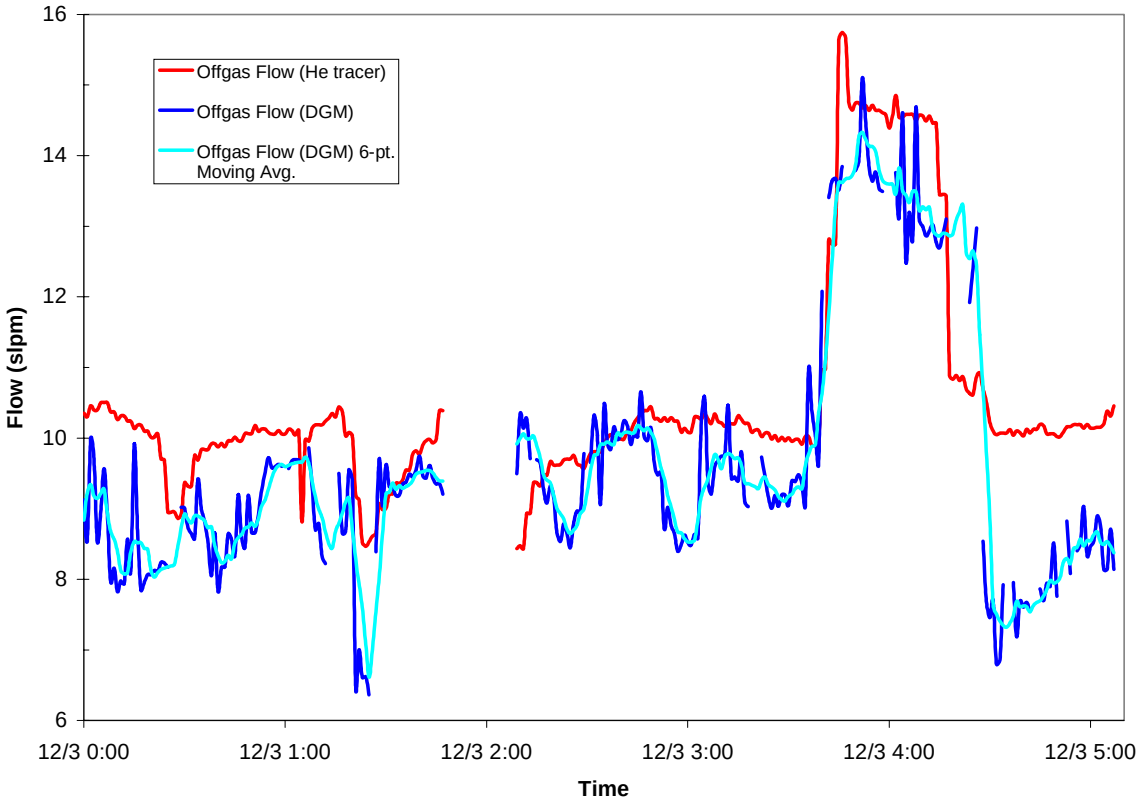
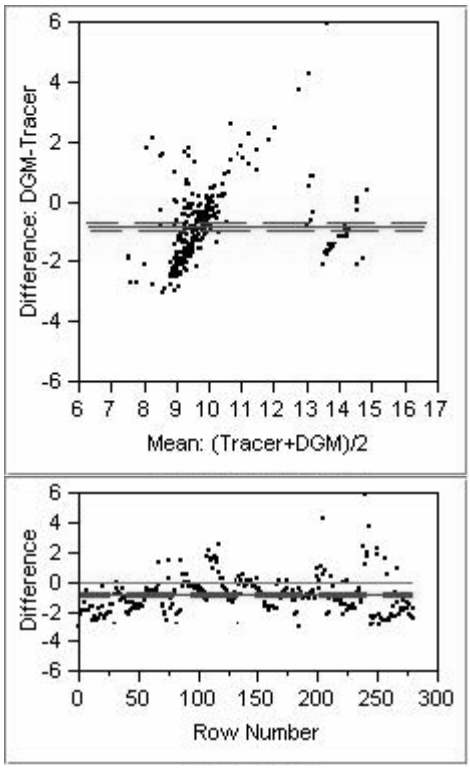


Figure 6.4 Offgas Flowrate Comparison

A matched pairs analysis was conducted using the JMP statistical software. The result was, for this data set, that the tracer flowrate was on average about 0.76 slpm higher than the DGM reading. The output from JMP is shown below.

Output from JMP:

Matched Pairs
Difference: DGM-Tracer



DGM	9.66273	t-Ratio	-10.0877
Tracer	10.4216	DF	280
Mean Difference	-0.7589	Prob > |t|	<.0001
Std Error	0.07523	Prob > t	1.0000
Upper95%	-0.6108	Prob < t	<.0001
Lower95%	-0.907		
N	281		
Correlation	0.72366		

6.14. Rheology Test Specifications

Table 6.6 Haake Specifications and Measuring Ranges

Sensor System M5		**Measuring Head**	**NV**	**MV1**	**SV1**
Torque: (τ)		Inner Cylinder - Radius R_i (mm) - Height L (mm)	R_2 R_3 17.85 20.1 60	 20.04 60	 10.1 60
Minimum	0.049 N·cm	Outer Cylinder - Radius R_o	R_1 R_4 17.5 20.5	 21	 11.55
Maximum	4.9 N·cm	Radii Ratio (R_o/R_i)	1.02	1.05	1.14
Deviation	±0.5% of maximum (0.0245 N·cm)	Factor A (Pa/%τ)	1.78	3.22	12.4
Speed: (D)		Factor M (s^{-1}/%D)	27.0	11.7	4.45
Minimum	0.05 rpm	**Viscosity (cP)**			
Maximum	500 rpm	Minimum (1% τ, 100% D)	0.659 @ 2700 s^{-1}	2.75 @ 1170 s^{-1}	27.86 @ 445 s^{-1}
Deviation	±0.5% of indicated	Maximum (100% τ, 0.01% D)	$0.659*10^6$ @ 0.27 s^{-1}	$2.752*10^6$ @ 0.117 s^{-1}	$27.86*10^6$ @ 0.0445 s^{-1}

Table 6.7 Haake Job Descriptions

Program	Up curve (s^{-1})/ time (min)	Hold (s^{-1})/ time (min)	Down curve (s^{-1})/ time (min)	Rotor	Comments
RPPNV	0-2000 / 4.0	2000 / 1.0	2000-0 / 4.0	NV	Low viscosity standards and supernate
RPPMV1	0-500 / 4.0	500 / 1.0	500-0 / 4.0	MV1	Med. viscosity standards and slurries
RPPSV1	0-440 / 4.0	440 / 1.0	440-0 / 4.0	SV1	High viscosity standards and slurries

6.15. Surrogate, Sr/TRU, and Additive Recipes

AN102 Surrogate Recipe for 2 liters at 6.5M sodium for Sr/TRU precipitation feed.

Add the following to 400 grams of water:

Compound	Formula	Mass Needed, g	Actual mass, g
Calcium Nitrate	$Ca(NO_3)_2 \cdot 4H_2O$	3.70	3.70
Cesium Nitrate	$CsNO_3$	0.055	0.055
Copper Nitrate	$Cu(NO_3)_2 \cdot 2.5H_2O$	0.11	0.11
Ferric Nitrate	$Fe(NO_3)_3 \cdot 9H_2O$	0.32	0.32
Lanthanum Nitrate	$La(NO_3)_3 \cdot 6H_2O$	0.05	0.05
Lead Nitrate	$Pb(NO_3)_2$	0.37	0.37
Manganous Chloride	$MnCl_2 \cdot 4H_2O$	0.08	0.08
Nickel Nitrate	$Ni(NO_3)_2 \cdot 6H_2O$	2.59	2.59
Potassium Nitrate	KNO_3	7.04	7.04
Strontium Nitrate	$Sr(NO_3)_2$	0.032	0.0327
Zinc Nitrate	$Zn(NO_3)_2 \cdot 6H_2O$	0.03	0.03
Zirconyl Nitrate		0.06	0.06
EDTA	Na_2EDTA	15.22	15.22
HEDTA	HEDTA	9.18	9.18
Sodium Gluconate		4.88	4.88
Glycolic Acid		24.09	24.09
Citric Acid		8.47	8.47
Nitrilotriacetic Acid		0.46	0.46
Iminodiacetic Acid		4.83	4.83
Boric Acid	H_3BO_3	0.29	0.29
Sodium Chloride	NaCl	7.96	7.96
Sodium Fluoride	NaF	6.18	6.18
Sodium Chromate	Na_2CrO_4	1.00	1.00
Sodium Sulfate	Na_2SO_4	24.39	24.39
Potassium Molybdate	K_2MoO_4	0.18	0.18

In a separate container mix the following:

Compound	Formula	Mass Needed, g	Actual Mass, g
Sodium Hydroxide	NaOH	201.52	201.52
Aluminum Nitrate	$Al(NO_3)_3 \cdot 9H_2O$	259.57	259.57
Sodium Phosphate	$Na3PO_4 \cdot 12H_2O$	25.42	25.4189
Sodium Formate	NaHCOO	25.02	25.0197
Sodium Acetate	$NaCH_3COO \cdot 9H_2O$	2.03	2.0275
Sodium Oxalate	$Na_2C_2O_4$	1.15	1.1471
Water		400	400

Combine two parts after thoroughly mixing.

Add 164.64 grams of sodium carbonate to mixed solution (actual added = 164.64 g).

Mix thoroughly.

In a separate container mix the following:

Compound	Formula	Mass Needed, g	Actual Mass, g
Sodium Nitrate	$NaNO_3$	149.42	149.42
Sodium Nitrite	$NaNO_2$	157.77	157.77
Water		200	200.00

Add and mix thoroughly. Combine with main solution.

Add 621.05 grams of water to the combined solution (actual added 621.05 g).

Record final weight: 3029.7 grams. (Some was removed for samples.

Sr/TRU Precipitate Surrogate Supernate Production

A mass of 2704.2 grams of the above surrogate was used. To it were added 184.09 grams of 17M sodium hydroxide solution, 112.13 grams of 2M strontium nitrate solution, and 127.63 grams of 1M sodium permanganate solution. These chemicals were added slowly to the surrogate in the order given.[23] The resulting mixture was then heated and maintained at 50°C for 4.5 hours under continuous mixing in an open vessel. The mixture was allowed to cool to room temperature. The solids were removed using a 0.45μm filter, leaving a relatively solid-free supernate surrogate solution.

The predicted sodium molarity with no evaporation loss was 6.6M. Analytical results for sodium molarity were very inconsistent. Results ranged from 7.2M to 7.8M sodium, with more results on the low end of the range. The measured density of 1.31 grams per cubic centimeter more nearly matched a 7.0M sodium solution. The sodium results were no more or less uncertain than the data for the radioactive supernate solution being simulated which was 7.1±0.4M sodium.

Dilutions to 6M and 5M were made using the density data obtained by Hansen[25]. Two equations were derived from his data:

Equation 6.1 Density = 0.0432*(sodium molarity) + 1.000

Equation 6.2 Mass fraction sodium = $0.02626*(\text{sodium molarity})^{0.79553}$

With these equations, the following two results were calculated. To prepare 6M from 7.1M, add 0.140±0.004 grams water per gram 7.1M supernate. To prepare 5M from 7.1M, add 0.320±0.004 grams water per gram 7.1M supernate. The following equation illustrates the calculation for preparing 6M from 7.1M supernate:

$$(50.9g)(7.1 moles/liter)(1 liter/1307g) = (50.9 + Xg)(6 moles/liter)(1 liter/1259g)$$
$$X = 7.22g\ water, \quad (7.22/50.9) \approx 0.140g\ water/g\ starting\ supernate$$

The uncertainty in the dilution mass derives from uncertainty in Equations 6.1 and 6.2.

Sr/TRU Precipitate Active Supernate Production

The pretreated radioactive AN102 supernate sample that was the starting point for the radioactive rheology work was taken following Sr/TRU precipitation, filtration, ion exchange and evaporation. The radioactive evaporation processing was at 50°C. When the sample cooled to 25°C and aged ~ 7 months, crystals formed as shown in the upper left photo in Figure 6.5 below. The insoluble solids content at 25°C increased from 0.3 wt. % as measured by Crowder et al.[4] in Fall of 2000, to ~ 4-5 wt. % when rheology testing started in July of 2001, even though the sample bottle had minimal air space and was capped and sealed with tape. After heating of the sample (see upper right photo in Figure 6.5), the recrystallized solids upon cooling (see lower right photo in Figure 6.5) appeared to be somewhat finer and less well packed than the solids in the as-received condition. The lower left photo in Figure 6.5 shows the settled solids as they appear after shaking at room temperature.

Figure 6.5 AN102 radioactive supernate. Clockwise from top left: as-received (already aged), free of insoluble solids after warming to 50°C, recrystallized and settled at room temperature, and shaken at room temperature.

Table 6.8 and Table 6.9 give the Vitreous State Laboratory spreadsheet calculations for the glass former addition masses for the radioactive slurry preparations and the surrogate slurry preparations.

Table 6.8 7.1M Radioactive Glass Former Slurry Addition Masses

										Recipe for glass LAWC21 using High Sulfate Active sample					23-May-00	7.1M
Envelope		Evapor. feed	GLASS	Conversion	AN102	AN102 wt%	Glass	LAWC21	Additives		Assay	Ratio	Target			
Constituents	calculated	AN-102 active	Oxides	to wt%	wt%	in glass @	Former	this target	this	Source in			Weight	other oxides		
	M	mg/L		" Oxides"	As glass	11.8% Na	Mix	for AN102	sample	Additives			(g)	present		
		5/5/00 email	Loading			100%	13.29%	100%	0.1329	86.71%				Additives	% Fe2O3	%SiO2	Vendor Inormation
Ag			Ag2O	0.00	0.00	0.0000		0.0000								
Al	0.31	8390	Al2O3	3.35	5.97	0.793	6.18	6.1519	5.359	Kyanite (Al2SiO5) 325 Mesh	0.990	0.540	5.439	1.16%	43.70%	Kyanite Mining
B		22.2	B2O3	0.02	0.03	0.0036	11.70	10.1490	10.145	H3BO3 (Technical Granular)	0.986	0.563	9.917			US Borax
Ba		0	BaO	0.00	0.00	0.0000		0.0000								
Ca		176	CaO	0.05	0.09	0.0123	7.40	6.4291	6.417	Wollanstonite NYAD 325 Mesh	0.993	0.475	7.382	0.40%	51.00%	NYCO Minerals
Cd		32.9	CdO	0.01	0.01	0.0019		0.0019								
Co		2.8	CoO	0.00	0.00	0.0002		0.0002								
Cr		117.0	Cr2O3	0.07	0.13	0.0171		0.0171								
Cu		5.6	CuO	0.00	0.00	0.0004		0.0004								
Fe		3.5	Fe2O3	0.00	0.00	0.0003	7.50	6.5037	6.503	Fe2O3 (Iron III oxide, -325 Mesh)	0.998	1.000	3.308			Alfa Aesar-Johnson Matthey
K	0.03	1230	K2O	0.31	0.56	0.074		0.0741								
La		6	La2O3	0.00	0.00	0.0004		0.0004								
Li		0	Li2O	0.00	0.00	0.0000	3.17	2.7488	2.749	Li2CO3 (Chemetall Foote Co. Tech. gr.)	0.99	0.404	3.729			Cyprus Foote Mineral Co.
Mg		0	MgO	0.00	0.00	0.0000	1.75	1.5175	1.517	Olivine (Mg2SiO4) 325 Mesh (#180)	0.990	0.480	1.733	7.68%	42.52%	UNIMIN Corp.
Mn		1	MnO2	0.00	0.00	0.0001		0.0001								
Mo		34.7	MoO3	0.01	0.02	0.0026		0.0026								
Na	7.61	175000	Na2O	49.84	88.81	11.80		11.8000								
Ni		200	NiO	0.05	0.10	0.0127		0.0127								
Pb		79.6	PbO	0.02	0.03	0.0043		0.0043								
Sn		24	SnO2	0.01	0.01	0.0015		0.0015								
Si		71	SiO2	0.03	0.06	0.0076	54.00	46.8326	46.825	SiO2 (Sil-co-Sil 75)	0.997	1.000	17.813			US SILICA
Sr		203	SrO	0.05	0.09	0.0120		0.0120								
Ti		0	TiO2	0.00	0.00	0.0000	1.30	1.1273	1.127	TiO2 (Rutile Airfloated)	0.954	1.000	0.641	0.71%	0.91%	Chemalloy
W		0	WO3	0.00	0.00	0.0000		0.0000								
Zn		1.9	ZnO	0.00	0.00	0.0001	3.50	3.0351	3.035	ZnO (Kadox-920)	0.997	1.000	1.652			Zinc Corp. of America
Zr		1	ZrO2	0.00	0.00	0.0001	3.50	3.0350	3.035	Zircon ZrSiO4 (Flour) Mesh 325	0.990	0.651	2.555		33.00%	American Mineral
Br		0	Br	0.00	0.00	0.0000		0.0000								
Cl		1860	Cl	0.39	0.70	0.0930		0.0930								
F		1060	F	0.22	0.40	0.0530		0.0530								
PO4		2170	P2O5	0.34	0.61	0.0811		0.0811		Total Sodium Moles			0.21	moles	20668 moles Na for 38.5 ml 7.1M test	
SO4	0.08	7570	SO3	1.33	2.38	0.3156		0.3156		Expected Glass yield			54.262	g		
NO2	1.01	46600	NO2	9.84						Sum of Additives (g)			54.169	g		
NO3	1.94	120000	NO3	25.35						Sugar as added reductant (decreased for TOC)			0.325	g	325.0826902 mg	
OH			OH	0.00												
CO3	0.67	40115	CO3	8.47												
oxalate		1010	C	0.21												
formate			C	0.00												
SUM			SUM	100.00	100.00	13.29	100.00	100.00	86.713							
NO2+NO3	2.95	M/l	VSL uses 12 moles Carbon (1 mole sucrose/342.3g) per 16 Moles NOx in order to mitigate foaming.													
TOC		21500.0	mg/L	This feed requires			63.08	g/L or	8.287	g. of sucrose per Mole Na						
								3.7240								
	This sample already includes		0.049 moles C, and sucrose has be lowered by							-1.39 g sucrose						

The additives for the 6M radioactive supernate were scaled for altered supernate volume and molarity from the above in the proportions (0.2361/0.20668).

The additives for the 5M radioactive supernate were scaled for altered supernate volume and molarity from the above in the proportions (0.1609/0.20668).

Table 6.9 7.1M Surrogate Glass Former Slurry Addition Masses

										Recipe for glass LAWC21 using 2nd Surrogate HS					27-Aug-01	
Envelope Constituents	calculated M	Evapor. feed AN-102 active mg/L	GLASS Oxides	Conversion to wt% "Oxides"	AN102 wt% As glass	AN102 wt% in glass @ 11.8% Na2	Glass Former Mix	LAWC21 this target for AN102	Additives this sample	Source in Additives	Assay	Ratio	Target Weight (g)	other oxides present		
		5/15/00 email	Loading		100%	13.34%	100%	0.1334	86.66%				Additives	% Fe2O3	%SiO2	Vendor Inormation
Ag			Ag2O	0.00	0.00	0.0000		0.0000								
Al	0.24	6349	Al2O3	3.13	5.68	0.758	6.22	6.1439	5.386	Kyanite (Al2SiO5) 325 Mesh	0.990	0.540	5.747	1.16%	43.70%	Kyanite Mining
B		25.0	B2O3	0.02	0.04	0.0051	11.70	10.1437	10.139	H3BO3 (Technical Granular)	0.986	0.563	10.420			US Borax
Ba			BaO	0.00	0.00	0.0000		0.0000								
Ca		96	CaO	0.03	0.06	0.0085	7.40	6.4210	6.412	Wollanstonite NYAD 325 Mesh	0.993	0.475	7.756	0.40%	51.00%	NYCO Minerals
Cd		0.04	CdO	0.00	0.00	0.0000		0.0000								
Co		0.0	CoO	0.00	0.00	0.0000		0.0000								
Cr		86.1	Cr2O3	0.07	0.12	0.0159		0.0159								
Cu		9.9	CuO	0.00	0.01	0.0008		0.0008								
Fe		1.9	Fe2O3	0.00	0.00	0.0002	7.50	6.4993	6.499	Fe2O3 (Iron III oxide, -325 Mesh)	0.998	1.000	3.475			Alfa Aesar-Johnson Matthey
K	0.03	1260	K2O	0.40	0.72	0.096		0.0959								
La		0	La2O3	0.00	0.00	0.0000		0.0000								
Li		5	Li2O	0.00	0.00	0.0006	3.17	2.7476	2.747	Li2CO3 (Chemetall Foote Co. Tech.	0.99	0.404	3.918			Cyprus Foote Mineral Co.
Mg		0.14	MgO	0.00	0.00	0.0000	1.75	1.5165	1.516	Olivine (Mg2SiO4) 325 Mesh (#180)	0.990	0.480	1.821	7.68%	42.52%	UNIMIN Corp.
Mn		35	MnO2	0.01	0.03	0.0035		0.0035								
Mo		24.1	MoO3	0.01	0.02	0.0023		0.0023								
Na	6.02	138500	Na2O	48.69	88.42	11.80		11.8000								
Ni		142	NiO	0.05	0.09	0.0114		0.0114								
Pb		52.1	PbO	0.01	0.03	0.0035		0.0035								
Sn		0	SnO2	0.00	0.00	0.0000		0.0000								
Si		19	SiO2	0.01	0.02	0.0026	53.97	46.7661	46.763	SiO2 (Sil-co-Sil 75)	0.997	1.000	18.684			US SILICA
Sr		0	SrO	0.00	0.00	0.0000		0.0000								
Ti		0.01	TiO2	0.00	0.00	0.0000	1.30	1.1265	1.127	TiO2 (Rutile Airfloated)	0.954	1.000	0.674	0.71%	0.91%	Chemalloy
W		0	WO3	0.00	0.00	0.0000		0.0000								
Zn		0.9	ZnO	0.00	0.00	0.0001	3.50	3.0330	3.033	ZnO (Kadox-920)	0.997	1.000	1.736			Zinc Corp. of America
Zr		0.2	ZrO2	0.00	0.00	0.0000	3.50	3.0330	3.033	Zircon ZrSiO4 (Flour) Mesh 325	0.990	0.651	2.685		33.00%	American Mineral
Br		0	Br	0.00	0.00	0.0000		0.0000								
Cl		3315	Cl	0.86	1.57	0.2095		0.2095								
F		1008	F	0.26	0.48	0.0637		0.0637								
PO4		1515	P2O5	0.30	0.54	0.0716		0.0716		Total Sodium Moles			0.22		0.2173	moles Na @7.1M
SO4	0.06	5530	SO3	1.20	2.18	0.2913		0.2913		Expected Glass yield			57.050	g		
NO2	0.79	36550	NO2	9.53						Sum of Additives (g)			56.915	g		
NO3	1.44	89000	NO3	23.21						Sugar as added reductant (decreased for TOC)			0.976	g		
OH			OH	0.00												
CO3	0.67	40115	CO3	10.46												
oxalate		1170	C	0.31												
formate		5445	C	1.42												
SUM			SUM	100.00	100.00	13.34	100.00	100.00	86.655							
NO2+NO3	2.23	M	VSL uses 12 moles Carbon (1 mole sucrose/342.3g) per 16 Moles NOx in order to mitigate foaming.													
TOC		8682.0	mg/L		This feed requires			47.71	g/L or	7.919 g. of sucrose per Mole Na						
								3.4374								
This sample already includes			0.026 moles C, and sucrose has be lowered by							-0.74 g sucrose						

The additives for the 6M surrogate supernate were scaled for altered supernate volume and molarity from the above in the proportions (0.2526/0.2173).

The additives for the 5M surrogate supernate were scaled for altered supernate volume and molarity from the above in the proportions (0.1686 /0.2173).

6.16. Additional Rheological Data

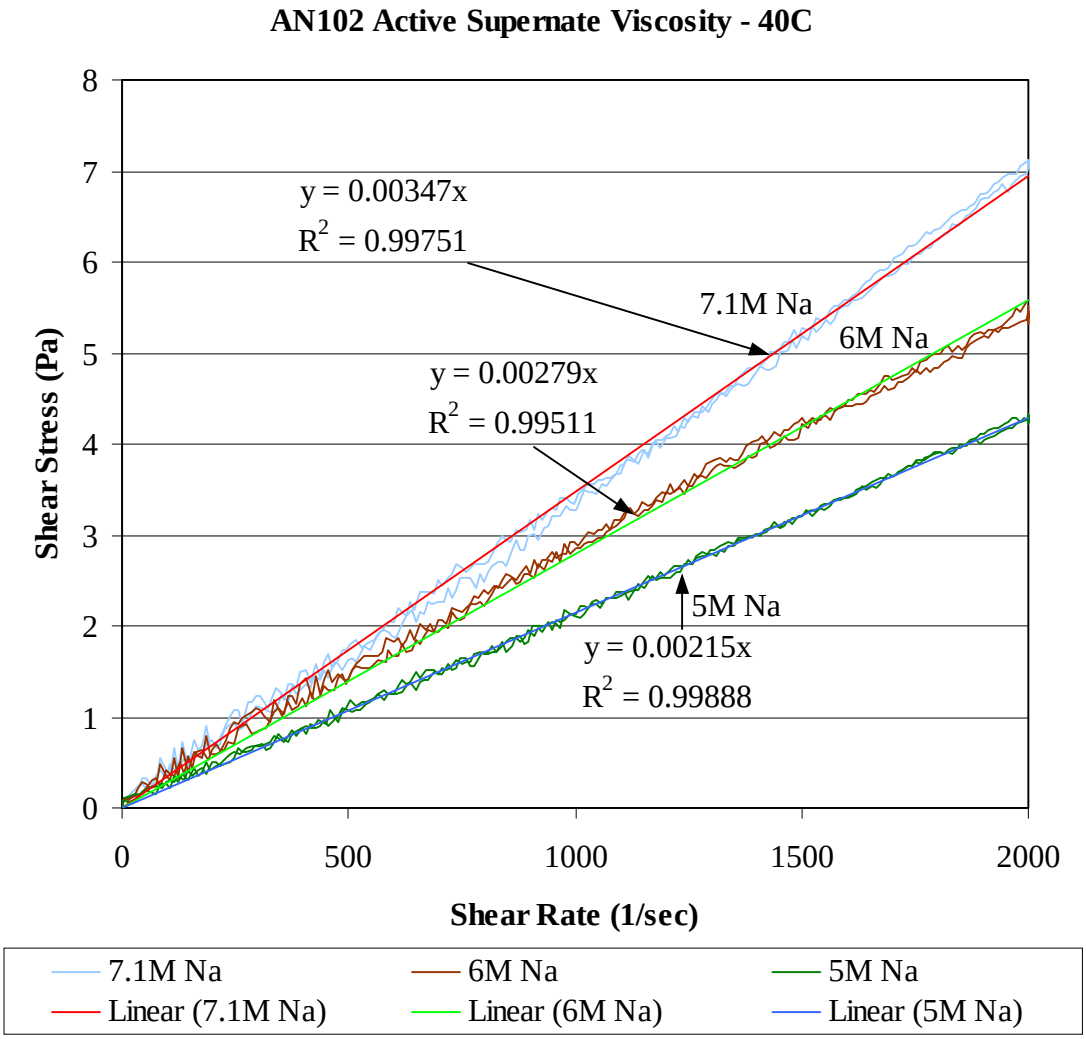


Figure 6.6 Radioactive Supernate Viscosities at 40°C

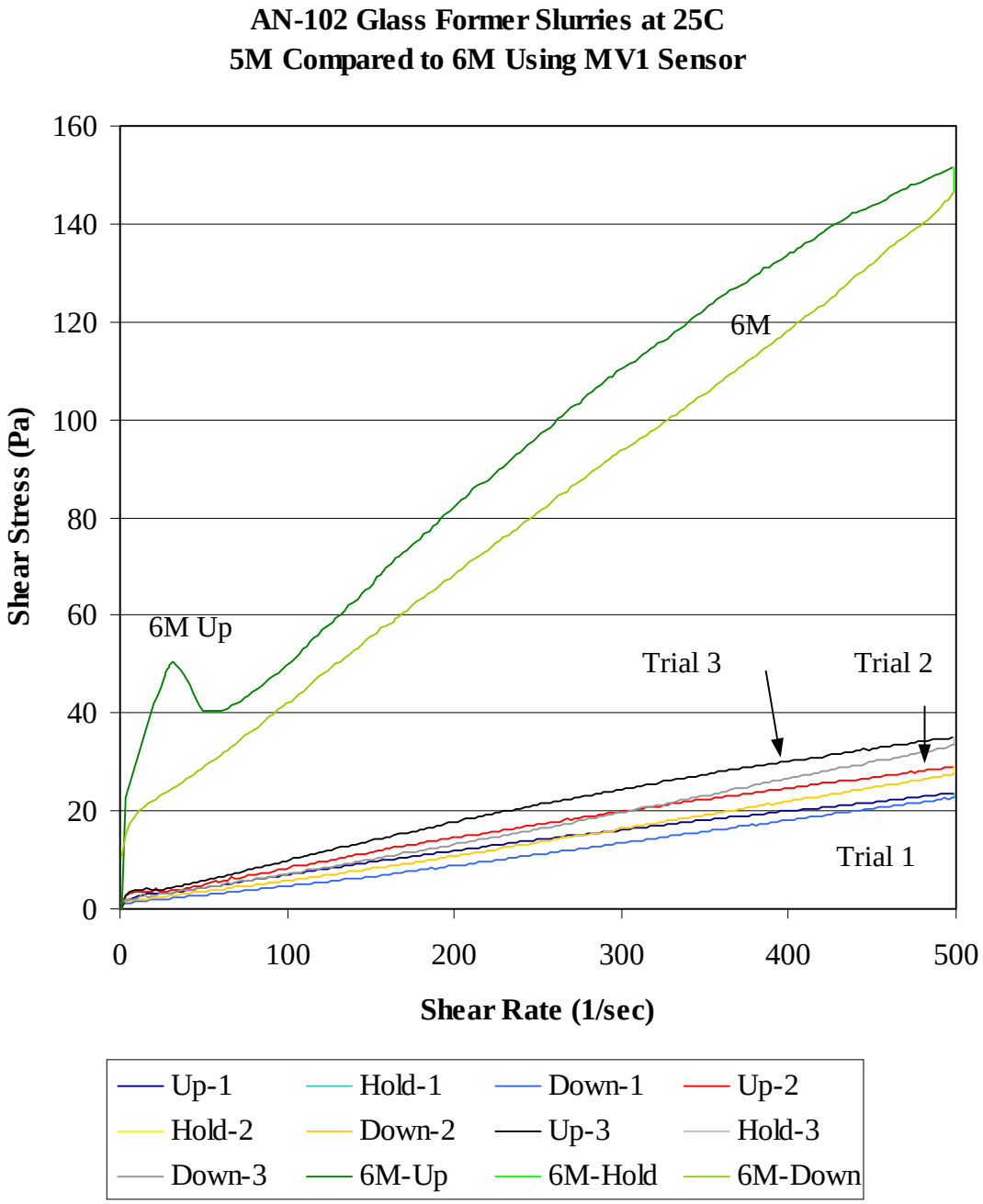


Figure 6.7 Repeated 5M Radioactive Trials with 6M for Comparison

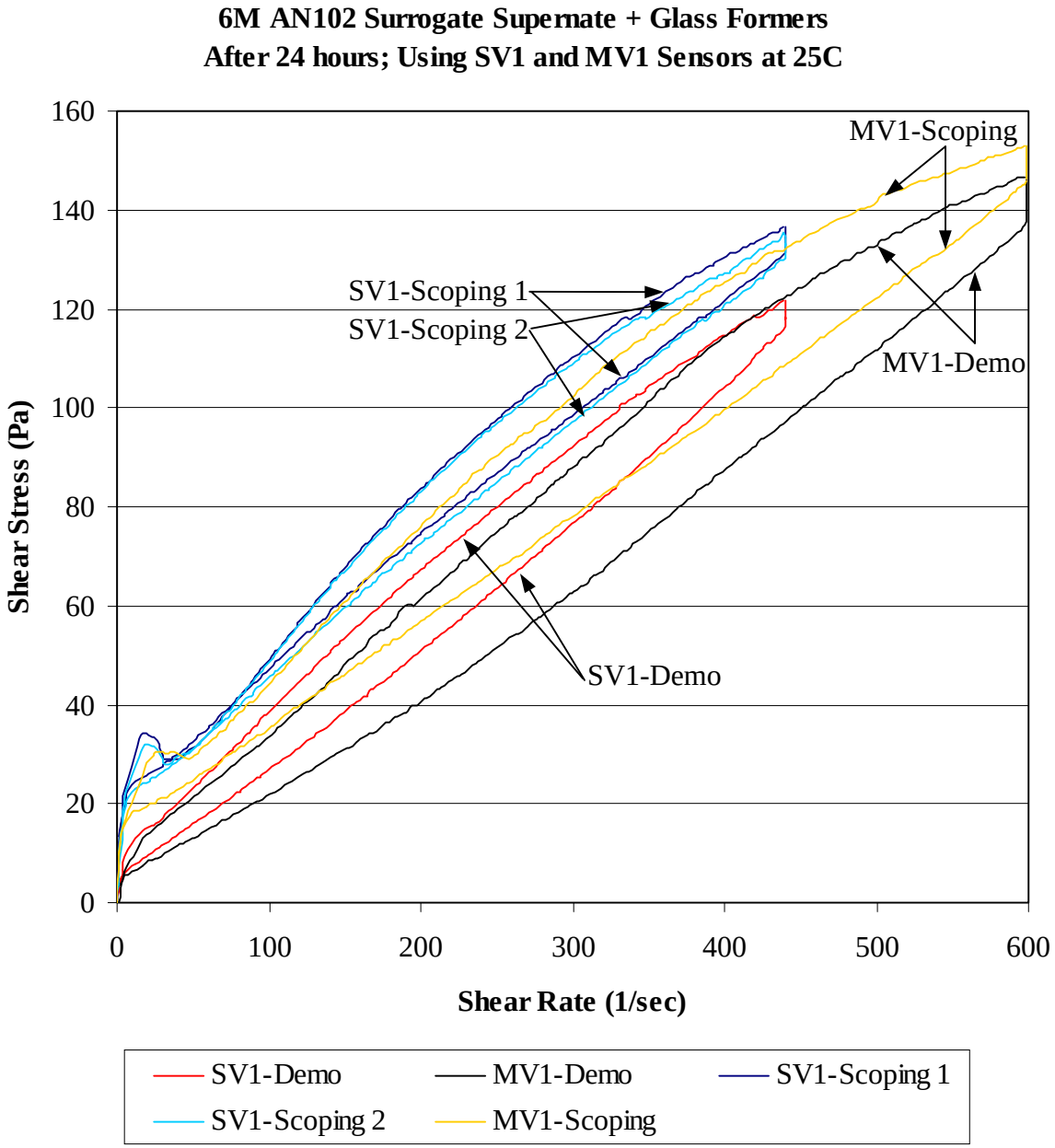


Figure 6.8 Composite of All 6M Surrogate Slurry Rheograms

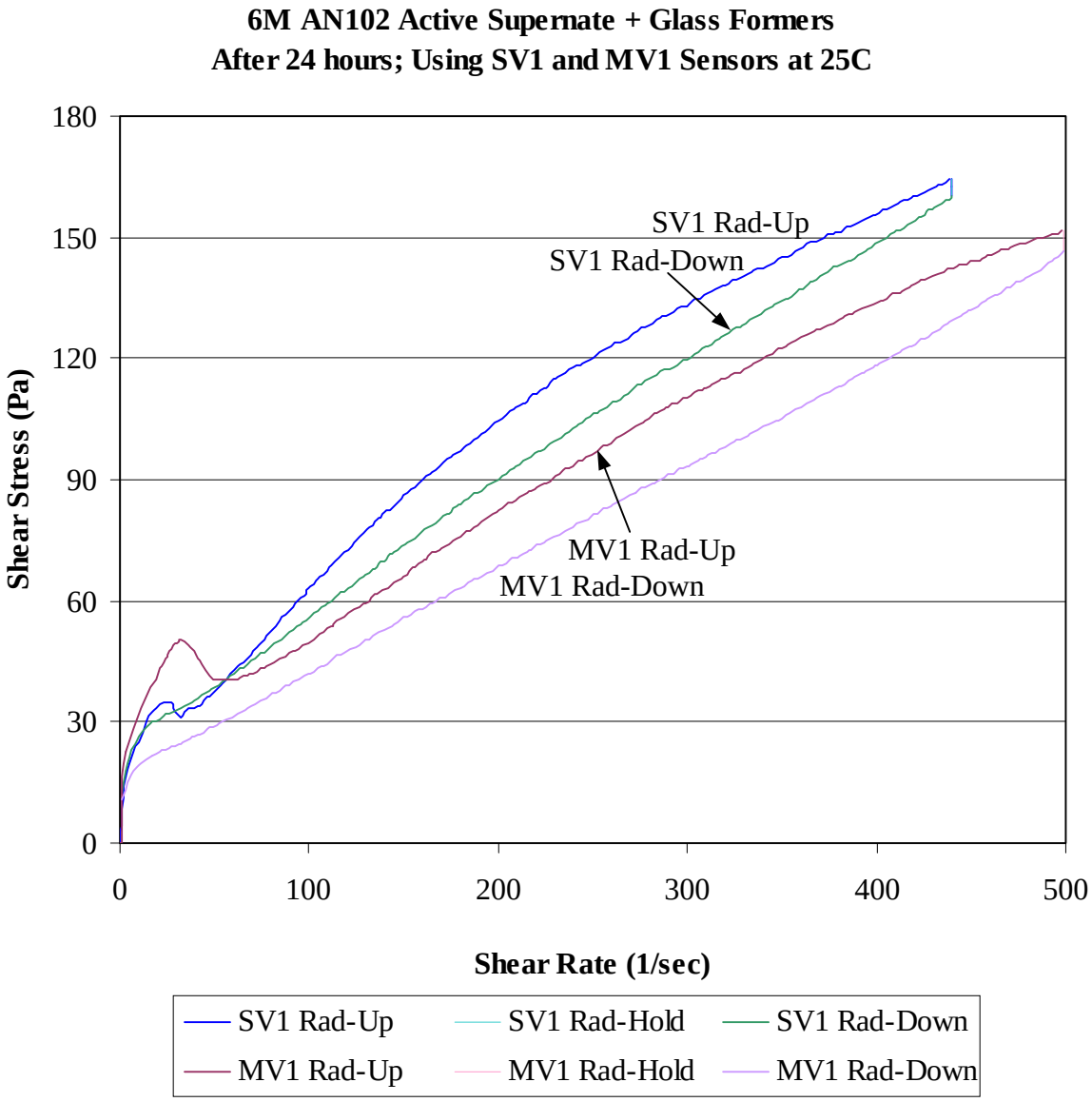


Figure 6.9 Radioactive 6M Melter Feed Comparison of SV1 to MV1 Rheograms

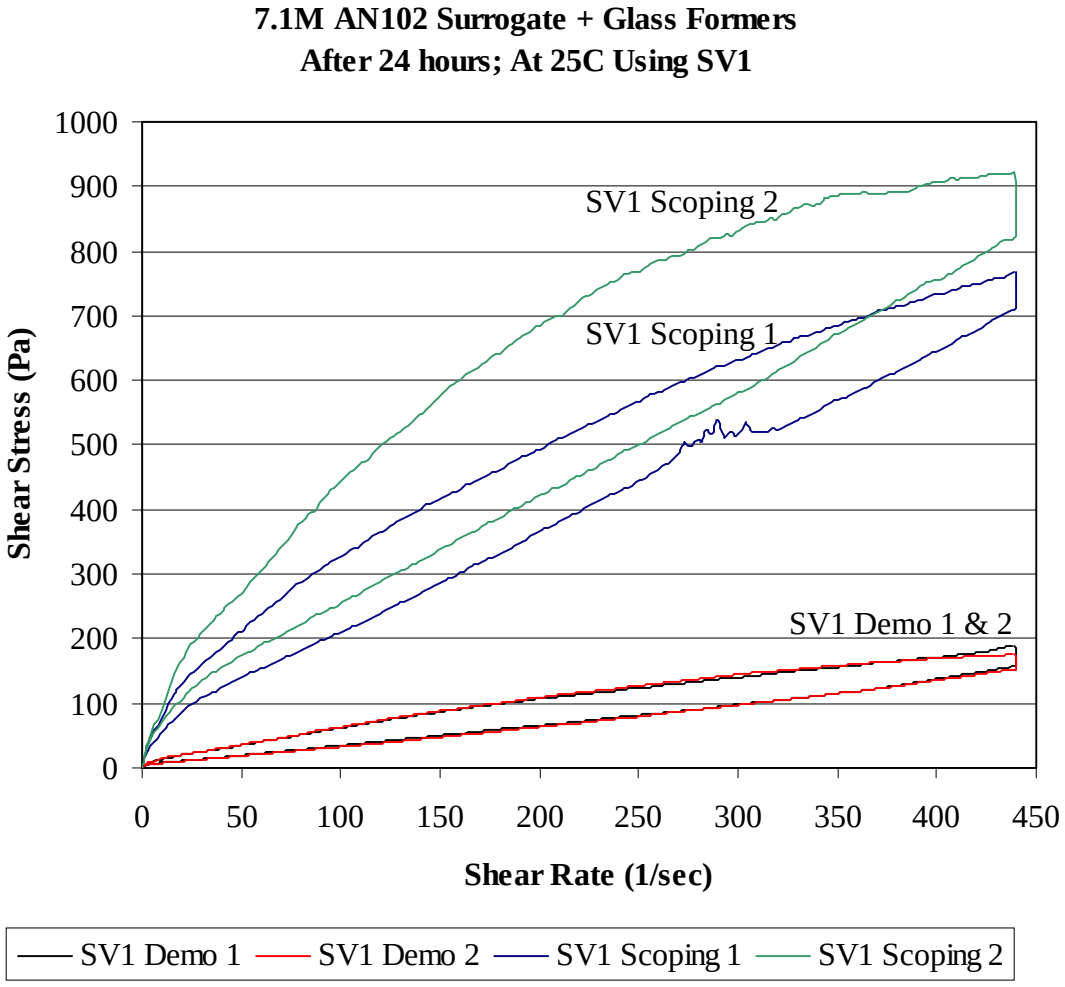


Figure 6.10 Composite of all 7.1M Surrogate Melter Feed Rheograms

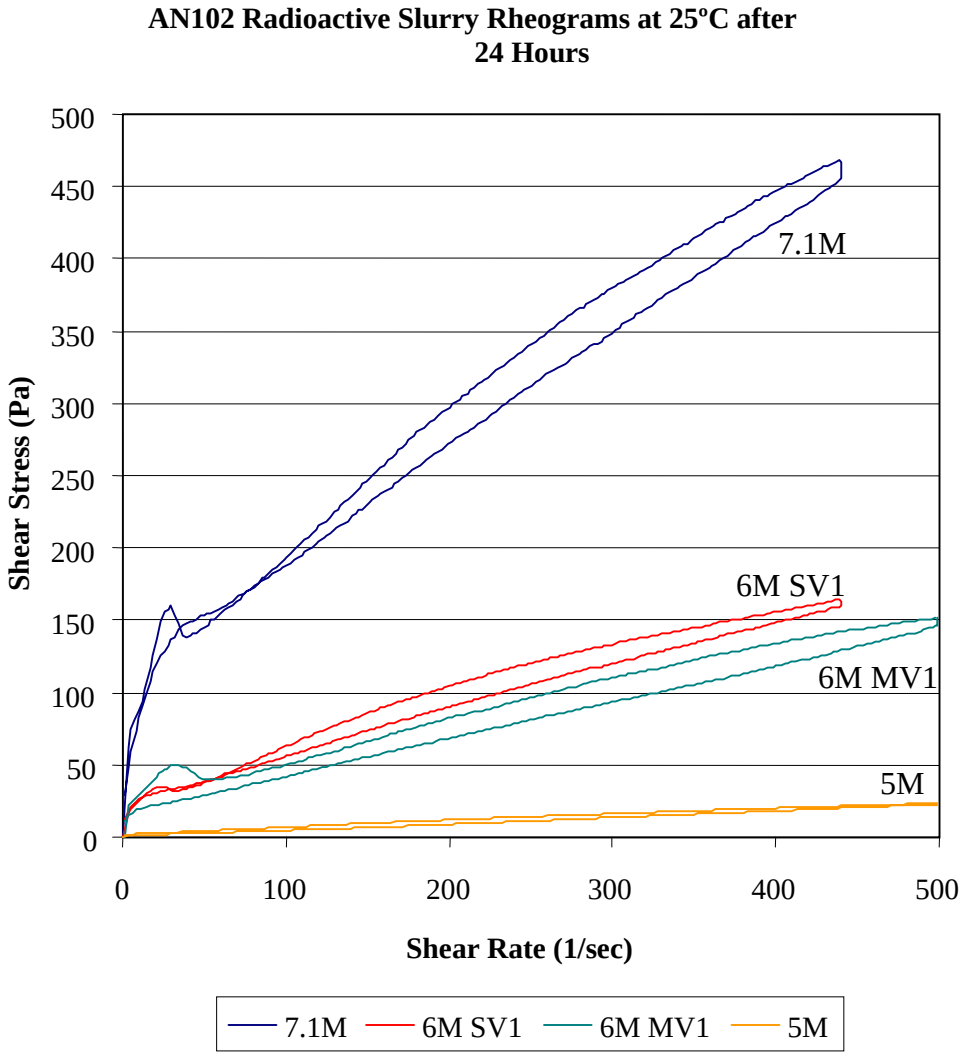


Figure 6.11 Primary Raw Rheological Data for AN102 Radioactive Melter Feeds

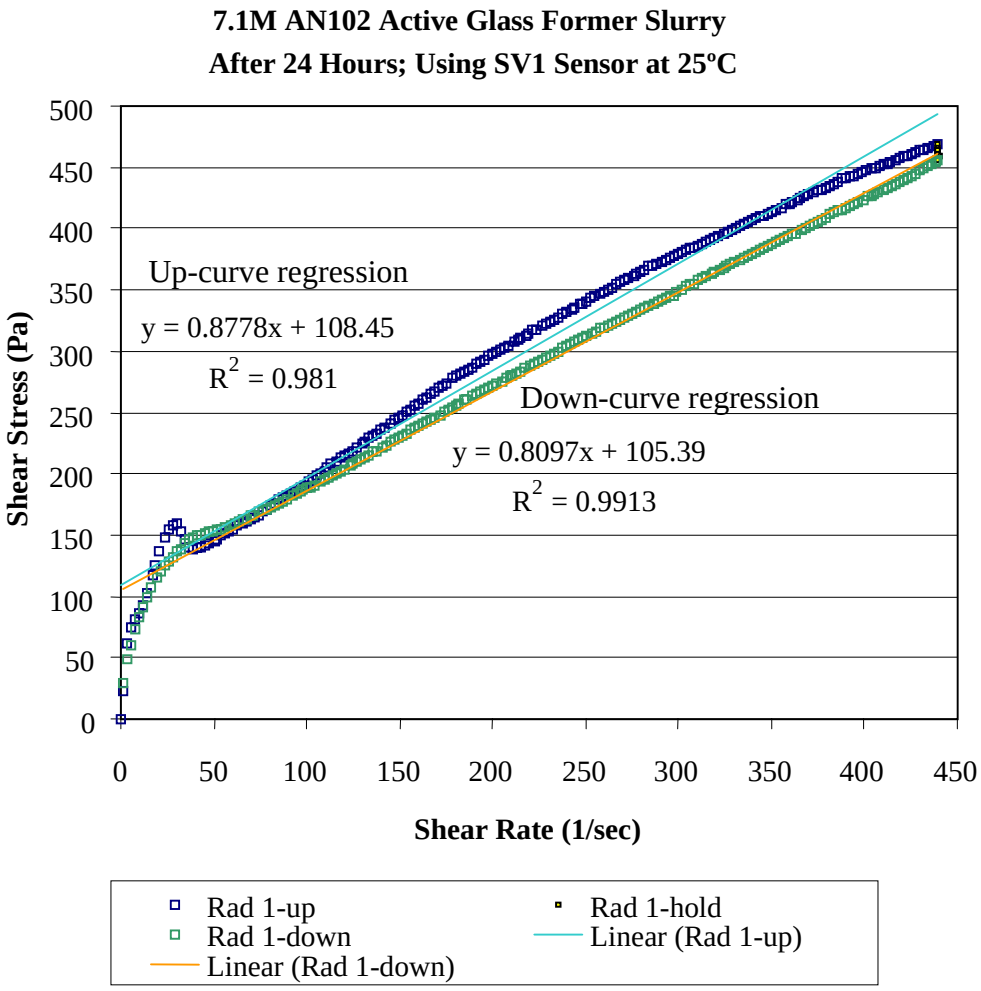


Figure 6.12 Example of Bingham Plastic Fluid Model Regression

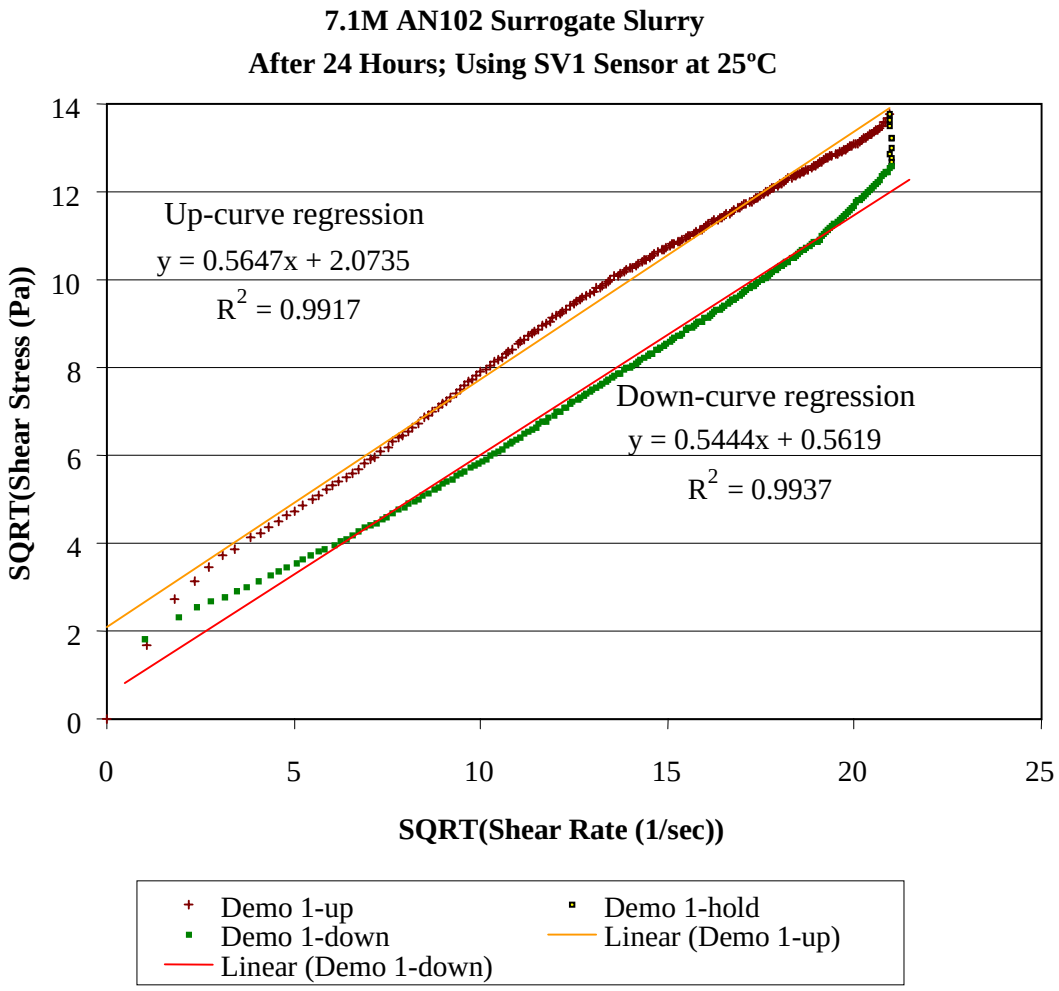


Figure 6.13 Example of Casson Fluid Model Regression

6.17. VOA and SVOA Analyses

VOA Analytes Measured in VOA Analyses	
Acetone	Benzene
Bromodichloromethane	Bromoform
Bromomethane	2-Butanone [Methyl Ethyl Ketone]
Carbon Disulfide	Carbon Tetrachloride
Chlorobenzene	Chloroethane
Chloroform	Chloromethane
1,1-Dichloroethane	1,2-Dichloroethane
1,1-Dichloroethene	cis-1,2-Dichloroethene
trans-1,2-Dichloroethene	1,2-Dichloropropane
cis-1,3-Dichloropropene	trans-1,3-Dichloropropene
Dibromochloromethane	Ethyl benzene
2-Hexanone	4-Methyl-2-Pentanone
Methylene Chloride	o-Xylene
p+m-xylenes	Styrene
Tetrachloroethene	1,1,2,2-Tetrachloroethane
1,1,1-Trichloroethane	Toluene
1,1,2-Trichloroethane	Trichloroethene
Vinyl Acetate	Vinyl Chloride

SVOA Analytes Measured in SVOA Analytses		
Acenaphthene	4-Chlorophenylphenylether	Hexachlorobenzene
Anthracene	Chrysene	Hexachlorobutadiene
Azobenzene	Di-n-butylphthalate	Hexachlorocyclopentadiene
Benz[a]anthracene	Di-n-octylphthalate	Hexachloroethane
Benzidine	Dibenzo[a,h]anthracene	Indeno[1,2,3-cd]pyrene
Benzo[a]pyrene	3,3'-Dichlorobenzidine	Isophorone
Benzo[b]fluoranthene	1,2-Dichlorobenzene	2-Nitrophenol
Benzo[ghi]perylene	1,3-Dichlorobenzene	4-Nitrophenol
Benzo[k]fluoranthene	1,4-Dichlorobenzene	N-Nitrosodi-n-propylamine
Bis(2-Chloroethyl)ether	2,4-Dichlorophenol	N-Nitrosodimethylamine
Bis(2-Chloroisopropyl)ether	Diethylphthalate	N-Nitrosodiphenylamine
Bis(2chloroethoxy)methane	2,4-Dimethylphenol	Naphthalene
Bis(2-ethylhexyl)phthalate	Dimethylphthalate	Nitrobenzene
4-Bromophenylphenylether	4,6-Dinitro-2-methylphenol	1,1'-Oxybis(3-Chloro)propane
Butylbenzylphthalate	2,4-Dinitrophenol	PentachlorophenolPhenanthrene
Carbazole	2,4-Dinitrotoluene	Phenol
4-Chloro-3-methylphenol	2,6-Dinitrotoluene	Pyrene1,2,4-Trichlorobenzene
2-Chloronaphthalene	Fluoranthene	2,4,6-Trichlorophenol
2-Chlorophenol	Fluorene	

6.18. PCT Spreadsheets

AN-102 Radioactive Glass

PROCEDURE ASTM-1285-97															
DATA AND RESULTS FOR 7 DAY PCT TEST				**TEST NAME**		**90C PCT WITH RPP ENVELOPE LAW LC GLASS**									
				GLASS. RPP LC RADIOACTIVE LAW GLASS											
PCT A, SA/V = 2000M-1									**LEACHATE DILUTION FACTORS:**						
SPREADSHEET REDUCED 70% FOR PRINT OUT									BLANKS: 5 ML SPL AND 0.05ML CONC HNO3					DF =10.1/10 = 1.01	
									RPP, ARM, LRM GLASSES, STDS 1, 2, 4, & 5:						
			DATE IN OVEN		4/19/01	**TIME IN OVEN**		1017		3ML SPL/0.05 ML CONC HNO3, 2 ML ASTM H2O				DF=5.05/3=1.683	
			DATE OUT OF OVEN		4/26/01	**TIME OUT OF OVEN**		1017	STDS. 3 & 6:	6ML STANDARD - Not Diluted					
						INITIAL pH = 6.88									
RAW EXPERIMENTAL DATA:					**INITIAL**	**FINAL**				**SRTC**					
SAMPLE		**WEIGHTS**		**WEIGHT**	**WEIGHT**	**WEIGHT**	**INIT.**	**WATER**	**FINAL**	**ADS**	**RESULTS (ppm) FOR ACIDIFIED LEACHATES.**				
NAME	**EMPTY**	**W/GLASS**	**GLASS**	**W/H2O**	**IN PCT**	**IN PCT**	**VOL.(ML)**	**LOSS**	**pH**	**NUMBER**	**B**	**Si**	**Na**	**Li**	**Al**
B77 Blank 1	120.920	N.A.	N.A.	135.958	339.250	339.261	15.038	-0.011	6.40	162497	0.014	0.047	0.336	0.024	0.088
B86 Blank 2	121.994	N.A.	N.A.	137.022	339.500	339.497	15.028	0.003	6.14	162503	0.012	0.0400	0.210	0.010	0.015
B220 Blank 3	121.248	N.A.	N.A.	136.290	340.133	340.115	15.042	0.018	6.98	162509	0.012	0.0180	0.121	0.002	0.001
BLANK AVERAGE									6.51		0.0127	0.0350	0.2223	0.0120	0.0347
SAMPLES															
P455 LCRAD-1	NA	NA	1.513	NA	338.463	338.468	15.445	-0.005	9.90	162500	7.927	31.245	22.298	4.108	1.104
443 LCRAD-2	NA	NA	1.540	NA	342.100	342.100	15.668	0.000	9.88	162506	7.235	29.444	20.617	3.821	1.373
445 LCRAD-3	NA	NA	1.531	NA	343.095	343.092	15.559	0.003	9.91	162512	7.266	29.258	20.784	3.852	1.277
446 LCRAD-4	NA	NA	1.591	NA	342.316	342.310	16.098	0.006	9.90	162516	7.397	30.163	21.137	3.894	1.325
CALCULATED RESULTS: **pH VALUES AND FILTERED LEACHATE CONCENTRATIONS CORRECTED FOR BLANKS**															
SAMPLE				**GLASS**	**INIT.**	**FINAL**	**%**	**pH VALUES**				**CONCENTRATIONS (PPM)**			
NAME				**WEIGHT**	**VOL.(ML)**	**VOL.(ML)**	**LOSS**	**INITIAL**	**FINAL**		**B**	**Si**	**Na**	**Li**	**Al**
P455 LCRAD-1				1.513	15.445	15.450	-0.03	6.88	9.90		13.34	52.59	37.53	6.91	1.86
443 LCRAD-2				1.540	15.668	15.668	0.00	6.88	9.88		12.18	49.55	34.70	6.43	2.31
445 LCRAD-3				1.531	15.559	15.556	0.02	6.88	9.91		12.23	49.24	34.98	6.48	2.15
446 LCRAD-4				1.591	16.098	16.092	0.04	6.88	9.90		12.45	50.76	35.57	6.55	2.23
AVERAGE											**12.55**	**50.54**	**35.69**	**6.60**	**2.14**
STANDARD DEVIATION											**0.54**	**1.52**	**1.28**	**0.22**	**0.20**
REL. STD. DEVIATION (%)											**4.31**	**3.00**	**3.57**	**3.31**	**9.23**
	NORMALIZED CALCULATIONS:				ELEMENTAL WEIGHT PERCENT IN LC RAD GLASS						**3.00**	**22.71**	**6.80**	**1.21**	**2.76**
					NORMALIZED MASS LOSS (GRAMS GLASS/LITER)						**0.418**	**0.223**	**0.525**	**0.545**	**0.077**
					NORMALIZED MASS LOSS (GRAMS GLASS/METER2)						**0.209**	**0.111**	**0.262**	**0.273**	**0.039**
					NORMALIZED MASS LOSS STANDARD DEVIATION						**0.009**	**0.003**	**0.009**	**0.009**	**0.004**
					NORMALIZED MASS LOSS PLUS 2 SIGMA						**0.227**	**0.118**	**0.281**	**0.291**	**0.046**
											B	**Si**	**Na**	**Li**	**Al**
QUALITY ASSURANCE INFORMATION:										**LIMS NO.**	**ICP RESULTS (PPM)**				
							STANDARD RESULTS:		S-1	162482	11.466	30.407	48.017	5.721	2.287
LABS= B-111						EXPIRATION DATE		2/28/02	S-2	162502	11.828	30.468	48.221	5.731	2.285
PH METER ACCUMET AB 15			BUFFERED TO PH 7AND 10.			LOT NO.	102202		S-3	162508	19.706	51.039	81.301	9.624	3.811
BALANCE SER.#=GT1478									S-4	162514	11.721	30.264	48.086	5.706	2.273
OVEN SER.B-111									S-5	162517	11.595	29.929	47.976	5.696	2.244
TEMPERATURE READOUT: GT-1248 FLUKE RTD									S-6	162518	19.582	50.822	81.278	9.619	3.800
FILTER SIZE: .45 MICRON															
										RESULTS CORRECTED FOR DILUTION FACTOR OF 1.68					
									S-1	162482	19.30	51.17	80.81	9.63	3.85
RESEARCHER: NED BIBLER									S-2	162502	19.91	51.28	81.16	9.65	3.85
									S-3	162508	19.71	51.04	81.30	9.62	3.81
									S-4	162514	19.73	50.93	80.93	9.60	3.83
									S-5	162517	19.51	50.37	80.74	9.59	3.78
									S-6	162518	19.58	50.82	81.28	9.62	3.80
						STANDARD COMPOSITION (PPM)					20.0+/-0.1	50.0+/-0.3	80.0+/-0.4	10.00+/-0.05	4.00+/-0.02

6.18 PCT Spreadsheets, **Continued**

Surrogate #2 Glass

PROCEDURE ASTM-1285-97															
DATA AND RESULTS FOR 7 DAY PCT TEST				**TEST NAME**		**90C PCT WITH RPP ENVELOPE LAW LC GLASS**									
				GLASS. RPP LC SURROGATE (BLANK) GLASS											
PCT A, SA/V = 2000M-1									**LEACHATE DILUTION FACTORS:**						
SPREADSHEET REDUCED 70% FOR PRINT OUT									BLANKS: 5 ML SPL AND 0.05ML CONC HNO3					DF =10.1/10 = 1.01	
									RPP, ARM, LRM GLASSES, STDS 1, 2, 4, & 5:						
			DATE IN OVEN		4/19/01	**TIME IN OVEN**		1017	3ML SPL/0.05 ML CONC HNO3, 2 ML ASTM H2O					DF=5.05/3=1.683	
			DATE OUT OF OVEN		4/26/01	**TIME OUT OF OVEN**		1017	STDS. 3 & 6: 6ML STANDARD - Not Diluted						
						INITIAL pH = 6.88									
RAW EXPERIMENTAL DATA:					**INITIAL**	**FINAL**				**SRTC**					
SAMPLE		**WEIGHTS**		**WEIGHT**	**WEIGHT**	**WEIGHT**	**INIT.**	**WATER**	**FINAL**	**ADS**	**RESULTS (ppm) FOR ACIDIFIED LEACHATES.**				
NAME	**EMPTY**	**W/GLASS**	**GLASS**	**W/H2O**	**IN PCT**	**IN PCT**	**VOL.(ML)**	**LOSS**	**pH**	**NUMBER**	**B**	**Si**	**Na**	**Li**	**Al**
B77 Blank 1	120.920	N.A.	N.A.	135.958	339.250	339.261	15.038	-0.011	6.40	162497	0.014	0.047	0.336	0.024	0.088
B86 Blank 2	121.994	N.A.	N.A.	137.022	339.500	339.497	15.028	0.003	6.14	162503	0.012	0.0400	0.210	0.010	0.015
B220 Blank 3	121.248	N.A.	N.A.	136.290	340.133	340.115	15.042	0.018	6.98	162509	0.012	0.0180	0.121	0.002	0.001
BLANK AVERAGE									6.51		0.0127	0.0350	0.2223	0.0120	0.0347
SAMPLES															
447-LCBLK-1	NA	NA	1.554	NA	342.694	342.697	15.718	-0.003	10.04	162498	8.040	31.144	25.873	3.569	2.165
471-LCBLK-2	NA	NA	1.573	NA	341.495	341.493	15.847	0.002	10.01	162504	7.954	31.098	26.380	3.611	2.150
477-LCBLK-3	NA	NA	1.602	NA	338.905	338.906	16.108	-0.001	9.97	162510	7.857	30.415	25.588	3.530	2.008
503-LCBLK-4	NA	NA	1.574	NA	340.383	340.385	15.872	-0.002	9.98	162515	7.889	30.793	25.936	3.582	2.103
CALCULATED RESULTS: pH VALUES AND FILTERED LEACHATE CONCENTRATIONS CORRECTED FOR BLANKS															
SAMPLE				**GLASS**	**INIT.**	**FINAL**	**%**	**pH VALUES**			**CONCENTRATIONS (PPM)**				
NAME				**WEIGHT**	**VOL.(ML)**	**VOL.(ML)**	**LOSS**	**INITIAL**	**FINAL**		**B**	**Si**	**Na**	**Li**	**Al**
447-LCBLK-1				1.554	15.718	15.721	-0.02	6.88	10.04		13.53	52.42	43.54	6.01	3.64
471-LCBLK-2				1.573	15.847	15.845	0.01	6.88	10.01		13.39	52.34	44.40	6.08	3.62
477-LCBLK-3				1.602	16.108	16.109	-0.01	6.88	9.97		13.22	51.19	43.06	5.94	3.38
503-LCBLK-4				1.574	15.872	15.874	-0.01	6.88	9.98		13.28	51.82	43.65	6.03	3.54
AVERAGE											**13.35**	**51.94**	**43.66**	**6.01**	**3.55**
STANDARD DEVIATION											**0.14**	**0.57**	**0.55**	**0.06**	**0.12**
REL. STD. DEVIATION (%)											**1.02**	**1.09**	**1.26**	**0.94**	**3.36**
	NORMALIZED CALCULATIONS:				ELEMENTAL WEIGHT PERCENT IN GLASS						**3.04**	**22.6**	**8.35**	**1.13**	**3.30**
					NORMALIZED MASS LOSS (GRAMS GLASS/LITER)						**0.439**	**0.230**	**0.523**	**0.532**	**0.107**
					NORMALIZED MASS LOSS (GRAMS GLASS/METER2)						**0.220**	**0.115**	**0.261**	**0.266**	**0.054**
					NORMALIZED MASS LOSS STANDARD DEVIATION						**0.002**	**0.001**	**0.003**	**0.003**	**0.002**
					NORMALIZED MASS LOSS PLUS 2 SIGMA						**0.224**	**0.117**	**0.268**	**0.271**	**0.057**
QUALITY ASSURANCE INFORMATION:											**B**	**Si**	**Na**	**Li**	**Al**
										LIMS NO.	**ICP RESULTS (PPM)**				
LABS= B-111							**STANDARD RESULTS:**		S-1	162482	11.466	30.407	48.017	5.721	2.287
PH METER ACCUMET AB 15			BUFFERED TO PH 7AND 10.			EXPIRATION DATE		2/28/02	S-2	162502	11.828	30.468	48.221	5.731	2.285
BALANCE SER.#=GT1478						LOT NO.	102202		S-3	162508	19.706	51.039	81.301	9.624	3.811
OVEN SER.B-111									S-4	162514	11.721	30.264	48.086	5.706	2.273
TEMPERATURE READOUT: GT-1248 FLUKE RTD									S-5	162517	11.595	29.929	47.976	5.696	2.244
FILTER SIZE: .45 MICRON									S-6	162518	19.582	50.822	81.278	9.619	3.800
											RESULTS CORRECTED FOR DILUTION FACTOR OF 1.68				
RESEARCHER: NED BIBLER									S-1	162482	19.30	51.17	80.81	9.63	3.85
									S-2	162502	19.91	51.28	81.16	9.65	3.85
									S-3	162508	19.71	51.04	81.30	9.62	3.81
									S-4	162514	19.73	50.93	80.93	9.60	3.83
									S-5	162517	19.51	50.37	80.74	9.59	3.78
									S-6	162518	19.58	50.82	81.28	9.62	3.80
						STANDARD COMPOSITION (PPM)					20.0+/-0.1	50.0+/-0.3	80.0+/-0.4	10.00+/-0.05	4.00+/-0.02

6.18 PCT Spreadsheets**, Continued**

LRM Glass

PROCEDURE ASTM-1285-97															
DATA AND RESULTS FOR 7 DAY PCT TEST				**TEST NAME**		**90C PCT WITH RPP ENVELOPE LAW LC GLASS**									
				GLASS. LRM STANDARD GLASS											
PCT A, SA/V = 2000M-1									**LEACHATE DILUTION FACTORS:**						
SPREADSHEET REDUCED 70% FOR PRINT OUT									BLANKS: 5 ML SPL AND 0.05ML CONC HNO3					DF =10.1/10 = 1.01	
									RPP, ARM, LRM GLASSES, STDS 1, 2, 4, & 5:						
			DATE IN OVEN		4/19/01	**TIME IN OVEN**		1017		3ML SPL/0.05 ML CONC HNO3, 2 ML ASTM H2O				DF=5.05/3=1.683	
			DATE OUT OF OVEN		4/26/01	**TIME OUT OF OVEN**		1017	STDS. 3 & 6:	6ML STANDARD - Not Diluted					
						INITIAL pH = 6.88									
RAW EXPERIMENTAL DATA:					**INITIAL**	**FINAL**				**SRTC**					
SAMPLE		**WEIGHTS**		**WEIGHT**	**WEIGHT**	**WEIGHT**	**INIT.**	**WATER**	**FINAL**	**ADS**	**RESULTS (ppm) FOR ACIDIFIED LEACHATES.**				
NAME	**EMPTY**	**W/GLASS**	**GLASS**	**W/H2O**	**IN PCT**	**IN PCT**	**VOL.(ML)**	**LOSS**	**pH**	**NUMBER**	**B**	**Si**	**Na**	**Li**	**Al**
B77 Blank 1	120.920	N.A.	N.A.	135.958	339.250	339.261	15.038	-0.011	6.40	162497	0.014	0.047	0.336	0.024	0.088
B86 Blank 2	121.994	N.A.	N.A.	137.022	339.500	339.497	15.028	0.003	6.14	162503	0.012	0.0400	0.210	0.010	0.015
B220 Blank 3	121.248	N.A.	N.A.	136.290	340.133	340.115	15.042	0.018	6.98	162509	0.012	0.0180	0.121	0.002	0.001
BLANK AVERAGE									6.51		0.0127	0.0350	0.2223	0.0120	0.0347
SAMPLES															
508 LRM-1	122.087	123.619	1.532	138.933	339.176	339.173	15.314	0.003	10.82	162501	17.818	51.241	103.390	0.077	8.823
526 LRM-2	122.226	123.735	1.509	138.818	341.304	341.296	15.083	0.008	10.86	162507	17.916	51.521	105.493	0.077	8.968
541 LRM-3	121.700	123.239	1.539	138.626	339.795	339.785	15.387	0.010	10.07	162513	18.863	52.518	109.960	0.081	9.111
CALCULATED RESULTS:	**pH VALUES AND FILTERED LEACHATE CONCENTRATIONS CORRECTED FOR BLANKS**														
SAMPLE				**GLASS**	**INIT.**	**FINAL**	**%**	**pH VALUES**					**CONCENTRATIONS (PPM)**		
NAME				**WEIGHT**	**VOL.(ML)**	**VOL.(ML)**	**LOSS**	**INITIAL**	**FINAL**		**B**	**Si**	**Na**	**Li**	**Al**
508 LRM-1				1.532	15.314	15.311	0.02	6.88	10.82	162501	29.99	86.24	174.01	0.13	14.85
526 LRM-2				1.509	15.083	15.075	0.05	6.88	10.86	162507	30.15	86.71	177.54	0.13	15.09
541 LRM-3				1.539	15.387	15.377	0.06	6.88	10.07	162513	31.75	88.39	185.06	0.14	15.33
AVERAGE								**AVERAGE**			**30.63**	**87.11**	**178.87**	**0.13**	**15.09**
STANDARD DEVIATION								**STANDARD DEVIATION**			**0.97**	**1.13**	**5.65**	**0.00**	**0.24**
REL. STD. DEVIATION (%)								**REL. STD. DEVIATION (%)**			**3.17**	**1.30**	**3.16**	**2.95**	**1.61**
	NORMALIZED CALCULATIONS:				**ELEMENTAL WEIGHT PERCENT IN GLASS**						**2.34**	**22.62**	**15.5**	**0.05**	**5.10**
					NORMALIZED MASS LOSS (GRAMS GLASS/LITER)						**1.31**	**0.39**	**1.15**	**0.26**	
					NORMALIZED MASS LOSS (GRAMS GLASS/METER2)						**0.654**	**0.193**	**0.577**	**0.132**	
					NORMALIZED MASS LOSS STANDARD DEVIATION						**0.021**	**0.002**	**0.018**	**0.004**	
					NORMALIZED MASS LOSS PLUS 2 SIGMA						**0.042**	**0.005**	**0.036**	**0.008**	
											B	**Si**	**Na**	**Li**	**Al**
QUALITY ASSURANCE INFORMATION:							**STANDARD RESULTS:**		S-1	**LIMS NO.**	**ICP RESULTS (PPM)**				
LABS= B-111						EXPIRATION DATE		2/28/02	S-2	162482	11.466	30.407	48.017	5.721	2.287
PH METER ACCUMET AB 15			BUFFERED TO PH 7AND 10.			LOT NO.	102202		S-3	162502	11.828	30.468	48.221	5.731	2.285
BALANCE SER.#=GT1478									S-4	162508	19.706	51.039	81.301	9.624	3.811
OVEN SER.B-111									S-5	162514	11.721	30.264	48.086	5.706	2.273
TEMPERATURE READOUT: GT-1248 FLUKE RTD									S-6	162517	11.595	29.929	47.976	5.696	2.244
FILTER SIZE: .45 MICRON										162518	19.582	50.822	81.278	9.619	3.800
										RESULTS CORRECTED FOR DILUTION FACTOR OF 1.68					
									S-1	162482	19.30	51.17	80.81	9.63	3.85
RESEARCHER: NED BIBLER									S-2	162502	19.91	51.28	81.16	9.65	3.85
									S-3	162508	19.71	51.04	81.30	9.62	3.81
									S-4	162514	19.73	50.93	80.93	9.60	3.83
									S-5	162517	19.51	50.37	80.74	9.59	3.78
									S-6	162518	19.58	50.82	81.28	9.62	3.80
						STANDARD COMPOSITION (PPM)					20.0+/-0.1	50.0+/-0.3	80.0+/-0.4	10.00+/-0.05	4.00+/-0.02

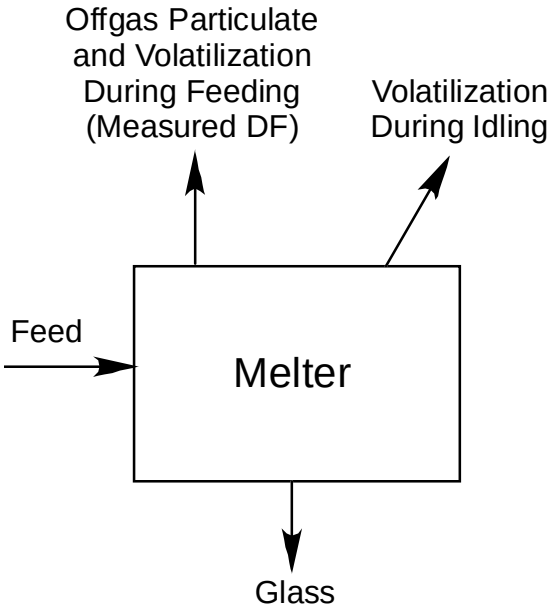
6.18 PCT Spreadsheets**, Continued**

ARM Glass

PROCEDURE ASTM-1285-97															
DATA AND RESULTS FOR 7 DAY PCT TEST			**TEST NAME**		**90C PCT WITH RPP ENVELOPE LAW LC GLASS**										
			GLASS. ARM STANDARD GLASS												
PCT A, SA/V = 2000M-1										**LEACHATE DILUTION FACTORS:**					
SPREADSHEET REDUCED 70% FOR PRINT OUT									BLANKS: 5 ML SPL AND 0.05ML CONC HNO3					DF =10.1/10 = 1.01	
									RPP, ARM, LRM GLASSES, STDS 1, 2, 4, & 5:						
			DATE IN OVEN	4/19/01	**TIME IN OVEN**		1017		3ML SPL/0.05 ML CONC HNO3, 2 ML ASTM H2O					DF=5.05/3=1.683	
			DATE OUT OF OVEN	4/26/01	**TIME OUT OF OVEN**		1017		STDS. 3 & 6: 6ML STANDARD - Not Diluted						
					INITIAL pH = 6.88										
RAW EXPERIMENTAL DATA:				**INITIAL**	**FINAL**					**SRTC**					
SAMPLE		**WEIGHTS**		**WEIGHT**	**WEIGHT**	**WEIGHT**	**INIT.**	**WATER**	**FINAL**	**ADS**	**RESULTS (ppm) FOR ACIDIFIED LEACHATES.**				
NAME	**EMPTY**	**W/GLASS**	**GLASS**	**W/H2O**	**IN PCT**	**IN PCT**	**VOL.(ML)**	**LOSS**	**pH**	**NUMBER**	**B**	**Si**	**Na**	**Li**	**Al**
B77 Blank 1	120.920	N.A.	N.A.	135.958	339.250	339.261	15.038	-0.011	6.40	162497	0.014	0.047	0.336	0.024	0.088
B86 Blank 2	121.994	N.A.	N.A.	137.022	339.500	339.497	15.028	0.003	6.14	162503	0.012	0.0400	0.210	0.010	0.015
B220 Blank 3	121.248	N.A.	N.A.	136.290	340.133	340.115	15.042	0.018	6.98	162509	0.012	0.0180	0.121	0.002	0.001
BLANK AVERAGE									6.51		0.0127	0.0350	0.2223	0.0120	0.0347
SAMPLES											**RESULTS (ppm) FOR ACIDIFIED LEACHATES.**				
543 ARM -1	121.698	123.221	1.523	138.451	339.614	339.604	15.230	0.010	10.1	162499	12.364	42.634	25.609	6.591	3.144
B9 ARM -2	122.883	124.418	1.535	139.769	340.720	340.714	15.351	0.006	10.2	162505	11.016	40.268	23.519	8.830	3.195
B53 ARM -3	122.200	123.718	1.518	138.908	340.323	340.321	15.190	0.002	10.1	162511	10.772	39.534	23.162	8.687	3.124
										CONTROL CHART VALUES FOR CONCENTRATIONS IN ARM GLASS PCT					
										HIGH	22.7	73.4	43.6	16.3	
CALCULATED RESULTS:	**pH VALUES AND FILTERED LEACHATE CONCENTRATIONS CORRECTED FOR BLANKS**									LOW	12.9	49.0	28.9	10.8	
SAMPLE			**GLASS**	**INIT.**	**FINAL**	**%**	**pH VALUES**			**ADS**	**CORRECTED CONCENTRATIONS (PPM)**				
NAME			**WEIGHT**	**VOL.(ML)**	**VOL.(ML)**	**LOSS**	**INITIAL**	**FINAL**		**NUMBER**	**B**	**Si**	**Na**	**Li**	**Al**
543 ARM -1			1.523	15.230	15.220	0.07	6.88	9.79		162499	20.81	71.75	43.10	11.09	5.29
B9 ARM -2			1.535	15.351	15.345	0.04	6.88	9.72		162505	18.54	67.77	39.58	14.86	5.38
B53 ARM -3			1.518	15.190	15.188	0.01	6.88	9.81		162511	18.13	66.54	38.98	14.62	5.26
AVERAGE											**19.16**	**68.69**	**40.55**	**13.52**	**5.31**
STANDARD DEVIATION											**1.44**	**2.73**	**2.22**	**2.11**	**0.06**
REL. STD. DEVIATION (%)											**7.53**	**3.97**	**5.49**	**15.60**	**1.16**
	NORMALIZED CALCULATIONS:			**ELEMENTAL WEIGHT PERCENT IN GLASS**											
				NORMALIZED MASS LOSS (GRAMS GLASS/LITER)								**NOT APPLICABLE**			
				NORMALIZED MASS LOSS STANDARD DEVIATION								**NOT APPLICABLE**			
				NORMALIZED MASS LOSS PLUS 2 SIGMA								**NOT APPLICABLE**			
											B	**Si**	**Na**	**Li**	**Al**
QUALITY ASSURANCE INFORMATION:										**LIMS NO.**	**ICP RESULTS (PPM)**				
						STANDARD RESULTS:			S-1	162482	11.466	30.407	48.017	5.721	2.287
LABS= B-111					EXPIRATION DATE		2/28/02		S-2	162502	11.828	30.468	48.221	5.731	2.285
PH METER ACCUMET AB 15			BUFFERED TO PH 7AND 10.		LOT NO.	102202			S-3	162508	19.706	51.039	81.301	9.624	3.811
BALANCE SER.#=GT1478									S-4	162514	11.721	30.264	48.086	5.706	2.273
OVEN SER.B-111									S-5	162517	11.595	29.929	47.976	5.696	2.244
TEMPERATURE READOUT: GT-1248 FLUKE RTD									S-6	162518	19.582	50.822	81.278	9.619	3.800
FILTER SIZE: .45 MICRON															
										RESULTS CORRECTED FOR DILUTION FACTOR OF 1.68					
									S-1	162482	19.30	51.17	80.81	9.63	3.85
RESEARCHER: NED BIBLER									S-2	162502	19.91	51.28	81.16	9.65	3.85
									S-3	162508	19.71	51.04	81.30	9.62	3.81
									S-4	162514	19.73	50.93	80.93	9.60	3.83
									S-5	162517	19.51	50.37	80.74	9.59	3.78
									S-6	162518	19.58	50.82	81.28	9.62	3.80
					STANDARD COMPOSITION (PPM)						20.0+/-0.1	50.0+/-0.3	80.0+/-0.4	10.00+/-0.05	4.00+/-0.02

6.19. Material Balance on a Volatile Metal in the Melter

There are two separate mechanisms by which a volatile metal (such as Tc^{99} or Cs^{137}) can exit the melter into the offgas stream. The diagram below shows these.



During feeding, a volatile metal will be evolved to the offgas as entrained particulate and volatilized metal. This amount is characterized by the decontamination factor (DF) values and percent retention values presented in this report. Along with this method of loss to the offgas, the metals can also be volatilized during idling of the melter, where there is no cold cap to help retain the metals. The reported DF values do not include the effect of this volatilization since they were measured only during feeding.

To estimate the volatilization, a number of assumptions had to be made. These assumptions, along with some details of the estimation method, are:

1. The volatilization rate constant of a given metal was constant whenever the cold cap was not present.

2. The volatilization can be described by an exponential decay.

3. The melter feedrate was converted to an oxide basis, or ‘g glass/time’.

4. All of the calculations are based on the calculated or measured concentration of the volatile metal in the melter feed.

5. The concentration was then converted to an oxide basis, such as μCi/g feed to μCi/g glass.

6. The concentration was then adjusted to account for the effect of the metal loss during feeding due to entrainment and volatilization:

$$C_{adj} = \frac{DF-1}{DF} C_{feed}$$

7. Only one glass sample was analyzed. This sample contained approximately 50% glass from the 5th and 6th cans, each. Each can's glass was homogenized somewhat (by crushing) and then subjected to reheating to 1150°C for 4 hours, followed by a cooldown.

8. The material balance assumes the volatile metal was lost from each sample separately during the reheating and then the samples were combined back together.

Material balance equation for feed addition:

In = Out + Accumulation

$$C_i\, m = C_o\, m + M\frac{dCo}{dt}$$

where C_i = concentration of species in melter feed on an oxide basis, μCi/g glass
C_o = concentration of species in the glass in the melter, μCi/g glass
m = melter feedrate on oxide basis, g feed as oxide / min
M = mass of glass in melter, g
C_{oi} = initial concentration of species in the melter at $t = t_o$
k_A = m/M
Note: Ci adjusted for loss of species to offgas during feeding (DF)

The solution is:

$$C_o = \frac{C_i(e^{k_A t} - e^{k_A t_o}) + C_{oi} e^{k_A t_o}}{e^{k_A t}}$$

Material balance equation for volatilization:

$$M\frac{dCo}{dt} + v = 0$$

where v = volatilization rate, μCi/min

The volatilization rate is assumed to be proportional to C_o, the concentration in the glass.

$$M\frac{dCo}{dt} + aC_o = 0$$

where a = a constant
k_V = a/M

The solution is:

$$\frac{C_o}{C_{oi}} = e^{-k_v(t-t_o)}$$

Rate of addition (minus DF loss), from analytical data and feedrate, for Tc^{99}:

Rate of addition = $C_i m$ = 0.02159 μCi/(g feed on oxide basis) x 19.11 g/min = 0.413 μCi/min

or 1.584E-4 μCi/g feed on oxide basis / min

Rate constant for loss of Tc^{99} :

k = 0.00263 min^{-1}

Rate of addition (minus DF loss), from analytical data and feedrate, for Cs^{137} :

Rate of addition = $C_i m$ = 0.03459 μCi/(g feed on oxide basis) x 19.11 g/min = 0.661 μCi/min

or 2.535E-4 μCi/g feed on oxide basis / min

Rate constant for loss of Cs^{137} :

k = 0.000411 min^{-1}

6.20. Offgas Particulate Sampling Data

Analytical Sample Volumes

All analytical samples for EPA Method 60 were adjusted to a fixed ending sample volume prior to analysis. The front-end samples (filter paper + washes of front end of the sampling train) were all adjusted to 300 mL volume. The back-end samples (impingers + washes of train after filter paper) were adjusted to 150 mL volume. Field blank and reagent blank samples were adjusted similarly.

The following pages present the 7 different offgas sampling data sets in the order of: Radioactive Samples 1-3, the Field Blank for the radioactive run (Rad Field Blank), the reagent blank, the Surrogate run and lastly, the Surrogate field blank.

				Rad Sample 1			
				liquid section			
				conc per 150 ml			
Method	Component	Units		3-159446			
				R1-LB			
							TOTAL (mg)
ICPES	Ag	mg/L		0.04			0.006
	Al	mg/L		19.8			2.97675
	B	mg/L		286			42.9741
	Ba	mg/L		0.162			0.0243
	Be	mg/L	<	0.005			0.00075
	Ca	mg/L		155			23.1966
	Cd	mg/L		0.026			0.0039
	Co	mg/L		0.064			0.0096
	Cr	mg/L		2.04			0.30585
	Cu	mg/L		1.63			0.2448
	Fe	mg/L		4.64			0.69555
	La	mg/L		0.176			0.0264
	Li	mg/L		3.36			0.504
	Mg	mg/L		4.06			0.60915
	Mn	mg/L		0.096			0.0144
	Mo	mg/L		0.121			0.01815
	Na	mg/L		25800			3870
	Ni	mg/L		1.008			0.1512
	P	mg/L		0.539			0.08085
	Pb	mg/L		0.615			0.09225
	Sb	mg/L		0.133			0.01995
	Si	mg/L		24.7			3.70065
	Sn	mg/L		0.145			0.02175
	Sr	mg/L		0.118			0.0177
	Ti	mg/L		0.655			0.09825
	Tl	mg/L		0.432			0.0648
	V	mg/L		0.06			0.009
	Zn	mg/L		6.23			0.93405
	Zr	mg/L		0.376			0.0564
AA (K)	K	mg/L		2.5665			0.384975
AA (AS)	As	ug/L	<	5			0.75
AA (SE)	Se	ug/L		1.2000			0.18
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60		<	3.39E+01	<	1.53E-05	2.29E-03
	Cs-137			2.33E+02		1.05E-04	1.57E-02
	Eu-154		<	2.01E+01	<	9.05E-06	1.36E-03
	Eu-155		<	2.75E+01	<	1.24E-05	1.86E-03
	Ra-226		<	2.18E+02	<	9.81E-05	1.47E-02
TTP-Table3	Cs-134		<	1.23E+01	<	5.54E-06	8.30E-04
TTP-Table3	Am-241		<	5.25E+01	<	2.36E-05	3.54E-03
TTP-Table3	Eu-152		<	1.12E+02	<	5.04E-05	7.56E-03
TTP-Table3	Ru-103		<	1.89E+01	<	8.51E-06	1.28E-03
TTP-Table3	Ru-106/Rh-106		<	1.41E+02	<	6.35E-05	9.52E-03
TTP-Table3	Sb-125		<	4.70E+01	<	2.12E-05	3.17E-03
TTP-Table3	Ce-144		<	6.28E+01	<	2.83E-05	4.24E-03
TTP-Table3	Sn-113		<	1.90E+01	<	8.55E-06	1.28E-03
TTP-Table3	Zn-65		<	4.14E+01	<	1.86E-05	2.79E-03
TTP-Table3	Nb-94		<	1.42E+01	<	6.39E-06	9.59E-04

				Rad Sample 1			
				liquid section			
Tank 50	Alpha Count			6.20E+00		2.79E-06	4.19E-04
Rad Screen	Beta Count			2.20E+03		9.90E-04	1.49E-01
Sr-90				3.27E+02		1.47E-04	2.21E-02
Tc-99				6.29E+02		2.83E-04	4.25E-02
				ug/L		uCi/mL	
Tc-99 ICPMS				3.61E+01		6.12E-04	9.17E-02
Pu-238				1.10E+00		4.95E-07	7.43E-05
Pu-239/240				1.35E+00		6.08E-07	9.11E-05
Pu-241			<	3.28E+01	<	1.48E-05	2.21E-03
Am-241				3.65E+00		1.64E-06	2.46E-04
Cm-244				2.11E+00		9.50E-07	1.42E-04
Cm-242			<	2.08E-01	<	9.36E-08	1.40E-05
Se-79				3.65E+01		1.64E-05	2.46E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			0.02
mass 231	231		<	0.15			0.02
mass 232 (Th)	232			1.48			0.22
mass 233	233		<	0.15			0.02
mass 234 (U)	234		<	0.15			0.02
mass 235 (U)	235		<	0.15			0.02
mass 236 (U)	236		<	0.15			0.02
mass 237 (Np)	237		<	0.15			0.02
mass 238 (Pu & U)	238			7.93			1.19
mass 239 (Pu)	239		<	0.15			0.02
mass 240 (Pu)	240		<	0.15			0.02
mass 241 (Am & Pu)	241		<	0.15			0.02
mass 242 (Pu)	242		<	0.15			0.02
mass 243 (Am)	243		<	0.15			0.02
mass 244 (Cm)	244		<	0.15			0.02
mass 245 (Cm)	245		<	0.15			0.02
mass 246	246		<	0.15			0.02
mass 247	247		<	0.15			0.02
idl (10 sigma)		0.01534					
dpm/mL x 4.50E-7 = uCi/mL							
1 disentegration/minute/mL * 1minute/60 seconds * 1Curie/3.7E10 dps *1E6 uCi/1 Curie = uCi/mL							

				Rad Sample 1			
				filter section			
				conc per 300 ml			
Method	Component	Units		3-159447			
				R1-FSB			
							TOTAL (mg)
ICPES	Ag	mg/L	<	0.038			0.0114
	Al	mg/L		50.1			15.0
	B	mg/L		196			59
	Ba	mg/L		0.06			0.018
	Be	mg/L	<	0.005			0.0015
	Ca	mg/L		17.2			5.2
	Cd	mg/L		0.164			0.0492
	Co	mg/L		0.219			0.0657
	Cr	mg/L		5.51			1.65
	Cu	mg/L		0.306			0.0918
	Fe	mg/L		36.5			11.0
	La	mg/L		0.043			0.0129
	Li	mg/L		14.2			4.3
	Mg	mg/L		0.639			0.1917
	Mn	mg/L		0.169			0.0507
	Mo	mg/L		1.267			0.3801
	Na	mg/L		273			82
	Ni	mg/L		0.726			0.218
	P	mg/L		0.816			0.2448
	Pb	mg/L		0.772			0.2316
	Sb	mg/L		0.725			0.2175
	Si	mg/L		1676			503
	Sn	mg/L		0.285			0.0855
	Sr	mg/L		0.131			0.0393
	Ti	mg/L		6.42			1.92
	Tl	mg/L		0.533			0.1599
	V	mg/L		0.04			0.012
	Zn	mg/L		28.4			8.5
	Zr	mg/L		4.36			1.31
AA (K)	K	mg/L		4.4790			1.3437
AA (AS)	As	ug/L	<	5			1.5
AA (SE)	Se	ug/L		24.2500			7.275
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60			6.95E+01		3.13E-05	9.39E-03
	Cs-137			1.08E+03		4.85E-04	1.45E-01
	Eu-154		<	3.38E+01	<	1.52E-05	4.56E-03
	Eu-155		<	4.81E+01	<	2.16E-05	6.49E-03
	Ra-226		<	3.79E+02	<	1.71E-04	5.12E-02
TTP-Table3	Cs-134		<	1.80E+01	<	8.10E-06	2.43E-03
TTP-Table3	Am-241		<	7.75E+01	<	3.49E-05	1.05E-02
TTP-Table3	Eu-152		<	1.49E+02	<	6.71E-05	2.01E-02
TTP-Table3	Ru-103		<	2.19E+01	<	9.86E-06	2.96E-03
TTP-Table3	Ru-106/Rh-106		<	2.18E+02	<	9.81E-05	2.94E-02
TTP-Table3	Sb-125		<	7.28E+01	<	3.28E-05	9.83E-03
TTP-Table3	Ce-144		<	8.59E+01	<	3.87E-05	1.16E-02
TTP-Table3	Sn-113		<	3.23E+01	<	1.45E-05	4.36E-03
TTP-Table3	Zn-65		<	4.89E+01	<	2.20E-05	6.60E-03
TTP-Table3	Nb-94		<	1.88E+01	<	8.46E-06	2.54E-03

				Rad Sample 1			
				filter section			
Tank 50	Alpha Count			3.82E+01		1.72E-05	5.16E-03
Rad Screen	Beta Count			1.26E+04		5.67E-03	1.70E+00
Sr-90				1.74E+03		7.83E-04	2.35E-01
Tc-99				5.48E+03		2.47E-03	7.40E-01
				ug/L		uCi/mL	
Tc-99 ICPMS				1.88E+02		3.20E-03	9.59E-01
Pu-238			<	2.29E+00	<	1.03E-06	3.09E-04
Pu-239/240				3.54E+00		1.59E-06	4.78E-04
Pu-241			<	3.92E+01	<	1.76E-05	5.29E-03
Am-241				9.56E+00		4.30E-06	1.29E-03
Cm-244				6.54E+00		2.94E-06	8.83E-04
Cm-242			<	1.06E-01	<	4.77E-08	1.43E-05
Se-79			<	2.61E+01	<	1.17E-05	3.52E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			0.05
mass 231	231		<	0.15			0.05
mass 232 (Th)	232			6.01			1.80
mass 233	233		<	0.15			0.05
mass 234 (U)	234		<	0.15			0.05
mass 235 (U)	235		<	0.15			0.05
mass 236 (U)	236		<	0.15			0.05
mass 237 (Np)	237		<	0.15			0.05
mass 238 (Pu & U)	238			3.57			1.07
mass 239 (Pu)	239		<	0.15			0.05
mass 240 (Pu)	240		<	0.15			0.05
mass 241 (Am & Pu)	241		<	0.15			0.05
mass 242 (Pu)	242		<	0.15			0.05
mass 243 (Am)	243		<	0.15			0.05
mass 244 (Cm)	244		<	0.15			0.05
mass 245 (Cm)	245		<	0.15			0.05
mass 246	246		<	0.15			0.05
mass 247	247		<	0.15			0.05
idl (10 sigma)		0.01534					

				Rad Sample 2			
				liquid section			
				conc per 150 ml			
Method	Component	Units		3-159448			
				R2-LB			
							TOTAL (mg)
ICPES	Ag	mg/L	<	0.038			0.0114
	Al	mg/L		0.775			0.2325
	B	mg/L		190			57
	Ba	mg/L		0.016			0.0048
	Be	mg/L	<	0.005			0.0015
	Ca	mg/L		3.58			1.07
	Cd	mg/L		0.017			0.0051
	Co	mg/L		0.034			0.0102
	Cr	mg/L		0.081			0.0243
	Cu	mg/L		2.31			0.69
	Fe	mg/L		1.54			0.46
	La	mg/L	<	0.042			0.0126
	Li	mg/L		0.206			0.0618
	Mg	mg/L		0.943			0.2829
	Mn	mg/L		0.021			0.0063
	Mo	mg/L		0.034			0.0102
	Na	mg/L		26.9			8.1
	Ni	mg/L		0.253			0.0759
	P	mg/L		0.231			0.0693
	Pb	mg/L		0.136			0.0408
	Sb	mg/L		0.066			0.0198
	Si	mg/L		34.5			10.4
	Sn	mg/L		0.125			0.0375
	Sr	mg/L	<	0.006			0.0018
	Ti	mg/L		0.031			0.0093
	Tl	mg/L		0.253			0.0759
	V	mg/L	<	0.027			0.0081
	Zn	mg/L		2.16			0.65
	Zr	mg/L	<	0.026			0.0078
AA (K)	K	mg/L		0.2840			0.0852
AA (AS)	As	ug/L	<	5			1.5
AA (SE)	Se	ug/L		1.8000			0.54
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60		<	6.18E+01	<	2.78E-05	4.17E-03
	Cs-137		<	7.01E+00	<	3.15E-06	4.73E-04
	Eu-154		<	5.86E+00	<	2.64E-06	3.96E-04
	Eu-155		<	1.11E+01	<	5.00E-06	7.49E-04
	Ra-226		<	1.08E+02	<	4.86E-05	7.29E-03
TTP-Table3	Cs-134		<	5.12E+00	<	2.30E-06	3.46E-04
TTP-Table3	Am-241		<	1.68E+01	<	7.56E-06	1.13E-03
TTP-Table3	Eu-152		<	3.50E+01	<	1.58E-05	2.36E-03
TTP-Table3	Ru-103		<	5.10E+00	<	2.30E-06	3.44E-04
TTP-Table3	Ru-106/Rh-106		<	5.77E+01	<	2.60E-05	3.89E-03
TTP-Table3	Sb-125		<	1.37E+01	<	6.17E-06	9.25E-04
TTP-Table3	Ce-144		<	2.43E+01	<	1.09E-05	1.64E-03
TTP-Table3	Sn-113		<	6.50E+00	<	2.93E-06	4.39E-04
TTP-Table3	Zn-65		<	1.16E+01	<	5.22E-06	7.83E-04
TTP-Table3	Nb-94		<	6.13E+00	<	2.76E-06	4.14E-04

				Rad Sample 2			
				liquid section			
Tank 50	Alpha Count		<	5.22E+00	<	2.35E-06	3.52E-04
Rad Screen	Beta Count			8.12E+01		3.65E-05	5.48E-03
Sr-90			<	3.12E+01	<	1.40E-05	2.11E-03
Tc-99				2.13E+01		9.59E-06	1.44E-03
				ug/L		uCi/mL	
Tc-99 ICPMS			<	8.88E-01	<	1.51E-05	2.26E-03
Pu-238			<	9.96E-01	<	4.48E-07	6.72E-05
Pu-239/240			<	1.31E+00	<	5.90E-07	8.84E-05
Pu-241			<	3.07E+01	<	1.38E-05	2.07E-03
Am-241				9.40E-01		4.23E-07	6.35E-05
Cm-244				4.75E-01		2.14E-07	3.21E-05
Cm-242			<	2.52E-02	<	1.13E-08	1.70E-06
Se-79			<	2.80E+01	<	1.26E-05	1.89E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			0.05
mass 231	231		<	0.15			0.05
mass 232 (Th)	232			0.17			0.05
mass 233	233		<	0.15			0.05
mass 234 (U)	234		<	0.15			0.05
mass 235 (U)	235		<	0.15			0.05
mass 236 (U)	236		<	0.15			0.05
mass 237 (Np)	237		<	0.15			0.05
mass 238 (Pu & U)	238			3.33			1.00
mass 239 (Pu)	239		<	0.15			0.05
mass 240 (Pu)	240		<	0.15			0.05
mass 241 (Am & Pu)	241		<	0.15			0.05
mass 242 (Pu)	242		<	0.15			0.05
mass 243 (Am)	243		<	0.15			0.05
mass 244 (Cm)	244		<	0.15			0.05
mass 245 (Cm)	245		<	0.15			0.05
mass 246	246		<	0.15			0.05
mass 247	247		<	0.15			0.05

				Rad Sample 2			
				filter section			
				conc per 300 ml			
Method	Component	Units		3-159449			
				R2-FSB			
							TOTAL (mg)
ICPES	Ag	mg/L	<	0.038			0.0114
	Al	mg/L		108			32
	B	mg/L		293			88
	Ba	mg/L		0.084			0.0252
	Be	mg/L	<	0.005			0.0015
	Ca	mg/L		6.41			1.92
	Cd	mg/L		0.298			0.0894
	Co	mg/L		0.427			0.1281
	Cr	mg/L		2.58			0.77
	Cu	mg/L		0.213			0.0639
	Fe	mg/L		16.4			4.9
	La	mg/L	<	0.042			0.0126
	Li	mg/L		8.02			2.41
	Mg	mg/L		0.783			0.2349
	Mn	mg/L		0.299			0.0897
	Mo	mg/L		0.481			0.1443
	Na	mg/L		452			136
	Ni	mg/L		0.365			0.110
	P	mg/L		0.898			0.2694
	Pb	mg/L		1.63			0.489
	Sb	mg/L		1.34			0.40
	Si	mg/L		3140			942
	Sn	mg/L		0.459			0.1377
	Sr	mg/L		0.096			0.0288
	Ti	mg/L		3.03			0.91
	Tl	mg/L		0.698			0.2094
	V	mg/L		0.035			0.0105
	Zn	mg/L		12.2			3.6
	Zr	mg/L		3.08			0.92
AA (K)	K	mg/L		11.1060			3.3318
AA (AS)	As	ug/L	<	5			1.5
AA (SE)	Se	ug/L		50.2500			15.075
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60		<	4.09E+01	<	1.84E-05	5.52E-03
	Cs-137			3.76E+03		1.69E-03	5.07E-01
	Eu-154		<	4.20E+01	<	1.89E-05	5.67E-03
	Eu-155		<	5.56E+01	<	2.50E-05	7.51E-03
	Ra-226		<	5.37E+02	<	2.42E-04	7.25E-02
TTP-Table3	Cs-134		<	2.12E+01	<	9.54E-06	2.86E-03
TTP-Table3	Am-241		<	1.10E+02	<	4.95E-05	1.49E-02
TTP-Table3	Eu-152		<	1.04E+02	<	4.68E-05	1.40E-02
TTP-Table3	Ru-103		<	4.11E+01	<	1.85E-05	5.55E-03
TTP-Table3	Ru-106/Rh-106		<	2.65E+02	<	1.19E-04	3.58E-02
TTP-Table3	Sb-125		<	1.33E+02	<	5.99E-05	1.80E-02
TTP-Table3	Ce-144		<	1.48E+02	<	6.66E-05	2.00E-02
TTP-Table3	Sn-113		<	4.91E+01	<	2.21E-05	6.63E-03
TTP-Table3	Zn-65		<	4.14E+01	<	1.86E-05	5.59E-03
TTP-Table3	Nb-94		<	1.42E+01	<	6.39E-06	1.92E-03

				Rad Sample 2			
				filter section			
Tank 50	Alpha Count			4.04E+01		1.82E-05	5.45E-03
Rad Screen	Beta Count			3.19E+04		1.44E-02	4.31E+00
Sr-90				8.78E+02		3.95E-04	1.19E-01
Tc-99				2.28E+04		1.03E-02	3.08E+00
				ug/L		uCi/mL	
Tc-99 ICPMS				6.57E+02		1.11E-02	3.34E+00
Pu-238				2.46E+00		1.11E-06	3.32E-04
Pu-239/240			<	1.14E+00	<	5.13E-07	1.54E-04
Pu-241			<	4.36E+01	<	1.96E-05	5.89E-03
Am-241				6.26E+00		2.82E-06	8.45E-04
Cm-244				3.55E+00		1.60E-06	4.79E-04
Cm-242			<	1.43E-01	<	6.44E-08	1.93E-05
Se-79				7.05E+01		3.17E-05	9.52E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			4.59E-02
mass 231	231		<	0.15			4.59E-02
mass 232 (Th)	232			4.34			1.30E+00
mass 233	233		<	0.15			4.59E-02
mass 234 (U)	234		<	0.15			4.59E-02
mass 235 (U)	235		<	0.15			4.59E-02
mass 236 (U)	236		<	0.15			4.59E-02
mass 237 (Np)	237		<	0.15			4.59E-02
mass 238 (Pu & U)	238			5.62			1.68E+00
mass 239 (Pu)	239		<	0.15			4.59E-02
mass 240 (Pu)	240		<	0.15			4.59E-02
mass 241 (Am & Pu)	241		<	0.15			4.59E-02
mass 242 (Pu)	242		<	0.15			4.59E-02
mass 243 (Am)	243		<	0.15			4.59E-02
mass 244 (Cm)	244		<	0.15			4.59E-02
mass 245 (Cm)	245		<	0.15			4.59E-02
mass 246	246		<	0.15			4.59E-02
mass 247	247		<	0.15			4.59E-02

				Rad Sample 3			
				liquid section			
				conc per 150 ml			
Method	Component	Units		3-159450			
				R3-LB			
							TOTAL (mg)
ICPES	Ag	mg/L	<	0.038			0.0114
	Al	mg/L		2.35			0.70
	B	mg/L		242			73
	Ba	mg/L		0.016			0.0048
	Be	mg/L	<	0.005			0.0015
	Ca	mg/L		3.22			0.97
	Cd	mg/L		0.017			0.0051
	Co	mg/L		0.04			0.012
	Cr	mg/L		0.065			0.0195
	Cu	mg/L		0.177			0.0531
	Fe	mg/L		1.65			0.49
	La	mg/L	<	0.042			0.0126
	Li	mg/L		0.021			0.0063
	Mg	mg/L		0.73			0.22
	Mn	mg/L		0.014			0.0042
	Mo	mg/L		0.032			0.0096
	Na	mg/L		12.5			3.7
	Ni	mg/L		0.089			0.0267
	P	mg/L		0.222			0.0666
	Pb	mg/L		0.154			0.0462
	Sb	mg/L		0.084			0.0252
	Si	mg/L		73.4			22.0
	Sn	mg/L		0.179			0.0537
	Sr	mg/L		0.008			0.0024
	Ti	mg/L		0.061			0.0183
	Tl	mg/L		0.332			0.0996
	V	mg/L	<	0.027			0.0081
	Zn	mg/L		1.24			0.37
	Zr	mg/L		0.1			0.03
AA (K)	K	mg/L		0.4660			0.1398
AA (AS)	As	ug/L	<	5			1.5
AA (SE)	Se	ug/L		3.1500			0.945
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60		<	7.06E+00	<	3.18E-06	4.77E-04
	Cs-137			1.09E+01		4.92E-06	7.38E-04
	Eu-154		<	6.47E+00	<	2.91E-06	4.37E-04
	Eu-155		<	1.07E+01	<	4.82E-06	7.22E-04
	Ra-226		<	9.76E+01	<	4.39E-05	6.59E-03
TTP-Table3	Cs-134		<	5.55E+00	<	2.50E-06	3.75E-04
TTP-Table3	Am-241		<	1.46E+01	<	6.57E-06	9.86E-04
TTP-Table3	Eu-152		<	3.61E+01	<	1.62E-05	2.44E-03
TTP-Table3	Ru-103		<	4.73E+00	<	2.13E-06	3.19E-04
TTP-Table3	Ru-106/Rh-106		<	5.11E+01	<	2.30E-05	3.45E-03
TTP-Table3	Sb-125		<	4.64E+00	<	2.09E-06	3.13E-04
TTP-Table3	Ce-144		<	2.22E+01	<	9.99E-06	1.50E-03
TTP-Table3	Sn-113		<	5.94E+00	<	2.67E-06	4.01E-04
TTP-Table3	Zn-65		<	1.28E+01	<	5.76E-06	8.64E-04
TTP-Table3	Nb-94		<	5.95E+00	<	2.68E-06	4.02E-04

				Rad Sample 3			
				liquid section			
Tank 50	Alpha Count		<	4.48E+00	<	2.02E-06	3.02E-04
Rad Screen	Beta Count			7.28E+01		3.28E-05	4.91E-03
Sr-90			<	3.12E+01	<	1.40E-05	2.11E-03
Tc-99				3.51E+01		1.58E-05	2.37E-03
				ug/L		uCi/mL	
Tc-99 ICPMS				5.19E+00		8.81E-05	1.32E-02
Pu-238			<	9.81E-01	<	4.41E-07	6.62E-05
Pu-239/240				1.75E+00		7.88E-07	1.18E-04
Pu-241			<	5.49E+01	<	2.47E-05	3.71E-03
Am-241				6.53E-01		2.94E-07	4.41E-05
Cm-244				1.55E+00		6.98E-07	1.05E-04
Cm-242			<	3.02E-02	<	1.36E-08	2.04E-06
Se-79			<	2.90E+01	<	1.31E-05	1.96E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			4.59E-02
mass 231	231		<	0.15			4.59E-02
mass 232 (Th)	232			0.92			2.75E-01
mass 233	233		<	0.15			4.59E-02
mass 234 (U)	234		<	0.15			4.59E-02
mass 235 (U)	235		<	0.15			4.59E-02
mass 236 (U)	236		<	0.15			4.59E-02
mass 237 (Np)	237		<	0.15			4.59E-02
mass 238 (Pu & U)	238			0.78			2.34E-01
mass 239 (Pu)	239		<	0.15			4.59E-02
mass 240 (Pu)	240		<	0.15			4.59E-02
mass 241 (Am & Pu)	241		<	0.15			4.59E-02
mass 242 (Pu)	242		<	0.15			4.59E-02
mass 243 (Am)	243		<	0.15			4.59E-02
mass 244 (Cm)	244		<	0.15			4.59E-02
mass 245 (Cm)	245		<	0.15			4.59E-02
mass 246	246		<	0.15			4.59E-02
mass 247	247		<	0.15			4.59E-02

				Rad Sample 3			
				filter section			
				conc per 300 ml			
Method	Component	Units		3-159451			
				R3-FSB			
							TOTAL (mg)
ICPES	Ag	mg/L	<	0.038			0.0114
	Al	mg/L		8.36			2.51
	B	mg/L		75.5			22.7
	Ba	mg/L		0.025			0.0075
	Be	mg/L	<	0.005			0.0015
	Ca	mg/L		3.34			1.00
	Cd	mg/L		0.101			0.0303
	Co	mg/L		0.125			0.0375
	Cr	mg/L		2.17			0.65
	Cu	mg/L		0.731			0.2193
	Fe	mg/L		14.3			4.3
	La	mg/L	<	0.042			0.0126
	Li	mg/L		5.80			1.74
	Mg	mg/L		0.2			0.06
	Mn	mg/L		0.051			0.0153
	Mo	mg/L		0.261			0.0783
	Na	mg/L		228			68
	Ni	mg/L		0.181			0.0543
	P	mg/L		0.581			0.1743
	Pb	mg/L		0.458			0.1374
	Sb	mg/L		0.395			0.1185
	Si	mg/L		1038			311
	Sn	mg/L		0.156			0.0468
	Sr	mg/L		0.05			0.015
	Ti	mg/L		2.48			0.74
	Tl	mg/L		0.317			0.0951
	V	mg/L	<	0.027			0.0081
	Zn	mg/L		11.5			3.4
	Zr	mg/L		1.10			0.33
AA (K)	K	mg/L		7.0110			2.1033
AA (AS)	As	ug/L	<	5			1.5
AA (SE)	Se	ug/L		38.0500			11.415
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60		<	3.81E+01	<	1.71E-05	5.14E-03
	Cs-137			2.17E+03		9.79E-04	2.94E-01
	Eu-154		<	3.41E+01	<	1.53E-05	4.60E-03
	Eu-155		<	4.32E+01	<	1.94E-05	5.83E-03
	Ra-226		<	4.45E+02	<	2.00E-04	6.01E-02
TTP-Table3	Cs-134		<	1.37E+01	<	6.17E-06	1.85E-03
TTP-Table3	Am-241		<	8.57E+01	<	3.86E-05	1.16E-02
TTP-Table3	Eu-152		<	1.32E+01	<	5.94E-06	1.78E-03
TTP-Table3	Ru-103		<	3.30E+01	<	1.49E-05	4.46E-03
TTP-Table3	Ru-106/Rh-106		<	2.35E+02	<	1.06E-04	3.17E-02
TTP-Table3	Sb-125		<	1.07E+02	<	4.82E-05	1.44E-02
TTP-Table3	Ce-144		<	1.10E+02	<	4.95E-05	1.49E-02
TTP-Table3	Sn-113		<	3.81E+01	<	1.71E-05	5.14E-03
TTP-Table3	Zn-65		<	3.84E+01	<	1.73E-05	5.18E-03
TTP-Table3	Nb-94		<	1.27E+01	<	5.72E-06	1.71E-03

				Rad Sample 3			
				filter section			
Tank 50	Alpha Count			2.16E+01		9.72E-06	2.92E-03
Rad Screen	Beta Count			2.55E+04		1.15E-02	3.44E+00
Sr-90				9.71E+02		4.37E-04	1.31E-01
Tc-99				1.88E+04		8.46E-03	2.54E+00
				ug/L		uCi/mL	
Tc-99 ICPMS				5.37E+02		9.12E-03	2.74E+00
Pu-238			<	7.07E-01	<	3.18E-07	9.54E-05
Pu-239/240			<	7.80E-01	<	3.51E-07	1.05E-04
Pu-241			<	3.91E+01	<	1.76E-05	5.28E-03
Am-241				4.26E+00		1.92E-06	5.75E-04
Cm-244				3.55E+00		1.60E-06	4.79E-04
Cm-242			<	1.39E-01	<	6.26E-08	1.88E-05
Se-79			<	2.20E+01	<	9.90E-06	2.97E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			4.59E-02
mass 231	231		<	0.15			4.59E-02
mass 232 (Th)	232			2.01			6.02E-01
mass 233	233		<	0.15			4.59E-02
mass 234 (U)	234		<	0.15			4.59E-02
mass 235 (U)	235		<	0.15			4.59E-02
mass 236 (U)	236		<	0.15			4.59E-02
mass 237 (Np)	237		<	0.15			4.59E-02
mass 238 (Pu & U)	238			2.65			7.95E-01
mass 239 (Pu)	239		<	0.15			4.59E-02
mass 240 (Pu)	240		<	0.15			4.59E-02
mass 241 (Am & Pu)	241		<	0.15			4.59E-02
mass 242 (Pu)	242		<	0.15			4.59E-02
mass 243 (Am)	243		<	0.15			4.59E-02
mass 244 (Cm)	244		<	0.15			4.59E-02
mass 245 (Cm)	245		<	0.15			4.59E-02
mass 246	246		<	0.15			4.59E-02
mass 247	247		<	0.15			4.59E-02

				Rad Field Blank			
				liquid section			
				conc per 150 ml			
Method	Component	Units		3-159452			
				RFB-LB			
							TOTAL (mg)
ICPES	Ag	mg/L	<	0.038			0.0114
	Al	mg/L		0.449			0.1347
	B	mg/L		0.227			0.0681
	Ba	mg/L		0.028			0.0084
	Be	mg/L	<	0.005			0.0015
	Ca	mg/L		2.53			0.76
	Cd	mg/L	<	0.006			0.0018
	Co	mg/L	<	0.03			0.009
	Cr	mg/L		0.126			0.0378
	Cu	mg/L		1.703			0.5109
	Fe	mg/L		0.837			0.2511
	La	mg/L	<	0.042			0.0126
	Li	mg/L		0.007			0.0021
	Mg	mg/L		0.367			0.1101
	Mn	mg/L		0.025			0.0075
	Mo	mg/L	<	0.01			0.003
	Na	mg/L		11.8			3.5
	Ni	mg/L		0.296			0.0888
	P	mg/L		0.159			0.0477
	Pb	mg/L	<	0.078			0.0234
	Sb	mg/L	<	0.048			0.0144
	Si	mg/L		11.0			3.3
	Sn	mg/L		0.105			0.0315
	Sr	mg/L		0.01			0.003
	Ti	mg/L	<	0.015			0.0045
	Tl	mg/L		0.124			0.0372
	V	mg/L	<	0.027			0.0081
	Zn	mg/L		0.263			0.0789
	Zr	mg/L	<	0.026			0.0078
AA (K)	K	mg/L		0.2315			0.06945
AA (AS)	As	ug/L		3.2500			0.975
AA (SE)	Se	ug/L		2.7000			0.81
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60		<	6.18E+00	<	2.78E-06	4.17E-04
	Cs-137		<	7.84E+00	<	3.53E-06	5.29E-04
	Eu-154		<	7.53E+00	<	3.39E-06	5.08E-04
	Eu-155		<	1.14E+01	<	5.13E-06	7.70E-04
	Ra-226		<	9.95E+01	<	4.48E-05	6.72E-03
TTP-Table3	Cs-134		<	4.24E+00	<	1.91E-06	2.86E-04
TTP-Table3	Am-241		<	1.79E+01	<	8.06E-06	1.21E-03
TTP-Table3	Eu-152		<	3.95E+01	<	1.78E-05	2.67E-03
TTP-Table3	Ru-103		<	4.31E+00	<	1.94E-06	2.91E-04
TTP-Table3	Ru-106/Rh-106		<	4.47E+01	<	2.01E-05	3.02E-03
TTP-Table3	Sb-125		<	1.42E+01	<	6.39E-06	9.59E-04
TTP-Table3	Ce-144		<	2.22E+01	<	9.99E-06	1.50E-03
TTP-Table3	Sn-113		<	5.84E+00	<	2.63E-06	3.94E-04
TTP-Table3	Zn-65		<	1.28E+01	<	5.76E-06	8.64E-04
TTP-Table3	Nb-94		<	6.96E+00	<	3.13E-06	4.70E-04

				Rad Field Blank			
				liquid section			
Tank 50	Alpha Count		<	3.44E+00	<	1.55E-06	2.32E-04
Rad Screen	Beta Count		<	1.92E+01	<	8.64E-06	1.30E-03
Sr-90			<	3.12E+01	<	1.40E-05	2.11E-03
Tc-99			<	1.12E+00	<	5.04E-07	7.56E-05
				ug/L		uCi/mL	
Tc-99 ICPMS			<	8.88E-01	<	1.51E-05	2.26E-03
Pu-238			<	1.66E+00	<	7.47E-07	1.12E-04
Pu-239/240			<	1.44E+00	<	6.48E-07	9.72E-05
Pu-241			<	2.24E+01	<	1.01E-05	1.51E-03
Am-241				2.79E-01		1.26E-07	1.88E-05
Cm-244				9.01E-02		4.05E-08	6.08E-06
Cm-242			<	2.71E-02	<	1.22E-08	1.83E-06
Se-79			<	2.90E+01	<	1.31E-05	1.96E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			4.59E-02
mass 231	231		<	0.15			4.59E-02
mass 232 (Th)	232		<	0.15			4.59E-02
mass 233	233		<	0.15			4.59E-02
mass 234 (U)	234		<	0.15			4.59E-02
mass 235 (U)	235		<	0.15			4.59E-02
mass 236 (U)	236		<	0.15			4.59E-02
mass 237 (Np)	237		<	0.15			4.59E-02
mass 238 (Pu & U)	238			1.52			4.56E-01
mass 239 (Pu)	239		<	0.15			4.59E-02
mass 240 (Pu)	240		<	0.15			4.59E-02
mass 241 (Am & Pu)	241		<	0.15			4.59E-02
mass 242 (Pu)	242		<	0.15			4.59E-02
mass 243 (Am)	243		<	0.15			4.59E-02
mass 244 (Cm)	244		<	0.15			4.59E-02
mass 245 (Cm)	245		<	0.15			4.59E-02
mass 246	246		<	0.15			4.59E-02
mass 247	247		<	0.15			4.59E-02

				Rad Field Blank			
				filter section			
				conc per 300 ml			
Method	Component	Units		3-159453			
				RFB-FSB			
							TOTAL (mg)
ICPES	Ag	mg/L	<	0.038			0.0114
	Al	mg/L		10.4			3.1
	B	mg/L		37.5			11.3
	Ba	mg/L		0.134			0.0402
	Be	mg/L	<	0.005			0.0015
	Ca	mg/L		33.8			10.1
	Cd	mg/L		0.099			0.0297
	Co	mg/L		0.135			0.0405
	Cr	mg/L		0.101			0.0303
	Cu	mg/L		0.279			0.0837
	Fe	mg/L		0.584			0.1752
	La	mg/L	<	0.042			0.0126
	Li	mg/L	<	0.006			0.0018
	Mg	mg/L		1.99			0.597
	Mn	mg/L		0.034			0.0102
	Mo	mg/L		0.089			0.0267
	Na	mg/L		47.5			14.2
	Ni	mg/L		0.110			0.033
	P	mg/L		0.227			0.0681
	Pb	mg/L		0.661			0.1983
	Sb	mg/L		0.437			0.1311
	Si	mg/L		1350			405
	Sn	mg/L		0.222			0.0666
	Sr	mg/L		0.694			0.2082
	Ti	mg/L		0.276			0.0828
	Tl	mg/L		0.322			0.0966
	V	mg/L	<	0.027			0.0081
	Zn	mg/L		0.196			0.0588
	Zr	mg/L		0.178			0.0534
AA (K)	K	mg/L		2.6400			0.792
AA (AS)	As	ug/L		4.8500			1.455
AA (SE)	Se	ug/L		4.7500			1.425
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60		<	6.18E+00	<	2.78E-06	8.34E-04
	Cs-137		<	7.01E+00	<	3.15E-06	9.46E-04
	Eu-154		<	5.67E+00	<	2.55E-06	7.65E-04
	Eu-155		<	1.02E+01	<	4.59E-06	1.38E-03
	Ra-226		<	1.05E+02	<	4.73E-05	1.42E-02
TTP-Table3	Cs-134		<	5.12E+00	<	2.30E-06	6.91E-04
TTP-Table3	Am-241		<	1.79E+01	<	8.06E-06	2.42E-03
TTP-Table3	Eu-152		<	3.15E+01	<	1.42E-05	4.25E-03
TTP-Table3	Ru-103		<	4.93E+00	<	2.22E-06	6.66E-04
TTP-Table3	Ru-106/Rh-106		<	5.11E+01	<	2.30E-05	6.90E-03
TTP-Table3	Sb-125		<	1.34E+01	<	6.03E-06	1.81E-03
TTP-Table3	Ce-144		<	2.45E+01	<	1.10E-05	3.31E-03
TTP-Table3	Sn-113		<	5.61E+00	<	2.52E-06	7.57E-04
TTP-Table3	Zn-65		<	1.38E+01	<	6.21E-06	1.86E-03
TTP-Table3	Nb-94		<	5.57E+00	<	2.51E-06	7.52E-04

				Rad Field Blank			
				filter section			
Tank 50	Alpha Count		<	3.20E+00	<	1.44E-06	4.32E-04
Rad Screen	Beta Count		<	1.92E+01	<	8.64E-06	2.59E-03
Sr-90			<	3.12E+01	<	1.40E-05	4.21E-03
Tc-99				2.03E+00		9.14E-07	2.74E-04
				ug/L		uCi/mL	
Tc-99 ICPMS				1.34E+00		2.27E-05	6.82E-03
Pu-238				1.89E+00		8.51E-07	2.55E-04
Pu-239/240			<	1.23E+00	<	5.54E-07	1.66E-04
Pu-241			<	2.93E+01	<	1.32E-05	3.96E-03
Am-241			<	3.77E+00	<	1.70E-06	5.09E-04
Cm-244				2.46E-01		1.11E-07	3.32E-05
Cm-242			<	3.18E-02	<	1.43E-08	4.29E-06
Se-79			<	2.20E+01	<	9.90E-06	2.97E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			4.59E-02
mass 231	231		<	0.15			4.59E-02
mass 232 (Th)	232			1.45			4.36E-01
mass 233	233		<	0.15			4.59E-02
mass 234 (U)	234		<	0.15			4.59E-02
mass 235 (U)	235		<	0.15			4.59E-02
mass 236 (U)	236		<	0.15			4.59E-02
mass 237 (Np)	237		<	0.15			4.59E-02
mass 238 (Pu & U)	238			3.86			1.16E+00
mass 239 (Pu)	239		<	0.15			4.59E-02
mass 240 (Pu)	240		<	0.15			4.59E-02
mass 241 (Am & Pu)	241		<	0.15			4.59E-02
mass 242 (Pu)	242		<	0.15			4.59E-02
mass 243 (Am)	243		<	0.15			4.59E-02
mass 244 (Cm)	244		<	0.15			4.59E-02
mass 245 (Cm)	245		<	0.15			4.59E-02
mass 246	246		<	0.15			4.59E-02
mass 247	247		<	0.15			4.59E-02

				Reagent Blank			
				liquid section			
				conc per 150 ml			
Method	Component	Units		3-159454			
				B-LB			
							TOTAL (mg)
ICPES	Ag	mg/L	<	0.038			0.0114
	Al	mg/L		0.151			0.0453
	B	mg/L		0.11			0.033
	Ba	mg/L	<	0.008			0.0024
	Be	mg/L	<	0.005			0.0015
	Ca	mg/L		0.225			0.0675
	Cd	mg/L	<	0.006			0.0018
	Co	mg/L	<	0.03			0.009
	Cr	mg/L	<	0.032			0.0096
	Cu	mg/L		0.495			0.1485
	Fe	mg/L		0.093			0.0279
	La	mg/L	<	0.042			0.0126
	Li	mg/L	<	0.006			0.0018
	Mg	mg/L		0.014			0.0042
	Mn	mg/L	<	0.006			0.0018
	Mo	mg/L	<	0.01			0.003
	Na	mg/L		1.778			0.5334
	Ni	mg/L		0.114			0.0342
	P	mg/L		0.073			0.0219
	Pb	mg/L	<	0.078			0.0234
	Sb	mg/L	<	0.048			0.0144
	Si	mg/L		10.6			3.2
	Sn	mg/L		0.103			0.0309
	Sr	mg/L	<	0.006			0.0018
	Ti	mg/L	<	0.015			0.0045
	Tl	mg/L		0.141			0.0423
	V	mg/L	<	0.027			0.0081
	Zn	mg/L		0.057			0.0171
	Zr	mg/L	<	0.026			0.0078
AA (K)	K	mg/L	<	0.1350			0.0405
AA (AS)	As	ug/L		3.0000			0.9
AA (SE)	Se	ug/L		1.0000			0.3
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60		<	7.58E+00	<	3.41E-06	5.12E-04
	Cs-137		<	9.70E+00	<	4.37E-06	6.55E-04
	Eu-154		<	5.93E+00	<	2.67E-06	4.00E-04
	Eu-155		<	9.75E+00	<	4.39E-06	6.58E-04
	Ra-226		<	1.02E+02	<	4.59E-05	6.89E-03
TTP-Table3	Cs-134		<	4.09E+00	<	1.84E-06	2.76E-04
TTP-Table3	Am-241		<	1.92E+01	<	8.64E-06	1.30E-03
TTP-Table3	Eu-152		<	3.28E+01	<	1.48E-05	2.21E-03
TTP-Table3	Ru-103		<	5.38E+00	<	2.42E-06	3.63E-04
TTP-Table3	Ru-106/Rh-106		<	5.97E+01	<	2.69E-05	4.03E-03
TTP-Table3	Sb-125		<	1.53E+01	<	6.89E-06	1.03E-03
TTP-Table3	Ce-144		<	2.24E+01	<	1.01E-05	1.51E-03
TTP-Table3	Sn-113		<	6.15E+00	<	2.77E-06	4.15E-04
TTP-Table3	Zn-65		<	1.16E+01	<	5.22E-06	7.83E-04
TTP-Table3	Nb-94		<	7.40E+00	<	3.33E-06	5.00E-04

				Reagent Blank			
				liquid section			
Tank 50	Alpha Count		<	3.19E+00	<	1.44E-06	2.15E-04
Rad Screen	Beta Count		<	1.92E+01	<	8.64E-06	1.30E-03
Sr-90			<	3.12E+01	<	1.40E-05	2.11E-03
Tc-99			<	1.12E+00	<	5.04E-07	7.56E-05
				ug/L		uCi/mL	
Tc-99 ICPMS				9.90E-01		1.68E-05	2.52E-03
Pu-238				9.41E-01		4.23E-07	6.35E-05
Pu-239/240			<	8.05E-01	<	3.62E-07	5.43E-05
Pu-241			<	3.18E+01	<	1.43E-05	2.15E-03
Am-241			<	2.02E+00	<	9.09E-07	1.36E-04
Cm-244				2.43E-01		1.09E-07	1.64E-05
Cm-242			<	2.74E-02	<	1.23E-08	1.85E-06
Se-79			<	2.90E+01	<	1.31E-05	1.96E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			4.59E-02
mass 231	231		<	0.15			4.59E-02
mass 232 (Th)	232		<	0.15			4.59E-02
mass 233	233		<	0.15			4.59E-02
mass 234 (U)	234		<	0.15			4.59E-02
mass 235 (U)	235		<	0.15			4.59E-02
mass 236 (U)	236		<	0.15			4.59E-02
mass 237 (Np)	237		<	0.15			4.59E-02
mass 238 (Pu & U)	238			2.40			7.21E-01
mass 239 (Pu)	239		<	0.15			4.59E-02
mass 240 (Pu)	240		<	0.15			4.59E-02
mass 241 (Am & Pu)	241		<	0.15			4.59E-02
mass 242 (Pu)	242		<	0.15			4.59E-02
mass 243 (Am)	243		<	0.15			4.59E-02
mass 244 (Cm)	244		<	0.15			4.59E-02
mass 245 (Cm)	245		<	0.15			4.59E-02
mass 246	246		<	0.15			4.59E-02
mass 247	247		<	0.15			4.59E-02

				Reagent Blank			
				filter section			
				conc per 300 ml			
Method	Component	Units		3-159455			
				B-FSB			
							TOTAL (mg)
ICPES	Ag	mg/L	<	0.038			0.0114
	Al	mg/L		6.73			2.019
	B	mg/L		32.2			9.7
	Ba	mg/L		0.07			0.021
	Be	mg/L	<	0.005			0.0015
	Ca	mg/L		19.2			5.8
	Cd	mg/L		0.12			0.036
	Co	mg/L		0.167			0.0501
	Cr	mg/L		0.097			0.0291
	Cu	mg/L		0.59			0.177
	Fe	mg/L		0.508			0.1524
	La	mg/L	<	0.042			0.0126
	Li	mg/L	<	0.006			0.0018
	Mg	mg/L		1.08			0.32
	Mn	mg/L		0.027			0.0081
	Mo	mg/L		0.093			0.0279
	Na	mg/L		27.5			8.2
	Ni	mg/L		0.209			0.063
	P	mg/L		0.191			0.0573
	Pb	mg/L		0.804			0.2412
	Sb	mg/L		0.529			0.1587
	Si	mg/L		1270			381
	Sn	mg/L		0.227			0.0681
	Sr	mg/L		0.431			0.1293
	Ti	mg/L		0.167			0.0501
	Tl	mg/L		0.305			0.0915
	V	mg/L	<	0.027			0.0081
	Zn	mg/L		0.102			0.0306
	Zr	mg/L		0.112			0.0336
AA (K)	K	mg/L		1.6065			0.48195
AA (AS)	As	ug/L		6.5000			1.95
AA (SE)	Se	ug/L		2.8000			0.84
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60		<	5.85E+00	<	2.63E-06	7.90E-04
	Cs-137			1.87E+01		8.40E-06	2.52E-03
	Eu-154		<	5.39E+00	<	2.43E-06	7.28E-04
	Eu-155		<	1.02E+01	<	4.59E-06	1.38E-03
	Ra-226		<	9.55E+01	<	4.30E-05	1.29E-02
TTP-Table3	Cs-134		<	5.55E+00	<	2.50E-06	7.49E-04
TTP-Table3	Am-241		<	1.59E+01	<	7.16E-06	2.15E-03
TTP-Table3	Eu-152		<	3.58E+01	<	1.61E-05	4.83E-03
TTP-Table3	Ru-103		<	4.20E+00	<	1.89E-06	5.67E-04
TTP-Table3	Ru-106/Rh-106		<	5.22E+01	<	2.35E-05	7.05E-03
TTP-Table3	Sb-125		<	1.53E+01	<	6.89E-06	2.07E-03
TTP-Table3	Ce-144		<	2.12E+01	<	9.54E-06	2.86E-03
TTP-Table3	Sn-113		<	6.64E+00	<	2.99E-06	8.96E-04
TTP-Table3	Zn-65		<	1.43E+01	<	6.44E-06	1.93E-03
TTP-Table3	Nb-94		<	4.93E+00	<	2.22E-06	6.66E-04

				Reagent Blank			
				filter section			
Tank 50	Alpha Count			8.20E+00		3.69E-06	1.11E-03
Rad Screen	Beta Count			3.52E+01		1.58E-05	4.75E-03
Sr-90			<	3.12E+01	<	1.40E-05	4.21E-03
Tc-99			<	3.93E-01	<	1.77E-07	5.31E-05
				ug/L		uCi/mL	
Tc-99 ICPMS				1.05E+00		1.78E-05	5.34E-03
Pu-238				7.07E+00		3.18E-06	9.54E-04
Pu-239/240				3.71E+00		1.67E-06	5.01E-04
Pu-241			<	3.81E+01	<	1.71E-05	5.14E-03
Am-241			<	5.44E+00	<	2.45E-06	7.34E-04
Cm-244				3.61E-01		1.62E-07	4.87E-05
Cm-242			<	4.89E-02	<	2.20E-08	6.60E-06
Se-79			<	2.20E+01	<	9.90E-06	2.97E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			4.59E-02
mass 231	231		<	0.15			4.59E-02
mass 232 (Th)	232			1.07			3.20E-01
mass 233	233		<	0.15			4.59E-02
mass 234 (U)	234		<	0.15			4.59E-02
mass 235 (U)	235		<	0.15			4.59E-02
mass 236 (U)	236		<	0.15			4.59E-02
mass 237 (Np)	237		<	0.15			4.59E-02
mass 238 (Pu & U)	238			1.10			3.29E-01
mass 239 (Pu)	239		<	0.15			4.59E-02
mass 240 (Pu)	240		<	0.15			4.59E-02
mass 241 (Am & Pu)	241		<	0.15			4.59E-02
mass 242 (Pu)	242		<	0.15			4.59E-02
mass 243 (Am)	243		<	0.15			4.59E-02
mass 244 (Cm)	244		<	0.15			4.59E-02
mass 245 (Cm)	245		<	0.15			4.59E-02
mass 246	246		<	0.15			4.59E-02
mass 247	247		<	0.15			4.59E-02

				Surrogate Run			
				liquid section			
				conc per 150 ml			
Method	Component	Units		3-159456			
				Sur-LB			
							TOTAL (mg)
ICPES	Ag	mg/L	<	0.038			0.0114
	Al	mg/L		1.36			0.41
	B	mg/L		384			115
	Ba	mg/L		0.017			0.0051
	Be	mg/L	<	0.005			0.0015
	Ca	mg/L		7.55			2.26
	Cd	mg/L		0.016			0.0048
	Co	mg/L	<	0.03			0.009
	Cr	mg/L	<	0.032			0.0096
	Cu	mg/L		0.15			0.045
	Fe	mg/L		0.435			0.1305
	La	mg/L	<	0.042			0.0126
	Li	mg/L		0.038			0.0114
	Mg	mg/L		0.357			0.1071
	Mn	mg/L		0.007			0.0021
	Mo	mg/L		0.033			0.0099
	Na	mg/L		17.9			5.4
	Ni	mg/L		0.054			0.0162
	P	mg/L		0.305			0.0915
	Pb	mg/L		0.194			0.0582
	Sb	mg/L		0.054			0.0162
	Si	mg/L		28.3			8.49
	Sn	mg/L		0.177			0.0531
	Sr	mg/L		0.012			0.0036
	Ti	mg/L		0.04			0.012
	Tl	mg/L		0.331			0.0993
	V	mg/L	<	0.027			0.0081
	Zn	mg/L		0.593			0.1779
	Zr	mg/L		0.030			0.009
AA (K)	K	mg/L		0.5345			0.16035
AA (AS)	As	ug/L	<	5			1.5
AA (SE)	Se	ug/L		3.1500			0.945
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60		<	6.49E+00	<	2.92E-06	4.38E-04
	Cs-137			5.06E+00		2.28E-06	3.42E-04
	Eu-154		<	6.35E+00	<	2.86E-06	4.29E-04
	Eu-155		<	9.40E+00	<	4.23E-06	6.35E-04
	Ra-226		<	1.20E+02	<	5.40E-05	8.10E-03
TTP-Table3	Cs-134		<	4.76E+00	<	2.14E-06	3.21E-04
TTP-Table3	Am-241		<	1.86E+01	<	8.37E-06	1.26E-03
TTP-Table3	Eu-152		<	3.98E+01	<	1.79E-05	2.69E-03
TTP-Table3	Ru-103		<	4.73E+00	<	2.13E-06	3.19E-04
TTP-Table3	Ru-106/Rh-106		<	5.45E+01	<	2.45E-05	3.68E-03
TTP-Table3	Sb-125		<	1.47E+01	<	6.62E-06	9.92E-04
TTP-Table3	Ce-144		<	2.28E+01	<	1.03E-05	1.54E-03
TTP-Table3	Sn-113		<	5.94E+00	<	2.67E-06	4.01E-04
TTP-Table3	Zn-65		<	1.33E+01	<	5.99E-06	8.98E-04
TTP-Table3	Nb-94		<	5.37E+00	<	2.42E-06	3.62E-04

				Surrogate Run			
				liquid section			
Tank 50	Alpha Count			6.40E+00		2.88E-06	4.32E-04
Rad Screen	Beta Count		<	1.92E+01	<	8.64E-06	1.30E-03
Sr-90			<	3.12E+01	<	1.40E-05	2.11E-03
Tc-99			<	1.12E+00	<	5.04E-07	7.56E-05
				ug/L		uCi/mL	
Tc-99 ICPMS			<	8.88E-01	<	1.51E-05	2.26E-03
Pu-238			<	9.71E-01	<	4.37E-07	6.55E-05
Pu-239/240			<	7.17E-01	<	3.23E-07	4.84E-05
Pu-241			<	2.91E+01	<	1.31E-05	1.96E-03
Am-241			<	1.01E+00	<	4.55E-07	6.82E-05
Cm-244			<	6.63E-02	<	2.98E-08	4.48E-06
Cm-242			<	2.78E-02	<	1.25E-08	1.88E-06
Se-79			<	2.90E+01	<	1.31E-05	1.96E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			4.59E-02
mass 231	231		<	0.15			4.59E-02
mass 232 (Th)	232			0.24			7.33E-02
mass 233	233		<	0.15			4.59E-02
mass 234 (U)	234		<	0.15			4.59E-02
mass 235 (U)	235		<	0.15			4.59E-02
mass 236 (U)	236		<	0.15			4.59E-02
mass 237 (Np)	237		<	0.15			4.59E-02
mass 238 (Pu & U)	238			0.83			2.50E-01
mass 239 (Pu)	239		<	0.15			4.59E-02
mass 240 (Pu)	240		<	0.15			4.59E-02
mass 241 (Am & Pu)	241		<	0.15			4.59E-02
mass 242 (Pu)	242		<	0.15			4.59E-02
mass 243 (Am)	243		<	0.15			4.59E-02
mass 244 (Cm)	244		<	0.15			4.59E-02
mass 245 (Cm)	245		<	0.15			4.59E-02
mass 246	246		<	0.15			4.59E-02
mass 247	247		<	0.15			4.59E-02

				Surrogate Run			
				filter section			
				conc per 300 ml			
Method	Component	Units		3-159457			
				Sur-FSB			
							TOTAL (mg)
ICPES	Ag	mg/L	<	0.038			0.0114
	Al	mg/L		22.8			6.8
	B	mg/L		76.5			23.0
	Ba	mg/L		0.052			0.0156
	Be	mg/L	<	0.005			0.0015
	Ca	mg/L		20.8			6.3
	Cd	mg/L		0.113			0.0339
	Co	mg/L		0.154			0.0462
	Cr	mg/L		0.983			0.2949
	Cu	mg/L		0.185			0.0555
	Fe	mg/L		30.7			9.2
	La	mg/L	<	0.042			0.0126
	Li	mg/L		5.80			1.74
	Mg	mg/L		0.539			0.1617
	Mn	mg/L		0.119			0.0357
	Mo	mg/L		0.892			0.2676
	Na	mg/L		100			30
	Ni	mg/L		0.498			0.150
	P	mg/L		0.544			0.1632
	Pb	mg/L		0.701			0.2103
	Sb	mg/L		0.545			0.1635
	Si	mg/L		1270			381
	Sn	mg/L		0.229			0.0687
	Sr	mg/L		0.265			0.0795
	Ti	mg/L		5.99			1.80
	Tl	mg/L		0.288			0.0864
	V	mg/L	<	0.027			0.0081
	Zn	mg/L		22.5			6.7
	Zr	mg/L		2.97			0.89
AA (K)	K	mg/L		2.5095			0.75285
AA (AS)	As	ug/L	<	5			1.5
AA (SE)	Se	ug/L		8.2500			2.475
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60		<	7.06E+00	<	3.18E-06	9.53E-04
	Cs-137		<	7.95E+00	<	3.58E-06	1.07E-03
	Eu-154		<	5.60E+00	<	2.52E-06	7.56E-04
	Eu-155		<	1.19E+01	<	5.36E-06	1.61E-03
	Ra-226		<	9.20E+01	<	4.14E-05	1.24E-02
TTP-Table3	Cs-134		<	4.09E+00	<	1.84E-06	5.52E-04
TTP-Table3	Am-241		<	1.84E+01	<	8.28E-06	2.48E-03
TTP-Table3	Eu-152		<	3.15E+01	<	1.42E-05	4.25E-03
TTP-Table3	Ru-103		<	4.20E+00	<	1.89E-06	5.67E-04
TTP-Table3	Ru-106/Rh-106		<	4.86E+01	<	2.19E-05	6.56E-03
TTP-Table3	Sb-125		<	1.37E+01	<	6.17E-06	1.85E-03
TTP-Table3	Ce-144		<	2.45E+01	<	1.10E-05	3.31E-03
TTP-Table3	Sn-113		<	5.84E+00	<	2.63E-06	7.88E-04
TTP-Table3	Zn-65		<	1.28E+01	<	5.76E-06	1.73E-03
TTP-Table3	Nb-94		<	5.57E+00	<	2.51E-06	7.52E-04

				Surrogate Run			
				filter section			
Tank 50	Alpha Count		<	3.06E+00	<	1.38E-06	4.13E-04
Rad Screen	Beta Count		<	1.92E+01	<	8.64E-06	2.59E-03
Sr-90			<	3.12E+01	<	1.40E-05	4.21E-03
Tc-99			<	3.27E-01	<	1.47E-07	4.41E-05
				ug/L		uCi/mL	
Tc-99 ICPMS			<	8.88E-01	<	1.51E-05	4.52E-03
Pu-238			<	2.35E+00	<	1.06E-06	3.17E-04
Pu-239/240			<	1.47E+00	<	6.62E-07	1.98E-04
Pu-241			<	4.02E+01	<	1.81E-05	5.43E-03
Am-241			<	2.02E+00	<	9.09E-07	2.73E-04
Cm-244			<	1.13E-01	<	5.09E-08	1.53E-05
Cm-242			<	3.83E-02	<	1.72E-08	5.17E-06
Se-79			<	2.20E+01	<	9.90E-06	2.97E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			4.59E-02
mass 231	231		<	0.15			4.59E-02
mass 232 (Th)	232			0.02			4.77E-03
mass 233	233		<	0.15			4.59E-02
mass 234 (U)	234		<	0.15			4.59E-02
mass 235 (U)	235		<	0.15			4.59E-02
mass 236 (U)	236		<	0.15			4.59E-02
mass 237 (Np)	237		<	0.15			4.59E-02
mass 238 (Pu & U)	238			0.02			5.99E-03
mass 239 (Pu)	239		<	0.15			4.59E-02
mass 240 (Pu)	240		<	0.15			4.59E-02
mass 241 (Am & Pu)	241		<	0.15			4.59E-02
mass 242 (Pu)	242		<	0.15			4.59E-02
mass 243 (Am)	243		<	0.15			4.59E-02
mass 244 (Cm)	244		<	0.15			4.59E-02
mass 245 (Cm)	245		<	0.15			4.59E-02
mass 246	246		<	0.15			4.59E-02
mass 247	247		<	0.15			4.59E-02

				Surrogate field blank			
				liquid section			
				conc per 150 ml			
Method	Component	Units		3-159458			
				SFB-LB			
							TOTAL (mg)
ICPES	Ag	mg/L	<	0.038			0.0114
	Al	mg/L		0.271			0.0813
	B	mg/L		0.305			0.0915
	Ba	mg/L	<	0.008			0.0024
	Be	mg/L	<	0.005			0.0015
	Ca	mg/L		0.707			0.2121
	Cd	mg/L	<	0.006			0.0018
	Co	mg/L	<	0.03			0.009
	Cr	mg/L		0.032			0.0096
	Cu	mg/L		0.206			0.0618
	Fe	mg/L		0.162			0.0486
	La	mg/L	<	0.042			0.0126
	Li	mg/L		0.136			0.0408
	Mg	mg/L		0.029			0.0087
	Mn	mg/L	<	0.006			0.0018
	Mo	mg/L	<	0.01			0.003
	Na	mg/L		22.4			6.7
	Ni	mg/L		0.08			0.024
	P	mg/L		0.084			0.0252
	Pb	mg/L	<	0.078			0.0234
	Sb	mg/L	<	0.048			0.0144
	Si	mg/L		19.4			5.8
	Sn	mg/L		0.048			0.0144
	Sr	mg/L	<	0.006			0.0018
	Ti	mg/L	<	0.015			0.0045
	Tl	mg/L		0.115			0.0345
	V	mg/L	<	0.027			0.0081
	Zn	mg/L		0.117			0.0351
	Zr	mg/L		0.034			0.0102
AA (K)	K	mg/L		0.1665			0.04995
AA (AS)	As	ug/L	<	5			1.5
AA (SE)	Se	ug/L		1.6000			0.48
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60		<	8.74E+00	<	3.93E-06	5.90E-04
	Cs-137		<	8.77E+00	<	3.95E-06	5.92E-04
	Eu-154		<	6.29E+00	<	2.83E-06	4.25E-04
	Eu-155		<	1.04E+01	<	4.68E-06	7.02E-04
	Ra-226		<	9.18E+01	<	4.13E-05	6.20E-03
TTP-Table3	Cs-134		<	4.38E+00	<	1.97E-06	2.96E-04
TTP-Table3	Am-241		<	1.61E+01	<	7.25E-06	1.09E-03
TTP-Table3	Eu-152		<	3.61E+01	<	1.62E-05	2.44E-03
TTP-Table3	Ru-103		<	4.93E+00	<	2.22E-06	3.33E-04
TTP-Table3	Ru-106/Rh-106		<	5.87E+01	<	2.64E-05	3.96E-03
TTP-Table3	Sb-125		<	1.20E+01	<	5.40E-06	8.10E-04
TTP-Table3	Ce-144		<	2.19E+01	<	9.86E-06	1.48E-03
TTP-Table3	Sn-113		<	5.26E+00	<	2.37E-06	3.55E-04
TTP-Table3	Zn-65		<	1.03E+01	<	4.64E-06	6.95E-04
TTP-Table3	Nb-94		<	5.95E+00	<	2.68E-06	4.02E-04

				Surrogate field blank			
				liquid section			
Tank 50	Alpha Count		<	2.97E+00	<	1.34E-06	2.00E-04
Rad Screen	Beta Count		<	1.92E+01	<	8.64E-06	1.30E-03
Sr-90			<	3.12E+01	<	1.40E-05	2.11E-03
Tc-99			<	1.12E+00	<	5.04E-07	7.56E-05
				ug/L		uCi/mL	
Tc-99 ICPMS			<	8.88E-01	<	1.51E-05	2.26E-03
Pu-238				1.69E+00		7.61E-07	1.14E-04
Pu-239/240			<	1.18E+00	<	5.31E-07	7.97E-05
Pu-241			<	2.70E+01	<	1.22E-05	1.82E-03
Am-241				2.17E+00		9.77E-07	1.46E-04
Cm-244			<	1.62E-01	<	7.29E-08	1.09E-05
Cm-242				1.31E-01		5.90E-08	8.84E-06
Se-79			<	2.90E+01	<	1.31E-05	1.96E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230		<	0.15			4.59E-02
mass 231	231		<	0.15			4.59E-02
mass 232 (Th)	232			3.65			1.09E+00
mass 233	233		<	0.15			4.59E-02
mass 234 (U)	234		<	0.15			4.59E-02
mass 235 (U)	235		<	0.15			4.59E-02
mass 236 (U)	236		<	0.15			4.59E-02
mass 237 (Np)	237		<	0.15			4.59E-02
mass 238 (Pu & U)	238			0.52			1.56E-01
mass 239 (Pu)	239		<	0.15			4.59E-02
mass 240 (Pu)	240		<	0.15			4.59E-02
mass 241 (Am & Pu)	241		<	0.15			4.59E-02
mass 242 (Pu)	242		<	0.15			4.59E-02
mass 243 (Am)	243		<	0.15			4.59E-02
mass 244 (Cm)	244		<	0.15			4.59E-02
mass 245 (Cm)	245		<	0.15			4.59E-02
mass 246	246		<	0.15			4.59E-02
mass 247	247		<	0.15			4.59E-02

				Surrogate field blank			
				filter section			
				conc per 300 ml			
Method	Component	Units		3-159459			
				SFB-FSB			
							TOTAL (mg)
ICPES	Ag	mg/L		0.038			0.0114
	Al	mg/L		14.8			4.4307
	B	mg/L		72.0			21.5937
	Ba	mg/L		0.02			0.006
	Be	mg/L		0.005			0.0015
	Ca	mg/L		0.501			0.1503
	Cd	mg/L		0.092			0.0276
	Co	mg/L		0.124			0.0372
	Cr	mg/L		0.172			0.0516
	Cu	mg/L		0.134			0.0402
	Fe	mg/L		1.19			0.3561
	La	mg/L		0.042			0.0126
	Li	mg/L		0.01			0.003
	Mg	mg/L		0.166			0.0498
	Mn	mg/L		0.02			0.006
	Mo	mg/L		0.1			0.03
	Na	mg/L		33.7			10.0992
	Ni	mg/L		0.080			0.024021906
	P	mg/L		0.166			0.0498
	Pb	mg/L		0.62			0.186
	Sb	mg/L		0.427			0.1281
	Si	mg/L		1420			426
	Sn	mg/L		0.21			0.063
	Sr	mg/L		0.007			0.0021
	Ti	mg/L		0.098			0.0294
	Tl	mg/L		0.339			0.1017
	V	mg/L		0.027			0.0081
	Zn	mg/L		0.083			0.0249
	Zr	mg/L		0.493			0.1479
AA (K)	K	mg/L		0.6160			0.1848
AA (AS)	As	ug/L		5			1.5
AA (SE)	Se	ug/L		3.4000			1.02
				dpm/mL		uCi/mL	TOTAL (uCi)
Gamma Scan	Co-60			5.67E+00	<	2.55E-06	7.65E-04
	Cs-137			2.13E+01		9.59E-06	2.88E-03
	Eu-154			6.22E+00	<	2.80E-06	8.40E-04
	Eu-155			1.22E+01	<	5.49E-06	1.65E-03
	Ra-226			8.98E+01	<	4.04E-05	1.21E-02
TTP-Table3	Cs-134			5.68E+00	<	2.56E-06	7.67E-04
TTP-Table3	Am-241			1.89E+01	<	8.51E-06	2.55E-03
TTP-Table3	Eu-152			3.84E+01	<	1.73E-05	5.18E-03
TTP-Table3	Ru-103			5.47E+00	<	2.46E-06	7.38E-04
TTP-Table3	Ru-106/Rh-106			4.30E+01	<	1.94E-05	5.81E-03
TTP-Table3	Sb-125			1.46E+01	<	6.57E-06	1.97E-03
TTP-Table3	Ce-144			2.59E+01	<	1.17E-05	3.50E-03
TTP-Table3	Sn-113			6.72E+00	<	3.02E-06	9.07E-04
TTP-Table3	Zn-65			1.29E+01	<	5.81E-06	1.74E-03
TTP-Table3	Nb-94			6.40E+00	<	2.88E-06	8.64E-04

				Surrogate field blank			
				filter section			
Tank 50	Alpha Count			3.80E+00		1.71E-06	5.13E-04
Rad Screen	Beta Count			2.12E+01		9.54E-06	2.86E-03
Sr-90				3.12E+01	<	1.40E-05	4.21E-03
Tc-99				1.54E-01	<	6.93E-08	2.08E-05
				ug/L		uCi/mL	
Tc-99 ICPMS				8.88E-01	<	1.51E-05	4.52E-03
Pu-238				2.47E+00		1.11E-06	3.33E-04
Pu-239/240				2.41E+00		1.08E-06	3.25E-04
Pu-241				4.17E+01	<	1.88E-05	5.63E-03
Am-241				3.92E+00	<	1.76E-06	5.29E-04
Cm-244				5.66E-02	<	2.55E-08	7.64E-06
Cm-242				5.66E-02	<	2.55E-08	7.64E-06
Se-79				2.20E+01	<	9.90E-06	2.97E-03
ICPMS	(10X dilution)			ug/L			ug
mass 230	230			0.15			4.59E-02
mass 231	231			0.15			4.59E-02
mass 232 (Th)	232			0.15			4.59E-02
mass 233	233			0.15			4.59E-02
mass 234 (U)	234			0.15			4.59E-02
mass 235 (U)	235			0.15			4.59E-02
mass 236 (U)	236			0.15			4.59E-02
mass 237 (Np)	237			0.15			4.59E-02
mass 238 (Pu & U)	238			0.37			1.12E-01
mass 239 (Pu)	239			0.15			4.59E-02
mass 240 (Pu)	240			0.15			4.59E-02
mass 241 (Am & Pu)	241			0.15			4.59E-02
mass 242 (Pu)	242			0.15			4.59E-02
mass 243 (Am)	243			0.15			4.59E-02
mass 244 (Cm)	244			0.15			4.59E-02
mass 245 (Cm)	245			0.15			4.59E-02
mass 246	246			0.15			4.59E-02
mass 247	247			0.15			4.59E-02

7. References

[1] C. A. Nash, et al., *Investigation of Varied Strontium-Transuranic Precipitation Chemistries for Crossflow Filtration*, **BNF-003-98-0171, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, April 18, 2000.

[2] C. A. Nash, H. H. Saito, W. R. Wilmarth, *Strontium-Transuranic Precipitation and Crossflow Filtration of 241-AN-102 Large C*, **SRT-RPP-2001-00006, Rev. 0 (WSRC-TR-2000-00506, Rev. 0)**, Westinghouse Savannah River Co., Aiken, SC, December 5, 2000.

[3] W. D. King, N. M. Hassan, D. J. McCabe, *Intermediate-Scale Ion Exchange Removal of Cesium and Technetium from Hanford Tank 241-AN-102***, SRT-RPP-2000-00014, Rev. 1 (WSRC-TR-2000-00420, Rev. 1)**, Westinghouse Savannah River Co., Aiken, SC, August 6, 2001.

[4] Mark L. Crowder, Charles L. Crawford, Hiroshi H. Saito, T. Bond Calloway, Jr., Luther V. Gibson, Jr., Mark A. Burdette, Stephen L. Crump, *Bench-Scale Evaporation of a Large Hanford Envelope C Sample (Tank 241-AN-102)*, **WSRC-TR-2000-00469, (SRT-RPP-2000-00043), Rev. 1**, Westinghouse Savannah River Co., Aiken, SC, May 2001.

[5] Daro Ferrara, Richard Groseclose, Robert Ray, Charles Crawford, Bond Calloway, *"Regulatory" Sample Analyses from A, B, C, LC and HLW Studies at SRTC*, **BNF-003-98-0082, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, January 7, 2000.

[6] *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Method 0060, Determination of Metals in Stack Emissions*, **USEPA Publication SW-846 Update III, Method 0060 Rev. 0**, December 1996.

[7] J. R. Zamecnik, *Description Of Melter And Offgas System for Large C Vitrification*, **BNF-003-98-141, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, August 17, 1999.

[8] G. S. Klinger, et al., *Organic Analysis of AW-101 and AN-107 Tank Waste***, Partial Draft Report: BNFL-RPT-001, Rev. 0**, Battelle Pacific Northwest Laboratories, Richland, WA, March 1999.

[9] *NFPA Standard on Explosion Prevention Systems 1992 Edition*, National Fire Protection Association, 1992.

[10] R. A. Jacobs, *Response to Technical Task Request HLW/DWPF/TTR-940013 – Off Gas LEL Analyzer Performance Improvement*, **WSRC-RP-94-0924, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, September 2, 1994.

[11] M. Plys, T. Anderson, I. Papp, N. Hunt, *Topical Report on the Management of Risks Posed by Explosive Hazards Present at the RPP-WTP*, **RPT-W375-SA-00002, Rev. 0**, BNFL Inc., Richland, WA, February 23, 2000.

[12] A. S. Choi, *Validation of DWPF Melter Off-Gas Combustion Model*, **WSRC-TR-2000-00100, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, June 23, 2000.

[13] A. S. Choi, *Material Balance for Hanford Waste Treatability Study Part B***, WSRC-TR-98-273, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, August 3, 1998.

7. References (continued)

[14] J. Howarth, *Sensitivity to LAW Vitrification Performance when Processing Sulfate Feed*, **BNFL Document CCN# 012046**, BNFL Inc., Richland, WA, March 8, 2000.

[15] GTS Duratek/ BNFL, Inc., *TWRS Privatization Project LAW Melter System 90 Percent Conceptual Design Report, Rev. 0*, BNFL Inc., Richland, WA, August 28, 1997.

[16] K. S. Matlack, I. S. Muller, I. L. Pegg, *Final Report: Results of Melter Tests Using TWRS LAW Envelope C Simulants*, Vitreous State Laboratory, The Catholic University of America, August 7, 1997.

[17] E. V. Morrey, *Comparision of Simulants to Actual Neutralized Current Acid Waste: Process and Product Testing of Three NCAW Core Samples from Tanks 101-AZ and 102-AZ*, **PNNL-11025**, Pacific Northwest National Laboratory, Richland, WA, October 1996.

[18] *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Method 0060*, **USEPA Publication SW-846 Update III, Method 0060 Rev. 0**, December 1996.

[19] *Determination of Metals Emissions from Stationary Sources (Method 29)*, **EPA Emission Measurement Center Pub. EMTIC TM-29**, April 25, 1996.

[20] M. E. Johnson, *TWRS-P Contract No. DE-AC06-96RL13308 – W375 – Analysis of Evaporator Condensates, Non-Condensable Fraction, and Concentrate, Melter Off-Gas Condensate and Non-Condensable Fraction, ILAW Glass, ILAW Glass Leachate*, **BNFL Doc. No. 000183**, BNFL Inc., Richland, WA, October 5, 1998.

[21] *Determination of Particulate Emissions form Stationary Sources (Method 5)***, EPA Emission Measurement Center Pub. EMTIC TM-005**, September 25, 1989.

[22] *An Alternate Procedure for Stack Gas Volumetric Flowrate Determination (Tracer Gas) (Method Alt-012)*, **EPA Emission Measurement Center Pub. EMTIC ALT-012**, May 23, 1994.

[23] M. E. Johnson, *TWRS-P Contract No. DE-AC06-96RL13308-W375 – Approval of Envelope C Surrogate Formulation for Sr/TRU Precipitation Tests*, November 6, 1998.

[24] M. E. Johnson, DRAFT – *Contract No. DE-AC06-96RL13308-W375-Conditions for Precipitation of Sr/TRU in Archive 241-AN-107 Sample*, July 7, 1999.

[25] E. K. Hansen and T. B. Calloway, *Characterization of Simulant LAW Envelope A, B, and C with Glass Formers*, **WSRC-TR-2000-00298, Rev. 0**, **(SRT-RPP-2000-00004)** Westinghouse Savannah River Co., Aiken, SC, August 24, 2000.

[26] A.Twarowski, *RPP-WTP Pilot Melter Feed System Performance Test Report Results*, TTR-PLT-031, Revision 0, October 13, 2000.

[27] I. S. Muller, H. Gan, and I. L. Pegg, *Physical and Rheological Properties of Waste Simulants and Melter Feeds for RPP-WTP LAW Vitrification*, **VSL-01R3520-1, Rev. 0**, Vitreous State Laboratory, Catholic University of America, Washington, D.C., January 16, 2001.

[28] J. R. Zamecnik and C. L. Crawford, *Task Technical and Quality Assurance Plan - Large Scale Vitrification of 241-AN-102 (Envelope C) Sample (Large C Vitrification)***, WSRC-**

7. References (continued)

TR-2000-00397 (SRT-RPP-2000-00034), Rev. 1, Westinghouse Savannah River Co., Aiken, SC, December 6, 2000.

[29] Laboratory Notebook, WSRC-NB-2000-00071, Westinghouse Savannah River Co.

[30] Laboratory Notebook, WSRC-NB-2000-00256, Westinghouse Savannah River Co.

[31] Laboratory Notebook, WSRC-NB-2000-00250, Westinghouse Savannah River Co.

[32] N. D. Hutson, *Run Plan for Initial Start-Up and Feeding of the BNFL (RPP-WTP) Large C Melter*, **BNF-003-98-0311, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, July 25, 2000.

[33] N. D. Hutson, *Run Plan for Start-Up and Feeding of the RPP-WTP Large C Melter – Surrogate #1 (Phase 2)*, **SRT-RPP-2000-00041, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, November 2, 2000.

[34] N. D. Hutson, *Run Plan for LC Melter – Surrogate #2*, **SRT-RPP-2000-00051, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, November 30, 2000.

[35] I. S. Muller (VSL) to C. L. Crawford, attachment *LAWC short summary for SRTC.doc* to electronic communication *Re: Final Confirmation of LC AN-102 High Sulfate Active Sample*, Westinghouse Savannah River Co., Aiken, SC, November 28, 2000.

[36] N. D. Hutson, *Run Plan for LC Melter – Radioactive Operation*, **SRT-RPP-2000-00055, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, December 7, 2000.

[37] R. F. Schumacher, *Summary of DWPF Waste Glass Physical Properties*, **WSRC-RD-91-11, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, January 30, 1991.

[38] American Minerals, Inc., *Material Data Sheet for Zircon (Zirconium Silicate),* American Minerals, Inc., King of Prussia, PA.

[39] A. S. Choi, *Maximum Total Organic Carbon Limit for DWPF Melter Feed (U),* **WSRC-TR-95-0119**, Westinghouse Savannah River Co., Aiken, SC, March 13, 1995.

[40] A. S. Choi, *Validation of DWPF Melter Off-Gas Combustion Model (U),* **WSRC-TR-2000-00100**, Westinghouse Savannah River Co., Aiken, SC, June 27, 2000.

[41] J. R. Zamecnik, *Analysis of Cascade Impactor and EPA Method 29 Data from the Americium/Curium Pilot Melter System*, **WSRC-RP-97-00937, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, November 19, 1997.

[42] J. R. Zamecnik, *Measurement of Cesium and Mercury Emissions From the Vitrification of Simulated High Level Radioactive Waste*, **Proceedings of the 1993 International Conference on Nuclear Waste Management and Environmental Remediation, Vol. 2**, Prague, Czech Republic, 1993.

[43] *RPP-WTP Pilot Melter Off-Gas System Sampling (High sulfate Envelope C) Test Results Report*, **TRR-PLT-56B, Rev. 0**, GTS DURATEK (2001).

[44] J. R. Zamecnik, D. H. Miller, J. T. Carter, *Measurement of Cesium Emissions During the Vitrification of Simulated High Level Radioactive Waste*, **Proceedings of the 22nd DOE/NRC Nuclear Air Cleaning and Treatment Conference**, Denver, CO, 1991.

7. References (continued)

[45] N. E. Bibler, T. L. Fellinger, S. L. Marra, R. J. O'Driscoll, J. W. Ray, W. T. Boyce, *Tc-99 and Cs-137 Volatility from the DWPF Production Melter During Vitrification of the First Macrobatch of HLW Sludge at the Savannah River Site*, **Mat. Res. Soc. Symp. Proc., Vol. 608**, p. 697 (2000).

[46] S. Arm (formerly with BNFL, Inc., currently with CH2M Hill Hanford Group), electronic mail to T. B. Calloway (SRTC) on 11/15/99, CHG Reference # is 009325.

[47] (a) W. L. Ebert and S. F. Wolfe, *Round-Robin Testing of a Reference Glass for Low-Activity Waste Forms*, **ANL-99/22,** Argonne National Laboratory, October, 1999.;

(b) W. L. Ebert and S.F. Wolf, *Dissolution Test for Low-Activity Waste Product Acceptance*, Argonne National Laboratory, **Proceedings of Spectrum '98**, pp. 724-731, Denver, Colorado, Sept. 13-18, 1998.

[48] D. Peeler, A. D. Cozzi, D. R. Best, C. J. Coleman and I. A. Reamer, *Characterization of the Low Level Waste Reference Glass (LRM),* **WSRC-TR-99-00095, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, March 30, 1999.

[49] Annual Book of ASTM Standards, Vol. 12.01. Association of Standards and Test Methods Committee C26, *Standard Test Methods for Determining Chemical Durability of Nuclear Waste Glasses: The Product Consistency Test (PCT),* **ASTM C1285-97**, pp. 774-791, 1998.

[50] Crucible-Scale Regulatory Glass Analysis: D. M. Ferrara, R. J. Ray, C. L. Crawford and W. P. Kubilius, *Results from Analysis of a Hanford Tank 241-AN-102 Crucible-Scale Glass Waste Form*, **WSRC-TR-2001-00566, Rev. 1 (SRT-RPP-2001-0013, Rev. 1)**, Westinghouse Savannah River Co., Aiken, SC, November 16, 2001; Large C Melter Regulatory Glass Analysis: D. M. Ferrara, R. J. Ray, C. L. Crawford, W. P. Kubilius and R. F. Schumacher, *Results from Analysis of a Hanford Tank 241-AN-102 Melter-Scale Glass Waste Form*, **WSRC-TR-2001-00584, (SRT-RPP-2001-00220, Rev. 0)**, Westinghouse Savannah River Co., Aiken, SC, April 26, 2002.

[51] Note: This work was initiated under the Tank Waste Remediation System Privatization Contract with DOE:

TWRS Privatization, **Contract No. DE-AC27-96RL13308, Mod. No. M014, Section C: Statement of Work**, November 2000. (See:

http://www.hanford.gov/doe/contracts/de-ac06-96rl13308/conformed/index.html)

The TWRS Contract was replaced by the Waste Treatment Plant DOE Contract in early 2001 with DOE:

WTP Contract, **Contract No. DE-AC27-01RV14136, Mod. No. M013, Section C: Statement of Work, February 2002**. (See:

http://www.hanford.gov/orp/contracts/de-ac27-01rv14136/toc.html

[52] G. B. Mellinger and J. L. Daniel, *Approved Reference and Testing Materials for Use in Nuclear Waste Management Research and Development Programs*, **PNL-4955-1**, Pacific Northwest Laboratory, December, 1983.

[53] C. M. Jantzen, N. E. Bibler, D. C. Beam, C. L. Crawford and M. A. Pickett, *Characterization of the Defense Waste Processing Facility (DWPF) Environmental*

7. References (continued)

Assessment (EA) Glass Standard Reference Material, **WSRC-TR-92-346, Rev. 1**, Westinghouse Savannah River Co., Aiken, SC, June 1, 1993.

[54] C. M. Jantzen, M. A. Pickett, K. G. Brown, T. B. Edwards, and D. C. Beam, *Process/Product Models for the DWPF: Part 1. Predicting the glass Durability from Composition Using a Thermodynamic Energy Hydration Model (THERMO)*, **Volume 2: Appendix G, Pages G9 – G11, WSRC-TR-93-672, Rev. 1,** Westinghouse Savannah River Co., Aiken, SC, 1995.

[55] J. R. Zamecnik, *Sampling of the Large C Melter Offgas using Appropriate Portions of EPA Methods*, **SRT-RPP-2000-00042**, Westinghouse Savannah River Co., Aiken, SC, November 8, 2000.

[56] F. Pennebaker, *Differences Between EPA Method 60 and Current ADS Methods*, **SRT-ADS-2001-0039**, Westinghouse Savannah River Co., Aiken, SC, January 31, 2001

[57] M. S. Hay, M. G. Bronikowski, C. W. Hsu, T. L. White, *Chemical Characterization of an Envelope C Sample from Hanford Tank 241-AN-102*, **BNF-003-98-250, Rev. 0**, Westinghouse Savannah River Co., Aiken, SC, July 31, 2000.