Composition and Property Measurements for PHA Phase 3 Glasses

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COMPOSITION AND PROPERTY MEASUREMENTS FOR PHA PHASE 3 GLASSES (U)

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COMPOSITION AND PROPERTY MEASUREMENTS FOR PHA PHASE 3 GLASSES (U)

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TABLE OF CONTENTS

Summary and Conclusions	1
Introduction	1
Results and Discussion	2
Chemical Compositions	2
PCT Results	6
Viscosity at 1150 °C	9
Liquidus Temperature (T_L)	10
Surface Crystallization	11
Phase Separation	11
Conclusions	12
References	13
Appendix: Supplemental Tables and Exhibits	15

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SUMMARY AND CONCLUSIONS

The results presented in this report are for six Phase 3 Precipitate Hydrolysis Aqueous (PHA) glasses, each of which was targeted to contain 22 wt% simulated PUREX sludge on an oxide basis. The target PHA concentration was varied from 7 to 10 to 13 wt % oxides both at 1.25 and 2.5 wt % (on an oxide basis) washed monosodium titanate (MST).

All six of these glasses were durable when compared to the Environmental Assessment (EA) glass (as determined by the 7-day Product Consistency Test, the PCT) and processible (from measured viscosity and bounding liquidus temperature data). Therefore, the results imply that the Defense Waste Processing Facility (DWPF) would be able to run these six glass formulations at 22 wt % PUREX waste loading on an oxide basis.

The models currently in DWPF's Product Composition Control System (PCCS) were used to predict durability, homogeneity, liquidus, and viscosity for these six glasses. All six glasses were predicted to be phase separated, and consequently prediction of glass durability is precluded with the current models. However, the measured durabilities (as determined by the PCT) were within the 95% confidence bands of the model. Further efforts will be required to resolve this issue on phase separation (inhomogeneity).

The liquidus model predicted acceptable liquidus temperatures for all six glasses. The bounding liquidus temperatures that were measured (<900°C) were below the model predictions. The measured viscosities were below the predictions of the model and therefore, conservative to the upper limit of viscosity. The lowest measured viscosity value was 33.1 poise at 1150°C, corresponding to the glass with the highest level of PHA and at the lower level of MST. The model predictions may not be conservative with respect to the lower operating limit.

INTRODUCTION

One of the Alternative Salt Disposition Flowsheets being considered would require that the Defense Waste Processing Facility (DWPF) vitrify a coupled feed containing high level waste (HLW) and Precipitate Hydrolysis Aqueous (PHA). A Technical Task Request (TTR) [1] was received by the Savannah River Technology Center (SRTC) requesting that a glass variability study be conducted to explore the processability and product quality of the glass composition region for this alternative to the In-Tank Precipitation (ITP) Process. A Task Technical and Quality Assurance (TT&QA) plan [2] was issued by SRTC in response to the TTR. The objective of this task is to obtain information on the feasibility of incorporating anticipated levels of PHA into DWPF glass with and without doubling the nominal levels of monosodium titanate (MST).

A set of target compositions from which the glasses supporting this task are to be selected was provided in the memorandum appearing as Attachment I of [3]. Process and product property predictions for these glasses are also provided in that attachment. The candidate glasses identified involved three sludge types: Purex, HM, and Blend; covered sludge loadings (in the glass) of 22, 26, and 30 oxide weight percent (wt%); utilized PHA loadings (in the glass) of 7, 10, and 13 oxide wt%; and included MST concentrations (in the glass) at 1.25 and 2.5 wt%. For each composition, the remainder of the glass consisted of Frit 202. The glasses, batched, and fabricated using the Purex sludge at a target loading of 22 wt% of the glass, were selected to comprise Phase 3 of this study. The general, target compositions of these glasses are provided in Table 1.

Table 1: General Composition of the PHA Phase 3 Glasses

Glass ID	Purex Sludge	PHA	MST	Frit
pha01	22%	7%	1.25%	69.75%
pha02	22%	10%	1.25%	66.75%
pha03	22%	13%	1.25%	63.75%
pha04	22%	7%	2.5%	68.50%
pha05	22%	10%	2.5%	65.50%
pha06	22%	13%	2.5%	62.50%

The properties of interest for these glasses included durability (as measured by the 7-day Product Consistency Test (PCT) [4]), viscosity at 1150 °C, and liquidus temperature. The purpose of this report is to provide and investigate comparisons between

- the measured and target compositions of this set of Phase 3 PHA glasses and
- the property measurements and their predictions.

The impact of these results on the path forward selected for this preliminary, PHA glass variability study will also be discussed.

RESULTS AND DISCUSSION

The six glasses comprising Phase 3 of the PHA study were designated as pha01 through pha06. Composition and property measurements of these glasses were conducted in parallel with the six glasses comprising Phase 3 of the other ITP replacement alternative, designated as the CST (Crystalline Silicotitanate) study. This approach helps ensure that the PHA and CST glasses are fabricated, characterized, and analyzed under very similar conditions. The CST Phase 3 results were reported in [5], and included in the attachments of that report are the analytical plans that were used to generate the measurements required to support both (PHA and CST) studies. These plans, which are identified in the discussion that follows, were prepared to support the overall Task Technical and QA plan [2] and the analytical study plan [6]. The results of these measurements (both composition and properties) are presented in this section.

Chemical Compositions

Table 2 provides the target oxide compositions for each of the PHA glasses. See Attachment I of [3] for details on the development of these target compositions. The Phase 3 glasses, as previously stated, appear as pha01 through pha06 in Table 2.

Table 2: Target Oxide Compositions (in weight percents, wt% 's) of the PHA Glasses

Table 27: Target Glass Compositions (in weight percents, wt% %) of the Fritt Glasses																	
				Glass													
Sludge	MST	PHA	Frit 202	ID	Al ₂ O ₃	B ₂ O ₃	BaO	CaO	Cr ₂ O ₃	CuO	Fe ₂ O ₃	K ₂ O	Li ₂ O	MgO	MnO	Na ₂ O	
22	1.250	7	69.750	pha01	2.540	7.974	0.084	0.945	0.106	0.568	9.899	3.350	4.785	1.448	1.727	7.869	
22	1.250	10	66.750	pha02	2.522	8.803	0.084	0.941	0.106	0.791	9.897	4.730	4.579	1.389	1.727	8.017	
22	1.250	13	63.750	pha03	2.504	9.632	0.084	0.936	0.106	1.014	9.894	6.110	4.373	1.329	1.727	8.165	
22	2.500	7	68.500	pha04	2.532	7.876	0.084	0.943	0.106	0.568	9.898	3.350	4.699	1.423	1.727	7.944	
22	2.500	10	65.500	pha05	2.514	8.705	0.084	0.939	0.106	0.791	9.896	4.730	4.493	1.364	1.727	8.092	
22	2.500	13	62.500	pha06	2.496	9.534	0.084	0.934	0.106	1.014	9.893	6.110	4.288	1.304	1.727	8.240	
26	1.250	7	65.750	pha07	2.901	7.660	0.099	1.092	0.125	0.576	11.685	3.365	4.510	1.381	2.041	8.116	
26	1.250	10	62.750	pha08	2.883	8.488	0.099	1.088	0.125	0.800	11.683	4.745	4.305	1.322	2.041	8.264	
26	1.250	13	59.750	pha09	2.865	9.317	0.099	1.083	0.125	1.023	11.681	6.125	4.099	1.262	2.041	8.412	
26	2.500	7	64.500	pha10	2.894	7.561	0.099	1.090	0.125	0.576	11.684	3.365	4.425	1.356	2.041	8.191	
26	2.500	10	61.500	pha11	2.876	8.390	0.099	1.086	0.125	0.800	11.682	4.745	4.219	1.297	2.041	8.339	
26	2.500	13	58.500	pha12	2.858	9.219	0.099	1.081	0.125	1.023	11.680	6.125	4.013	1.237	2.041	8.487	
30	1.250	7	61.750	pha13	3.263	7.345	0.114	1.239	0.144	0.585	13.472	3.380	4.236	1.314	2.355	8.363	
30	1.250	10	58.750	pha14	3.245	8.174	0.114	1.234	0.144	0.808	13.470	4.760	4.030	1.255	2.355	8.511	
30	1.250	13	55.750	pha15	3.227	9.003	0.114	1.230	0.144	1.031	13.467	6.140	3.824	1.195	2.355	8.659	
30	2.500	7	60.500	pha16	3.256	7.246	0.114	1.237	0.144	0.585	13.471	3.379	4.150	1.289	2.355	8.438	
30	2.500	10	57.500	pha17	3.238	8.075	0.114	1.233	0.144	0.808	13.469	4.759	3.945	1.230	2.355	8.586	
30	2.500	13	54.500	pha18	3.220	8.904	0.114	1.228	0.144	1.031	13.466	6.139	3.739	1.170	2.355	8.734	

Table 2: Target Oxide Compositions (in weight percents, wt%'s) of the PHA Glasses (continued)

Sludge	Glass														(SO ₄)
	MST	PHA	Frit 202	ID	NIo	P ₂ O ₅	PbO	SiO ₂	TiO ₂	U ₃ O ₈	ZnO	ZrO ₂	F	Cl	
22	1.250	7	69.750	pha01	0.930	0.030	0.096	53.684	1.128	2.003	0.086	0.109	0.032	0.240	0.173
22	1.250	10	66.750	pha02	0.930	0.030	0.096	51.404	1.127	2.003	0.086	0.109	0.032	0.240	0.173
22	1.250	13	63.750	pha03	0.930	0.030	0.096	49.124	1.125	2.003	0.086	0.109	0.032	0.240	0.173
22	2.500	7	68.500	pha04	0.930	0.030	0.096	52.734	2.226	2.003	0.086	0.109	0.032	0.240	0.173
22	2.500	10	65.500	pha05	0.930	0.030	0.096	50.454	2.225	2.003	0.086	0.109	0.032	0.240	0.173
22	2.500	13	62.500	pha06	0.930	0.030	0.096	48.174	2.224	2.003	0.086	0.109	0.032	0.240	0.173
26	1.250	7	65.750	pha07	1.099	0.036	0.114	50.766	1.126	2.367	0.102	0.129	0.038	0.283	0.205
26	1.250	10	62.750	pha08	1.099	0.036	0.114	48.486	1.125	2.367	0.102	0.129	0.038	0.283	0.205
26	1.250	13	59.750	pha09	1.099	0.036	0.114	46.206	1.124	2.367	0.102	0.129	0.038	0.283	0.205
26	2.500	7	64.500	pha10	1.099	0.036	0.114	49.816	2.224	2.367	0.102	0.129	0.038	0.283	0.205
26	2.500	10	61.500	pha11	1.099	0.036	0.114	47.536	2.223	2.367	0.102	0.129	0.038	0.283	0.205
26	2.500	13	58.500	pha12	1.099	0.036	0.114	45.256	2.222	2.367	0.102	0.129	0.038	0.283	0.205
30	1.250	7	61.750	pha13	1.268	0.041	0.132	47.849	1.125	2.731	0.118	0.149	0.043	0.327	0.236
30	1.250	10	58.750	pha14	1.268	0.041	0.132	45.569	1.123	2.731	0.118	0.149	0.043	0.327	0.236
30	1.250	13	55.750	pha15	1.268	0.041	0.132	43.289	1.122	2.731	0.118	0.149	0.043	0.327	0.236
30	2.500	7	60.500	pha16	1.268	0.041	0.132	46.899	2.223	2.731	0.118	0.149	0.043	0.327	0.236
30	2.500	10	57.500	pha17	1.268	0.041	0.132	44.619	2.221	2.731	0.118	0.149	0.043	0.327	0.236
30	2.500	13	54.500	pha18	1.268	0.041	0.132	42.339	2.220	2.731	0.118	0.149	0.043	0.327	0.236

Predictions for the properties of interest generated for these target compositions by the models utilized by the Defense Waste Processing Facility (DWPF) are also included in the discussion provided in Attachment I of [3]. These properties, for a given composition, relate to its processability and its product quality. For a given composition, acceptable property characteristics and reliable property predictions (using the current DWPF models) are of interest. Comparisons between property predictions and property measurements are provided for these Phase 3 PHA glasses in the discussion that follows.

Glasses were batched and fabricated to the target compositions corresponding to rows pha01 through pha06 of Table 2. In addition to the Phase 3 glasses (both PHA and CST), a standard glass (Batch 1) and a standard uranium-bearing glass were included in the planning of these analyses (for possible bias correction). An analytical plan (in the form of a memorandum) was provided to assist the SRTC-Mobile Laboratory (SRTC-ML) in conducting these analyses (see Attachment I of [5]). Due to an equipment problem at that laboratory, the samples were subsequently submitted to the Analytical Development Section (ADS) of SRTC for analysis.

Glasses were batched using the appropriate combinations of Purex sludge, glass formers, PHA, and MST. The simulated Purex sludge was batched from dry chemicals and has an oxide composition provided in Table 3 of Attachment I of [3]. PHA was batched from chemicals and has an oxide composition provided in Table 2 of Attachment I of [3]. A basic MST solution was obtained from D. Hobbs. This material was washed and then dried. The composition of MST was determined by the SRTC-ML and is presented in Table 1 of Attachment I of [3]. Frit 202, Lot 14 was obtained from the DWPF. The Frit 202 composition is given in Table 7 of Attachment I in [3].

For each glass, the combined powders (~120 grams) were added to a 250 mL Pt-Au crucible and placed in a calibrated furnace, heated to 1150°C at a rate of 10°C/minute, and then held for four hours at 1150°C. The crucible was then removed and the glass immediately poured onto a clean stainless steel plate.

Tables A.1 and A.2 in the Appendix provide the composition measurements obtained by ADS following an analytical plan similar to that provided in Attachment I of this report.¹ Two dissolutions (microwave and peroxide fusion) were used to generate these composition measurements. Table A.1 provides the peroxide fusion (pf) results and Table A.2 the microwave (MW) results. Calcium and silicon cation concentrations were measured using both preparation methods.

¹ ADS LIMS numbers were assigned to the dissolved samples.

Exhibit A.1 in the Appendix provides a plot of the measurements by glass sample id by oxide. The patterns presented by the measurements for glass pha01 are of concern. The measurements corresponding to one of the two microwave dissolutions of this glass have been labeled in these plots as a "z." Note that almost all of the measurements derived from the microwave dissolution method reveal a discrepancy between the results from the duplicate preparations by this method. The results represented by the "z" are outliers (perhaps due to an incomplete dissolution of the glass sample) and will not be included in the analyses that follow.

A review of the results from the standards was conducted for insight into the possibility that the ICP calibration contributes (in a systematic way) to the variation seen in the oxide measurements for the Phase 3 glasses. Exhibits A.2 and A.3 in the Appendix provide plots of the oxide measurements per analytical block by oxide by dissolution method. Table 3 provides the average measured composition for the two types of standards included in this analytical plan by analytical block. The reference values for the standards are also provided in this table.

Table 3: Measurements from Glass Standards

Oxide	std (Batch 1)			Ustd (Uranium-bearing Standard)		
	Analytical Block		Reference	Analytical Block		Reference
	1	2		1	2	
	3 obs	3 obs	Value	2 obs	2 obs	Value
Al ₂ O ₃	4.935	4.860	4.877	4.121	4.087	4.100
B ₂ O ₃	7.627	7.967	7.777	8.818	9.362	9.209
CaO (pf)	1.237	1.231	1.220	1.337	1.326	1.301
CaO (MW)	1.231	1.287	1.220	1.355	1.416	1.301
CaO (avg)	1.234	1.259	1.220	1.346	1.371	1.301
Cr ₂ O ₃	0.112	0.112	0.107	0.270	0.272	0.000
CuO	0.402	0.399	0.399	0.020	0.021	0.000
Fe ₂ O ₃	13.579	13.227	12.839	14.156	13.883	13.196
K ₂ O	3.196	3.195	3.327	2.892	2.938	2.999
Li ₂ O	4.514	4.515	4.429	3.122	3.128	3.057
MgO	1.429	1.432	1.419	1.197	1.207	1.210
MnO	1.729	1.739	1.726	2.820	2.849	2.892
Na ₂ O	9.240	9.142	9.003	12.188	12.077	11.795
NiO	0.800	0.780	0.751	1.161	1.129	1.120
SiO ₂ (pf)	48.207	47.709	50.220	44.711	43.969	45.353
SiO ₂ (MW)	51.425	52.137	50.220	45.150	46.382	45.353
SiO ₂ (avg)	49.816	49.923	50.220	44.930	45.176	45.353
TiO ₂	0.710	0.699	0.677	1.040	1.025	1.049
U ₃ O ₈	0.349	0.340	0.000	2.639	2.452	2.406
ZrO ₂	0.177	0.137	0.098	0.022	0.022	0.000
Sum of Oxides	99.919	99.796	98.869	100.774	101.113	99.687

The analytical results from the Batch 1 samples were used to bias-correct for a possible ICP calibration effect (a block effect) in the other measurements.² This was accomplished for each oxide in turn by taking the original oxide measurement, noting its block, and then multiplying the measurement by the ratio of the corresponding reference value for Batch 1 divided by the average oxide measurement for Batch 1 in that block. The calcium and silicon values for each dissolution method were adjusted via this process. This approach was used to bias-correct the composition measurements of the Phase 3 and standard glasses.

Exhibit A.4 in the Appendix provides plots of these measurements for each oxide over all of the glasses (including the standards), and Table 4 provides summary information for these measurements. The sums of oxides for the target, measured, and measured bias-corrected (bc) compositions are also provided. A review of these sums shows that they are all within the interval of 95 to 105 weight

² Bias corrections of this type have been advantageous (see for example "A Statistical Review of Data from the SRTC Mobile Laboratory," WSRC-RP-98-00430, Revision 0, June 15, 1998) but not always. In some instances, bias correction does not improve the accuracy of the results. Measurements are bias-corrected in this report, and bias-corrected values are considered in the comparisons that follow. Conclusions, developed from these comparisons, that are insensitive to the way the glass compositions are represented (target, measured, or bias-corrected) demonstrate robustness to which representation might be nearer the true composition for each glass.

percent with the lowest value being 96.5 wt% for the bias-corrected composition of pha05 and the largest, 100.9 wt%, for the measured composition of the uranium-bearing standard glass. Another observation from this exhibit and table is the closeness of the TiO₂ measurements to their respective targets for these PHA glasses. A problem was seen in Phases 1 [3] and 2 [7]. Namely, the TiO₂ measurements for the PHA glasses fell short of their respective target values even though the measurements for the standards compared very favorably to their targets. This behavior prompted a re-evaluation of a source of TiO₂, the MST. A subsequent analysis of MST revealed a larger than expected moisture content. However, as discussed in [3], glasses for Phases 1 and 2 were batched and fabricated prior to this discovery. Batching formulations were subsequently modified to account for the additional loss that would be expected for this situation. Glasses for Phase 3 were and glasses for Phase 4 are to be batched in a manner fully accounting for the loss of the additional moisture. In addition, Phase 4 is to include selected glasses from Phases 1 and 2 that are to be re-batched using the new formulations. This will provide better coverage of the higher MST loadings for these phases of the CST study. Note that the results seen in Phase 3 indicate that the targeted MST loadings were achieved for the glasses of this phase.

**Table 4: Target, Measured, and Bias-Corrected Compositions (in wt%)
for the PHA Phase 3 Glasses**

	<i>Batch 1</i>			<i>Uranium Standard (Ustd)</i>			<i>pha01</i>		
	Target	Measured	Measured Bias-cor.	Target	Measured	Bias-cor.	Target	Measured	Measured Bias-cor.
Al ₂ O ₃	4.877	4.898	4.877	4.100	4.104	4.086	2.540	2.868	2.856
B ₂ O ₃	7.777	7.797	7.777	9.209	9.090	9.065	7.974	9.171	9.147
CaO	1.220	1.246	1.220	1.301	1.358	1.329	0.945	1.041	1.003
Cr ₂ O ₃	0.107	0.112	0.107	0.000	0.271	0.258	0.106	0.178	0.170
CuO	0.399	0.401	0.399	0.000	0.020	0.020	0.568	0.580	0.578
Fe ₂ O ₃	12.839	13.403	12.839	13.196	14.019	13.430	9.899	9.970	9.550
K ₂ O	3.327	3.196	3.327	2.999	2.915	3.035	3.350	2.973	3.095
Li ₂ O	4.429	4.514	4.429	3.057	3.125	3.066	4.785	4.751	4.661
MgO	1.419	1.430	1.419	1.210	1.202	1.193	1.448	1.464	1.453
MnO	1.726	1.734	1.726	2.892	2.835	2.822	1.727	2.065	2.056
Na ₂ O	9.003	9.191	9.003	11.795	12.132	11.885	7.869	8.873	8.692
NiO	0.751	0.790	0.751	1.120	1.145	1.089	0.930	0.949	0.902
SiO ₂	50.220	49.869	50.220	45.353	45.053	45.408	53.684	52.702	51.831
TiO ₂	0.677	0.704	0.677	1.049	1.033	0.992	1.128	1.160	1.115
U ₃ O ₈	0.000	0.344	0.344	2.406	2.545	2.545	2.003	1.542	1.542
ZrO ₂	0.098	0.157	0.098	0.000	0.022	0.014	0.109	0.160	0.101
Sum of Oxides	98.869	99.857	99.284	99.687	100.943	100.311	99.065	99.093	98.689
	<i>pha02</i>			<i>pha03</i>			<i>pha04</i>		
	Target	Measured	Measured Bias-cor.	Target	Measured	Bias-cor.	Target	Measured	Measured Bias-cor.
Al ₂ O ₃	2.522	2.718	2.707	2.504	2.542	2.531	2.532	2.517	2.507
B ₂ O ₃	8.803	8.523	8.497	9.632	9.368	9.341	7.876	8.901	8.875
CaO	0.941	1.009	0.987	0.936	0.941	0.921	0.943	0.953	0.932
Cr ₂ O ₃	0.106	0.169	0.161	0.106	0.172	0.164	0.106	0.137	0.131
CuO	0.791	0.680	0.677	1.014	1.009	1.004	0.568	0.565	0.563
Fe ₂ O ₃	9.897	9.859	9.445	9.894	9.995	9.575	9.898	8.351	8.000
K ₂ O	4.730	3.663	3.813	6.110	5.606	5.836	3.350	3.099	3.226
Li ₂ O	4.579	4.679	4.591	4.373	4.458	4.374	4.699	4.936	4.843
MgO	1.389	1.387	1.376	1.329	1.358	1.347	1.423	1.475	1.464
MnO	1.727	1.999	1.990	1.727	1.699	1.691	1.727	1.794	1.786
Na ₂ O	8.017	8.249	8.081	8.165	8.181	8.014	7.944	8.401	8.230
NiO	0.930	0.924	0.878	0.930	0.851	0.809	0.930	0.828	0.787
SiO ₂	51.404	51.174	51.557	49.124	48.797	49.167	52.734	55.094	55.471
TiO ₂	1.127	1.170	1.124	1.125	1.168	1.123	2.226	2.373	2.280
U ₃ O ₈	2.003	1.659	1.659	2.003	2.760	2.760	2.003	1.081	1.081
ZrO ₂	0.109	0.153	0.097	0.109	0.223	0.135	0.109	0.135	0.086
Sum of Oxides	99.075	98.088	97.713	99.081	99.201	98.865	99.068	100.714	100.334

**Table 4: Target, Measured, and Bias-Corrected Compositions (in wt%)
for the PHA Phase 3 Glasses (continued)**

	<i>pha05</i>			<i>pha06</i>		
	Target	Measured	Blas-cor.	Target	Measured	Blas-cor.
Al ₂ O ₃	2.514	2.508	2.497	2.496	2.602	2.591
B ₂ O ₃	8.705	7.974	7.953	9.534	9.196	9.173
CaO	0.939	0.920	0.900	0.934	0.972	0.951
Cr ₂ O ₃	0.106	0.150	0.143	0.106	0.153	0.146
CuO	0.791	0.722	0.719	1.014	0.953	0.949
Fe ₂ O ₃	9.896	9.975	9.555	9.893	10.019	9.598
K ₂ O	4.730	4.309	4.485	6.110	5.757	5.994
Li ₂ O	4.493	4.596	4.509	4.288	4.353	4.271
MgO	1.364	1.386	1.375	1.304	1.316	1.305
MnO	1.727	1.629	1.621	1.727	1.789	1.780
Na ₂ O	8.092	8.054	7.889	8.240	8.270	8.101
NiO	0.930	0.846	0.804	0.930	0.874	0.831
SiO ₂	50.454	48.402	48.834	48.174	48.432	48.793
TiO ₂	2.225	2.296	2.206	2.224	2.309	2.219
U ₃ O ₈	2.003	2.869	2.869	2.003	2.441	2.441
ZrO ₂	0.109	0.153	0.096	0.109	0.160	0.101
Sum of Oxides	99.078	96.861	96.532	99.086	99.670	99.318

PCT Results

The six PHA glasses making up Phase 3, after being batched and fabricated, were subjected to the 7-day Product Consistency Test (PCT) as an assessment of their durabilities [4]. More specifically, Method A of the PCT (ASTM C1285) was used for these measurements. Since durability is the critical product quality metric for vitrified nuclear waste, a review of the PCTs for these glasses was seen as a prerequisite for additional testing of these glasses. The PCTs were to be conducted in triplicate for the Phase 3 glasses. In addition, PCTs were also conducted in triplicate for samples of the Environmental Assessment (EA) glass, the ARM glass, and a blank (ASTM Type I water). An analytical plan supporting these tests was provided in the form of a memorandum (see Attachment II of [5]). This plan was intended to provide assistance to the SRTC-ML in measuring the compositions of the solutions resulting from these PCTs. However, due to equipment problems, the SRTC-ML was unable to conduct these analyses. The Analytical Development Section (ADS) of SRTC used a modified version of the analytical plan (ADS LIMS numbers were assigned to the blind samples) to perform these analyses. Of primary interest were the concentrations (in parts per million, ppm) of boron (B), lithium (Li), sodium (Na), and silicon (Si). Samples of a multi-element solution standard were also included in this analytical plan (as a check on the accuracy of the Inductively Coupled Plasma (ICP) – Emission Spectrometer used for these measurements).

The results from these tests are given in Table A.3 of the Appendix. Any measurement determined to be below detection was replaced by its detection limit in subsequent analyses. PCT leachate concentrations are typically normalized using the cation composition (expressed as a weight percent) in the glass to obtain a grams-per-liter (g/L) leachate concentration. The normalization of the PCTs is usually conducted using the measured compositions of the glasses. This is the preferred normalization process for the PCTs. For completeness, the target cation compositions will also be used to conduct this normalization.

As is the usual convention, the common logarithm of the normalized PCT (normalized leachate, NL) for each element of interest will be determined and used for comparisons. To accomplish this computation, one must

1. Determine the common logarithm of the elemental parts per million (ppm) leachate concentration for each of the triplicates and each of the elements of interest (these values are provided in Table A.3 of the Appendix),
2. Average the common logarithms over the triplicates for each element of interest, and then

Normalizing Using Measured Composition (preferred method)

3. Subtract a quantity equal to 1 plus the common logarithm of the average cation measured concentration (expressed as a weight percent of the glass) from the average computed in step 2.

Or

Normalizing Using Target Composition

3. Subtract a quantity equal to 1 plus the common logarithm of the target cation concentration (expressed as a weight percent of the glass) from the average computed in step 2.

As a preliminary step to completing these normalizations of the PCTs, a review of the data was conducted. Exhibit A.5 in the Appendix provides plots of the leachate concentrations by sample id and by element with and without the EA and the blank samples. No problems are seen in these data, in that the results are reasonably consistent across all Phase 3 and standard glasses. Table 5 provides a look at the results from the three analyses of the multi-element standard solution that were included in each block of the analytical plan. These results also indicate consistent and reasonably accurate results from these analyses.

Table 5: Measurements of Standard Solution

Block	Sequence	B (ppm)	Si (ppm)	Na (ppm)	Li (ppm)
1	1	19.5	48.9	82.7	9.9
1	1	19.8	49.5	84.2	10.1
1	1	19.7	49.0	83.5	10.0
Block 1	average	19.6	49.1	83.5	10.0
2	2	19.4	49.6	81.8	9.7
2	2	19.5	49.3	81.6	9.7
3	2	19.4	49.2	81.4	9.7
Block 2	average	19.4	49.4	81.6	9.7
3	3	19.1	48.8	80.6	9.5
3	3	19.3	49.0	81.5	9.6
3	3	19.3	49.3	82.1	9.7
Block 3	average	19.2	49.0	81.4	9.6
4	4	19.2	49.0	81.8	9.7
4	4	19.4	49.1	82.4	9.8
4	4	19.3	49.1	82.2	9.7
Block 4	average	19.3	49.1	82.1	9.7
5	5	19.7	49.0	83.4	10.0
5	5	19.8	49.0	83.7	10.1
5	5	19.8	49.0	83.7	10.1
Block 5	average	19.7	49.0	83.6	10.0
6	6	19.5	48.6	83.0	10.0
6	6	19.6	48.6	83.3	10.0
6	6	19.7	49.0	83.7	10.1
Block 6	average	19.6	48.7	83.3	10.0
Overall	average	19.5	49.0	82.6	9.9
Reference	Value	20	50	81	10
% Difference		-2.6%	-1.9%	2.0%	-1.5%

Table 6 provides the results from the normalization process using the information in Table 4 and Table A.3. Exhibit A.6 in the Appendix provides scatter plots for these results offering an opportunity to investigate the consistency in the leaching across the elements for the glasses of this study. This consistency is typically demonstrated by a high degree of linear correlation among the values. For the PCTs normalized using the target compositions, these correlations range from 86% (between Na and Si) to 97% (between B and Na). The correlations among the PCTs normalized, using the measured compositions and the bias-corrected measurements, range from 85% (between Na and Si) to 99% (between Na and Li).

Table 6: Normalized PCT

Glass ID	Composition	log NL [B (g/L)]	log NL [Si (g/L)]	log NL [Na (g/L)]	log NL [Li (g/L)]	NL [B (g/L)]	NL [Si (g/L)]	NL [Na (g/L)]	NL [Li (g/L)]
ARM	reference comp. [8]	-0.29085	-0.54854	-0.27396	-0.21652	0.51	0.28	0.53	0.61
EA	reference comp. [8]	1.28207	0.63353	1.18838	1.04022	19.15	4.30	15.43	10.97
pha01	measured	0.16802	-0.17747	0.11093	0.13608	1.47	0.66	1.29	1.37
	measured, bias-cor.	0.16916	-0.17023	0.11988	0.14439	1.48	0.68	1.32	1.39
	target	0.22876	-0.18548	0.16308	0.13299	1.69	0.65	1.46	1.36
pha02	measured	0.10400	-0.22546	0.06252	0.08270	1.27	0.60	1.15	1.21
	measured, bias-cor.	0.10532	-0.22870	0.07145	0.09095	1.27	0.59	1.18	1.23
	target	0.08996	-0.22741	0.07491	0.09208	1.23	0.59	1.19	1.24
pha03	measured	0.24524	-0.15256	0.19801	0.20929	1.76	0.70	1.58	1.62
	measured, bias-cor.	0.24650	-0.15584	0.20697	0.21755	1.76	0.70	1.61	1.65
	target	0.23317	-0.15546	0.19886	0.21765	1.71	0.70	1.58	1.65
pha04	measured	0.18716	-0.13764	0.15247	0.17857	1.54	0.73	1.42	1.51
	measured, bias-cor.	0.18843	-0.14060	0.16140	0.18683	1.54	0.72	1.45	1.54
	target	0.24029	-0.11862	0.17676	0.19994	1.74	0.76	1.50	1.58
pha05	measured	0.11243	-0.20595	0.04395	0.06108	1.30	0.62	1.11	1.15
	measured, bias-cor.	0.11357	-0.20981	0.05294	0.06938	1.30	0.62	1.13	1.17
	target	0.07434	-0.22399	0.04190	0.07092	1.19	0.60	1.10	1.18
pha06	measured	0.19514	-0.17575	0.15701	0.17256	1.57	0.67	1.44	1.49
	measured, bias-cor.	0.19623	-0.17897	0.16598	0.18082	1.57	0.66	1.47	1.52
	target	0.17947	-0.17343	0.15859	0.17909	1.51	0.67	1.44	1.51

As seen in Table 6, the durabilities for the PHA Phase 3 glasses are much better than that of EA. (This is indicated for each glass by its normalized leachate being much smaller than that of EA.). Figure 1 provides an opportunity for a closer look at these results using measured and bias-corrected compositions. Figure 1 is a plot of the DWPF model that relates the logarithm of the normalized PCT (in this case for B) to a linear function of a free energy of hydration term (ΔG_p , kcal/100g glass) derived from the glass (measured and bias-corrected) compositions [8]. Prediction limits (at 95% confidence) for individual PCT results are also plotted around this linear fit. The PCT results for EA (shown as a diamond), ARM (shown as a "z"), and the PHA glasses (each shown as an "x") are presented on this plot. Note that the PHA results reveal acceptable and predictable PCTs (i.e., PCTs that are well predicted by the current DWPF durability model). Figure 2 provides a plot of the boron results based upon target compositions. Exhibit A.7 in the Appendix provides similar plots of the PHA durability measurements versus the DWPF durability models for B, Si, Na, and Li. The behavior seen in the plots for Si, Na, and Li is similar to that demonstrated by the B results: acceptable and predictable durabilities.

Figure 1.
Log NL(B) (g/L) By del Gp
 (Using Measured & Bias-corrected and
 EA and ARM reference compositions)

Figure 2.
Log NL(B) (g/L) By del Gp
 (Using PHA target compositions and
 EA and ARM reference compositions)

Viscosity at 1150 °C

Viscosity measurements were made on two of the six Phase 3 PHA glasses at SRTC using a Harrop, high-temperature viscometer [9]. The viscosity (in Poise) of each of these glasses at 1150 °C is to be estimated from a Fulcher equation fitted to a set of viscosity measurements taken over an appropriate range of temperatures. The functional form of the (three-parameter) Fulcher equation (expressed in Poise) used to fit these data is given by equation (1):

$$\ln \hat{\eta} = A + \frac{B}{(T - C)} \quad (1)$$

where A, B, and C represent the parameters of the model that are to be determined from the available measurements (represented by $\hat{\eta}$, expressed in Poise) at various temperatures (represented by T). The fitted model is then used to predict the viscosity of the given glass at 1150 °C.

Although no definitive error analysis has been completed on the use of the Harrop viscometer, SRTC has conducted several sets of viscosity measurements using this viscometer with good results [10]. Two crucible/spindle sets were used in conducting these measurements, which were sequenced according to the plan provided in Attachment IV of [7]. This plan covered glasses from Phases 2 through 4 for both CST and PHA and called for these measurements to be followed by measurements of the Batch 1 standard glass with both crucible/spindle sets. Measurements of Batch 1 that were conducted before the planned measurements were reported in [10] and in [3]. Only glasses pha01 and pha03 were measured for viscosity. Exhibit A.8 of the Appendix provides the measured viscosities, the results of the Fulcher fits, and the predictions at 1150 °C for these two PHA Phase 3 glasses. The information presented in this exhibit (along with predictions from the DWPF viscosity model and the Batch 1 results from [10] and [3]) is summarized in Table 7.

Table 7: Viscosity Results (in Poise) By Glass ID

Glass ID	Viscosity (Poise) @ 1150 °C	Predicted (measured composition)	Predicted (bias-corrected composition)	Predicted (target composition)
Batch 1	48.6, 49.7, 46.4, 48.9, 47.3	44.2 (Sharp-Schurtz) ³		56.2
pha01	43.9	57.7	57.7	70.2
pha02	Not measured	56.0	60.8	53.1
pha03	33.1	39.4	42.6	39.1
pha04	Not measured	71.8	77.3	67.4
pha05	Not measured	45.8	50.1	50.6
pha06	Not measured	39.0	42.1	36.9

The melt viscosities at 1150°C for the two PHA glasses (pha01 and pha03) are within the DWPF operating range, although significantly lower than the viscosities of the sludge-only glasses that have been run in the DWPF for the last several years. Based upon the measurements for these two glasses and the predictions for the others, processing these glasses in the DWPF would evidently not be a problem from a viscosity perspective.

Whether one uses the targeted, measured, or bias-corrected measured compositions to predict viscosities using the current model, the model viscosities are higher than the measured viscosities for the two glasses tested. A trend observed in these data is a decrease in measured viscosity as the PHA concentration is increased in the glass from 7 to 13 wt %.

Liquidus Temperature (T_L)

The standard ASTM procedure for measuring liquidus temperature uses a gradient furnace. The equipment for determining liquidus temperature by this method is being installed and tested within SRTC in a clean laboratory. Due to the presence of depleted uranium in the glass samples (as well as the early stage of equipment setup), we were not able to use this method for liquidus determination. A decision was, therefore, made to perform isothermal melts using reasonable quantities of the glass to bound the liquidus temperature.

XRD was selected as the method of detection for crystal formation in these glasses. It is estimated that the sensitivity of XRD (non-quantitative) is ~ 0.7 to 1 wt% for a crystalline phase (in this case, Trevorite [11]). Therefore, for this type of measurement, absence of detection of a crystalline phase was evidence that the liquidus temperature is less than the temperature of that isothermal hold. On the other hand, detection of Trevorite (or any other primary crystalline phase) indicates that the liquidus temperature is higher than the temperature of the isothermal hold.

Each glass underwent an isothermal hold at 900°C. Approximately 5 grams of glass were placed in a small platinum crucible and transferred to a furnace already heated to 1150°C. After a four-hour hold period, the temperature was reduced to 900°C and held at that temperature for 24 hours. The crucible was then removed from the furnace, and the glass allowed to cool within the crucible at room temperature. For these experiments, twelve glasses were treated together. The twelve glasses consisted of the six CST and six PHA glasses containing 22 wt% Purex simulated sludge. Therefore, the CST and PHA glasses experienced essentially identical heat treatments. The six PHA glasses at 900°C were submitted for XRD analysis. Care was taken to obtain glass that was not part of the top glass surface. The glass pieces, although mainly from the bulk, usually included part of the bottom surface (i.e., that surface in contact with the crucible).

The XRD analysis revealed no crystals in any of the glasses to the detection limit of the technique (~0.7 to 1.0 wt%). Therefore, the bounding estimates of liquidus temperatures for these six PHA glasses were:

3

Sharp-Schurtz is the analytic arm of Owens Corning Fiberglas and is now known as Owens Corning Testing (OCT).

Table 8: Liquidus Temperatures

GLASS ID	LIQUIDUS TEMPERATURE
pha01	<900°C
pha02	<900°C
pha03	<900°C
pha04	<900°C
pha05	<900°C
pha06	<900°C

These bounding liquidus temperatures are well below the nominal PAR value of 1025°C [12] and readily meet DWPF processing requirements for liquidus. The model predictions for these six glasses ranged from 949°C to 964°C using targeted chemical compositions, from 923°C to 968°C using measured compositions, and 917°C to 960°C using bias-corrected compositions. These data suggest that the predictions may be conservative for these glasses. A new liquidus model is being developed with a goal of preventing unnecessarily conservative constraints on liquidus.

Surface Crystallization

For liquidus measurements, crystal formation is considered only in the interior or bulk glass region. Therefore, samples submitted for XRD analysis were bulk samples. However, crystals can form at the interface of the glass and the crucible and/or the glass and air. For completeness, the detection of these surface crystals on the top of the glass is provided in Table 9 as a function of temperature. Only 900°C data are provided since XRD revealed no crystals in the six PHA glasses isothermally held at 900°C for 24 hours. Consequently, no higher temperature isothermal holds were conducted.

Table 9. Surface Crystals for the Six PHA Glasses at 900°C after the 24 hour heat treatment.

	pha01	pha02	pha03	pha04	pha05	pha06
1150°C	No test	No test	No test	No test	No test	No test
1000°C	No test	No test	No test	No test	No test	No test
950°C	No test	No test	No test	No test	No test	No test
900°C	None	None	None	None	None	None

As shown in the table, no surface crystallization was detected for any of the glasses at 900°C.

Phase Separation

The formation of separate amorphous phases in glass is referred to as amorphous phase separation or inhomogeneity. Crystal formation, as indicated by liquidus measurements, on the other hand, is also a type of phase separation, but reflects crystalline particles within the glass matrix. Amorphous phase separation is to be avoided since the models currently used to predict durability do not apply for glasses predicted to be phase separated. The limit for the homogeneity constraint in the PCCS is nominally (for the Property Acceptance Region, PAR) a value of 211 [12]. For the measurement acceptance region (MAR), the value will be even higher. In order to pass this constraint, the calculated value must be greater than the MAR value. The homogeneity values calculated using the targeted and measured chemical compositions are all below the PAR value. These values are given in Table 10:

Table 10: Homogeneity Property Predictions

Glass ID	Homogeneity Property Prediction based on (Acceptability Requires a Value > 211)		
	Target Composition	Measured Composition	Bias-Corrected Composition
pha01	200.1	204.2	199.9
pha02	199.8	199.1	196.9
pha03	199.4	198.6	196.6
pha04	198.4	195.7	193.9
pha05	198.0	193.3	191.3
pha06	197.7	198.7	196.6

The homogeneity constraint was developed for glasses that do contain PHA. Therefore, the predictability of phase separation by this model should be applicable. A significant search for phase separation in these glasses is beyond the scope of work for this task, except when routine SEM analysis is performed. For these six glasses no SEM analyses were performed.

CONCLUSIONS

The results presented in this report are for six Phase 3 PHA glasses, each of which was targeted to contain 22 wt% simulated PUREX sludge on an oxide basis. The target PHA concentration was varied from 7 to 10 to 13 wt % oxides both at 1.25 and 2.5 wt % (on an oxide basis) washed MST.

All six of these glasses were durable when compared to the EA glass (as determined by the 7-day PCT) and processible (from measured viscosity and bounding liquidus temperature data). Therefore, the results imply that DWPF would be able to run these six glass formulations at 22 wt % PUREX waste loading on an oxide basis.

The models currently in DWPF's PCCS were used to predict durability, homogeneity, liquidus, and viscosity for these six glasses. All six glasses were predicted to be phase separated, and consequently prediction of glass durability is precluded with the current models. However, the measured durabilities (as determined by the PCT) were within the 95% confidence bands of the model. Further efforts will be required to resolve this issue on phase separation (inhomogeneity).

The liquidus model predicted acceptable liquidus temperatures for all six glasses. The bounding liquidus temperatures that were measured (<900°C) were below the model predictions. The measured viscosities were below the predictions of the model and therefore, conservative to the upper limit of viscosity. The lowest measured viscosity value was 33.1 poise at 1150°C, corresponding to the glass with the highest level of PHA and at the lower level of MST. The model predictions may not be conservative with respect to the lower operating limit.

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Appendix:

Supplemental Tables and Exhibits

**Table A.1: Composition Measurements Using Peroxide Fusion Dissolutions
(expressed as cation weight fractions)**

Glass ID	Block	Seq	LIMS #	Lab ID	B	Ca	Si
Batch 1	1	1	130832a	NA2O2 - BATCH 1-STD1	0.02437	0.00897	0.24418
pha06	1	2	130821a	Na2O2 A08pf2	0.02802	0.00672	0.22878
pha04	1	6	130823a	Na2O2 A12pf2	0.02672	0.00687	0.26446
pha04	1	7	130812a	Na2O2 A12pf1	0.02628	0.00690	0.25590
Ustd	1	8	130835a	NA2O2 - U STD-1	0.02699	0.00990	0.20714
pha03	1	10	130809a	Na2O2 A02pf1	0.02779	0.00668	0.22578
pha02	1	13	130829a	Na2O2 A05pf2	0.02601	0.00742	0.24439
pha03	1	14	130811a	Na2O2 A02pf2	0.02828	0.00625	0.22926
Batch 1	1	15	130833a	NA2O2 - BATCH 1-STD2	0.02367	0.00883	0.23907
pha01	1	16	130808a	Na2O2 A01pf1	0.02817	0.00747	0.24866
pha05	1	17	130813a	Na2O2 A10pf1	0.02569	0.00671	0.23427
Ustd	1	22	130836a	NA2O2 - U Std-2	0.02778	0.00946	0.21495
pha05	1	23	130826a	Na2O2 A10pf2	0.02257	0.00590	0.20867
pha01	1	24	130815a	Na2O2 A01pf2	0.02739	0.00716	0.24145
pha02	1	25	130818a	Na2O2 A05pf1	0.02474	0.00682	0.23498
pha06	1	26	130814a	Na2O2 A08pf1	0.02790	0.00715	0.23250
Batch 1	1	29	130834a	NA2O2 - BATCH 1-STD3	0.02302	0.00860	0.23790
Batch 1	2	1	130832b	NA2O2 - BATCH 1-STD1	0.02385	0.00888	0.23525
pha06	2	2	130814b	Na2O2 A08pf1	0.02911	0.00748	0.23418
pha01	2	3	130815b	Na2O2 A01pf2	0.02965	0.00762	0.25596
pha05	2	4	130813b	Na2O2 A10pf1	0.02622	0.00688	0.23358
pha02	2	6	130829b	Na2O2 A05pf2	0.02710	0.00775	0.24687
Ustd	2	8	130835b	NA2O2 - U STD-1	0.02844	0.01014	0.21174
pha03	2	13	130809b	Na2O2 A02pf1	0.02937	0.00714	0.23375
Batch 1	2	15	130833b	NA2O2 - BATCH 1-STD2	0.02480	0.00936	0.24325
pha02	2	16	130818b	Na2O2 A05pf1	0.02803	0.00756	0.25469
pha01	2	19	130808b	Na2O2 A01pf1	0.02872	0.00778	0.24737
pha06	2	21	130821b	Na2O2 A08pf2	0.02921	0.00704	0.23489
Ustd	2	22	130836b	NA2O2 - U Std-2	0.02971	0.01010	0.22188
pha03	2	23	130811b	Na2O2 A02pf2	0.03093	0.00685	0.24507
pha04	2	24	130812b	Na2O2 A12pf1	0.02864	0.00757	0.27264
pha05	2	25	130826b	Na2O2 A10pf2	0.02458	0.00652	0.21907
pha04	2	27	130823b	Na2O2 A12pf2	0.02894	0.00761	0.27943
Batch 1	2	29	130834b	NA2O2 - BATCH 1-STD3	0.02558	0.00934	0.25263

Notes:

1. Measurements at their detection limits were given values equal to the detection limits.
2. The CST Phase 3 measurements are not shown in this table even though there were completed as part of the same analytical plan. See [5] for a complete listing of the data.

Table A.2: Composition Measurements From Microwave Preparation
(expressed as cation weight fractions)

Glass					ICP-ES																AA ⁴
ID	Block	Seq	LIMS #	Lab ID	Al	Ca	Cr	Cu	Fe	Li	Mg	Mn	Na	Nb	Ni	Si	Ti	U	Zr	K	
Batch 1	1	1	130751a	MW BATCH 1 STD-1	0.02614	0.00876	0.00077	0.00319	0.09412	0.02098	0.00860	0.01337	0.06867	0.00048	0.00626	0.21866	0.00424	0.00300	0.00230	0.02667	
pha05	1	2	130745a	MW A10MW2	0.01343	0.00668	0.00103	0.00577	0.07063	0.02138	0.00838	0.01264	0.06042	0.00053	0.00681	0.22618	0.01392	0.02513	0.00143	0.03601	
pha01	1	3	130733a	MW A01MW1	0.01519	0.00716	0.00122	0.00463	0.07063	0.02211	0.00882	0.01597	0.06626	0.00052	0.00756	0.23698	0.00701	0.01306	0.00120	0.02445	
pha06	1	4	130728a	MW A08MW1	0.01391	0.00673	0.00106	0.00755	0.07097	0.02018	0.00798	0.01387	0.06193	0.00050	0.00697	0.22019	0.01398	0.02232	0.00118	0.04664	
Ustd	1	8	130754a	MW U STD-1	0.02184	0.00939	0.00186	0.00017	0.09933	0.01456	0.00726	0.02198	0.09063	0.00052	0.00916	0.20997	0.00626	0.02223	0.00017	0.02437	
pha04	1	12	130737a	MW A12MW1	0.01344	0.00640	0.00092	0.00448	0.05904	0.02305	0.00895	0.01387	0.06371	0.00049	0.00655	0.24880	0.01436	0.01046	0.00097	0.02562	
pha05	1	14	130742a	MW A10MW1	0.01324	0.00651	0.00102	0.00572	0.07011	0.02109	0.00830	0.01249	0.05947	0.00050	0.00671	0.22963	0.01378	0.02482	0.00102	0.03490	
Batch 1	1	15	130752a	MW BATCH 1 STD-2	0.02633	0.00878	0.00076	0.00321	0.09623	0.02108	0.00871	0.01352	0.06890	0.00048	0.00633	0.22886	0.00429	0.00285	0.00082	0.02686	
pha03	1	16	130735a	MW A02MW1	0.01365	0.00685	0.00118	0.00817	0.07111	0.02068	0.00820	0.01317	0.06120	0.00051	0.00685	0.21826	0.00708	0.02441	0.00363	0.04590	
pha06	1	18	130738a	MW A08MW2	0.01376	0.00691	0.00105	0.00773	0.07047	0.02012	0.00785	0.01372	0.06105	0.00052	0.00696	0.22144	0.01390	0.02185	0.00134	0.00472	
pha01	1	19	130749a	MW A01MW2	0.04359	0.00422	0.00090	0.00050	0.06355	0.01925	0.00111	0.02073	0.06785	0.00923	0.00355	0.23877	0.01978	0.01120	0.00924	0.00137	
pha02	1	21	130750a	MW A05MW2	0.01452	0.00709	0.00120	0.00471	0.06970	0.02180	0.00841	0.01568	0.06283	0.00051	0.00746	0.23687	0.00695	0.01164	0.00111	0.02417	
Ustd	1	22	130755a	MW U STD-2	0.02178	0.00971	0.00184	0.00015	0.09869	0.01444	0.00718	0.02171	0.09020	0.00050	0.00910	0.20803	0.00621	0.02252	0.00016	0.02365	
pha02	1	23	130736a	MW A05MW1	0.01447	0.00715	0.00111	0.00626	0.06966	0.02154	0.00827	0.01514	0.05989	0.00051	0.00729	0.23490	0.00718	0.01770	0.00114	0.03611	
pha03	1	24	130740a	MW A02MW2	0.01359	0.00677	0.00120	0.00807	0.07016	0.02043	0.00814	0.01304	0.06046	0.00051	0.00679	0.22411	0.00702	0.02417	0.00101	0.04612	
pha04	1	25	130748a	MW A12MW2	0.01324	0.00642	0.00093	0.00458	0.05881	0.02281	0.00877	0.01376	0.06137	0.00052	0.00657	0.24786	0.01431	0.00990	0.00099	0.02552	
Batch 1	1	29	130753a	MW BATCH 1 STD-3	0.02589	0.00898	0.00076	0.00324	0.09458	0.02083	0.00854	0.01328	0.06807	0.00051	0.00627	0.22849	0.00424	0.00302	0.00080	0.02607	
Batch 1	2	1	130751b	MW BATCH 1 STD-1	0.02605	0.00887	0.00078	0.00321	0.09261	0.02112	0.00869	0.01358	0.06849	0.00048	0.00616	0.21700	0.00421	0.00280	0.00139	0.02590	
pha01	2	2	130749b	MW A01MW2	0.04363	0.00419	0.00090	0.00052	0.06275	0.01964	0.00113	0.02126	0.06832	0.00928	0.00350	0.23537	0.01972	0.00929	0.00944	0.00156	
pha01	2	6	130733b	MW A01MW1	0.01517	0.00721	0.00121	0.00464	0.06884	0.02202	0.00884	0.01602	0.06539	0.00052	0.00735	0.23576	0.00689	0.01310	0.00116	0.02492	
Ustd	2	8	130754b	MW U STD-1	0.02168	0.00942	0.00187	0.00019	0.09701	0.01446	0.00730	0.02210	0.08931	0.00052	0.00889	0.20584	0.00616	0.02171	0.00020	0.02451	
pha04	2	9	130748b	MW A12MW2	0.01336	0.00633	0.00099	0.00454	0.05812	0.02298	0.00893	0.01408	0.06137	0.00052	0.00653	0.24654	0.01422	0.00886	0.00105	0.02614	
pha05	2	10	130742b	MW A10MW1	0.01320	0.00668	0.00102	0.00581	0.06906	0.02153	0.00837	0.01266	0.05948	0.00050	0.00654	0.22951	0.01369	0.02417	0.00104	0.03610	
pha06	2	12	130728b	MW A08MW1	0.01387	0.00682	0.00106	0.00761	0.06951	0.02034	0.00800	0.01397	0.06161	0.00050	0.00678	0.21923	0.01378	0.01960	0.00112	0.04856	
Batch 1	2	15	130752b	MW BATCH 1 STD-2	0.02574	0.00884	0.00076	0.00320	0.09279	0.02100	0.00866	0.01348	0.06785	0.00048	0.00616	0.22752	0.00421	0.00285	0.00084	0.02692	
pha02	2	19	130750b	MW A05MW2	0.01424	0.00689	0.00119	0.00459	0.06800	0.02186	0.00842	0.01576	0.06218	0.00051	0.00718	0.23222	0.00683	0.01010	0.00111	0.02488	
pha03	2	20	130735b	MW A02MW1	0.01330	0.00671	0.00117	0.00803	0.06951	0.02097	0.00825	0.01328	0.06092	0.00051	0.00660	0.22449	0.00699	0.02215	0.00098	0.04726	
pha02	2	21	130736b	MW A05MW1	0.01432	0.00701	0.00112	0.00616	0.06848	0.02174	0.00836	0.01534	0.05989	0.00051	0.00712	0.22876	0.00710	0.01684	0.00116	0.03648	
Ustd	2	22	130755b	MW U STD-2	0.02158	0.00953	0.00185	0.00015	0.09720	0.01460	0.00726	0.02204	0.08987	0.00050	0.00886	0.20522	0.00613	0.01987	0.00013	0.02475	
pha06	2	23	130738b	MW A08MW2	0.01355	0.00672	0.00102	0.00756	0.06936	0.02025	0.00791	0.01385	0.06081	0.00052	0.00677	0.21993	0.01371	0.01904	0.00109	0.04873	
pha05	2	24	130745b	MW A10MW2	0.01321	0.00672	0.00103	0.00577	0.06927	0.02139	0.00839	0.01266	0.05962	0.00053	0.00653	0.22909	0.01367	0.02320	0.00103	0.03605	
pha03	2	25	130740b	MW A02MW2	0.01328	0.00658	0.00115	0.00795	0.06887	0.02074	0.00817	0.01315	0.06019	0.00051	0.00653	0.22407	0.00693	0.02290	0.00099	0.04682	
pha04	2	26	130737b	MW A12MW1	0.01325	0.00642	0.00091	0.00447	0.05766	0.02287	0.00894	0.01388	0.06284	0.00049	0.00637	0.24462	0.01401	0.00743	0.00099	0.02563	
Batch 1	2	29	130753b	MW BATCH 1 STD-3	0.02537	0.00868	0.00077	0.00316	0.09215	0.02079	0.00855	0.01334	0.06711	0.00051	0.00608	0.22451	0.00415	0.00302	0.00082	0.02676	

Notes:

1. Measurements at their detection limits were given values equal to the detection limits.
2. The CST Phase 3 measurements are not shown in this table even though there were completed as part of the same analytical plan. See [5] for a complete listing of the data.

4

The potassium values were generated via Atomic Absorption (AA).

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Table A.3: Composition of PCT Leachate Solutions

Table A15: Composition of 1 x 1 x 1 cm Samples					Concentrations in ppm (as reported)										Concentrations in ppm (after correcting for dilution)										Common Logarithm of ppm Concentrations			
Glass ID	Blk	Seq	LIMS #	Sample ID	B	Li	Na	Pb	Si	B	Si	Na	Li	Pb	log[B]	log[Si]	log[Na]	log[Li]										
std	1	1	130358	PCT - Std-bl-1	19.467	9.920	82.739	0.029	48.894	19.467	48.894	82.739	9.920	0.029	1.28930	1.68926	1.91771	0.99651										
					7.695	7.064	16.958	0.029	43.149	12.825	71.916	28.264	11.774	0.048	1.10807	1.85683	1.45123	1.07091										
pha20	1	2	130359	PCT - U15	10.666	8.746	22.974	0.029	36.623	17.777	61.040	38.291	14.577	0.048	1.24986	1.78561	1.58309	1.16367										
					25.880	18.770	52.431	0.029	98.211	43.134	163.688	87.387	31.284	0.048	1.63482	2.21402	1.94145	1.49532										
pha01	1	8	130365	PCT - U70	19.758	10.106	84.244	0.029	49.510	19.758	49.510	84.244	10.106	0.029	1.29574	1.69469	1.92554	1.00458										
					0.040	0.004	0.140	0.029	0.049	0.067	0.082	0.233	0.007	0.048	-1.17608	-1.08795	-0.63201	-2.17608										
blank	1	12	130366	PCT - U22	18.321	14.002	46.087	0.029	67.873	30.536	113.124	76.813	23.337	0.048	1.48481	2.05355	1.88544	1.36805										
					16.104	12.604	36.821	0.029	72.007	26.841	120.014	61.370	21.007	0.048	1.42879	2.07923	1.78795	1.32237										
pha17c	1	15	130372	PCT - U53	19.500	15.079	40.172	0.029	83.599	32.501	139.335	66.955	25.132	0.048	1.51189	2.14406	1.82578	1.40023										
					19.669	10.002	83.454	0.029	48.968	19.669	48.968	83.454	10.002	0.029	1.29378	1.68991	1.92145	1.00009										
pha05	1	17	130374	PCT - U21	19.376	9.692	81.811	0.044	49.598	19.376	49.598	81.811	9.692	0.044	1.28726	1.69546	1.91281	0.98641										
					19.103	14.526	39.357	0.060	84.950	31.839	141.586	65.596	24.210	0.100	1.50296	2.15102	1.81688	1.39400										
std	2	4	130376	STD-B2-1	25.208	18.027	50.859	0.058	99.572	42.014	165.957	84.767	30.046	0.097	1.62340	2.22000	1.92823	1.47778										
					0.046	0.015	0.223	0.033	0.114	0.077	0.190	0.372	0.025	0.055	-1.11538	-0.72124	-0.42984	-1.60205										
pha01	2	5	130380	U61	16.346	12.096	41.316	0.054	68.290	27.244	113.819	68.861	20.160	0.090	1.43527	2.05622	1.83798	1.30450										
					19.467	9.705	81.562	0.046	49.333	19.467	49.333	81.562	9.705	0.046	1.28930	1.69314	1.91149	0.98700										
blank	2	6	130381	U79	10.834	8.533	22.828	0.056	37.276	18.057	62.128	38.047	14.222	0.093	1.25665	1.79329	1.58033	1.15296										
					16.630	12.671	37.466	0.063	73.560	27.717	122.603	62.445	21.119	0.105	1.44275	2.08850	1.79550	1.32467										
std	2	9	130384	STD-B2-2	8.791	7.793	18.940	0.056	47.755	14.652	79.593	31.567	12.989	0.093	1.16590	1.90088	1.49924	1.11356										
					19.419	9.658	81.390	0.049	49.189	19.419	49.189	81.390	9.658	0.049	1.28823	1.69187	1.91057	0.98489										
pha05	3	1	130394	STD-B3-1	19.113	9.522	80.567	0.047	48.760	19.113	48.760	80.567	9.522	0.047	1.28133	1.68806	1.90616	0.97873										
					19.146	14.629	39.472	0.060	84.914	31.911	141.526	65.788	24.382	0.100	1.50394	2.15084	1.81815	1.38707										
pha01	3	5	130395	U18	24.418	17.562	49.704	0.049	96.916	40.697	161.530	82.842	29.271	0.082	1.60957	2.20825	1.91825	1.46643										
					7.776	7.025	16.932	0.055	44.519	12.960	74.200	28.221	11.709	0.092	1.11261	1.87040	1.45057	1.06850										
std	3	9	130402	STD-B3-2	19.265	9.648	81.451	0.053	49.003	19.265	49.003	81.451	9.648	0.053	1.28477	1.69022	1.91090	0.98444										
					17.668	13.075	44.236	0.045	68.667	29.447	114.447	73.728	21.792	0.075	1.46905	2.05861	1.86763	1.33830										
pha17c	3	11	130404	U81	15.094	11.763	35.089	0.051	70.979	25.157	118.301	58.483	19.605	0.085	1.40066	2.07299	1.76703	1.29238										
					10.834	8.521	22.911	0.043	36.743	18.057	61.240	38.186	14.202	0.072	1.25665	1.78703	1.58190	1.15235										
pha17c	3	13	130406	U26	19.339	9.711	82.099	0.035	49.310	19.339	49.310	82.099	9.711	0.035	1.28643	1.69294	1.91434	0.98726										
					19.165	9.690	81.752	0.042	48.956	19.165	48.956	81.752	9.690	0.042	1.28251	1.68981	1.91250	0.98632										
std	4	1	130411	STD-B4-1	30.246	19.709	57.031	0.045	96.535	50.411	160.895	95.054	32.849	0.075	1.70253	2.20654	1.97797	1.51652										
					25.802	20.743	53.426	0.089	113.181	43.004	188.639	89.045	34.572	0.148	1.63351	2.27563	1.94961	1.53873										
pha03	4	3	130413	PCT - U24	26.071	17.434	51.640	0.029	89.886	43.453	149.813	86.068	29.057	0.048	1.63802	2.17555	1.93484	1.46325										
					26.878	15.967	58.565	0.032	74.546	44.798	124.246	97.610	26.612	0.053	1.65125	2.09428	1.98950	1.42508										
pha04	4	8	130418	PCT - U29	19.377	9.759	82.363	0.029	49.126	19.377	49.126	82.363	9.759	0.029	1.28729	1.69131	1.91573	0.98941										
					6.956	6.290	16.621	0.030	41.026	11.594	68.378	27.702	10.484	0.050	1.06422	1.83492	1.44252	1.02051										
std	4	9	130419	PCT - STD-B4-2	38.600	12.142	111.398	0.039	57.005	64.346	950.102	185.670	202.371	0.065	2.80845	2.97777	3.26874	2.30615										
					19.714	15.355	41.745	0.038	85.842	32.857	143.073	69.576	25.592	0.063	1.51663	2.15556	1.84246	1.40811										
pha06	4	5	130415	PCT - U55	28.647	18.380	58.580	0.041	88.212	47.746	147.023	97.635	30.634	0.068	1.67894	2.16739	1.98961	1.48620										
					6.784	6.091	17.489	0.052	39.855	11.307	66.426	29.149	10.152	0.087	1.05334	1.82234	1.46462	1.00655										
pha12c	4	15	130425	PCT - U75	19.309	9.719	82.229	0.034	49.077	19.309	49.077	82.229	9.719	0.034	1.28576	1.69088	1.91503	0.98762										
					19.309	9.719	82.229	0.034	49.077	19.309	49.077	82.229	9.719	0.034	1.28576	1.69088	1.91503	0.98762										
pha32	4	16	130426	PCT - STD-B4-3																								

Notes:

- Measurements at their detection limits were given values equal to the detection limits.
- The CST Phase 3 and 4 measurements are not shown in this table even though there were completed as part of the same analytical plan. See [5] for a complete listing of the data. The PHA Phase 4 measurements are shown in this table, but no addition investigation into these data is provided in this report.

Table A.3: Composition of PCT Leachate Solutions
(continued)

					Concentrations in ppm (as reported)					Concentrations in ppm (after correcting for dilution)					Common Logarithm of ppm Concentrations			
Glass																		
ID	Blk	Seq	LIMS #	Sample ID	B	Li	Na	Pb	Si	B	Si	Na	Li	Pb	log[B]	log[Si]	log[Na]	log[Li]
std	5	1	130428	PCT - STD-B5-1	19.670	10.009	83.367	0.029	49.025	19.670	49.025	83.367	10.009	0.029	1.29380	1.69042	1.92099	1.00039
pha03	5	2	130429	PCT - U19	30.785	20.231	57.501	0.029	96.080	51.309	160.137	95.837	33.719	0.048	1.71020	2.20449	1.98153	1.52788
pha26	5	3	130430	PCT - U63	7.723	6.989	17.924	0.030	43.292	12.872	72.155	29.874	11.649	0.050	1.10964	1.85827	1.47529	1.06627
pha02	5	4	130431	PCT - U46	20.360	15.854	42.292	0.029	83.835	33.934	139.728	70.488	26.424	0.048	1.53064	2.14528	1.84812	1.42200
pha18c	5	5	130432	PCT - U14	29.831	17.563	64.045	0.029	78.043	49.719	130.074	106.744	29.272	0.048	1.69653	2.11419	2.02834	1.46646
pha32	5	6	130433	PCT - U40	6.981	6.327	18.006	0.029	40.552	11.635	67.588	30.011	10.545	0.048	1.06578	1.82987	1.47728	1.02306
pha04	5	8	130435	PCT - U10	25.970	21.137	54.134	0.029	114.372	43.284	190.624	90.225	35.229	0.048	1.63633	2.28018	1.95533	1.54690
std	5	9	130436	PCT - STD-B5-2	19.787	10.053	83.700	0.029	48.985	19.787	48.985	83.700	10.053	0.029	1.29638	1.69006	1.92273	1.00230
pha12c	5	12	130439	PCT - U09	23.641	15.633	49.987	0.029	78.468	39.402	130.783	83.313	26.056	0.048	1.59552	2.11655	1.92072	1.41590
pha06	5	14	130441	PCT - U69	26.835	18.083	52.672	0.029	90.100	44.726	150.170	87.788	30.139	0.048	1.65056	2.17658	1.94344	1.47913
EA	5	16	130443	PCT - U77	43.471	14.619	123.358	0.029	63.060	724.531	1051.021	2056.008	243.655	0.048	2.86006	3.02161	3.31303	2.38678
blank	5	17	130444	PCT - U88	0.099	0.013	0.188	0.029	0.087	0.165	0.145	0.313	0.022	0.048	-0.78251	-0.83862	-0.50398	-1.66420
std	5	18	130445	PCT - STD-B5-3	19.762	10.069	83.741	0.029	48.953	19.762	48.953	83.741	10.069	0.029	1.29583	1.68978	1.92294	1.00299
std	6	1	130446	PCT - STD-B6-1	19.528	9.989	82.971	0.029	48.559	19.528	48.559	82.971	9.989	0.029	1.29066	1.68627	1.91893	0.99952
pha04	6	3	130448	PCT - U44	24.807	20.383	51.824	0.029	110.133	41.346	183.559	86.375	33.972	0.048	1.61643	2.26378	1.93639	1.53113
pha32	6	4	130449	PCT - U30	6.980	6.354	18.030	0.029	40.017	11.634	66.696	30.051	10.590	0.048	1.06571	1.82410	1.47785	1.02491
EA	6	5	130450	PCT - U58	39.043	12.446	111.786	0.029	56.482	650.730	941.386	1863.137	207.438	0.048	2.81340	2.97377	3.27025	2.31689
pha06	6	6	130451	PCT - U68	27.686	18.652	54.244	0.029	91.908	46.144	153.183	90.408	31.087	0.048	1.66412	2.18521	1.95621	1.49258
pha26	6	8	130453	PCT - U84	7.185	6.532	16.821	0.029	41.306	11.975	68.845	28.036	10.887	0.048	1.07828	1.83787	1.44771	1.03690
std	6	9	130454	PCT - STD-B6-2	19.632	10.025	83.330	0.029	48.630	19.632	48.630	83.330	10.025	0.029	1.29297	1.68690	1.92080	1.00108
pha12c	6	11	130456	PCT - U50	5.797	4.220	12.956	0.029	20.378	9.662	33.964	21.594	7.033	0.048	0.98506	1.53102	1.33433	0.84717
pha02	6	13	130458	PCT - U34	20.470	16.126	43.177	0.029	86.547	34.117	144.248	71.963	26.877	0.048	1.53298	2.15911	1.85711	1.42938
pha18c	6	14	130459	PCT - U33	31.304	18.573	66.733	0.029	79.072	52.174	131.789	111.224	30.956	0.048	1.71746	2.11988	2.04620	1.49074
pha03	6	15	130460	PCT - U01	31.086	20.415	57.814	0.029	96.338	51.811	160.567	96.359	34.026	0.048	1.71442	2.20566	1.98389	1.53181
blank	6	17	130462	PCT - U87	0.061	0.006	0.332	0.029	0.052	0.102	0.087	0.553	0.010	0.048	-0.99281	-1.06214	-0.25700	-1.99999
std	6	18	130463	PCT - STD-B6-3	19.707	10.052	83.703	0.029	48.974	19.707	48.974	83.703	10.052	0.029	1.29462	1.68997	1.92274	1.00225

Notes:

- Measurements at their detection limits were given values equal to the detection limits.
- The CST Phase 3 and 4 measurements are not shown in this table even though there were completed as part of the same analytical plan. See [5] for a complete listing of the data. The PHA Phase 4 measurements are shown in this table, but no additional investigation into these data is provided in this report.

Exhibit A.1: Measurements by Glass Sample ID by Oxide

Al₂O₃ By Glass Sample ID

B₂O₃ By Glass Sample ID

CaO MW By Glass Sample ID

Exhibit A.1: Measurements by Glass Sample ID by Oxide
(continued)

CaO pf By Glass Sample ID

CaO By Glass Sample ID

Cr2O3 By Glass Sample ID

Exhibit A.1: Measurements by Glass Sample ID by Oxide
(continued)

CuO By Glass Sample ID

Fe2O3 By Glass Sample ID

K2O By Glass Sample ID

Exhibit A.1: Measurements by Glass Sample ID by Oxide
(continued)

Li₂O By Glass Sample ID

MgO By Glass Sample ID

MnO By Glass Sample ID

Exhibit A.1: Measurements by Glass Sample ID by Oxide
(continued)

Na₂O By Glass Sample ID

NiO By Glass Sample ID

SiO₂ MW By Glass Sample ID

**Exhibit A.1: Measurements by Glass Sample ID by Oxide
(continued)**

SiO₂ pf By Glass Sample ID

SiO₂ By Glass Sample ID

TiO₂ By Glass Sample ID

**Exhibit A.1: Measurements by Glass Sample ID by Oxide
(continued)**

U3O8 By Glass Sample ID

ZrO2 By Glass Sample ID

Sum of Oxides By Glass Sample ID

Exhibit A.2: Peroxide Fusion Measurements of Glass Standards by Oxide
(+ u-std; small square Batch 1 standard)

B2O3 (wt%) By Block (pf)

SiO2 pf (wt%) By Block (pf)

Ca pf (wt%) By Block (pf)

Exhibit A.3: Microwave Measurements of Glass Standards by Oxide
(+ u-std; small square Batch 1 standard)

**Al₂O₃ (wt%) By Block
(MW)**

**Cr₂O₃ (wt%) By Block
(MW)**

**CaO MW (wt%) By
Block (MW)**

**CuO (wt%) By Block
(MW)**

Exhibit A.3: Microwave Measurements of Glass Standards by Oxide
 (+ u-std; small square Batch 1 standard)
 (continued)

**Fe₂O₃ (wt%) By Block
 (MW)**

**Li₂O (wt%) By Block
 (MW)**

**K₂O (wt%) By Block
 (MW)**

**MgO (wt%) By Block
 (MW)**

Exhibit A.3: Microwave Measurements of Glass Standards by Oxide
(+ u-std; small square Batch 1 standard)
(continued)

**MnO (wt%) By Block
(MW)**

**NiO (wt%) By Block
(MW)**

**Na2O (wt%) By Block
(MW)**

**SiO2 MW (wt%) By
Block (MW)**

Exhibit A.3: Microwave Measurements of Glass Standards by Oxide

(+ u-std; small square Batch 1 standard)

(continued)

**TiO₂ (wt%) By Block
(MW)** **ZrO₂ (wt%) By Block
(MW)** **U₃O₈ (wt%) By Block
(MW)**

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

Al₂O₃

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)
B2O3

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

CaO

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

Cr₂O₃

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

CuO

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

Fe₂O₃

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

K2O

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

MgO

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

MnO

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

Na₂O

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

NiO

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

SiO₂

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

TiO₂

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

U308

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

ZrO₂

Exhibit A.4: Comparisons of Measurements versus Target Compositions
(concentrations in weight percents)

Sum of Oxides

Exhibit A.5: Plots of the Leachate Concentrations by Sample ID by Element
(with and without the EA and blank samples)

B (ppm) By Sample ID

Si (ppm) By Sample ID

Exhibit A.5: Plots of the Leachate Concentrations by Sample ID by Element
(with and without the EA and blank samples)
(continued)

Na (ppm) By Sample ID

Li (ppm) By Sample ID

Exhibit A.6: Scatter Plots of the Normalized PCT's**Correlations Using Target Compositions**

Variable	log NL[B g/L]	log NL[Si g/L]	log NL[Na g/L]	log NL[Li g/L]
log NL[B g/L]	1.0000	0.8782	0.9675	0.8653
log NL[Si g/L]	0.8782	1.0000	0.8556	0.9063
log NL[Na g/L]	0.9675	0.8556	1.0000	0.9385
log NL[Li g/L]	0.8653	0.9063	0.9385	1.0000

Correlations Using Measured Compositions

Variable	log NL[B g/L]	log NL[Si g/L]	log NL[Na g/L]	log NL[Li g/L]
log NL[B g/L]	1.0000	0.8503	0.9800	0.9690
log NL[Si g/L]	0.8503	1.0000	0.8500	0.8787
log NL[Na g/L]	0.9800	0.8500	1.0000	0.9955
log NL[Li g/L]	0.9690	0.8787	0.9955	1.0000

Correlations Using Bias-Corrected Measured Compositions

Variable	log NL[B g/L]	log NL[Si g/L]	log NL[Na g/L]	log NL[Li g/L]
log NL[B g/L]	1.0000	0.8395	0.9802	0.9692
log NL[Si g/L]	0.8395	1.0000	0.8307	0.8658
log NL[Na g/L]	0.9802	0.8307	1.0000	0.9955
log NL[Li g/L]	0.9692	0.8658	0.9955	1.0000

Scatterplot Matrix

Exhibit A.7: Durability Predictions versus Measured

(Reference compositions were used to normalize the EA and ARM PCTs; their compositions were not remeasured as part of this study).

Log NL(B) (g/L) By del Gp(m)
(based on measured and bias-corrected compositions)

Log NL(B) (g/L) By del Gp(m)
(based on target composition)

Log NL(Si) (g/L) By del Gp(m)
(based on measured and bias-corrected compositions)

Log NL(Si) (g/L) By del Gp(m)
(based on target composition)

**Exhibit A.7: Durability Predictions versus Measured
(Continued)**

(Reference compositions were used to normalize the EA and ARM PCTs; their compositions were not remeasured as part of this study).

Log NL (Na) (g/L) By del Gp(m)
(based on measured and bias-corrected compositions)

Log NL (Na) (g/L) By del Gp(m)
(based on target composition)

log[NL(Li) g/L] By del Gp(m)
(based on measured and bias-corrected compositions)

log[NL(Li) g/L] By del Gp(m)
(based on target composition)

Exhibit A.8: Viscosity Measurements, Fulcher Fits, and Predictions at 1150 °C**pha01**

Parameter	Estimate	ApproxStdErr
A	-3.52792291	0.09027284
B	6929.6311284	159.360098
C	202.04229825	10.0876431

Graph

Temp (Deg C)	Visc (Poise)	ln Visc (Fulcher)	ln(Visc Poise)	Visc Pred (Poise)
1201	30.24246	3.408938	3.409247	30.23
1146	45.24542	3.813117	3.812101	45.29
1092	70.79435	4.25855	4.259779	70.71
1038.5	116.2714	4.756574	4.755927	116.35
985.5	203.7991	5.31701	5.317135	203.77
1150	?	3.782141	?	43.91

Exhibit A.8: Viscosity Measurements, Fulcher Fits, and Predictions at 1150 °C
(continued)

pha03

Parameter	Estimate	ApproxStdErr
A	-3.365534533	0.36580795
B	6348.6671882	628.300941
C	225.15607459	42.2182192

Graph

Temp (Deg C)	Visc (Poise)	ln Visc (Fulcher)	ln(Visc Poise)	Visc Pred (Poise)
1202	23.00083	3.133628	3.13553	22.96
1145	34.26556	3.536362	3.534141	34.34
1091	52.63746	3.966811	3.963428	52.82
1037	86.52033	4.454524	4.460379	86.02
984	148.1978	5.000701	4.998548	148.52
1150	?	3.499048	?	33.08

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