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THE IMPACT OF HIGHER WASTE LOADING ON GLASS PROPERTIES:

The Effects of Uranium and Thorium

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Executive Summary

In this study, glasses are designed or selected to assess the impacts of U_3O_8 and ThO_2 on various glass properties of interest. More specifically, glasses were fabricated in which Th replaced U (on a molar basis) to assess the impact of ThO_2 on the durability response (as measured by the Product Consistency Test (PCT)) and viscosity. Based on the measured normalized boron release (NL [B]) values, the results indicated that the Th-enriched glasses were less durable than their U-based counterparts. Although molar substitution of Th or U had a negative impact, all of the glasses were more durable than the Environmental Assessment glass – the highest release being 7.39 g/L as compared to 16.695 g/L as reported for EA. With respect to model predictions, THERMO™ predicts that a molar substitution of thorium for uranium should increase glass durability. However, these data suggest that the signs and/or magnitudes of the ΔG_i values associated with U_3O_8 and ThO_2 are inconsistent with the theory on which the current model is based for the limited number of glasses tested. It should be noted that these glasses cover a narrow compositional region. With respect to the impact on viscosity, the data suggest that there may be a bias in the model. That is, the model currently does not contain a U_3O_8 or ThO_2 term – but perhaps it should to account for their contributions to the measured (or actual) viscosity results.

In addition, a series of glasses were produced to assess the impact of higher waste loadings (WLs) on select glass properties. The PCT results suggest that durable glasses can be made at relatively high WLs (exceeding 40 wt%). Comparisons between the measured PCTs and their predictions indicate that the current model is applicable, with all of the quenched glasses falling within the 95% confidence bands. The viscosity data for the higher WL glasses suggest that the current model may be extremely accurate for some systems but for different regions the model may be biased high or low – an observation that is consistent with that of Harbour et al. (1999).

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Acronyms

AES	atomic emission spectroscopy
ANOVA	analysis of variance
ARM	Approved Reference Material
ASTM	American Society for Testing and Materials
ccc	centerline canister cooled
ΔG_p	preliminary glass dissolution estimator based on free energy of hydration (in kcal/mol)
ΔG_i	partial molar hydration free energy in (kcal/mol) for the i^{th} oxide of the glass
DWPF	Defense Waste Processing Facility
EA	Environmental Assessment
HLF	H modified low heat feed
HWL	high waste loading
HHF	H modified high heat feed
ICP	inductively coupled plasma
IRD	Independent Research and Development
LM	lithium metaborate
MAR	Measurement Acceptability Region
NL	normalized leachate
PAR	Property Acceptability Region
PCCS	Product Composition Control System
PCT	Product Consistency Test
PHF	PUREX high heat feed
PLF	PUREX low heat feed
PMF	PUREX mixed feed

PMP	Performance Management Plan
RC	Reduction of Constraints
SB	sludge batch
SP	sodium peroxide
SRTC-ML	Savannah River Technology Center – Mobile Laboratory
T_L	liquidus temperature
THERMO™	Thermodynamic Hydration Energy Reaction Model
TTR	technical task request
U_{std}	uranium standard
$\eta_{1150°C}$	melt viscosity at 1150°C
WAC	Waste Acceptance Criteria
WL	waste loading

Contents

1.0 Introduction 1
2.0 Objectives 3
3.0 Glass Selection Process 5
3.1 Thorium-Containing Glass Selection 5
3.2 High Waste Loading (HWL) Glass Selection 14
3.3 Tank 40 High Waste Loading Glasses 16
3.4 Targeted Compositions and Predicted Properties 17
4.0 Experimental 21
4.1 Chemical Composition Analysis 22
4.2 Product Consistency Test 22
4.3 High Temperature Viscosity 22
5.0 Results 25
5.1 Visual Observations of Homogeneity 25
5.2 A Statistical Review of the Chemical Composition Measurements 25
5.2.1 Measurements in Analytical Sequence 26
5.2.2 Batch 1 and Uranium Standard Results 26
5.2.3 Composition Measurements by Glass Number 27
5.2.4 Measured versus Targeted Compositions 27
5.3 A Statistical Review of the PCT Measurements 29
5.3.1 Measurements in Analytical Sequence 29
5.3.2 Results for the Samples of the Multi-Element Solution Standard 29
5.3.3 Measurements by Glass Number 30
5.3.4 Quenched versus Centerline Canister Cooled PCTs 30
5.3.5 Normalized PCT Results 31
5.4 Comparisons Between Th/U Glass Pairs 33
5.4.1 Compositional Analysis 33
5.4.2 Predicted versus Measured PCTs for the Th Glasses 36
5.4.3 Viscosity Measurements of the Th Glasses 39
5.5 High Waste Loaded (HWL) Glasses 40
5.6 Tank 40 Glasses 45
6.0 Summary 47
7.0 Recommendations 49
8.0 References 51
Appendix A: 53
Appendix B: 63

List of Figures

Figure 3-1. Computation of the amount of U_3O_8 to replace with ThO_2 for the PHF type sludge and resulting glasses at 35% waste loading (ω). 12
Figure 5-1. NL[B (g/L) PCTs for HWL Glasses of Interest for Both Heat Treatments Based Upon Targeted Compositions. 42

List of Tables

Table 3-1. SB3 and SB4 Sludge Information for the 33 RC Glasses 5
Table 3-2. Oxide Ranges for Sludge "Others" 6
Table 3-3. Target Glass Compositions for the RC Study 8
Table 3-4. Property Predictions for the 33 RC Glasses 9
Table 3-5. Iron, Thorium, and Uranium Information for "Basic" Sludge Types (WCSludge.xls) 10
Table 3-6. Glass Compositions for the ThO_2-Based Glasses 13
Table 3-7. Property Predictions for the ThO_2-Based "rcth" Glasses 13
Table 3-8. Sludge Compositions for the New High Waste Loading and ThO_2-Containing Glasses 15
Table 3-9. Glass Compositions for the New High Waste Loading and ThO_2-Containing Glasses 15
Table 3-10. Property Predictions for the SB3 and SB4 High Waste Loading and ThO_2 Glasses 16
Table 3-11. Recent Tank 40 Sample Information (Aqua Regia) 17
Table 3-12. Sludge Composition for High Waste Loading "tk40" Glasses 18
Table 3-13. Property Predictions for High Waste Loading "tk40" Glasses 18
Table 3-14. Glass Compositions for High Waste Loading "tk40" Glasses 18
Table 3-15. Glass Compositions for the New High Waste Loading and ThO_2-Containing Glasses 19
Table 3-16. Property Predictions for the SB3 and SB4 High Waste Loading and ThO_2 Glasses 20
Table 5-1. Results from Samples of the Multi-Element Solution Standard 30
Table 5-2. Normalized PCTs by Glass ID/Compositional View, Shaded by Glass Group 32
Table 5-3. Compositional Comparisons for Th-Loaded Glasses 35
Table 5-4. Normalized PCT Results for "rc" and "rcth" Glass Pairs 36
Table 5-5. ΔGp Values for Quenched "rc" and "rcth" Glass Pairs Based on Targeted Compositions 37
Table 5-6. Predicted and Measured Viscosity ($\eta_{1150°C}$) 39
Table 5-7. NL[B (g/L)] PCTs for HWL Glasses of Interest for Both Heat Treatments Based Upon Targeted Compositions. 41
Table 5-8. Predicted and Measured Viscosity ($\eta_{1150°C}$) 44
Table 5-9. Normalized PCTs for the "tk40" Glasses. 45
Table 5-10. Predicted and Measured Viscosity ($\eta_{1150°C}$) 46

1.0 Introduction

In support of accelerated mission goals, glass formulation efforts have been focused on melt rate, waste loading, and waste throughput for the Defense Waste Processing Facility (DWPF). With respect to increased waste loading (WL), Brown et al. (2001a) developed a new liquidus temperature (T_L) model that may allow higher waste loadings for future DWPF operations. Peeler et al. (2002a) have demonstrated via model-based assessments that coupling the new T_L model with alternative frit compositions can lead to significant increases in waste loadings for certain systems. Higher WLs have recently been targeted in DWPF with the implementation of the new T_L model and Frit 320 for SB2 (e.g., WLs of 35 wt% or higher are being targeted as compared to 28% with the Frit 200/SB2 system). As WL increases, components of the sludge become more critical in terms of dictating glass properties. For example, sludge components such as Fe_2O_3, Cr_2O_3, NiO, and MnO have been studied quite extensively at higher concentrations given their influence on spinel formation and/or T_L and the desire to access higher WLs.[1]

Although current DWPF models were based on a limited number of radioactive glasses, the effects of U_3O_8 and ThO_2 are not as well known as the effects of other components – especially at higher concentrations given higher WLs are being or will be targeted. In fact, only one of the current Product Composition Control System (PCCS) models (i.e., the durability model or ΔG_P) contains U_3O_8 and ThO_2 terms. The other primary PCCS models (viscosity and T_L) do not include terms for these radioactive components. This suggests that U_3O_8 and ThO_2 have no effect (or minimal effect) on these two primary processing properties over the compositional range in which the models were developed.

The effect of uranium on various high-level waste glass properties has been previously studied. Vienna et al. (1995), Li et al. (1995), and Langowski (1996) studied glasses containing up to 15 wt% UO_2. Their results indicated that uranium had little effect on the centerline canister cooled (ccc) glass crystallization, durability as defined by the Product Consistency Test (PCT), and viscosity of high level waste glasses. Peeler et al. (2002b) also evaluated specific DWPF glasses containing relatively high concentrations of U_3O_8 (~5.4 wt%). Although the focus of that study was not specifically on the impact of U_3O_8 on various glass properties, the results indicated that the current durability model was either applicable or conservative with respect to predicting the measured durability response.

In this study, glasses are designed or selected to assess the impacts of U_3O_8 and ThO_2 on various glass properties of interest.[2] A primary interest will be to fabricate a limited number of glasses in which Th replaces U (on a molar basis) to assess the impact of ThO_2 on the PCT response and viscosity. Assessments or comparisons of the predicted versus measured impacts will also be made. As previously mentioned, as higher WLs are targeted, the concentration of these two components will increase and a preliminary assessment of their impact on various glass properties is warranted. In addition, a series of glasses will be produced to assess the impact of higher WLs on select glass properties.

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[1] Waste loading in this report is simply calculated as the HLW oxide fraction of the final glass.

[2] ThO_2 in the tank farm stems primarily from the THOREX process. The ThO_2 resulting from this process was transferred to a limited number of tanks and, thus, based on the blending strategies used could result in elevated concentrations. Based on the current Performance Management Plan (PMP) (HLW-2002-00161), SB8 is projected to have elevated levels of ThO_2.

The study glasses are based on projected sludge compositions, candidate frits, and WLs of interest resulting from model-based assessments. It should be noted that changes in projected sludge compositions, use of alternative frits, or a combination of both is likely so the glasses fabricated and tested in this study may not be representative of specific DWPF glasses. Although this possibility exists, the glasses will provide insight into the effects of U_3O_8 and ThO_2 on glasses within the general DWPF compositional region of interest.

2.0 Objectives

The primary objective of this task is to assess the impacts of U_3O_8 and ThO_2 on the PCT response and viscosity. This assessment will provide preliminary insight into the applicability of the current models to elevated concentrations of these components. An evaluation of the predicted impact (or lack thereof) as compared to the measured impact will be performed.

A secondary objective is to assess the impact of higher WLs on both PCT and viscosity. In this series of glasses, although U_3O_8 concentrations will be relatively high, the effect of U_3O_8 can not be isolated. That is, as WL increases, not only does the U_3O_8 concentration increase but also all other sludge components. Therefore, the assessments on the selected properties will be viewed accordingly.

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3.0 Glass Selection Process

This section provides a detailed discussion regarding the glass selection process that was used to meet programmatic objectives. In Section 3.1, compositional information on the basic sludge types and projected blends is initially discussed. Based on this review, a specific sludge type is selected as the "technical" basis for making (and subsequently assessing the impact of) molar substitutions between U_3O_8 and ThO_2. In Section 3.2, high waste loading glasses are defined that target relatively high U_3O_8 concentrations.

3.1 Thorium-Containing Glass Selection

The primary focus of this study is to assess the impact of U_3O_8 and ThO_2 on viscosity and durability (as defined by the PCT) for glasses within a compositional region of interest to DWPF. To reduce the number of glasses and the complexity of the study, this work will leverage or utilize existing DWPF composition – property information of interest. More specifically, glasses that were fabricated and for which specific properties were measured as part of the Reduction of Constraints (RC) task will be used (see Peeler et al. (2002b) for more details). Table 3-1 provides the sludge information for the 33 glasses selected for the RC study which was designed to cover what was believed to be at the time the remaining sludge-only operation in DWPF, namely Sludge Batch 3 (SB3) and Sludge Batch 4 (SB4). Note that the ThO_2 concentrations in these glasses were considered negligible and are contained in the "Others" constituent.

Table 3-1. SB3 and SB4 Sludge Information for the 33 RC Glasses (from Peeler and Edwards 2002b).

Type	Al_2O_3	CaO	Fe_2O_3	MgO	MnO	Na_2O	NiO	SiO_2	U_3O_8	Others
HLF	0.0322	0.0490	0.4785	0.0346	0.1597	0.1273	0.0089	0.0596	0.0202	0.0299
HHF	0.4387	0.0209	0.1350	0.0174	0.0993	0.1274	0.0107	0.0999	0.0204	0.0302
PHF	0.0890	0.0175	0.3440	0.0289	0.1135	0.1283	0.0839	0.0095	0.1547	0.0306
PLF	0.1252	0.0449	0.4626	0.0112	0.0523	0.1251	0.0188	0.0232	0.1066	0.0300
PMF	0.0816	0.0327	0.4127	0.0189	0.1065	0.1321	0.0507	0.0169	0.1171	0.0308
SB3	0.1180	0.0428	0.4526	0.0130	0.0574	0.1277	0.0256	0.0221	0.1105	0.0304
SB4	0.1155	0.0405	0.4183	0.0182	0.0990	0.1284	0.0204	0.0435	0.0858	0.0304

[a] Sludge types
HLF: H modified low heat feed
PLF: PUREX low heat feed
PHF: PUREX high heat feed
PMF: PUREX mixed feed
HHF: H modified high heat feed
SB3: sludge batch 3
SB4: sludge batch 4

The SB3 and SB4 sludge composition information was originally collected based upon the various basic sludge types (e.g., HLF, HHF, PLF, PMF, and PHF) that comprised the material in the projected sludge-only batches (i.e., SB1a, SB1b, and SB2-4). However, it was readily apparent that not every one of these basic types could actually be processed individually in DWPF. For example, because the projected HLF sludge only contains approximately 3.2% Al_2O_3, there was no way that a glass could be produced in DWPF that would satisfy the constraint on Al_2O_3 of 3% without introducing high concentrations of Al_2O_3 in the frit. More specifically, WLs of approximately 100% would be required to meet this constraint, which is infeasible. Thus, many of the RC glasses had to represent more feasible blends of the basic sludge types based upon the projected SB3 and SB4 information.

The composition of the minor components (referred to as "Others" in Table 3-1) is shown in Table 3-2. The "Others" component was developed as part of the glass-selection effort for the SB2/Frit 320 variability study (Brown et al. 2001b), and as previously noted has a relatively low ThO_2 concentration (1.75 wt%).

Table 3-2. Oxide Ranges for Sludge "Others"

	Grams/100 g Sludge Oxides		%Oxide in "Others"
	Minimum	Maximum	Mean
B_2O_3	3.25E-02	4.28E-02	1.32
BaO	4.20E-02	5.80E-02	1.74
CdO	1.67E-01	2.21E-01	6.79
CoO	2.10E-02	3.51E-02	0.94
Cr_2O_3	2.23E-01	5.19E-01	11.75
CuO	6.42E-02	1.01E-01	2.80
La_2O_3	4.70E-02	7.19E-02	2.03
Li_2O	1.61E-01	2.13E-01	6.55
ThO_2	4.09E-02	6.15E-02	1.75
RuO_2	6.98E-02	9.54E-02	2.88
MoO_3	8.08E-03	1.11E-02	0.33
P_2O_5	7.54E-01	2.16E+00	44.60
PbO	1.10E-01	1.56E-01	4.61
SnO_2	1.87E-02	4.50E-02	1.00
SrO	2.45E-02	3.42E-02	1.02
TiO_2	3.14E-02	4.59E-02	1.33
V_2O_5	3.18E-02	4.59E-02	1.34
ZnO	6.88E-02	1.03E-01	2.94
ZrO_2	9.65E-02	1.55E-01	4.26
SUM	2.01	4.17	100.00

Based on the individual sludge types and projected SB3 and SB4 blends, thirty-three glass compositions were defined for the RC study. Table 3-3 identifies the targeted compositions for the RC glasses.[3] The targeted ThO_2 concentration for each RC glass has been removed from the "Others" component and shown as a "major" oxide in this table. The targeted ThO_2 values are indeed negligible (< ~0.02 wt% in glass). Table 3-4 provides the relevant property prediction information for these 33 glasses for completeness. Note in Table 3-3 and Table 3-4 the glasses have been sorted based on both sludge type and frit with WLs in descending order – not by "rc" number. Thirteen (13) of the glasses were made using Frit 165, seven (7) were made from Frit 200, and the remaining thirteen (13) glasses were made using Frit 320.

To support the primary programmatic objective, it is desired to make a subset of glasses like those represented in Table 3-3 but with ThO_2 substitutions for U_3O_8. These glasses would have

[3] As discussed later in this section, three glasses (rc-30, rc-40, and rc-50) are shaded to indicate that these were the baseline glasses used to assess the impact of U_3O_8 and ThO_2 on PCT and viscosity.

identical property predictions (within batching and measurement uncertainty) – with the exception of durability. A conscious decision was made not to fabricate and test glasses with identical predicted durabilities. Since ThO_2 and U_3O_8 have $\Delta G_{p,i}$'s that are opposite in sign (Jantzen et al 1995), it would require adjusting yet another oxide concentration to obtain equivalent durability predictions. This is considered an unnecessary complication for this study. Jantzen et al. (1995) reported the ΔG_i values for U_3O_8 and ThO_2 as -23.77 kcal/mol and +19.23 kcal/mol, respectively. The ΔG_i signs suggest that U_3O_8 will have a negative impact on durability while ThO_2 should increase durability.

By designing the glasses to have equivalent predicted properties, with the exception of durability, as assessment of the projected positive impact of substituting ThO_2 for U_3O_8 can be made relative to the measured PCT response. More specifically, an evaluation as to whether the predicted impact is realized can be assessed. Given the absence of both U_3O_8 and ThO_2 from the T_L and viscosity models, each pair of glasses with the ThO_2 substituted for U_3O_8 will have the same predicted processing properties.

Table 3-3. Target Glass Compositions for the RC Study (in mass fraction) [from Peeler et al. 2002b]

GlassID	Category	WL(%)	Frit ID	Al_2O_3	B_2O_3	CaO	Cr_2O_3	Fe_2O_3	Li_2O	MgO	MnO	Na_2O	NiO	SiO_2	ThO_2	U_3O_8	ZrO_2	Others
RC-36	165-HHF OL	15.0	165	0.0658	0.0851	0.0031	0.0005	0.0202	0.0598	0.0111	0.0149	0.1296	0.0016	0.5930	0.0001	0.0031	0.0087	0.0034
RC-31	165-HHF OL	20.0	165	0.0877	0.0801	0.0042	0.0007	0.0270	0.0564	0.0115	0.0199	0.1295	0.0021	0.5640	0.0001	0.0041	0.0083	0.0044
RC-30	165-PHF OL	35.0	165	0.0312	0.0651	0.0061	0.0013	0.1204	0.0462	0.0166	0.0397	0.1294	0.0294	0.4453	0.0002	0.0541	0.0070	0.0080
RC-37	165-PLF OL	25.0	165	0.0313	0.0751	0.0112	0.0009	0.1157	0.0530	0.0103	0.0131	0.1288	0.0047	0.5158	0.0001	0.0267	0.0078	0.0055
RC-29	165-PLF OL	30.0	165	0.0376	0.0701	0.0135	0.0011	0.1388	0.0496	0.0104	0.0157	0.1285	0.0057	0.4830	0.0002	0.0320	0.0074	0.0064
RC-25	165-PLF OL	35.0	165	0.0438	0.0651	0.0157	0.0012	0.1619	0.0462	0.0104	0.0183	0.1283	0.0066	0.4501	0.0002	0.0373	0.0069	0.0080
RC-35	165-SB3 OL	27.5	165	0.0325	0.0726	0.0118	0.0010	0.1245	0.0513	0.0108	0.0158	0.1294	0.0070	0.4991	0.0001	0.0304	0.0076	0.0061
RC-34	165-SB3 OL	30.0	165	0.0354	0.0701	0.0128	0.0011	0.1358	0.0496	0.0109	0.0172	0.1293	0.0077	0.4826	0.0002	0.0331	0.0074	0.0068
RC-26	165-SB3 OL	35.0	165	0.0413	0.0651	0.0150	0.0013	0.1584	0.0462	0.0110	0.0201	0.1292	0.0090	0.4497	0.0002	0.0387	0.0070	0.0078
RC-27	165-SB4 OL	27.5	165	0.0318	0.0726	0.0111	0.0010	0.1150	0.0513	0.0123	0.0272	0.1296	0.0056	0.5050	0.0001	0.0236	0.0076	0.0062
RC-28	165-SB4 OL	30.0	165	0.0347	0.0701	0.0122	0.0011	0.1255	0.0496	0.0125	0.0297	0.1295	0.0061	0.4890	0.0002	0.0257	0.0074	0.0067
RC-32	165-SB4 OL	35.0	165	0.0404	0.0651	0.0142	0.0013	0.1464	0.0462	0.0129	0.0346	0.1294	0.0071	0.4572	0.0002	0.0300	0.0070	0.0080
RC-33	165-SB4 OL	37.5	165	0.0433	0.0627	0.0152	0.0013	0.1569	0.0445	0.0131	0.0371	0.1294	0.0077	0.4413	0.0002	0.0322	0.0067	0.0084
RC-40	200-PHF OL	35.0	200	0.0312	0.0781	0.0061	0.0013	0.1204	0.0332	0.0231	0.0397	0.1164	0.0294	0.4583	0.0002	0.0541	0.0005	0.0080
RC-41	200-PLF OL	25.0	200	0.0313	0.0901	0.0112	0.0009	0.1157	0.0380	0.0178	0.0131	0.1138	0.0047	0.5308	0.0001	0.0267	0.0003	0.0055
RC-42	200-PLF OL	30.0	200	0.0376	0.0841	0.0135	0.0011	0.1388	0.0356	0.0174	0.0157	0.1145	0.0057	0.4970	0.0002	0.0320	0.0004	0.0064
RC-44	200-SB3 OL	27.5	200	0.0325	0.0871	0.0118	0.0010	0.1245	0.0368	0.0181	0.0158	0.1149	0.0070	0.5136	0.0001	0.0304	0.0004	0.0060
RC-38	200-SB3 OL	30.0	200	0.0354	0.0841	0.0128	0.0011	0.1358	0.0356	0.0179	0.0172	0.1153	0.0077	0.4966	0.0002	0.0331	0.0004	0.0068
RC-39	200-SB4 OL	30.0	200	0.0347	0.0841	0.0122	0.0011	0.1255	0.0356	0.0195	0.0297	0.1155	0.0061	0.5030	0.0002	0.0257	0.0004	0.0067
RC-43	200-SB4 OL	32.5	200	0.0376	0.0811	0.0132	0.0012	0.1360	0.0344	0.0194	0.0322	0.1160	0.0066	0.4866	0.0002	0.0279	0.0004	0.0072
RC-50	320-PHF OL	35.0	320	0.0312	0.0521	0.0061	0.0013	0.1204	0.0527	0.0101	0.0397	0.1229	0.0294	0.4713	0.0002	0.0541	0.0005	0.0080
RC-52	320-PLF OL	25.0	320	0.0313	0.0601	0.0112	0.0009	0.1157	0.0605	0.0028	0.0131	0.1213	0.0047	0.5458	0.0001	0.0267	0.0003	0.0055
RC-54	320-PLF OL	30.0	320	0.0376	0.0561	0.0135	0.0011	0.1388	0.0566	0.0034	0.0157	0.1215	0.0057	0.5110	0.0002	0.0320	0.0004	0.0064
RC-47	320-PLF OL	35.0	320	0.0438	0.0521	0.0157	0.0012	0.1619	0.0527	0.0039	0.0183	0.1218	0.0066	0.4761	0.0002	0.0373	0.0004	0.0080
RC-46	320-PMF OL	37.5	320	0.0306	0.0502	0.0123	0.0014	0.1548	0.0508	0.0071	0.0399	0.1246	0.0190	0.4563	0.0002	0.0439	0.0005	0.0084
RC-56	320-SB3 OL	27.5	320	0.0325	0.0581	0.0118	0.0010	0.1245	0.0586	0.0036	0.0158	0.1221	0.0070	0.5281	0.0001	0.0304	0.0004	0.0060
RC-49	320-SB3 OL	30.0	320	0.0354	0.0561	0.0128	0.0011	0.1358	0.0566	0.0039	0.0172	0.1223	0.0077	0.5106	0.0002	0.0331	0.0004	0.0068
RC-45	320-SB3 OL	35.0	320	0.0413	0.0521	0.0150	0.0013	0.1584	0.0527	0.0045	0.0201	0.1227	0.0090	0.4757	0.0002	0.0387	0.0005	0.0078
RC-51	320-SB4 OL	27.5	320	0.0318	0.0581	0.0111	0.0010	0.1150	0.0586	0.0050	0.0272	0.1223	0.0056	0.5340	0.0001	0.0236	0.0004	0.0062
RC-57	320-SB4 OL	30.0	320	0.0347	0.0561	0.0122	0.0011	0.1255	0.0566	0.0055	0.0297	0.1225	0.0061	0.5170	0.0002	0.0257	0.0004	0.0067
RC-55	320-SB4 OL	35.0	320	0.0404	0.0521	0.0142	0.0013	0.1464	0.0527	0.0064	0.0346	0.1229	0.0071	0.4832	0.0002	0.0300	0.0005	0.0080
RC-48	320-SB3 OL	37.5	320	0.0443	0.0502	0.0160	0.0013	0.1697	0.0508	0.0049	0.0215	0.1229	0.0096	0.4583	0.0002	0.0414	0.0005	0.0084
RC-53	320-SB4 OL	40.0	320	0.0462	0.0482	0.0162	0.0014	0.1673	0.0488	0.0073	0.0396	0.1234	0.0082	0.4494	0.0002	0.0343	0.0005	0.0090

Table 3-4. Property Predictions for the 33 RC Glasses

Glass ID	Category	WL (%)	η (Poise)	Homogeneity	Al_2O_3 (wt%)	Σalkali (wt%)	ΔGp (kcal/mol)	NL [B (g/L)]	New T_L(°C)	DWPF PAR Operating Window
RC-36	165-HHF OL	15.0	95	189.47	6.581	18.941	-11.2575	1.37	626.8	Durable; Visc; Not Homog; New T_L; Al_2O_3; alkali
RC-31	165-HHF OL	20.0	104	200.25	9.30	19.04	-10.4422	0.975	713.9	Durable; Visc; Not Homog; New T_L; Al_2O_3; alkali
RC-30	165-PHF OL	35.0	24.8	199.06	3.115	17.559	-12.4203	2.224	1067.4	Durable; Visc; Not Homog; Not New T_L; Al_2O_3; alkali
RC-37	165-PLF OL	25.0	36.3	213.22	3.13	18.177	-11.6332	1.602	842.9	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-29	165-PLF OL	30.0	29.5	224.44	3.756	17.812	-11.2191	1.348	924.9	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-25	165-PLF OL	35.0	23.3	235.66	4.382	17.448	-10.805	1.134	999.3	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-35	165-SB3 OL	27.5	32.4	215.91	3.245	18.065	-11.631	1.6	888.6	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-34	165-SB3 OL	30.0	29	221.25	3.54	17.89	-11.4426	1.479	929.4	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-26	165-SB3 OL	35.0	22.8	231.94	4.13	17.538	-11.0658	1.264	1005.6	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-27	165-SB4 OL	27.5	35.4	210.82	3.177	18.085	-12.1026	1.948	850.3	Durable; Visc; Not Homog; New T_L; Al_2O_3; alkali
RC-28	165-SB4 OL	30.0	32.2	215.70	3.466	17.911	-11.9571	1.833	889.0	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-32	165-SB4 OL	35.0	26	225.46	4.044	17.563	-11.666	1.624	961.8	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-33	165-SB4 OL	37.5	23.1	230.34	4.333	17.389	-11.5205	1.528	996.1	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-40	200-PHF OL	35.0	46.8	199.06	3.115	14.959	-10.5661	1.027	1157.1	Durable; Visc; Not Homog; Not New T_L; Al_2O_3; alkali
RC-41	200-PLF OL	25.0	67.6	213.22	3.13	15.177	-9.4937	0.657	914.0	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-42	200-PLF OL	30.0	55.1	224.44	3.245	15.012	-9.2222	0.586	993.4	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-44	200-SB3 OL	27.5	60.4	215.91	3.245	15.165	-9.5628	0.676	960.9	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-38	200-SB3 OL	30.0	54.3	221.25	3.54	15.09	-9.4457	0.644	1000.5	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-39	200-SB4 OL	30.0	59.5	215.70	3.466	15.111	-9.9602	0.798	960.3	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-43	200-SB4 OL	32.5	53.7	220.58	3.755	15.037	-9.886	0.773	996.4	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-50	320-PHF OL	35.0	31.0	201.15	3.115	17.559	-12.0028	1.869	1029.8	Durable; Visc; Not Homog; Not New T_L; Al_2O_3; alkali
RC-52	320-PLF OL	25.0	44.4	215.63	3.13	18.177	-11.1515	1.31	801.9	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-54	320-PLF OL	30.0	36.5	226.69	3.756	17.812	-10.7695	1.118	887.7	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-47	320-PLF OL	35.0	29.1	237.74	4.382	17.448	-10.3875	0.953	965.7	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-46	320-PMF OL	37.5	23.2	220.96	3.06	17.531	-11.8554	1.757	999.8	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-56	320-SB3 OL	27.5	39.8	218.23	3.245	18.065	-11.1654	1.318	849.3	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-49	320-SB3 OL	30.0	35.9	223.50	3.466	17.911	-10.993	1.227	891.9	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-45	320-SB3 OL	35.0	28.5	234.02	4.13	17.538	-10.6483	1.063	971.7	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-51	320-SB4 OL	27.5	43.2	213.15	3.177	18.085	-11.637	1.604	810.8	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-57	320-SB4 OL	30.0	39.4	217.95	3.54	17.89	-11.5075	1.52	851.3	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-55	320-SB4 OL	35.0	32.2	227.55	4.044	17.563	-11.2485	1.365	927.5	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-48	320-SB3 OL	37.5	25.1	239.28	4.425	17.362	-10.4759	0.989	1009.1	Durable; Visc; Homog; New T_L; Al_2O_3; alkali
RC-53	320-SB4 OL	40.0	25.5	237.15	4.622	17.215	-10.9896	1.225	997.9	Durable; Visc; Homog; New T_L; Al_2O_3; alkali

Given compositional and durability measurements have been made on the 33 RC glasses (Peeler et al. (2002b)), identification of base glasses from which U_3O_8 / ThO_2 substitutions can be made is needed. Based on the historic information provided in Table 3-5, the HMF and HHF types are likely to be highest in ThO_2. Unfortunately, only two of the RC glasses (i.e., RC-36 and RC-31) were based on the HHF sludge type and both are low WL glasses, 15% and 20%, respectively. Given the low WLs, the resulting U_3O_8 concentration in glass is projected to be less than one-half percent. In addition, both glasses were produced based solely on Frit 200, which would limit the assessment to a specific sludge / frit combination (one that is not of particular interest due to lower targeted WLs and potentially lower melt rates). Thus, these glasses were not considered as primary candidates for exploring the ThO_2 effects for the properties of interest.

Table 3-5 indicates that the HMF sludge is also likely to be high in ThO_2. Peeler et al. (2001a) indicated that only 1.4% of the projected SB4 blend was based on the HMF sludge type. Therefore, no specific RC glasses were based solely on this sludge type meaning that data do not exist from which the impact of ThO_2 can be assessed.

HLF is the next highest ThO_2-based sludge type projected. As previously stated, its low Al_2O_3 concentrations would require ~100% WLs which are unrealistic, and therefore, no specific RC glasses were produced using this sludge type due to this issue.

Table 3-5. Iron, Thorium, and Uranium Information for "Basic" Sludge Types (WCSludge.xls)

	lb			lb-moles				Moles/moles $Fe(OH)_3$		molar
Type	$Fe(OH)_3$	ThO_2	$UO_2(OH)_2$	$Fe(OH)_3$	ThO_2	$UO_2(OH)_2$	U_3O_8	ThO_2	U_3O_8	ThO_2/U_3O_8
HHF	238700	30830	29350	2233.6	116.8	96.5	32.2	0.05228	0.01441	3.629
HLF	307900	732	31500	2881.1	2.8	103.6	34.5	0.00096	0.01199	0.080
HMF	259460	21801	29995	2427.8	82.6	98.7	32.9	0.03401	0.01354	2.511
PHF	583900	921	131500	5463.7	3.5	432.5	144.2	0.00064	0.02639	0.024
PLF	1103000	181	178900	10321.0	0.7	588.4	196.1	0.00007	0.01900	0.004
PMF	843450	551	155200	7892.4	2.1	510.5	170.2	0.00026	0.02156	0.012

Thus as a fall back position, the three PHF glasses (i.e., rc-30, rc-40, and rc-50) with the highest U_3O_8 concentrations (that are also produced using all three frits) will be considered for examination of ThO_2 effects. From Table 3-1, the PHF-based sludge has over 15% U_3O_8, which translates into over 5.4% U_3O_8 in their respective RC glasses (these glasses are shaded in Table 3-3).

In terms of defining the "counterpart" Th-based glasses, a mass, Δ_{ThO2}, of U_3O_8 in each of the PHF-type sludge glasses will be replaced by ThO_2 on a molar basis such that the molar ratio of ThO_2 to U_3O_8 is that (i.e., 3.629) given for the HHF type sludge in Table 3-5. This worst-case amount (Δ_{ThO2} = 8.208g in the sludge) was computed using MathCad® and the results are provided in Figure 3-1. Therefore, the sludge would have 7.261g of U_3O_8, 8.208g of ThO_2, and 3.06g of the same (ThO_2-containing) Others.

Thus three new glasses (i.e., rcth-30, rcth-40, and rcth-50) can be produced differing in only ThO_2 and U_3O_8 concentrations from the corresponding rc-30, rc-40, and rc-50 glasses described (and shaded) in Table 3-3. The targeted U_3O_8, ThO_2, and "Others" concentrations in the "rcth" glasses are 2.54 wt%, 2.89 wt% and 1.07 wt%, respectively – see Table 3-6. With respect to predicted properties, given U_3O_8 and ThO_2 terms are only associated with the durability model, all other predicted properties should be equivalent between the base "rc" glasses and their Th-enriched "rcth" counterparts. Measuring the durability response for these glasses will allow for an assessment of the impact of ThO_2 as well as confirmation that the magnitude and sign of the predicted impact (e.g., the ΔG_i value) are justified. Given there is no predicted impact of ThO_2 on viscosity or T_L, the data collected on these glasses can be compared to see if a measurable or practical impact on these properties can be observed. It should be noted that only viscosity will be assessed in this report. This is not to belittle the significance of T_L, but due to the intensive labor requirements to formally measure T_L (particularly on radioactive glasses) and the funding level under which this task is being performed, this property will not be assessed.

Table 3-7 summarizes the predicted properties for the "rcth" glasses. As noted in the second (Sludge ID) and fourth (wt% WL) columns, all three glasses are based on the PHF sludge type and target a 35% WL. The third column (Frit ID) provides the frit basis that ultimately drives the differences in predicted properties. Given the total alkali concentrations of the Frit 165- and Frit 320-based glasses (rcth-30 and rcth-50, respectively) are equivalent (17.56 wt%) and are greater than the Frit 200 glass (14.96 wt% in rcth-40), the lower viscosities, lower ΔG_P values, higher NL [B] releases, and lower T_L values relative to Frit 200 predictions are in-line with expectations. The predicted differences between rcth-30 and rcth-50 are strictly due to the differences in frit compositions. Even though all three glasses are predicted to be inhomogeneous they do meet one of the two alternative constraints that can be used to relax the homogeneity constraint to the PAR. More specifically, these glasses target 3.115 wt% Al_2O_3 and have total alkali concentrations less than 19.3 wt%. It should also be noted that these glasses also violate the T_L PAR limit of 1010°C using the new T_L model. Of particular interest is the rcth-40 T_L prediction of 1157°C which is much higher than the Frit 165 (~1067°C) or Frit 320 (~1030°C) based glass predictions. Therefore, the projected WLs being used are artificially high as DWPF could not process these glasses due to T_L restrictions based on current PCCS predictions. Although restricted from current operations, the high WLs targeted do provide the opportunity to assess the impact of U_3O_8 and/or ThO_2 on other glass properties (namely PCT and viscosity).

Original glass information:

$$xU3O8_{g0} = \omega \cdot xU3O8_{s0} + (1-\omega) \cdot xU3O8_{f}$$
$$xThO2_{g0} = \omega \cdot xThO2_{s0} + (1-\omega) \cdot xThO2_{f}$$

Glasses after substitutoin of ThO2 for U3O8 of:

$$xU3O8_{gf} = \omega \cdot (xU3O8_{s0} - \Delta ThO2) + (1-\omega) \cdot xU3O8_{f}$$
$$xThO2_{gf} = \omega \cdot (xThO2_{s0} + \Delta ThO2) + (1-\omega) \cdot xThO2_{f}$$

But how much ThO2 do I want to substitute for U3O8? The maximum molar ratio of ThO2 to U3O8 from th sludge information is:

$\theta := 3.62875861$ $\omega := 0.35$

So I want:

$$\frac{(xThO2_{s0} + \Delta ThO2) \cdot MThO2^{-1}}{(xU3O8_{s0} - \Delta ThO2) \cdot MU3O8^{-1}} = \theta$$

where: $xU3O8_{s0} := 0.154681 \cdot 100$ $xU3O8_{s0} = 15.468$ $MU3O8 := 842.0852$ $xU3O8_{f} := 0.0$

$xThO2_{s0} := (0.03063125 - 0.0175) \cdot 100$ $xThO2_{s0} = 0.054$ $MThO2 := 264.0368$ $xThO2_{f} := 0.0$

$100 \omega \cdot 0.03063125 = 1.072$

$$\frac{(xThO2_{s0} + \Delta ThO2) \cdot MThO2^{-1}}{(xU3O8_{s0} - \Delta ThO2) \cdot MU3O8^{-1}} = \theta \quad \text{or} \quad \Delta ThO2 := \frac{(-MU3O8 \cdot xThO2_{s0} + \theta \cdot MThO2 \cdot xU3O8_{s0})}{(MU3O8 + \theta \cdot MThO2)}$$

$\Delta ThO2 = 8.208$ $xU3O8_{s0} - \Delta ThO2 = 7.261$

$\omega \cdot \Delta ThO2 = 2.873$

$$\frac{(xThO2_{s0} + \Delta ThO2) \cdot MThO2^{-1}}{(xU3O8_{s0} - \Delta ThO2) \cdot MU3O8^{-1}} - \theta = 0 \quad \text{to check}$$

$xU3O8_{gf} := \omega \cdot (xU3O8_{s0} - \Delta ThO2) + (1-\omega) \cdot xU3O8_{f}$ $xU3O8_{gf} = 2.541$

$xThO2_{gf} := \omega \cdot (xThO2_{s0} + \Delta ThO2) + (1-\omega) \cdot xThO2_{f}$ $xThO2_{gf} = 2.891$

$xU3O8_{gf} + xThO2_{gf} = 5.433$

Original glass information:

$xU3O8_{g0} := \omega \cdot xU3O8_{s0} + (1-\omega) \cdot xU3O8_{f}$ $xU3O8_{g0} = 5.414$

$xThO2_{g0} := \omega \cdot xThO2_{s0} + (1-\omega) \cdot xThO2_{f}$ $xThO2_{g0} = 0.019$

$xU3O8_{g0} + xThO2_{g0} = 5.433$

Figure 3-1. Computation of the amount of U_3O_8 to replace with ThO_2 for the PHF type sludge and resulting glasses at 35% waste loading (ω).

Table 3-6. Glass Compositions for the ThO_2-Based Glasses

	Glass Composition														
GlassID	Al_2O_3	B_2O_3	BaO	CaO	CdO	CoO	Cr_2O_3	CuO	Fe_2O_3	La_2O_3	Li_2O	MgO	MnO	MoO_3	Na_2O
rcth-30	0.03115	0.06514	0.000187	0.00613	0.000728	0.000101	0.001260	0.000300	0.12040	0.000218	0.04620	0.01663	0.03973	0.000035	0.12939
rcth-40	0.03115	0.07814	0.000187	0.00613	0.000728	0.000101	0.001260	0.000300	0.12040	0.000218	0.03320	0.02313	0.03973	0.000035	0.11639
rcth-50	0.03115	0.05214	0.000187	0.00613	0.000728	0.000101	0.001260	0.000300	0.12040	0.000218	0.05270	0.01013	0.03973	0.000035	0.12289

	Glass Composition (continued)													
GlassID	NiO	P_2O_5	PbO	RuO_2 (NM)	SiO_2	SnO_2	SrO	ThO_2	TiO_2	U_3O_8	V_2O_5	ZnO	ZrO_2	Others*
rcth-30	0.029380	0.004782	0.000494	0.000309	0.44534	0.000107	0.000109	0.028914	0.000143	0.025412	0.000144	0.000315	0.006957	0.010721
rcth-40	0.029380	0.004782	0.000494	0.000309	0.45834	0.000107	0.000109	0.028914	0.000143	0.025412	0.000144	0.000315	0.000457	0.010721
rcth-50	0.029380	0.004782	0.000494	0.000309	0.47134	0.000107	0.000109	0.028914	0.000143	0.025412	0.000144	0.000315	0.000457	0.010721

* The components in "Others" have already been included in the glass composition (e.g., ThO_2) but the fractions of "Others" are provided for completeness.

Table 3-7. Property Predictions for the ThO_2-Based "rcth" Glasses

GlassID	SludgeID	Frit ID	WL (%)	Al_2O_3 (wt%)	R_2O Wt%)	η (Poise)	Homog.	ΔG_p (kcal/mol)	NL[B] (g/L)	New T_L (°C)	Violates PAR
rcth-30	PHF OL	165	35.0	3.115	17.56	24.8	199.1	-12.13	1.970	1067.4	Not Homog; Not New TL
rcth-40	PHF OL	200	35.0	3.115	14.96	46.8	199.1	-10.28	0.910	1157.1	Not Homog; Not New TL
rcth-50	PHF OL	320	35.0	3.115	17.56	31.0	201.1	-11.71	1.656	1029.8	Not Homog; Not New TL

3.2 High Waste Loading (HWL) Glass Selection

To support secondary programmatic objectives, a set of glasses was designed at relatively high waste loadings to assess the impact of uranium on the primary properties of interest. These glasses are based on projections of SB3 and SB4 processing. Peeler et al. (2002b) identified six possible types of glasses that represented possible SB3 and SB4 operations. These are:

- SB3-Frit 165 (rc-35, -34, and -26 at 27.5%, 30%, and 35% WL, respectively),
- SB4-Frit 165 (rc-27, -28, -32, and -33 at 27.5%, 30%, 35%, and 37.5% WL, respectively),
- SB3-Frit 200 (rc-44 and -38 at 27.5% and 30% WL, respectively),
- SB4-Frit 200 (rc-39 and -43 at 30% and 32.5% WL, respectively),
- SB3-Frit 320 (rc-56, -57, -45, and -48 at 27.5%, 30%, 35%, and 37.5%, respectively)
- SB4-Frit 320 (rc-51, -49, -55, and –53 at 27.5%, 30%, 35%, and 40%, respectively)

Again, it should be noted that changes in projected sludge compositions and/or blending strategies, use of alternative frits, or a combination of both is likely; so the glasses fabricated and tested in this study may not be representative of a specific DWPF flowsheet. In fact, recent changes to the sequencing strategy have indicated that SB3 will be blended with some fraction of SB2, if true, this essentially eliminates the potential of processing SB3 alone. This being the case, the assessments previously performed for SB3-only projections will only provide insight into future glass formulation or flowsheet development issues. The physical property measurements for the glasses identified in this study may not be fully representative of a specific flowsheet, but they will provide insight into the effects of U_3O_8 and ThO_2 on glasses within the general DWPF compositional region of interest.

For this set of high WL glasses, the maximum WL was established through a trial-and-error series in which the predicted T_L value was proximate to 1050°C using the newly T_L model as defined by Brown et al. (2000a). It should be noted that the use of the 1050°C limit is relatively aggressive in terms of establishing a maximum WL limit. In fact during the DWPF SME acceptability decision process, once measurement uncertainties are accounted for, these glasses would likely not be classified as processable. However, the use of the 1050°C limit does provide a consistent basis from which to establish the upper WLs for each system which will push U_3O_8 concentrations to higher limits than expected – thus meeting the intent of this study. These glasses are denoted as rchwl-01 through rchwl-06 and their sludge and glass compositions are provided in Table 3-8 and Table 3-9, respectively.

Table 3-8. Sludge Compositions for the New High Waste Loading and ThO_2-Containing Glasses

				Sludge										
GlassID	Category	WL (%)	Type	Al_2O_3	CaO	Fe_2O_3	MgO	MnO	Na_2O	NiO	SiO_2	ThO_2	U_3O_8	Others
rchwl-01	165-SB3 OL Centroid	38.1	SB3 OL Centroid	0.1180	0.0428	0.4526	0.0130	0.0574	0.1277	0.0256	0.0221	0.0000	0.1105	0.0304
rchwl-02	165-SB4 OL Centroid	41.6	SB4 OL Centroid	0.1155	0.0405	0.4183	0.0182	0.0990	0.1284	0.0204	0.0435	0.0000	0.0858	0.0304
rchwl-03	200-SB3 OL Centroid	33.3	SB3 OL Centroid	0.1180	0.0428	0.4526	0.0130	0.0574	0.1277	0.0256	0.0221	0.0000	0.1105	0.0304
rchwl-04	200-SB4 OL Centroid	36.4	SB4 OL Centroid	0.1155	0.0405	0.4183	0.0182	0.0990	0.1284	0.0204	0.0435	0.0000	0.0858	0.0304
rchwl-05	320-SB3 OL Centroid	40.3	SB3 OL Centroid	0.1180	0.0428	0.4526	0.0130	0.0574	0.1277	0.0256	0.0221	0.0000	0.1105	0.0304
rchwl-06	320-SB4 OL Centroid	43.9	SB4 OL Centroid	0.1155	0.0405	0.4183	0.0182	0.0990	0.1284	0.0204	0.0435	0.0000	0.0858	0.0304

Table 3-9. Glass Compositions for the New High Waste Loading and ThO_2-Containing Glasses

	Glass Composition													
GlassID	Al_2O_3	B_2O_3	BaO	CaO	CdO	CoO	Cr_2O_3	CuO	Fe_2O_3	La_2O_3	Li_2O	MgO	MnO	MoO_3	Na_2O
rchwl-01	0.04496	0.06205	0.000202	0.01630	0.000787	0.000109	0.001363	0.000325	0.17246	0.000235	0.04409	0.01113	0.02187	0.000038	0.12911
rchwl-02	0.04806	0.05857	0.000220	0.01686	0.000859	0.000119	0.001487	0.000354	0.17403	0.000257	0.04171	0.01341	0.04117	0.000042	0.12932
rchwl-03	0.03929	0.08017	0.000176	0.01424	0.000688	0.000095	0.001191	0.000284	0.15073	0.000206	0.03401	0.01765	0.01911	0.000033	0.11588
rchwl-04	0.04206	0.07647	0.000193	0.01475	0.000752	0.000104	0.001301	0.000310	0.15227	0.000225	0.03253	0.01934	0.03602	0.000037	0.11668
rchwl-05	0.04755	0.04792	0.000213	0.01724	0.000833	0.000115	0.001441	0.000343	0.18242	0.000249	0.04856	0.00522	0.02313	0.000040	0.12308
rchwl-06	0.05072	0.04506	0.000232	0.01779	0.000907	0.000126	0.001569	0.000374	0.18365	0.000271	0.04575	0.00799	0.04344	0.000044	0.12367

	Glass Composition (continued)													
GlassID	NiO	P_2O_5	PbO	RuO_2 (NM)	SiO_2	SnO_2	SrO	ThO_2	TiO_2	U_3O_8	V_2O_5	ZnO	ZrO_2	Others*
rchwl-01	0.009759	0.005172	0.000535	0.000334	0.42932	0.000116	0.000118	0.000203	0.000154	0.042092	0.000155	0.000341	0.006684	0.011596
rchwl-02	0.008491	0.005645	0.000584	0.000365	0.41521	0.000127	0.000129	0.000222	0.000168	0.035684	0.000170	0.000372	0.006379	0.012657
rchwl-03	0.008529	0.004520	0.000467	0.000292	0.47424	0.000101	0.000103	0.000177	0.000135	0.036789	0.000136	0.000298	0.000432	0.010135
rchwl-04	0.007430	0.004940	0.000511	0.000319	0.46103	0.000111	0.000113	0.000194	0.000147	0.031223	0.000148	0.000326	0.000472	0.011075
rchwl-05	0.010322	0.005471	0.000565	0.000353	0.43873	0.000123	0.000125	0.000215	0.000163	0.044522	0.000164	0.000361	0.000523	0.012266
rchwl-06	0.008961	0.005957	0.000616	0.000385	0.42301	0.000134	0.000136	0.000234	0.000178	0.037657	0.000179	0.000393	0.000569	0.013357

* The components in “Others” have already been included in the glass composition (e.g., ThO_2) but the fractions of “Others” are provided for completeness.

Table 3-10 summarizes the predicted properties for the "rchwl" glasses. These glasses all have predicted liquidus temperatures (based on the new model) of between 1049.1 and 1049.7°C (or differences from 1050°C much smaller than can be measured). As previously noted, the use of the new T_L model does provide the opportunity for higher waste loadings for future DWPF SB3 and SB4 operations. The projected WLs range from 33.3 wt% (for the SB3/Frit 200 system) to 43.9 wt% (for the SB4/Frit 320 system). It should be noted that these glasses are not acceptable based on the use of a 1010°C PAR criterion. In addition, it is unlikely that these glasses would be classified as acceptable once measurement uncertainty was applied to define the Measurement Acceptability Region (MAR). Therefore, the primary focus of these glasses will be to assess the impact of higher U_3O_8 concentrations on durability and viscosity. This is not to belittle the importance of T_L but given the intensive labor requirements to formally measure T_L this property will not be assessed.

Table 3-10. Property Predictions for the SB3 and SB4 High Waste Loading and ThO_2 Glasses

GlassID	SludgeID	Frit ID	WL (%)	R_2O	η (Poise)	Homog.	ΔG_p (kcal/mol)	NL[B] (g/L)	New T_L(C)	Violates PAR
rchwl-01	SB3 OL	165	38.1	0.1732	19.3	238.6	-10.83	1.147	1049.7	Not Visc; Not New TL
rchwl-02	SB4 OL	165	41.6	0.1710	18.7	238.3	-11.28	1.384	1049.6	Not Visc; Not New TL
rchwl-03	SB3 OL	200	33.3	0.1499	46.6	228.3	-9.29	0.604	1049.5	Not New TL
rchwl-04	SB4 OL	200	36.4	0.1492	45.1	228.2	-9.77	0.737	1049.1	Not New TL
rchwl-05	SB3 OL	320	40.3	0.1716	21.5	245.2	-10.28	0.912	1049.2	Not Visc; Not New TL
rchwl-06	SB4 OL	320	43.9	0.1694	20.7	244.6	-10.79	1.126	1049.5	Not Visc; Not New TL

With respect to predicted viscosities, it should be noted that the lower limit on melt viscosity of 20 poise is violated by four of the six proposed "rchwl" glasses. Those glasses failing the lower viscosity limit are rchwl-01, -02, -05, and -06. The high alkali content of Frit 165 and Frit 320 is one of the contributing factors to the lower predicted viscosities of these glasses. The predicted durability response is also frit dependent with the Frit 200 glasses predicted to be more durable relative to the Frit 320 and Frit 165 based glasses. It should be mentioned that direct property comparisons should be used with caution as there are WL differences among the glasses.

It should be noted that the "rchwl" glasses do not have counterpart "rc" glasses from which properties can be compared. The "rchwl" glasses were designed strictly to push WLs to the extent (reasonably) possible in order to assess or compare the predicted impact (or lack thereof) of high WLs (and hence higher U_3O_8 concentrations) to the measured impact.

3.3 Tank 40 High Waste Loading Glasses

Various Waste Acceptance Criteria (WAC) samples have been taken of the Tank 40 sludge material (after one and two washes) and analyzed. The various concentrations for the major constituents relative to those of the major insoluble constituent, namely Fe, are presented in Table 3-11. The "WAC-I" samples were collected after a single wash of the Tank 40 material and analyses were performed on samples of the material as they were received and also after "over-washing" to remove the majority of the soluble species. The second set of Tank 40 WAC samples (i.e., "WAC-II") was collected after additional washing of the Tank 40 material and agitation for a period of 32 hours and 60 hours. Note that the results of the WAC-II analyses are very similar.

Table 3-11. Recent Tank 40 Sample Information (Aqua Regia)

SampleID	Reps	Al/Fe	Ca/Fe	Mg/Fe	Mn/Fe	Na/Fe	Ni/Fe	Si/Fe	U/Fe
WAC-I As-received	2	0.3076	0.0935	0.0796	0.1339	1.5232	0.0544	0.0312	0.2689
WAC-I "Insoluble"	2	0.2278	0.0965	0.0800	0.1349	0.0960	0.0503	0.0335	0.2669
WAC-II 32-h	10	0.2700	0.0971	0.0805	0.1365	0.8175	0.0506	0.0136	0.3111
WAC-II 60-h	10	0.2705	0.0977	0.0804	0.1363	0.8144	0.0502	0.0136	0.3097
WAC-II Average	--	0.2703	0.0974	0.0804	0.1364	0.8160	0.0504	0.0136	0.3104

The information in Table 3-11 appears consistent with additional washing of the Tank 40 material. That is, both Al and Na, which are known to be soluble, appear to decrease with increased washing of the sludge material. The only issues concerning the Tank 40 analyses concern the differences in the Si/Fe and U/Fe values. The differences in the Si/Fe values may be due to measurement difficulties at low Si concentrations and the U/Fe values were confirmed by the fusion analyses performed on the WAC-I samples. This, and the fact that more replicates are available, suggests that the WAC-II results should be used to develop a Tank 40 sludge composition for testing at high waste loadings. Thus the WAC-II Average results from Table 3-11 will be used to represent the Tank 40 information.

However, there is one other missing piece of information: the final washing endpoint. That is, the sludge represented in Table 3-11 was washed further and the concentrations upon which the ratios in the above table were computed changed. However, only the ratios for the Al and Na to Fe changed since these are soluble components. For example, the Al/Fe values in the above table vary approximately with the Na concentration according to:

$$(\text{Al/Fe}) \approx 0.1819+0.005555*\text{Na}+0.0002335*(\text{Na}-14.2152)^2$$

Furthermore, it is assumed that Na (and correspondingly OH and NO_2) will be removed from the above material such that the resulting Na concentration will be 7.5g Na/100g resulting total solids (or the midpoint of the nominal 6-9 wt% Na range). The resulting concentrations are provided in Table 3-12 where the maximum “Others” concentration is used. The waste loadings were varied to produce glasses (i.e., tk40-01, tk40-02, and tk40-03) with predicted liquidus temperatures of approximately 1050ºC as indicated in Table 3-13. The targeted glass compositions are provided in Table 3-14.

It should be noted that the “tk40” glasses do not have counterpart “rc” glasses from which properties can be compared. The “tk40” glasses were designed strictly to push WLs to the extent (reasonably) possible in order to assess or compare the predicted impact (or lack thereof) of high WLs (and hence higher U_3O_8 concentrations) to the measured impact.

3.4 Targeted Compositions and Predicted Properties

Table 3-15 and Table 3-16 summarize the targeted glass compositions and predicted properties, respectively, of the twelve glasses designed for this study.

Table 3-12. Sludge Composition for High Waste Loading "tk40" Glasses

	Sludge										
Type	Al_2O_3	CaO	Fe_2O_3	MgO	MnO	Na_2O	NiO	SiO_2	ThO_2	U_3O_8	Others
Tank 40 WAC	0.1341	0.0413	0.4336	0.0405	0.0534	0.1271	0.0195	0.0088	0.0000	0.1110	0.0306

Table 3-13. Property Predictions for High Waste Loading "tk40" Glasses

GlassID	SludgeID	Frit ID	WL (%)	R_2O	η (Poise)	Homog.	ΔG_p (kcal/mol)	NL[B] (g/L)	New T_L (°C)	Violates PAR
tk40-01	Tank 40	165	36.9	0.1738	21.7	234.3	-10.89	1.173	1049.88	Not New TL
tk40-02	Tank 40	200	32.2	0.1501	51.6	224.5	-9.31	0.608	1048.88	Not New TL
tk40-03	Tank 40	320	39.1	0.1723	24.3	240.8	-10.33	0.929	1049.22	Not New TL

Table 3-14. Glass Compositions for High Waste Loading "tk40" Glasses

	Glass Composition														
GlassID	Al_2O_3	B_2O_3	BaO	CaO	CdO	CoO	Cr_2O_3	CuO	Fe_2O_3	La_2O_3	Li_2O	MgO	MnO	MoO_3	Na_2O
tk40-01	0.04949	0.06325	0.000197	0.01525	0.000767	0.000106	0.001328	0.000316	0.16001	0.000229	0.04491	0.02124	0.01971	0.000037	0.12893
tk40-02	0.04319	0.08149	0.000172	0.01331	0.000670	0.000093	0.001159	0.000276	0.13963	0.000200	0.03455	0.02659	0.01720	0.000033	0.11550
tk40-03	0.05245	0.04888	0.000208	0.01616	0.000813	0.000113	0.001407	0.000335	0.16955	0.000243	0.04950	0.01582	0.02088	0.000040	0.12277

	Glass Composition (continued)													
GlassID	NiO	P_2O_5	PbO	RuO_2 (NM)	SiO_2	SnO_2	SrO	ThO_2	TiO_2	U_3O_8	V_2O_5	ZnO	ZrO_2	Others*
tk40-01	0.007183	0.005041	0.000521	0.000326	0.43234	0.000113	0.000115	0.000198	0.000150	0.040968	0.000151	0.000332	0.006792	0.012743
tk40-02	0.006268	0.004399	0.000455	0.000284	0.47745	0.000099	0.000101	0.000173	0.000131	0.035750	0.000132	0.000290	0.000420	0.011242
tk40-03	0.007611	0.005342	0.000552	0.000345	0.44194	0.000120	0.000122	0.000210	0.000159	0.043411	0.000160	0.000352	0.000510	0.013447

* The components in "Others" have already been included in the glass composition (e.g., ThO_2) but the fractions of "Others" are provided for completeness.

Table 3-15. Glass Compositions for the New High Waste Loading and ThO_2-Containing Glasses

	Glass Composition														
GlassID	Al_2O_3	B_2O_3	BaO	CaO	CdO	CoO	Cr_2O_3	CuO	Fe_2O_3	La_2O_3	Li_2O	MgO	MnO	MoO_3	Na_2O
rcth-30	0.03115	0.06514	0.000187	0.00613	0.000728	0.000101	0.001260	0.000300	0.12040	0.000218	0.04620	0.01663	0.03973	0.000035	0.12939
rcth-40	0.03115	0.07814	0.000187	0.00613	0.000728	0.000101	0.001260	0.000300	0.12040	0.000218	0.03320	0.02313	0.03973	0.000035	0.11639
rcth-50	0.03115	0.05214	0.000187	0.00613	0.000728	0.000101	0.001260	0.000300	0.12040	0.000218	0.05270	0.01013	0.03973	0.000035	0.12289
rchwl-01	0.04496	0.06205	0.000202	0.01630	0.000787	0.000109	0.001363	0.000325	0.17246	0.000235	0.04409	0.01113	0.02187	0.000038	0.12911
rchwl-02	0.04806	0.05857	0.000220	0.01686	0.000859	0.000119	0.001487	0.000354	0.17403	0.000257	0.04171	0.01341	0.04117	0.000042	0.12932
rchwl-03	0.03929	0.08017	0.000176	0.01424	0.000688	0.000095	0.001191	0.000284	0.15073	0.000206	0.03401	0.01765	0.01911	0.000033	0.11588
rchwl-04	0.04206	0.07647	0.000193	0.01475	0.000752	0.000104	0.001301	0.000310	0.15227	0.000225	0.03253	0.01934	0.03602	0.000037	0.11668
rchwl-05	0.04755	0.04792	0.000213	0.01724	0.000833	0.000115	0.001441	0.000343	0.18242	0.000249	0.04856	0.00522	0.02313	0.000040	0.12308
rchwl-06	0.05072	0.04506	0.000232	0.01779	0.000907	0.000126	0.001569	0.000374	0.18365	0.000271	0.04575	0.00799	0.04344	0.000044	0.12367
tk40-01	0.04949	0.06325	0.000197	0.01525	0.000767	0.000106	0.001328	0.000316	0.16001	0.000229	0.04491	0.02124	0.01971	0.000037	0.12893
tk40-02	0.04319	0.08149	0.000172	0.01331	0.000670	0.000093	0.001159	0.000276	0.13963	0.000200	0.03455	0.02659	0.01720	0.000033	0.11550
tk40-03	0.05245	0.04888	0.000208	0.01616	0.000813	0.000113	0.001407	0.000335	0.16955	0.000243	0.04950	0.01582	0.02088	0.000040	0.12277

	Glass Composition (continued)													
GlassID	NiO	P_2O_5	PbO	RuO_2 (NM)	SiO_2	SnO_2	SrO	ThO_2	TiO_2	U_3O_8	V_2O_5	ZnO	ZrO_2	Others*
rcth-30	0.029380	0.004782	0.000494	0.000309	0.44534	0.000107	0.000109	0.028914	0.000143	0.025412	0.000144	0.000315	0.006957	0.010721
rcth-40	0.029380	0.004782	0.000494	0.000309	0.45834	0.000107	0.000109	0.028914	0.000143	0.025412	0.000144	0.000315	0.000457	0.010721
rcth-50	0.029380	0.004782	0.000494	0.000309	0.47134	0.000107	0.000109	0.028914	0.000143	0.025412	0.000144	0.000315	0.000457	0.010721
rchwl-01	0.009759	0.005172	0.000535	0.000334	0.42932	0.000116	0.000118	0.000203	0.000154	0.042092	0.000155	0.000341	0.006684	0.011596
rchwl-02	0.008491	0.005645	0.000584	0.000365	0.41521	0.000127	0.000129	0.000222	0.000168	0.035684	0.000170	0.000372	0.006379	0.012657
rchwl-03	0.008529	0.004520	0.000467	0.000292	0.47424	0.000101	0.000103	0.000177	0.000135	0.036789	0.000136	0.000298	0.000432	0.010135
rchwl-04	0.007430	0.004940	0.000511	0.000319	0.46103	0.000111	0.000113	0.000194	0.000147	0.031223	0.000148	0.000326	0.000472	0.011075
rchwl-05	0.010322	0.005471	0.000565	0.000353	0.43873	0.000123	0.000125	0.000215	0.000163	0.044522	0.000164	0.000361	0.000523	0.012266
rchwl-06	0.008961	0.005957	0.000616	0.000385	0.42301	0.000134	0.000136	0.000234	0.000178	0.037657	0.000179	0.000393	0.000569	0.013357
tk40-01	0.007183	0.005041	0.000521	0.000326	0.43234	0.000113	0.000115	0.000198	0.000150	0.040968	0.000151	0.000332	0.006792	0.012743
tk40-02	0.006268	0.004399	0.000455	0.000284	0.47745	0.000099	0.000101	0.000173	0.000131	0.035750	0.000132	0.000290	0.000420	0.011242
tk40-03	0.007611	0.005342	0.000552	0.000345	0.44194	0.000120	0.000122	0.000210	0.000159	0.043411	0.000160	0.000352	0.000510	0.013447

* The components in "Others" have already been included in the glass composition (e.g., ThO_2) but the fractions of "Others" are provided for completeness.

Table 3-16. Property Predictions for the SB3 and SB4 High Waste Loading and ThO_2 Glasses

GlassID	SludgeID	Frit ID	WL (%)	R_2O	η (Poise)	Homog.	ΔG_p (kcal/mol)	NL[B] (g/L)	New T_L(C)	Violates PAR
rcth-30	PHF OL	165	35.0	0.1756	24.8	199.1	-12.13	1.970	1067.4	Not Homog; Not New TL
rcth-40	PHF OL	200	35.0	0.1496	46.8	199.1	-10.28	0.910	1157.1	Not Homog; Not New TL
rcth-50	PHF OL	320	35.0	0.1756	31.0	201.1	-11.71	1.656	1029.8	Not Homog; Not New TL
Rchwl-01	SB3 OL	165	38.1	0.1732	19.3	238.6	-10.83	1.147	1049.7	Not Visc; Not New TL
Rchwl-02	SB4 OL	165	41.6	0.1710	18.7	238.3	-11.28	1.384	1049.6	Not Visc; Not New TL
Rchwl-03	SB3 OL	200	33.3	0.1499	46.6	228.3	-9.29	0.604	1049.5	Not New TL
Rchwl-04	SB4 OL	200	36.4	0.1492	45.1	228.2	-9.77	0.737	1049.1	Not New TL
Rchwl-05	SB3 OL	320	40.3	0.1716	21.5	245.2	-10.28	0.912	1049.2	Not Visc; Not New TL
Rchwl-06	SB4 OL	320	43.9	0.1694	20.7	244.6	-10.79	1.126	1049.5	Not Visc; Not New TL
tk40-01	Tank 40	165	36.9	0.1738	21.7	234.3	-10.89	1.173	1049.88	Not New TL
tk40-02	Tank 40	200	32.2	0.1501	51.6	224.5	-9.31	0.608	1048.88	Not New TL
tk40-03	Tank 40	320	39.1	0.1723	24.3	240.8	-10.33	0.929	1049.22	Not New TL

4.0 Experimental

Table 3-15 identified the targeted compositions of the glasses to be prepared for this study. Each glass was prepared from the proper proportions of reagent-grade metal oxides, carbonates, H_3BO_3, and salts in 150-g batches using SRTC technical procedure “Glass Batching – ITS-0001” (SRTC 2002a). Batch sheets were filled out as the materials were weighed.[4] Once batched, the glasses were melted using SRTC technical procedure “Glass Melting – ITS-0003” (SRTC 2002b). In general, the raw materials were thoroughly mixed and placed into a 95% Platinum/5% Gold 250-mL crucible. The batch was subsequently placed into a high-temperature furnace, and the temperature was increased at ~8°C/min until the target melt temperature (1150°C) was reached. After an isothermal hold at 1150°C for 1.0 h, the crucible was removed, and the glass was poured onto a clean, stainless steel plate and allowed to air cool. Observations of the resulting pour patty and residual crucible glass were documented.

The pour patty and residual crucible glass were ground, and the crushed glass was subsequently transferred to its original 95% Platinum/5% Gold 250-mL crucible for a second melt. Based on visual observations after the initial melt (i.e., undissolved solids in select systems), the melt temperature was increased to 1200°C. This increase agrees well or is in line with the relatively high T_L predictions (especially for the “rcth” glasses). After an isothermal hold at 1200°C for 1.0 h, the crucible was removed, and the glass was poured onto a clean stainless steel plate and allowed to air cool. Observations of the resulting pour patty and residual crucible glass were documented.[5] Approximately 140 g of glass was removed (poured) from the crucible while ~10 g remained in the crucible along the walls. The pour patty was used as a sampling stock for the various heat treatments and property measurements (i.e., chemical composition and durability). It should be noted that the glasses were batched and melted under oxidizing conditions to eliminate possible effects of components with potential multiple oxidation states, including uranium.

To bound the effects of thermal history on the product performance, approximately 25 g of each study glass were heat treated to simulate cooling along the centerline of a DWPF-type canister (Marra and Jantzen 1993). This cooling regime is commonly referred to as the centerline canister cooled (ccc) curve. This terminology will be used in this report to differentiate samples from different cooling regimes (quenched versus ccc).

As mentioned in Section 2.0, applicability of the ΔG_P model to the study glasses is of interest. Although the ΔG_P model was developed based on a homogeneous glass (Plodinec et al. (1995) and Jantzen et al. (1995)), application to inhomogeneous glasses does have potential (and technical) merit, given that the impact of the developing secondary phase(s) is minimal to the overall performance. More specifically, as a new phase precipitates in a previously homogeneous glass, it affects the glass matrix in which it is embedded, both chemically and mechanically. These changes may impact the rate of glass dissolution in water and thus change the chemical durability of the glass (Jantzen and Bickford 1985; Cicero et al. 1993; Kim et al. 1995). In this report, the ΔG_P model will be applied to both quenched and ccc glasses to assess the applicability of the model. It should be noted that previous studies (Harbour et al. 2000; Herman et al. 2001)

[4] Batch sheets can be found in WSRC-NB-2001-00056.

[5] Observations of homogeneity with respect to crystallization were documented in WSRC-NB-2001-00056 for both the pour patty and the residual crucible glass.

have also applied the ΔG_P model to both quenched and ccc glasses. However, the primary focus with respect to the model applicability will be in reference to quenched glasses.

4.1 Chemical Composition Analysis

To confirm that the "as-fabricated" glasses corresponded to the defined target compositions, a representative sample from each glass pour patty was submitted to the SRTC Mobile Laboratory (SRTC-ML) for chemical analysis. Edwards (see Appendix A) provided an analytical plan that accompanied these samples. This plan identified the cations to be analyzed and the dissolution techniques (i.e., sodium peroxide fusion [SP] and lithium-metaborate [LM]) to be used. Each glass was prepared in duplicate for the cation dissolution techniques (SP and LM). Concentrations (as mass %) for the cations of interest were measured by inductively coupled plasma – atomic emission spectroscopy (ICP – AES). The analytical plan was developed in such a way as to provide the opportunity to evaluate potential sources of error. Glass standards were intermittently run to assess the performance of the ICP – AES over the course of these analyses and for potential bias-correction needs. The measurements were conducted to assess whether or not the targeted glass compositions were adequately met.

4.2 Product Consistency Test

The PCT was performed on each glass to assess chemical durability using technical procedure "Nuclear Waste Glass Product Consistency Test (PCT) Method – GTOP-3-025" (ASTM 1998). The PCT was conducted in triplicate for each glass (both quenched and ccc versions). Also included in this experimental test matrix were the Environmental Assessment (EA) glass (Jantzen et al. 1993), the Approved Reference Material (ARM-1) glass, and blanks from the sample cleaning batch. Samples were ground, washed, and prepared according to procedure. Fifteen mL of Type I American Society for Testing and Materials (ASTM) water were added to 1.5 g of glass in stainless steel vessels. The vessels were closed, sealed, and placed in an oven at 90 ± 2°C where the samples were maintained for 7 days. The resulting solutions (once cooled) were sampled (filtered and acidified), labeled (according to the analytical plan), and analyzed. Edwards provided an analytical plan for the SRTC-ML analysis (see Appendix B). The overall philosophy of this plan was to provide an opportunity to assess the consistency (repeatability) of the PCT and analytical procedures in the effort to evaluate chemical durability of the study glasses. Normalized release rates were calculated based on targeted, measured, and bias-corrected compositions using the average of the logs of the leachate concentrations.

4.3 High Temperature Viscosity

Viscosity as a function of temperature was measured by a rotating spindle technique (Schumacher and Peeler 1998). Each glass sample was heated to ~1150°C in a platinum crucible and maintained until thermal equilibrium was reached. A torque measurement was then taken and subsequent measurements recorded at higher and lower temperatures using a hysteresis type approach. Viscosity within the temperature interval of 1050° - 1150°C was measured first before going to lower or higher temperatures. The hysteresis approach allows for the potential impacts of crystallization (at lower temperatures) and volatilization (at higher temperatures) to be assessed.

The viscosity was calculated from the measured temperature, the percent torque, and the spindle speed. Each set of viscosity measurements was fit to a Fulcher equation as shown in Equation 1.

$$\ln(\text{Viscosity}) = A + B / (T - C) \qquad (1)$$

In this equation, ln (Viscosity) represents the natural logarithm of the calculated viscosity (Poise), and A, B, and C represent the parameters of the Fulcher Equation. The temperature (in °C) is represented as T. The viscosity at 1150°C ($\eta_{1150°C}$) was predicted for each glass based on the Fulcher fit.

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5.0 Results

5.1 Visual Observations of Homogeneity

Visual observations of each glass indicated a single-phase glass was produced. The classification of single phase was based on the absence of undissolved solids and/or crystallization in the pour patty and the residual crucible glass after the second melt at 1200°C. It should be noted that the increased melt temperature did aid in the homogenization process. As will be discussed in Section 5.2, compositional analysis indicates that the higher processing temperatures did not significantly increase volatility (at least within associated measurement errors). Although the melt temperature exceeds the nominal DWPF melter temperature of 1150°C, the objectives of the task are not compromised as it is strictly the impact of U3O8 and/or ThO2 on glass properties that is of interest – not the pathway required to produce a homogeneous glass. In fact, the information presented in Table 3-16 indicated that select glasses have relatively high predicted T_L values which would require higher melt temperatures. For example, the predicted T_L of rcth-40 is 1157.1°C; thus, in theory, the glass would not completely melt (or at a minimum would contain a certain fraction of crystallization) if an 1150°C melt temperature was used.

5.2 A Statistical Review of the Chemical Composition Measurements

In this section, the measured versus targeted compositions of the 13 glasses that were included in this study are presented and compared. The targeted compositions for these glasses are provided in Table 3-15 (and repeated in Table C.1 of Appendix C).[6] As specified by the analytical plan (see Appendix A), two dissolution methods were utilized in measuring these chemical compositions: samples prepared by lithium metaborate (LM) dissolution were used to measure elemental concentrations of aluminum (Al), calcium (Ca), chromium (Cr), iron (Fe), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), phosphorous (P), silicon (Si), thorium (Th), uranium (U), and zirconium (Zr) while samples from glasses prepared by sodium peroxide fusion (SP) dissolution were used to measure elemental concentrations of boron (B) and lithium (Li). Note that beyond the minor components of Cr, P, and Zr, there are additional minor components not listed in Table C.1 whose concentrations were not measured. For each study glass, measurements were obtained from samples prepared in duplicate by each of these dissolution methods. All of the prepared samples were analyzed (twice for each element of interest) by ICP-AES (with the instrumentation being re-calibrated between the duplicate analyses).

Table C.2 in Appendix C provides the elemental concentration measurements derived from the samples prepared using LM, and Table C.3 in Appendix C provides the measurements derived from the samples prepared using SP. Measurements for standards (Batch 1 and a uranium standard, U_{std}) that were included in the SRTC-ML analytical plan along with the study glasses are also provided in these two tables.

[6] Table C.1 also contains “RC-38U”. This glass has been included in portions of this report to document the results although it is of little interest to the task objectives. RC-38U was a glass fabricated and tested during the RC Phase 1 study that contains approximately 25 wt% U_3O_8 due to a batching error.

The elemental concentrations were converted to oxide concentrations by multiplying the values for each element by the gravimetric factor for the corresponding oxide. During this process, an elemental concentration that was determined to be below the detection limit of the analytical procedures used by the SRTC-ML was reduced to half of that detection limit as the oxide concentration was determined.

In the sections that follow, the analytical sequence of the measurements is explored, the measurements of the standards are investigated and used for bias correction, the measurements for each glass are reviewed, the average chemical compositions (measured and bias-corrected) for each glass are determined, and comparisons are made between the measurements and the targeted compositions for the glasses.

5.2.1 Measurements in Analytical Sequence

Exhibit C.1 in Appendix C provides plots of the measurements generated by the SRTC-ML for samples prepared using the LM method. These plots are in analytical sequence with different symbols and colors being used to represent each of the study and standard glasses. Similar plots for samples prepared using the SP method are provided in Exhibit C.2 in Appendix C. These plots include all of the measurement data from Tables C.2 and C.3. A review of these plots indicates no significant patterns or trends in the analytical process over the course of these measurements, and there appear to be no obvious outliers in these chemical composition measurements.

5.2.2 Batch 1 and Uranium Standard Results

In this section, the SRTC-ML measurements of the chemical compositions of the Batch 1 and uranium standard (U_{std}) glasses are reviewed. These measurements are investigated across the ICP analytical blocks, and the results are used to bias correct the measurements for the study glasses.

Exhibit C.3 in Appendix C provides statistical analyses of the Batch 1 and U_{std} results generated by the LM prep method by analytical block for each oxide of interest. The results include analysis of variance (ANOVA) investigations looking for statistically significant differences among the block means for each of the oxides for each of the standards. The results from these statistical tests for the Batch 1 standard may be summarized as follows: the Cr_2O_3, MgO, MnO, and NiO measurements indicate a significant ICP calibration effect on these averages at the 5% significance level. For the U_{std}, none of the measurements indicate a significant ICP calibration effect on these averages at the 5% significance level. The reference values for the oxide concentrations of the standards are given in the header for each set of measurements in the exhibit.

Exhibit C.4 in Appendix C provides a similar set of analyses for the measurements derived from samples prepared via the SP method. In this exhibit, none of the measurements for Batch 1 or for U_{std} show a significant ICP calibration effect on the oxide averages at the 5% significance level.

Significant ICP calibration effects for some of the oxides suggest that it may be helpful to bias correct the oxide measurements of the study glasses for the effect of the ICP calibration on each of the analytical blocks. The basis for this bias correction is presented as part of Exhibits C.3 and

C.4 – the average measurement for Batch 1 for each ICP block for Al_2O_3, B_2O_3, CaO, Cr_2O_3, Fe_2O_3, Li_2O, MgO, MnO, Na_2O, NiO, and SiO_2 and the average measurement for U_{std} for each ICP block for U_3O_8. The Batch 1 results served as the basis for bias correcting all of the oxides (that were bias corrected) except uranium. The U_{std} results were used to bias correct for uranium. For the other oxides, the Batch 1 results were used to conduct the bias correction as long as the reference value for the oxide concentration in the Batch 1 glass was greater than or equal to 0.1 wt%. Thus, applying this approach and based upon the information in the exhibits, the Batch 1 results were used to bias correct the Al_2O_3, B_2O_3, CaO, Cr_2O_3, Fe_2O_3, Li_2O, MgO, MnO, Na_2O, NiO, and SiO_2 measurements. No bias correction was conducted for P_2O_5 or ZrO_2.

The bias correction was conducted as follows. For each oxide, let $\bar{a}_{ij}$ be the average measurement for the i^{th} oxide at analytical block j for Batch 1 (or U_{std} for uranium), and let t_i be the reference value for the i^{th} oxide for Batch 1 (or for U_{std} if uranium). (The averages and reference values are provided in Exhibits C.3 and C.4.) Let $\bar{c}_{ijk}$ be the average measurement for the i^{th} oxide at analytical block j for the k^{th} glass. The bias adjustment was conducted as follows

$$\bar{c}_{ijk} \bullet \left(1 - \frac{\bar{a}_{ij} - t_i}{\bar{a}_{ij}}\right) = \bar{c}_{ijk} \bullet \frac{t_i}{\bar{a}_{ij}}$$

Bias-corrected measurements are indicated by a "bc" suffix, and such adjustments were performed for all of the oxides of this study except P_2O_5 or ZrO_2. Both measured and measured "bc" values are included in the discussion that follows. In these discussions bias-corrected values for P_2O_5 and ZrO_2 are included for completeness (i.e., to allow a sum of oxides to be computed for the bias-corrected results). These bias-corrected values are the same as the original P_2O_5 and ZrO_2 values (i.e., once again, no bias correction was performed for these two oxides).

5.2.3 Composition Measurements by Glass Number

Exhibits C.5 and C.6 in Appendix C provide plots of the oxide concentration measurements by Glass ID (including both the Batch 1and U_{std} glasses) for the measured and bias-corrected (bc) values for the LM and SP preparation methods, respectively. Different symbols and colors are used to represent the different glasses. These plots show the individual measurements across the duplicates of each preparation method and the two ICP calibrations. A review of the plots presented in these exhibits reveals the repeatability of the four individual, oxide values for each glass. No problems are evident in these plots.[7]

More detailed discussions of the average, measured chemical compositions of the study glasses are provided in the sections that follow.

5.2.4 Measured versus Targeted Compositions

The four measurements for each oxide for each glass (over both preparation methods) were averaged to determine a representative chemical composition for each glass. These determinations were conducted both for the measured and for the bias-corrected data. A sum of

[7] Note that for RC-38U, the U_3O_8 concentration is approximately 25 wt%.

oxides was also computed for each glass based upon both the measured and bias-corrected values. Exhibit C.7 in Appendix C provides plots for each glass for each oxide to help highlight the comparisons among the measured, bias-corrected, and targeted values.

In general, the results suggest that targeted compositions were obtained for most study glasses. There are a few exceptions to this latter statement based on the observations from the plots of Exhibit C.7. For nearly every study glass the measured Al_2O_3 values are greater than their respective targeted concentrations. Given the consistency of all measured values for the study glasses to be high, this may be an indicator of a consistent batching and/or measurement issue. However, given the average % difference between targeted and measured compositions is ~ 3.9%, the bias is not of practical concern with respect to the test objectives. The measured Fe_2O_3 and P_2O_5 values are consistently above their targeted values. With respect to Fe_2O_3 values, the average % difference between target and measured is ~7.4% (biased low). Given Fe_2O_3 is in sufficient concentration (e.g., not a minor component) and its analysis is one of the more accurate (based on historical results), there does appear to be a bias in the study glasses.

The measured P_2O_5 values also appear to be biased low for each study glass. Given the low targeted concentrations (< 0.6 wt% in glass), the high % differences (as shown in Table C.4) are not unusual but the consistently low bias may be an indicator of a consistent batching and/or measurement issue.

For rcth-40 (and using a 5% difference between target and measured compositions from Table C.4 as a guide), the measured values for B_2O_3, Fe_2O_3, Li_2O, MgO, MnO, Na_2O, NiO, P_2O_5, and ThO_2 fell below their respective targets. The measured values for Al_2O_3, CaO, U_3O_8, and ZrO_2 were above their targets for this glass. Therefore, consideration of these potential issues should be accounted for during the assessment of this glass with respect to the test objectives.

It should also be noted that the measured Cr_2O_3 concentration (~ 0.25 wt%) for the U_{std} glass is much higher than the reported value (0%). This result is consistent with previous assessments and does not represent or cause concern for potential contamination, batching, or measurement errors.

Table C.4 in Appendix C provides a summary of the average compositions as well as the targeted compositions, some associated differences, and relative differences. Notice that the targeted sums of oxides for the glasses do not sum to 100% due to the minor components of the study glasses that are not listed and an incomplete coverage of the oxides in the Batch 1 and U_{std} glasses. All of the sums of oxides (both measured and bias-corrected) for the study glasses fall within the interval of 95 to 105 wt%.

Entries in Table C.4 show the relative differences between the measured or bias-corrected values and the targeted values. These differences are shaded when they are greater than or equal to 5%. Overall, comparisons between the measured and targeted compositions suggest that the majority of the study glasses adequately hit the targeted composition. For some specific components (e.g., Al_2O_3, P_2O_5, and Fe_2O_3) there appears to be evidence of a bias that may be an indicator of a consistent batching and/or measurement issue. With the exception of rcth-40, these differences are not seen as being of practical concern.

5.3 A Statistical Review of the PCT Measurements

The study glasses, after being batched and fabricated, were subjected to the 7-day PCT as an assessment of their durabilities. More specifically, Method A of the PCT (ASTM 1998) was used for these measurements. The analytical plan, presented in Appendix B, was provided to the SRTC-ML to support the measurement of the compositions of the solutions resulting from the PCTs. Samples of a multi-element, standard solution were also included in the analytical plan (as a check on the accuracy of the ICP-AES used for these measurements). In this and the following sections, the measurements generated by the SRTC-ML for these PCTs are presented and reviewed.

Table D.1 in Appendix D provides the elemental leachate concentration measurements determined by the SRTC-ML for the solution samples generated by the PCTs. One of the quality control checkpoints for the PCT procedure is solution-weight loss over the course of the 7-day test. None of these PCT results indicated a solution-weight loss problem. Any measurement in Table D.1 below the detection limit of the analytical procedure (indicated by a "<") was replaced by ½ of the detection limit in subsequent analyses. In addition to adjustments for detection limits, the values were adjusted for the acid dilution factors: the values for the study and ARM glasses in Table D.1 were multiplied by 1.6667 to determine the values in parts per million (ppm) and the values for EA were multiplied by 16.6667.

In the sections that follow, the analytical sequence of the measurements is explored, the measurements of the standards are investigated and used to assess the overall accuracy of the ICP-AES measurement process, the measurements for each glass are reviewed, plots are provided that explore the effects of heat treatment on the PCTs for these glasses, the PCTs are normalized using the compositions (targeted, measured, and bias-corrected) presented in Table C.4, and the normalized PCTs are compared to durability predictions for these compositions generated from the current DWPF models (Jantzen et al. 1995).

5.3.1 Measurements in Analytical Sequence

Exhibits D.1 and D.2 in Appendix D provide plots of the leachate (ppm) concentrations in analytical sequence as generated by the SRTC-ML including the standards with and without EA, respectively. A different color is used for each glass with a small, solid square used to represent the standards, a plus ("+") being used to represent the quenched glasses, and a solid circle ("•") used to represent the ccc glasses. Based on these exhibits, the results of the triplicate ppm values for each glass appear consistent with no obvious outliers for B, Na, Li, and Si.

5.3.2 Results for the Samples of the Multi-Element Solution Standard

Exhibit D.3 in Appendix D provides analyses of the SRTC-ML measurements of the samples of the multi-element solution standard by ICP analytical (or calibration) block. An ANOVA investigating for statistically significant differences among the block averages for these samples for each element of interest is included in these exhibits. These results indicate a statistically significant (at the 5% level) difference among the block averages for the Li and Si measurements. However, no bias correction of the PCT results for the study glasses was conducted. This approach was taken since the triplicate PCTs for a single study glass were placed in different ICP blocks. Averaging the ppm's for each set of triplicates helps to minimize the impact of the ICP effects.

Table 5-1 summarizes the average measurements and the reference values for the 4 primary elements of interest. The results indicate consistent and accurate measurements from the SRTC-ML processes used to conduct these analyses.

Table 5-1. Results from Samples of the Multi-Element Solution Standard

Analytical Block	Avg B (ppm)	Avg Li (ppm)	Avg Na (ppm)	Avg Si (ppm)
1	19.87	9.73	83.93	49.90
2	19.93	9.73	85.47	49.90
3	20.20	9.75	83.77	49.50
4	19.83	9.67	86.13	50.67
5	20.57	9.75	87.27	51.20
6	20.03	9.78	85.37	50.53
Grand Average	20.07	9.74	85.32	50.28
Reference Value	20	10	81	50
% difference	0.36%	-2.64%	5.34%	0.57%

5.3.3 Measurements by Glass Number

Exhibit D.4 in Appendix D provides plots of the leachate concentrations for each type of submitted sample: the standards (multi-element solution standard, ARM, EA, and blanks) and the study glasses (ccc and quenched). These plots allow for the assessment of the repeatability of the measurements, which suggests some scatter in the triplicate values for some analytes for some of the glasses. With the exception of the values for rcth-30, all of the triplicate values (for both quenched and ccc versions) are extremely consistent. The values for B, Li, Na, and Si for the rcth-30 samples appear to have a larger variation but do not present a practical concern. For example, consider the B ppm values for rcth-30 which range from approximately 125 to 175 ppm. These values will not translate into a significant or practical difference during the durability assessment. Therefore, none of the ppm values have been excluded from the calculations that follow.

5.3.4 Quenched versus Centerline Canister Cooled PCTs

Exhibits D.5 and D.6 in Appendix D provide a closer look at the effect of heat treatment on the PCTs for the study glasses using the averages of the ppm values and of the logarithms of these values, respectively. These exhibits provide paired t-tests between the quenched and ccc PCTs for the study glasses for each of the four elements of interest. None of these differences appear to be statistically significant at a significance level of 5%. However, this does not suggest that significant differences between quenched and ccc views of individual glasses will not be observed.

5.3.5 Normalized PCT Results

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 targeted cation and the bias-corrected cation compositions were also 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 was determined and used for comparison. 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 D.1 of Appendix D),

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.

Or Normalizing Using Measured Bias-Corrected Composition

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

Exhibit D.7 in Appendix D provides scatter plots for these results and offers an opportunity to investigate the consistency in the leaching across the elements for the glasses of this study. Various views of these plots are provided in this exhibit: all of the glasses (study and standard glasses over all of the compositional views and heat treatments) and the study glasses in separate views of the data using the targeted, measured, and bias-corrected compositional views for each of the two heat treatments.

Consistency in the leaching across the elements is typically demonstrated by a high degree of linear correlation among the values for pairs of these elements. A high degree of correlation is seen for these data for most of the pairs of the elements; the smallest correlation (~76%) is between B and Si for the targeted/ccc data.

Table 5-2 summarizes the normalized PCTs for the glasses of this study. The results are provided by compositional view as well as heat treatment in this table.

Table 5-2. Normalized PCTs by Glass ID/Compositional View, Shaded by Glass Group

			Results from quenched Glasses							
Glass ID	Heat Treatment	Composition	log NL [B(g/L)]	log NL [Li(g/L)]	log NL [Na(g/L)]	log NL [Si(g/L)]	NL B(g/L)	NL Li(g/L)	NL Na(g/L)	NL Si(g/L)
ARM	-	see [Jantzen et al. 1995]	-0.2692	-0.2161	-0.2728	-0.5310	0.54	0.61	0.53	0.29
EA	-	see [Jantzen et al. 1995]	1.2301	0.9561	1.1177	0.5834	16.99	9.04	13.11	3.83
RC-38U	ccc	Measured	0.2058	0.2723	-0.0213	-0.1114	1.61	1.87	0.95	0.77
RC-38U	ccc	Measured bc	0.2078	0.2615	-0.0050	-0.1067	1.61	1.83	0.99	0.78
RC-38U	ccc	Targeted	0.1745	0.2367	-0.0164	-0.1104	1.49	1.72	0.96	0.78
RC-38U	quenched	Measured	0.4274	0.4150	0.1596	-0.0628	2.68	2.60	1.44	0.87
RC-38U	quenched	Measured bc	0.4294	0.4042	0.1759	-0.0581	2.69	2.54	1.50	0.87
RC-38U	quenched	Targeted	0.3961	0.3794	0.1645	-0.0617	2.49	2.40	1.46	0.87
rchwl-01	ccc	Measured	0.1070	0.1114	0.0504	-0.1794	1.28	1.29	1.12	0.66
rchwl-01	ccc	Measured bc	0.1091	0.1005	0.0667	-0.1747	1.29	1.26	1.17	0.67
rchwl-01	ccc	Targeted	0.0911	0.0856	0.0609	-0.1750	1.23	1.22	1.15	0.67
rchwl-01	quenched	Measured	0.2893	0.2501	0.1940	-0.0875	1.95	1.78	1.56	0.82
rchwl-01	quenched	Measured bc	0.2914	0.2393	0.2104	-0.0827	1.96	1.73	1.62	0.83
rchwl-01	quenched	Targeted	0.2734	0.2243	0.2045	-0.0830	1.88	1.68	1.60	0.83
rchwl-02	ccc	Measured	0.0215	0.0546	0.0205	-0.1920	1.05	1.13	1.05	0.64
rchwl-02	ccc	Measured bc	0.0236	0.0437	0.0369	-0.1873	1.06	1.11	1.09	0.65
rchwl-02	ccc	Targeted	0.0164	0.0256	0.0297	-0.2007	1.04	1.06	1.07	0.63
rchwl-02	quenched	Measured	0.1907	0.1871	0.1383	-0.1298	1.55	1.54	1.37	0.74
rchwl-02	quenched	Measured bc	0.1928	0.1763	0.1546	-0.1251	1.56	1.50	1.43	0.75
rchwl-02	quenched	Targeted	0.1856	0.1582	0.1474	-0.1385	1.53	1.44	1.40	0.73
rchwl-03	ccc	Measured	0.4345	0.3719	0.1924	-0.1874	2.72	2.35	1.56	0.65
rchwl-03	ccc	Measured bc	0.4366	0.3611	0.2088	-0.1826	2.73	2.30	1.62	0.66
rchwl-03	ccc	Targeted	0.4284	0.3523	0.2055	-0.1809	2.68	2.25	1.61	0.66
rchwl-03	quenched	Measured	0.0588	0.0360	-0.0125	-0.2505	1.14	1.09	0.97	0.56
rchwl-03	quenched	Measured bc	0.0608	0.0252	0.0039	-0.2458	1.15	1.06	1.01	0.57
rchwl-03	quenched	Targeted	0.0527	0.0164	0.0007	-0.2441	1.13	1.04	1.00	0.57
rchwl-04	ccc	Measured	0.3388	0.2373	0.0980	-0.2743	2.18	1.73	1.25	0.53
rchwl-04	ccc	Measured bc	0.3408	0.2264	0.1143	-0.2696	2.19	1.68	1.30	0.54
rchwl-04	ccc	Targeted	0.3291	0.2148	0.1090	-0.2683	2.13	1.64	1.29	0.54
rchwl-04	quenched	Measured	0.0939	0.0651	0.0203	-0.2412	1.24	1.16	1.05	0.57
rchwl-04	quenched	Measured bc	0.0959	0.0542	0.0367	-0.2364	1.25	1.13	1.09	0.58
rchwl-04	quenched	Targeted	0.0842	0.0426	0.0314	-0.2352	1.21	1.10	1.08	0.58
rchwl-05	ccc	Measured	0.0419	0.1001	0.0291	-0.1516	1.10	1.26	1.07	0.71
rchwl-05	ccc	Measured bc	0.0439	0.0893	0.0455	-0.1469	1.11	1.23	1.11	0.71
rchwl-05	ccc	Targeted	0.0237	0.0808	0.0436	-0.1424	1.06	1.20	1.11	0.72
rchwl-05	quenched	Measured	0.2256	0.2025	0.1470	-0.0823	1.68	1.59	1.40	0.83
rchwl-05	quenched	Measured bc	0.2276	0.1916	0.1634	-0.0776	1.69	1.55	1.46	0.84
rchwl-05	quenched	Targeted	0.2075	0.1832	0.1615	-0.0731	1.61	1.52	1.45	0.85
rchwl-06	ccc	Measured	0.0860	0.1508	0.0930	-0.1224	1.22	1.42	1.24	0.75
rchwl-06	ccc	Measured bc	0.0880	0.1399	0.1093	-0.1177	1.22	1.38	1.29	0.76
rchwl-06	ccc	Targeted	0.0703	0.1266	0.1020	-0.1089	1.18	1.34	1.26	0.78
rchwl-06	quenched	Measured	0.1871	0.1858	0.1367	-0.1061	1.54	1.53	1.37	0.78
rchwl-06	quenched	Measured bc	0.1892	0.1749	0.1531	-0.1014	1.55	1.50	1.42	0.79
rchwl-06	quenched	Targeted	0.1715	0.1616	0.1458	-0.0926	1.48	1.45	1.40	0.81
rcth-30	ccc	Measured	0.7548	0.7059	0.5855	0.2718	5.69	5.08	3.85	1.87
rcth-30	ccc	Measured bc	0.7569	0.6952	0.6019	0.2765	5.71	4.96	4.00	1.89
rcth-30	ccc	Targeted	0.7466	0.6945	0.6013	0.2812	5.58	4.95	3.99	1.91
rcth-30	quenched	Measured	0.8770	0.8092	0.6819	0.3094	7.53	6.44	4.81	2.04
rcth-30	quenched	Measured bc	0.8791	0.7984	0.6983	0.3141	7.57	6.29	4.99	2.06
rcth-30	quenched	Targeted	0.8688	0.7977	0.6978	0.3188	7.39	6.28	4.99	2.08
rcth-40	ccc	Measured	0.7345	0.7069	0.5338	0.1464	5.43	5.09	3.42	1.40
rcth-40	ccc	Measured bc	0.7365	0.6961	0.5502	0.1511	5.45	4.97	3.55	1.42
rcth-40	ccc	Targeted	0.6773	0.6418	0.5303	0.1564	4.76	4.38	3.39	1.43

			Results from quenched Glasses							
Glass ID	Heat Treatment	Composition	log NL [B(g/L)]	log NL [Li(g/L)]	log NL [Na(g/L)]	log NL [Si(g/L)]	NL B(g/L)	NL Li(g/L)	NL Na(g/L)	NL Si(g/L)
rcth-40	quenched	Measured	0.6324	0.5887	0.4382	0.0291	4.29	3.88	2.74	1.07
rcth-40	quenched	Measured bc	0.6344	0.5779	0.4546	0.0338	4.31	3.78	2.85	1.08
rcth-40	quenched	Targeted	0.5752	0.5236	0.4347	0.0391	3.76	3.34	2.72	1.09
rcth-50	ccc	Measured	0.4193	0.4098	0.3045	0.0858	2.63	2.57	2.02	1.22
rcth-50	ccc	Measured bc	0.4214	0.3990	0.3209	0.0906	2.64	2.51	2.09	1.23
rcth-50	ccc	Targeted	0.4072	0.3898	0.3162	0.0916	2.55	2.45	2.07	1.23
rcth-50	quenched	Measured	0.5037	0.4573	0.3769	0.1216	3.19	2.87	2.38	1.32
rcth-50	quenched	Measured bc	0.5058	0.4464	0.3933	0.1264	3.20	2.80	2.47	1.34
rcth-50	quenched	Targeted	0.4917	0.4372	0.3886	0.1273	3.10	2.74	2.45	1.34
tk40-01	ccc	Measured	0.1246	0.1145	0.0463	-0.1995	1.33	1.30	1.11	0.63
tk40-01	ccc	Measured bc	0.1267	0.1037	0.0626	-0.1947	1.34	1.27	1.16	0.64
tk40-01	ccc	Targeted	0.1046	0.0891	0.0494	-0.1906	1.27	1.23	1.12	0.64
tk40-01	quenched	Measured	0.1796	0.1403	0.0984	-0.1815	1.51	1.38	1.25	0.66
tk40-01	quenched	Measured bc	0.1816	0.1295	0.1148	-0.1768	1.52	1.35	1.30	0.67
tk40-01	quenched	Targeted	0.1595	0.1149	0.1015	-0.1726	1.44	1.30	1.26	0.67
tk40-02	ccc	Measured	0.2153	0.1402	0.0216	-0.2839	1.64	1.38	1.05	0.52
tk40-02	ccc	Measured bc	0.2174	0.1293	0.0380	-0.2791	1.65	1.35	1.09	0.53
tk40-02	ccc	Targeted	0.2056	0.1183	0.0312	-0.2755	1.61	1.31	1.07	0.53
tk40-02	quenched	Measured	0.0025	-0.0113	-0.0514	-0.2825	1.01	0.97	0.89	0.52
tk40-02	quenched	Measured bc	0.0046	-0.0221	-0.0350	-0.2778	1.01	0.95	0.92	0.53
tk40-02	quenched	Targeted	-0.0072	-0.0331	-0.0419	-0.2741	0.98	0.93	0.91	0.53
tk40-03	ccc	Measured	0.1220	0.1387	0.0626	-0.1345	1.32	1.38	1.15	0.73
tk40-03	ccc	Measured bc	0.1241	0.1279	0.0789	-0.1298	1.33	1.34	1.20	0.74
tk40-03	ccc	Targeted	0.1127	0.1245	0.0744	-0.1171	1.30	1.33	1.19	0.76
tk40-03	quenched	Measured	0.2062	0.1731	0.1322	-0.1146	1.61	1.49	1.36	0.77
tk40-03	quenched	Measured bc	0.2083	0.1622	0.1486	-0.1098	1.62	1.45	1.41	0.78
tk40-03	quenched	Targeted	0.1969	0.1588	0.1441	-0.0972	1.57	1.44	1.39	0.80

Prior to a more detailed analysis of the PCT data, some general observations are provided. All of the glasses (including both quenched and ccc versions) have NL [B] less than 8 g/L. Although this value is higher than that typically accepted in DWPF, all of the measured releases are much less than that of the Environmental Assessment (EA) glass with a reported NL [B] of 16.695 g/L. The NL [B] releases (based on targeted compositions) range from a low of 0.98 g/L (for tk40-02 quenched) to a high of 7.38 g/L (for rcth-30 quenched). The "rcth" series appears to contain all of the higher normalized release glasses with NL [B]'s ranging from ~ 7.5 g/L to ~2.5 g/L. This may be an initial indication of the impact of ThO_2 on the PCT response. For the "high waste loading (hwl)" series, all of the NL [B] releases are less than 2.8 g/L; this suggests that high WL glasses can yield very acceptable PCT responses. Finally, the NL [B]'s for the "tk40" series are essentially constant (or within measurement error) ranging from 0.98 g/L (for tk40-02 quenched) to 1.65 g/L (for tk40-02 ccc). Again, these data indicate that highly durable products can be produced even when high WL is coupled with high alkali containing frits to improve melt rate, WL, and/or waste throughput for DWPF.

5.4 Comparisons Between Th/U Glass Pairs

5.4.1 Compositional Analysis

Three of the glasses (rcth-30, rcth-40, and rcth-50) in this study were fabricated to target the same composition as their counterpart glasses from another study (rc-30, rc-40, and rc-50). The exception being that Th was used to replace part of the U (on a molar basis) in the three original "rc" glasses.

The target and measured compositions for rc-30, rc-40, and rc-50 were reported by Peeler et al. (2002b). The measured, measured bias-corrected, and targeted compositions for these three glasses as well as the corresponding values for their Th counterparts are provided in Table 5-3. Note that the targeted compositions of each pair of glasses are the same with the exception of their Th and U values.

A review of the % differences between the measured compositions of the three pairs suggests that 2 of the 3 pairs are essentially the same glass (with the exception of U_3O_8 and ThO_2) values – which were intentionally changed. This latter statement is based on the use of a 5% difference to discern similar and dissimilar compositions for the major components. The exception is the comparison between rc-40 and rcth-40. The comparisons suggest that the % difference between Fe_2O_3, Al_2O_3, and B_2O_3 are greater than 5% which based on the general rules being applied, would classify these two glasses as not being similar. This agrees well with the discussion in Section 5.2.4 indicating a potential batching and/or measurement issue for the rcth-40 glass. Again, comparisons between these two glasses will be made but should be viewed accordingly.

The replacement of U with Th for these glasses provides an opportunity to investigate for an effect of Th on the PCT response and on viscosity. The investigations into these effects on glass properties are covered in the following subsections.

Table 5-3. Compositional Comparisons for Th-Loaded Glasses

	Measured (wt%)	Measured Bias-Corrected (wt%)	Targeted (wt%)	Measured (wt%)	Measured Bias-Corrected (wt%)	Targeted (wt%)
		rcth-40			**rc-40**	
Al_2O_3 (wt%)	3.3633	3.4335	3.1150	3.1933	3.1669	3.1150
B_2O_3 (wt%)	6.8503	6.8183	7.8140	7.4863	7.3950	7.8140
CaO (wt%)	0.7006	0.6640	0.6130	0.7143	0.6584	0.6130
Cr_2O_3 (wt%)	0.1220	0.1307	0.1260	0.1001	0.0978	0.1260
Fe_2O_3 (wt%)	10.9944	10.9762	12.0400	11.6056	11.5725	12.0400
Li_2O (wt%)	2.8580	2.9298	3.3200	3.1917	3.3182	3.3200
MgO (wt%)	2.1763	2.0925	2.3130	2.2335	2.0905	2.3130
MnO (wt%)	3.6961	3.7002	3.9730	3.8607	3.7374	3.9730
Na_2O (wt%)	11.5456	11.1188	11.6390	11.7883	11.2917	11.6390
NiO (wt%)	2.6945	2.5935	2.9380	2.7139	2.6862	2.9380
P_2O_5 (wt%)	0.3643	0.3643	0.4782	0.3844	0.3844	0.4782
SiO_2 (wt%)	46.9042	46.3936	45.8340	47.2785	46.1796	45.8340
ThO_2 (wt%)	2.6598	2.6598	2.8914	0.0000	0.0000	0.0000
U_3O_8 (wt%)	2.7652	3.0789	2.5412	5.3713	5.6465	5.4138
ZrO_2 (wt%)	0.0507	0.0507	0.0457	0.0365	0.0365	0.0457
Sum of Oxides (wt%)	97.7454	97.0049	99.6815	99.9582	98.2616	99.6627
		rcth-50			**rc-50**	
Al_2O_3 (wt%)	3.2972	3.3660	3.1150	3.2358	3.1978	3.1150
B_2O_3 (wt%)	5.0713	5.0474	5.2140	4.9989	4.9517	5.2140
CaO (wt%)	0.6891	0.6531	0.6130	0.7034	0.6461	0.6130
Cr_2O_3 (wt%)	0.1184	0.1268	0.1260	0.1144	0.1080	0.1260
Fe_2O_3 (wt%)	11.2768	11.2581	12.0400	11.3125	11.2544	12.0400
Li_2O (wt%)	5.0324	5.1595	5.2700	5.0378	5.2800	5.2700
MgO (wt%)	1.0160	0.9767	1.0130	0.9932	0.9342	1.0130
MnO (wt%)	3.7638	3.7688	3.9730	3.8349	3.7147	3.9730
Na_2O (wt%)	12.6240	12.1568	12.2890	12.5263	11.9745	12.2890
NiO (wt%)	2.7518	2.6484	2.9380	2.7550	2.7242	2.9380
P_2O_5 (wt%)	0.3844	0.3844	0.4782	0.3781	0.3781	0.4782
SiO_2 (wt%)	47.7599	47.2400	47.1340	48.0808	47.2423	47.1340
ThO_2 (wt%)	2.7537	2.7537	2.8914	0.0000	0.0000	0.0000
U_3O_8 (wt%)	2.4911	2.7736	2.5412	5.3536	5.6062	5.4138
ZrO_2 (wt%)	0.0706	0.0706	0.0457	0.0358	0.0358	0.0457
Sum of Oxides (wt%)	99.1004	98.3839	99.6815	99.3603	98.0482	99.6627
		rcth-30			**rc-30**	
Al_2O_3 (wt%)	3.3869	3.4576	3.1150	3.2594	3.2456	3.1150
B_2O_3 (wt%)	6.3915	6.3617	6.5140	6.3352	6.2925	6.5140
CaO (wt%)	0.6937	0.6574	0.6130	0.6723	0.6069	0.6130
Cr_2O_3 (wt%)	0.0950	0.1018	0.1260	0.1060	0.1028	0.1260
Fe_2O_3 (wt%)	10.9587	10.9407	12.0400	11.3339	11.3324	12.0400
Li_2O (wt%)	4.4996	4.6125	4.6200	4.5265	4.6401	4.6200
MgO (wt%)	1.6797	1.6167	1.6630	1.6469	1.5546	1.6630
MnO (wt%)	3.7961	3.8036	3.9730	3.8930	3.7921	3.9730
Na_2O (wt%)	13.4193	12.9230	12.9390	13.2407	12.6235	12.9390
NiO (wt%)	2.7295	2.6249	2.9380	2.7982	2.7797	2.9380
P_2O_5 (wt%)	0.3156	0.3156	0.4782	0.3844	0.3844	0.4782
SiO_2 (wt%)	45.5136	45.0182	44.5340	45.8345	45.3040	44.5340
ThO_2 (wt%)	2.7992	2.7992	2.8914	0.0000	0.0000	0.0000
U_3O_8 (wt%)	2.4822	2.7638	2.5412	5.4656	5.7562	5.4138
ZrO_2 (wt%)	0.5660	0.5660	0.6957	0.6838	0.6838	0.6957
Sum of Oxides (wt%)	99.3266	98.5629	99.6815	100.1804	99.0987	99.6627

5.4.2 Predicted versus Measured PCTs for the Th Glasses

As seen in Table 5-4, the durabilities for the paired "Th/U" glasses are much better than that of EA. The most durable glass (based on a NL [B] using the targeted composition) is rc-40 (quenched) with a 1.95 g/L release. The least durable (based on a NL [B] using the targeted composition) glass is rcth-30 with a 7.39 g/L release. Although the rcth-30 glass does have a relatively high boron release, its value is still less than that of EA (16.695 g/L).

Table 5-4. Normalized PCT Results for "rc" and "rcth" Glass Pairs

Glass ID	Heat Treatment	Composition	log NL [B(g/L)]	Log NL [Li(g/L)]	log NL [Na(g/L)]	log NL [Si(g/L)]	NL B(g/L)	NL Li(g/L)	NL Na(g/L)	NL Si(g/L)
rc-30	ccc	Measured	0.4053	0.3862	0.3139	0.0921	2.54	2.43	2.06	1.24
rc-30	ccc	Measured bc	0.4083	0.3843	0.3346	0.0972	2.56	2.42	2.16	1.25
rc-30	ccc	Targeted	0.3932	0.3773	0.3239	0.1046	2.47	2.38	2.11	1.27
rc-30	quenched	Measured	0.7389	0.6196	0.5863	0.2415	5.48	4.17	3.86	1.74
rc-30	quenched	Measured bc	0.7419	0.6177	0.6070	0.2466	5.52	4.15	4.05	1.76
rc-30	quenched	Targeted	0.7268	0.6107	0.5963	0.2540	5.33	4.08	3.95	1.80
rcth-30	ccc	Measured	0.7548	0.7059	0.5855	0.2718	5.69	5.08	3.85	1.87
rcth-30	ccc	Measured bc	0.7569	0.6952	0.6019	0.2765	5.71	4.96	4.00	1.89
rcth-30	ccc	Targeted	0.7466	0.6945	0.6013	0.2812	5.58	4.95	3.99	1.91
rcth-30	quenched	Measured	0.8770	0.8092	0.6819	0.3094	7.53	6.44	4.81	2.04
rcth-30	quenched	Measured bc	0.8791	0.7984	0.6983	0.3141	7.57	6.29	4.99	2.06
rcth-30	quenched	Targeted	0.8688	0.7977	0.6978	0.3188	7.39	6.28	4.99	2.08
rc-40	ccc	Measured	0.5115	0.4523	0.3676	0.0733	3.25	2.83	2.33	1.18
rc-40	ccc	Measured bc	0.5169	0.4525	0.3863	0.0836	3.29	2.84	2.43	1.21
rc-40	ccc	Targeted	0.4929	0.4351	0.3732	0.0868	3.11	2.72	2.36	1.22
rc-40	quenched	Measured	0.3079	0.2265	0.1991	-0.1002	2.03	1.69	1.58	0.79
rc-40	quenched	Measured bc	0.3132	0.2268	0.2178	-0.0900	2.06	1.69	1.65	0.81
rc-40	quenched	Targeted	0.2893	0.2094	0.2046	-0.0867	1.95	1.62	1.60	0.82
rcth-40	ccc	Measured	0.7345	0.7069	0.5338	0.1464	5.43	5.09	3.42	1.40
rcth-40	ccc	Measured bc	0.7365	0.6961	0.5502	0.1511	5.45	4.97	3.55	1.42
rcth-40	ccc	Targeted	0.6773	0.6418	0.5303	0.1564	4.76	4.38	3.39	1.43
rcth-40	quenched	Measured	0.6324	0.5887	0.4382	0.0291	4.29	3.88	2.74	1.07
rcth-40	quenched	Measured bc	0.6344	0.5779	0.4546	0.0338	4.31	3.78	2.85	1.08
rcth-40	quenched	Targeted	0.5752	0.5236	0.4347	0.0391	3.76	3.34	2.72	1.09
rc-50	ccc	Measured	0.3564	0.3540	0.2812	0.1291	2.27	2.26	1.91	1.35
rc-50	ccc	Measured bc	0.3605	0.3532	0.3008	0.1368	2.29	2.26	2.00	1.37
rc-50	ccc	Targeted	0.3381	0.3344	0.2895	0.1378	2.18	2.16	1.95	1.37
rc-50	quenched	Measured	0.4722	0.3755	0.3702	0.1392	2.97	2.37	2.35	1.38
rc-50	quenched	Measured bc	0.4764	0.3747	0.3897	0.1469	3.00	2.37	2.45	1.40
rc-50	quenched	Targeted	0.4539	0.3559	0.3785	0.1479	2.84	2.27	2.39	1.41
rcth-50	ccc	Measured	0.4193	0.4098	0.3045	0.0858	2.63	2.57	2.02	1.22
rcth-50	ccc	Measured bc	0.4214	0.3990	0.3209	0.0906	2.64	2.51	2.09	1.23
rcth-50	ccc	Targeted	0.4072	0.3898	0.3162	0.0916	2.55	2.45	2.07	1.23
rcth-50	quenched	Measured	0.5037	0.4573	0.3769	0.1216	3.19	2.87	2.38	1.32
rcth-50	quenched	Measured bc	0.5058	0.4464	0.3933	0.1264	3.20	2.80	2.47	1.34
rcth-50	quenched	Targeted	0.4917	0.4372	0.3886	0.1273	3.10	2.74	2.45	1.34

Table 5-5 provides an opportunity for a closer comparison of the PCTs between the "rc" and "rcth" glass pairs. Note that only the quenched versions of the glasses are provided. The ccc versions have been removed given the possible presence of devitrification (due to the slow cooling) and potential implication of misrepresenting the predictability or applicability of the model. Although not included in this table, an assessment of predictability is performed later in this section.

Table 5-5. ΔGp Values for Quenched "rc" and "rcth" Glass Pairs Based on Targeted Compositions

Glass Pair	Base Frit	NL [B] (g/L) Measured	NL [B] (g/L) Predicted	ΔG_p (kcal/mol)
rc-30	Frit 165	5.33	2.224	-12.4325
rcth-30	Frit 165	7.39	1.970	-12.1438
rc-40	Frit 200	1.95	1.027	-10.5783
rcth-40	Frit 200	3.76	0.900	-10.2896
rc-50	Frit 320	2.84	1.869	-12.0151
rcth-50	Frit 320	3.10	1.656	-11.7263

Jantzen et al. (1995) reported the ΔG_i values for U_3O_8 and ThO_2 as -23.77 kcal/mol and +19.23 kcal/mol, respectively. The ΔG_i signs suggest that U_3O_8 will have a negative impact on durability while ThO_2 will increase durability. This is reflected by the ΔG_P values associated with the "rc" glasses being less negative than their counterpart "rcth" glasses. This is also reflected in the predicted g/L NL [B] release values where the "rcth" glasses have smaller g/L values indicating a more durable product is to be expected.

The results of the measured PCT responses are quite interesting. First, the measured NL [B] release values for the "rcth" glasses are greater than their "rc" counterparts – for all three frit systems. This suggests that the sign and/or magnitude of the ΔG_i value associated with U_3O_8 and ThO_2 is inconsistent with the theory as reported by Jantzen et al. (1995). For example, assume ThO_2 has no impact on PCT. As one replaces U_3O_8 with ThO_2 (e.g., rc-30 to rcth-30), durability should improve based on model predictions given the negative ΔG_i value for U_3O_8. Based on the measured PCT response, durability decreased. This implies (a) ThO_2 is not neutral, (b) U_3O_8 does not decrease durability given rcth-30 had less U_3O_8 but a higher NL [B], and/or (c) the interactions are complex and have not been accounted for by the current model for this compositional region. It should be noted that this latter statement is based solely on the limited number of glasses within a narrow compositional region. Although the differences between rc-40 and rcth-40 are consistent with the other two pairs, the results should be viewed with caution given the uncertainties associated with the measured composition of rcth-40.

Another interesting observation is the effect of frit composition on the measured PCT response. Model predictions suggest that the Frit 200-based glasses will be the most durable by about a factor of 2 over the Frit 320 and Frit 165 based glasses. Although the measured responses do support the factor of 2 difference between the Frit 200 and Frit 165 glasses, the Frit 320-based glasses appear to respond better than predicted.

In addition, the measured NL [B] release values for both the "rc" and the "rcth" glasses are significantly greater than predicted values. This suggests that the model is under predicting the PCT response for these glasses – a condition one wishes to avoid. This may also indicate that the durability response is not predictable for all (or select) study glasses. Peeler et al. (2002b) showed that the model was applicable for the rc-30, rc-40, and rc-50 quenched glasses (i.e., the model predicted the durability response). The term predictability in this context is based on the

95% two-sided confidence interval as generated by the THERMO™ ΔG_P model. The durability of a glass is considered predictable if its PCT response is within the 95% confidence interval for an individual PCT prediction.

Exhibit D.8 in Appendix D provides plots of the DWPF models that relate the logarithm of the normalized PCT (for each element of interest) to a linear function of a free energy of hydration term (ΔG_p, kcal/100g glass) derived from all of the glass compositional views (Jantzen et al. 1995). Prediction limits (at a 95% confidence) for an individual PCT result are also plotted along with the linear fit. The EA and ARM results from this study are also indicated on these plots. With respect to the applicability of the model, the primary focus will be on the quenched glasses given the higher potential for ccc glasses to be "inhomogeneous" (i.e., crystallization could have resulted during the slow cooling).

Each different frit-based system will be discussed separately below with respect to the model's applicability. First consider the Frit 320-based glasses (rc-50 and rcth-50). For all compositional views considering only quenched glasses, the PCT responses for both rc-50 and rcth-50 are predictable by the model. Based on the information shown in Exhibit D.8, the ccc versions of the Frit 320-based glasses are also predictable by the model for all compositional views. If crystallization is present in the ccc versions, its effect on the PCT response had no impact on the model's applicability. It should be noted, that although the measured data do lie within the 95% confidence bands, the model actually under predicts the responses (i.e., all of the measured data lie above the solid line that is the model prediction).

For rc-40, the Frit 200-based glass, the PCT response is predictable by the model for all compositional views. However, for rcth-40, there are no compositional views under which the model is applicable (i.e., all of the compositional views lie outside the upper 95% confidence band). Given the compositional uncertainties of rcth-40, the targeted and measured-bias corrected views of this glass may be suspect with respect to the model's applicability. But the measured compositional view should reflect the model's ability to predict the measured PCT response. The fact that the "Th-based" versions of this glass are not predictable could be a reflection of the use of inappropriate ΔG_i values for both U_3O_8 and ThO_2. As with the Frit 320-based glasses, all of the measured PCT responses are under predicted by the model.

Finally, consider the Frit 165-based glasses (rc-30 and rcth-30). Two of the three compositional views for the quenched rc-30 glass are predictable by the model. All three of the rcth-30 compositional views are not predictable. Given they all lie above the 95% confidence band, the model once again under predicts the measured response.

In summary, the model is applicable to the U_3O_8-based "rc" glasses although the measured responses are slightly under predicted. With respect to the ThO_2-based "rcth" glasses, only the PCT responses for the Frit 320-based glasses were predicted by the model. The model was not applicable for the Frit 200 or Frit 165 based glasses as they fell outside the upper 95% confidence band which could be indicative of inappropriate ΔG_i values or complex interactions occurring that are not being accounted for by the current model. The mere fact that the model under predicted all of the measured PCT responses is troublesome. It should be noted that the confidence limits are 95% which suggests that 5% of the glasses could be "unpredictable".

5.4.3 Viscosity Measurements of the Th Glasses

Given U_3O_8 and ThO_2 terms are only associated with the durability model, all other predicted properties, specifically viscosity, should be equivalent between the base "rc" glasses and their Th-enriched "rcth" counterparts. Table 5-6 summarizes the predicted and measured viscosities for each "paired" system.

Table 5-6. Predicted and Measured Viscosity ($\eta_{1150°C}$) Values for the "rc" and "rcth" Glasses.

GlassID	SludgeID	Frit ID	WL (%)	Predicted η 1150°C (Poise)	Measured η 1150°C (Poise)
rc-30	PHF OL	165	35.0	24.8	18.06
rcth-30	PHF OL	165	35.0	24.8	20.52
rc-40	PHF OL	200	35.0	46.8	30.35
rcth-40	PHF OL	200	35.0	46.8	36.21
rc-50	PHF OL	320	35.0	31.0	22.53
rcth-50	PHF OL	320	35.0	31.0	23.50

The viscosity data provide insight into three areas: (1) general observations in terms of frit composition, (2) predicted versus measured values and (2) the impact of ThO_2 on viscosity.

Given the only targeted difference between the three sets of glasses ("rc" and "rcth") is the frit used, a general assessment on the impact to viscosity is warranted. The use of the more refractory Frit 200 does result in a higher predicted and measured viscosity as compared to both Frit 320 and Frit165-based systems. This is primarily a result of the higher alkali contents of the Frit 320 and Frit 165 systems.

Next consider the predicted versus measured viscosity issue. As shown in Table 5-6, all of the measured viscosity values ($\eta_{1150°C}$) are lower than the predicted values. The difference between measured and predicted ranging from approximately 4 Poise (rcth-30) to 16 Poise (rc-40). The largest differences are associated with the Frit 200 system as the rc-40 and rcth-40 glasses yield differences of 16.45 Poise and 10.59 Poise respectively. The differences associated with the rcth-40 glass should be viewed with caution given the compositional uncertainties as previously discussed. Given the measurement uncertainties of the viscometer (as demonstrated through a viscosity round robin (see Edwards et al. (1999)), these differences are "real" which suggest that there may be a bias in the model. That is, the model currently does not contain a U_3O_8 or ThO_2 term – but perhaps it should to account for their contributions to the measured (or actual) viscosity results.

Of primary interest is an assessment of the impact of ThO_2 on the viscosity. Comparisons between the "rc" and "rcth" counterparts will provide insight into this potential effect. Differences between the "paired" glasses are quite small – ranging from 5.86 Poise (rc-40 and rcth-40) to 0.97 Poise (rc-50 and rcth-50). Given the compositional uncertainties associated with rcth-40, the 5.86 Poise difference should be viewed with caution. The difference between the rc-

30 and rcth-30 glasses is 2.46 Poise. Based on these data, the impact of ThO_2 on viscosity appears to be minimal (and not a practical concern). Trends do suggest that ThO_2 slightly increases viscosity but U_3O_8 appears to have a more pronounced impact (lower viscosity) for this set of glasses. However, based on the results described above, the impact of U_3O_8 may be real and perhaps adjustments to the model should be made to account for its contribution.

5.5 High Waste Loaded (HWL) Glasses

The "hwl" series of glasses included in this study were to promote an assessment of the impact of higher WLs (ranging from 33.3 – 43.9 wt% WL) on various glass properties. In this series, molar substitutions of ThO_2 for U_3O_8 did not occur so one can not isolate the impact of either of these two components on the specific property of interest. In fact, as WLs are increased, a single oxide of interest can be focused on but one must remember that the resulting property is a complex function of the overall glass composition – not just a single oxide. Therefore, the assessment of higher WLs on the properties of interest should be viewed "globally" and the results will provide general guidance as DWPF targets higher WLs.

The glasses in this series were designated as rchwl-01 through rchwl-06, and they extend combinations of selected frits with SB3 and SB4 (to higher waste loadings). To promote comparisons of interest, the normalized PCT responses for B (g/L) for these "hwl" glasses are reported in Table 5-7. Also shown in Table 5-7, are the PCT responses for the corresponding glasses at lower waste loadings as reported by Peeler et al. (2002b). For each frit/sludge system, the glasses provide a series of WLs to assess the impact of WL on the PCT response. To facilitate the discussions of each frit/sludge system, the data provided in Table 5-7 are plotted in Figure 5-1. As previously mentioned, the "hwl" series of glasses is extremely durable with NL [B] values of 2.7 g/L or less (for both quenched and ccc versions). The "x"'s and "□"'s represent the quenched and ccc version of each glass, respectively. Note that the x- and y-axes for each plot may differ and may suggest a "general" trend when actually there is no measurable response.

Table 5-7. NL[B (g/L)] PCTs for HWL Glasses of Interest for Both Heat Treatments Based Upon Targeted Compositions.

Frit/Sludge System	Glass ID	Waste Loading (%)	Quenched NL[B (g/L)]	ccc NL[B (g/L)]
Frit 165/SB4	rc-27	27.5	2.075	1.847
	rc-28	30	1.446	1.395
	rc-32	35	1.355	1.320
	rc-33	37.5	1.451	1.422
	rchwl-02	41.6	1.533	1.038
Frit 165/SB3	rc-35	27.5	1.428	1.408
	rc-34	30	1.337	1.308
	rc-26	35	1.531	1.476
	rchwl-01	38.1	1.877	1.233
Frit 200/SB3	rc-44	27.5	1.002	1.057
	rc-38	30	0.948	1.018
	rchwl-03	33.3	1.129	2.682
Frit 200/SB4	rc-39	30	0.989	1.569
	rc-43	32.5	1.125	2.427
	rchwl-04	36.4	1.214	2.133
Frit 320/SB3	rc-56	27.5	1.290	1.326
	rc-57	30.0	1.285	1.759
	rc-45	35.0	1.331	1.466
	rc-48	37.5	1.541	1.491
	rchwl-05	40.3	1.612	1.056
Frit 320/SB4	rc-51	27.5	1.428	1.308
	rc-49	30	1.326	1.259
	rc-55	35	1.509	1.527
	rc-53	40	1.556	1.325
	rchwl-06	43.9	1.484	1.176

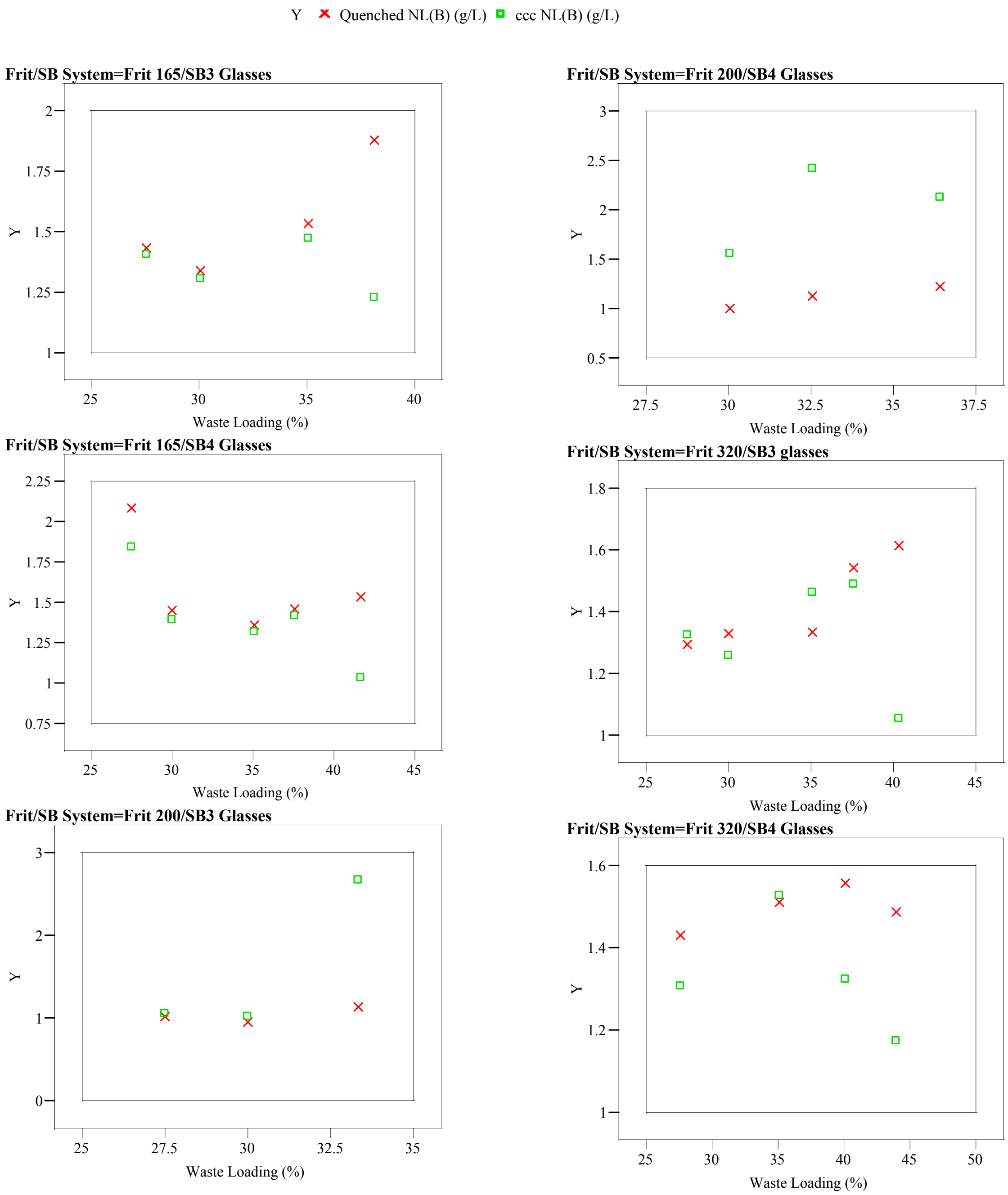

Figure 5-1. NL[B (g/L) PCTs for HWL Glasses of Interest for Both Heat Treatments Based Upon Targeted Compositions.

Each frit/sludge system will be presented separately in the following discussion. First consider the Frit 165/SB3 system. For the quenched glasses, the general trend in the PCT response is that as WLs increase above 35%, durability decreases. Although the durability decreases, rchwl-01 (Frit165/SB3 at 38.1% WL) has a measured NL [B] of 1.887 g/L – very acceptable with respect to the EA glass. In fact, the difference between rc-26 and rchwl-01 is ~0.3 g/L which is of little practical concern. The ccc versions of this series indicate essentially no change in durability as WL increases. Of particular interest is the comparison between the quenched and ccc versions at each WL. With the exception of the 38.1% glass, there is essentially no difference between the PCT responses for the two different heat treatments. The ccc version of the rchwl-01 glass has a "lower" release (higher durability) than its quenched counterpart.

For the Frit 165/SB4 system, the durability of both the quenched and ccc glasses initially increases (decrease in NL [B] release) from 27.5 to 30% WL and levels out through 38% WL. It should be noted that the change in PCT response as a function of WL is on the order of 0.2 – 0.4 g/L – not a significant or practical change. An increase to 41.6% WL results in essentially no change in the PCT response for the quenched glasses, but an increase in durability for the ccc version. As with the Frit 165/SB3 system, there appears to be a measurable difference in the PCT response at the highest WL between the quenched and ccc versions.

The PCT response for the Frit 200/SB3 system is essentially constant over a WL range of 27.5 – 33.0 wt% for the quenched glasses. Once again, the difference between the quenched and ccc versions of the upper WL glass (rchwl-03) is significantly different. However, in this case, the quenched version is more durable than its ccc counterpart – opposite to that observed with the Frit 165-based glasses (rchwl-01 and rchwl-02). However, a NL [B] of 2.682 g/L for rchwl-03 ccc is acceptable as compared to the 16.695 g/L for EA.

For the Frit 200/SB4 system, all of the ccc glasses have higher releases than their quenched counterparts – almost a factor of 2 difference at each WL. For the quenched glasses, the NL [B] remains essentially constant at approximately 1.0 g/L for WLs of 30 to 36.4%. The NL [B] for the ccc glasses initially increases with an increased WL from 30 to 32.5%, but decreases once 36.4% WL is targeted. The maximum difference in NL [B] for the ccc glasses is 0.858 g/L which, although probably a measurable difference, is of no practical concern. Again, at the higher WL, the quenched version of the glass is more durable than its ccc counterpart.

For the Frit 320/SB3 system, the general trend in the quenched data suggests that there is a gradual decrease in durability as WL increases or that durability is essentially constant from 27.5 to 35% WL with a slight decrease in durability at the 37.5 and 40.3% WLs. The reason for the possible dual descriptions of the data is based on how one interprets what defines a "measurable" difference. The difference in NL [B] for the quenched PCTs is 0.322 g/L – although perhaps a measurable difference – it is of no practical concern. As with previous systems, the most interesting result is the "major" difference in the PCT response for different heat treatments of rchwl-05 (40.3% WL). The ccc version is more durable than the quenched version – consistent with the Frit 165-based glasses.

The last system to discuss is based on Frit 320/SB4 – please note the y-axis scale (1.0 – 1.6 g/L). With NL [B] values ranging from 1.326 to 1.556 g/L, there is essentially no impact on PCT as WL increases for the quenched glasses. The same could be said about the ccc versions with NL [B] ranging from 1.176 to 1.527 g/L. The most interesting effect for this series is the fact that the quenched versions are less durable than their ccc counterparts – with the exception of rc-55 at 35% WL.

Comparisons between the measured PCTs for the HWL glasses and their predictions are facilitated by the plots provided in Exhibit D.9 in Appendix D. These plots show the ΔG_P model predictions and associated 95% confidence intervals (for individual PCT predictions) for B, Li, Na, and Si. With respect to the predictability of the model, all of the quenched glasses fall within the 95% confidence bands so the model is applicable for this series of glasses (for all compositional views). For the ccc glasses, select PCT response fall outside the upper 95% confidence band indicating the that model may not be applicable to these glasses. It should be noted that the ccc glasses are more likely to contain crystallization that could render the model inapplicable.

Table 5-8 summarizes the predicted and measured viscosity values for the "hwl" glass series. Given the targeted WLs are different, direct comparisons among the "rchwl" glasses should be made with caution. In general, however, the Frit 165 and Frit 320 glasses have lower predicted viscosities relative to the more refractory Frit 200 systems.

Table 5-8. Predicted and Measured Viscosity ($\eta_{1150°C}$) Values for the "rchwl" Glasses.

GlassID	SludgeID	Frit ID	WL (%)	Predicted η 1150°C (Poise)	Measured η 1150°C (Poise)
rchwl-01	SB3 OL	165	38.1	19.3	21.52
rchwl-02	SB4 OL	165	41.6	18.7	21.16
rchwl-03	SB3 OL	200	33.3	46.6	40.90
rchwl-04	SB4 OL	200	36.4	45.1	37.55
rchwl-05	SB3 OL	320	40.3	21.5	23.69
rchwl-06	SB4 OL	320	43.9	20.7	21.22

The following discussion is based on a comparison of the predicted versus measured viscosities for each glass. Comparisons between or among glasses will not be attempted based on differences in WL, frit and/or sludge compositions. The measured viscosities for the 165-based glasses (rchwl-01 and rchwl-02) are in-line with the predicted values. The differences are approximately 2 Poise that is considered to be within experimental error and uncertainty. Since increased WL results in increased uranium content, these data suggest no effect of U_3O_8 as reflected by the current model – this is counter to the results discussed in Section 5.4.3 for the "rc" and "rcth" glasses) which suggest that the impact may be system dependent. Similar results are observed with the Frit 320-based glasses. More specifically, there does not appear to be a significant difference between the predicted and measured viscosities.

The results for the Frit 200-based glasses (rchwl-03 and rchwl-04) suggest that the measured viscosity is lower than the predicted viscosity. Assuming this is a significant difference, then these data could support the observations from the "rc" and "rcth" glasses that indicated that the presence of an U_3O_8-term may be needed in the viscosity model. The fact that the model under predicts and over predicts these U_3O_8-based glasses indicates that the model's predictability may be compositionally dependent. That is, for given compositional regions, the model may be extremely accurate but for different regions the model may be biased high or low – an observation that is consistent with that of Harbour et al. (1999).

5.6 Tank 40 Glasses

The final set of glasses developed for this study was based on Tank 40. It should be noted that the "tk40" glasses do not have counterpart "rc" glasses from which properties can be compared. The "tk40" glasses were designed strictly to push WLs to the extent (reasonably) possible in order to assess or compare the predicted impact (or lack thereof) of high WLs (and hence higher U_3O_8 concentrations) to the measured impact on PCT and viscosity.

Table 5-9 summarizes the PCT responses for the quenched and ccc version of these glasses for all three compositional views. A general observation of the data suggests that all glasses are extremely acceptable with NL [B] releases being less than ~1.7 g/L for both quenched and ccc glasses (as compared to 16.695 g/L for EA). These data again suggest that durable glasses can be made at relatively high WLs (the WLs ranged from 32.2% to 39.1% for the Frit 200 and Frit 320-based systems, respectively).

The predictability of the PCTs for the Tank 40 glasses is investigated in Exhibit D.10 of Appendix D. These plots show the ΔG_P model predictions and associated 95% confidence intervals (for individual PCT predictions) for B, Li, Na, and Si. With respect to the predictability of the model, all of the quenched glasses fall within the 95% confidence bands so the model is applicable for this series of glasses (for all compositional views).

Table 5-9. Normalized PCTs for the "tk40" Glasses.

Glass ID	Heat Treatment	Composition	log NL [B(g/L)]	log NL [Li(g/L)]	log NL [Na(g/L)]	log NL [Si(g/L)]	NL B(g/L)	NL Li(g/L)	NL Na(g/L)	NL Si(g/L)
tk40-01	ccc	Measured	0.1246	0.1145	0.0463	-0.1995	1.33	1.30	1.11	0.63
tk40-01	ccc	Measured bc	0.1267	0.1037	0.0626	-0.1947	1.34	1.27	1.16	0.64
tk40-01	ccc	Targeted	0.1046	0.0891	0.0494	-0.1906	1.27	1.23	1.12	0.64
tk40-01	quenched	Measured	0.1796	0.1403	0.0984	-0.1815	1.51	1.38	1.25	0.66
tk40-01	quenched	Measured bc	0.1816	0.1295	0.1148	-0.1768	1.52	1.35	1.30	0.67
tk40-01	quenched	Targeted	0.1595	0.1149	0.1015	-0.1726	1.44	1.30	1.26	0.67
tk40-02	ccc	Measured	0.2153	0.1402	0.0216	-0.2839	1.64	1.38	1.05	0.52
tk40-02	ccc	Measured bc	0.2174	0.1293	0.0380	-0.2791	1.65	1.35	1.09	0.53
tk40-02	ccc	Targeted	0.2056	0.1183	0.0312	-0.2755	1.61	1.31	1.07	0.53
tk40-02	quenched	Measured	0.0025	-0.0113	-0.0514	-0.2825	1.01	0.97	0.89	0.52
tk40-02	quenched	Measured bc	0.0046	-0.0221	-0.0350	-0.2778	1.01	0.95	0.92	0.53
tk40-02	quenched	Targeted	-0.0072	-0.0331	-0.0419	-0.2741	0.98	0.93	0.91	0.53
tk40-03	ccc	Measured	0.1220	0.1387	0.0626	-0.1345	1.32	1.38	1.15	0.73
tk40-03	ccc	Measured bc	0.1241	0.1279	0.0789	-0.1298	1.33	1.34	1.20	0.74
tk40-03	ccc	Targeted	0.1127	0.1245	0.0744	-0.1171	1.30	1.33	1.19	0.76
tk40-03	quenched	Measured	0.2062	0.1731	0.1322	-0.1146	1.61	1.49	1.36	0.77
tk40-03	quenched	Measured bc	0.2083	0.1622	0.1486	-0.1098	1.62	1.45	1.41	0.78
tk40-03	quenched	Targeted	0.1969	0.1588	0.1441	-0.0972	1.57	1.44	1.39	0.80

Table 5-10 summarizes the predicted versus measured viscosity results for the tk40 glasses. Although a "constant" targeted sludge composition was used, detailed comparisons between or among glasses will not be attempted due to differences in both WL and frit composition. Generally speaking, the Frit 200 glass is predicted to have higher viscosities than either the Frit 165 or Frit 320 glasses. This is in-line with expectations given the higher alkali content of Frit 165 and Frit 320.

The measured viscosities for all of the tk40 glasses were higher than predicted. These data suggest that the model is under predicting the actual glass viscosity. Again, the model's predictability appears to be dependent upon the compositional region of interest – assuming no measurement bias in the data.

Table 5-10. Predicted and Measured Viscosity ($\eta_{1150°C}$) Values for the "tk40" Glasses.

GlassID	SludgeID	Frit ID	WL (%)	Predicted η 1150°C (Poise)	Measured η 1150°C (Poise)
tk40-01	Tank 40	165	36.9	21.7	26.45
tk40-02	Tank 40	200	32.2	51.6	57.45
tk40-03	Tank 40	320	39.1	24.3	32.25

6.0 Summary

In support of accelerated mission goals, glass formulation efforts have been focused on melt rate, waste loading, and waste throughput for the Defense Waste Processing Facility (DWPF). With respect to increased waste loading (WL), Brown et al. (2001a) developed a new liquidus temperature (T_L) model that may allow higher waste loadings for future DWPF operations. Peeler et al. (2002a) have demonstrated via model-based assessments that coupling the new T_L model with alternative frit compositions can lead to the potential for significant increases in waste loadings for certain systems. Higher WLs have recently been targeted in DWPF with the implementation of the new T_L model and Frit 320 for SB2 (e.g., WLs of 35 wt% or higher are being targeted as compared to 28% with the Frit 200/SB2 system). As WL increases, components of the sludge become more critical in terms of dictating glass properties. For example, sludge components such as Fe_2O_3, Cr_2O_3, NiO, and MnO have been studied quite extensively at higher concentrations given their influence on spinel formation and/or T_L and the desire to access higher WLs.

In this study, glasses were designed or selected to assess the impacts of U_3O_8 and ThO_2 on various glass properties of interest. The primary interest was to assess the impact of ThO_2 on the PCT response and viscosity. In addition, two sets of glasses (rchwl and tk40 glasses) were designed to assess the impact of higher waste loadings on these same glass properties. The following conclusions can be drawn from the data.

The Impact of U_3O_8 and ThO_2 on PCT and Viscosity

The "rc" versus "rcth" series of glasses allow for a direct assessment of the impact of ThO_2 and U_3O_8 on PCT and viscosity responses as well as confirmation that the magnitudes and signs of the predicted impact (i.e., the ΔG_i values) are justified for the PCT model. Molar substitutions resulted in identical predicted processing properties since U_3O_8 and ThO_2 terms are only associated with the durability model.

Based on the measured normalized boron release (NL [B]) values, the results indicated that the Th-enriched glasses were less durable than their U-based counterparts. Although molar substitutions of Th or U had a negative impact, all of the glasses were more durable than the Environmental Assessment glass – the highest release being 7.39 g/L as compared to 16.695 g/L as reported for EA. With respect to model predictions, these data suggest that the signs and/or magnitudes of the ΔG_i values associated with U_3O_8 and ThO_2 are inconsistent with the theory on which the current model is based for the limited number of glasses tested. For example, assume ThO_2 has no impact on PCT. As one replaces U_3O_8 with ThO_2 (e.g., rc-30 to rcth-30), durability should improve based on model predictions given the negative ΔG_i value for U_3O_8. Based on the measured PCT response, durability decreased. This implies (a) ThO_2 is not neutral, (b) U_3O_8 does not decrease durability given rcth-30 had less U_3O_8 but a higher NL [B], and/or (c) the interactions are complex and have not been accounted for by the current model for this compositional region. It should be noted that this latter statement is based solely on a limited number of glasses within the narrow compositional region of this study.

With respect to the impact of U_3O_8 and ThO_2 on viscosity, insight into three areas was discussed: (1) general observations in terms of frit composition, (2) predicted versus measured values and (3) the impact of ThO_2 on viscosity. The most important areas are (2) and (3) which are briefly summarized below. All of the measured viscosity values ($\eta_{1150°C}$) were lower than the predicted values. The difference between measured and predicted ranged from approximately 4 Poise (rcth-30) to 16 Poise (rc-40). Given the measurement uncertainties of the viscometer, most of these differences appear "real" which suggests that there may be a bias in the model. That is, the model currently does not contain a U_3O_8 or ThO_2 term – but perhaps it should to account for their contributions to the measured (or actual) viscosity results.

The second area of primary interest is the assessment of the impact of ThO_2 on the viscosity. Differences between the "paired" glasses are quite small – ranging from 5.86 Poise (rc-40 and rcth-40) to 0.97 Poise (rc-50 and rcth-50). Given the compositional uncertainties associated with rcth-40, the 5.86 Poise difference should be viewed with caution. The difference between the rc-30 and rcth-30 glasses is 2.46 Poise. Based on these limited data, the impact of ThO_2 on viscosity appears to be minimal (and not a practical concern). Trends do suggest that ThO_2 slightly increases viscosity, but U_3O_8 appears to have a more pronounced negative impact (lowering viscosity) for this set of glasses. However, based on the results described above, the impact of U_3O_8 may be real and perhaps adjustments to the model should be made to account for its contribution.

High Waste Loading Glasses

The "hwl" and "tk40" glasses were designed to provide insight into the impacts of higher WLs on both PCT and viscosity. Based on the data, the following conclusions can be drawn. For these two sets of glasses, molar substitutions of ThO_2 for U_3O_8 did not occur so one can not isolate the impact of either of these two components on the specific property of interest. In fact, as WLs are increased, a single oxide of interest can be focused on but one must remember that the resulting property behavior is a complex function of the overall glass composition – not just a single oxide. Therefore, the assessment of the impact of higher WLs on the properties of interest should be viewed "globally" with the results providing general guidance as DWPF targets higher WLs.

With respect to PCT analysis, the results suggest that durable glasses can be made at relatively high WLs. Comparisons between the measured PCTs for these two sets and their predictions indicate that the current model is applicable, with all of the quenched glasses falling within the 95% confidence bands.

The viscosity data for these two sets of glasses suggest that the current model may be extremely accurate for some systems but for different regions the model may be biased high or low – an observation that is consistent with that of Harbour et al. (1999).

7.0 Recommendations

Based on the results of this study, the following recommendations are made:

(1) Assess the impact of the U_3O_8 and ThO_2 terms on both the viscosity and durability models over a broader compositional region. Glasses should be selected within (and covering more globally) the compositional envelope over which DWPF processing is expected.

(2) Perform X-ray diffraction analysis on the higher waste loading glasses (both quenched and ccc versions) to assess the potential formation of crystallization. The results presented in this report suggest a significant difference in the durability response between the quenched and ccc versions for the high waste loading glass series. This difference may be a result of devitrification and its impact to the residual (or continual) glass matrix composition. Also of interest would be the type of crystallization (if any) detected in these samples – in light of the high waste loadings.

(3) Assess the impact of U_3O_8 and ThO_2 on liquidus temperature. Due to the budgetary constraints of this task, T_L was not assessed for the study glasses. Prior to assessing this property, consideration should be given as to whether or not the glasses identified in this study in which WL was determined by pushing T_L predictions proximate to 1050°C should be utilized. It is likely that these glasses would not be processable in DWPF after accounting for uncertainties. Thus additional glasses may be needed to assess the impact of U_3O_8 and ThO_2 over a compositional region of interest to DWPF.

(4) Assess the impact of U_3O_8 and ThO_2 on melt rate or melt behavior. Given higher concentrations of U_3O_8 and/or ThO_2 could be present in future sludge batches, an assessment of their impact on melt rate or melt behavior is warranted.

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8.0 References

ASTM 1998. **Standard Test Methods for Determining Chemical Durability of Nuclear Waste Glasses: The Product Consistency Test (PCT)**, ASTM C-1285-98, 1998.

Brown KG, CM Jantzen, and G Ritzhaupt. 2001a. *Relating Liquidus Temperature to Composition for Defense Waste Processing Facility (DWPF) Process Control,* WSRC-TR-2001-00520, Westinghouse Savannah River Company, Aiken, South Carolina.

Brown KG, TB Edwards, CC Herman, and DK Peeler. 2001b. *Selecting Glass Compositions for the DWPF SB2/Frit 320 Variability Study*, WSRC-RP-2001-00775, Westinghouse Savannah River Company, Aiken, SC.

Cicero CA, SL Marra, and MK Andrews. 1993. *Phase Stability Determinations of DWPF Waste Glasses (U),* WSRC-TR-93-227, Westinghouse Savannah River Company, Aiken, SC.

Edwards, TB, JR Harbour, RF Schumacher, and RJ Workman. 1999. *Measurement of DWPF Glass Viscosity – Final Report*, WSRC-RP-99-01053, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Harbour JR, TB Edwards, and RJ Workman. 2000. *Summary of Results for Macrobatch 3 Variability Study (U),* WSRC-TR-2000-00351, Revision 0, Westinghouse Savannah River Company, Aiken, SC.

Herman CC, TB Edwards, and DM Marsh. 2001. *Summary of Results for the Expanded Macrobatch 3 Variability Study (U)*, WSRC-TR-2001-00511, Revision 0, Westinghouse Savannah River Company, Aiken, SC.

Jantzen CM, and DF Bickford. 1985. Leaching of Devitrified Glass Containing Simulated SRP Nuclear Waste, *Sci. Basis for Nuclear Waste Management,* VIII, CM Jantzen, JA Stone and RC Ewing (eds.), Materials Research Society, Pittsburgh, PA 135-146.

Jantzen CM, NE Bibler, DC Beam, CL Crawford, and MA Pickett. 1993. *Characterization of the DWPF Environmental Assessment (EA) Glass Standard Reference Material (U)*, WSRC-TR-92-346, Revision. 1, Westinghouse Savannah River Company, Aiken, SC.

Jantzen, CM, JB Pickett, KG Brown, TB Edwards, and DC Beam. 1995. *Process/Product Models for the Defense Waste Processing Facility (DWPF): Part I. Predicting Glass Durability from Composition Using a Thermodynamic Hydration Energy Reaction Model (THERMO) (U)*, WSRC-TR-93-672, Revision 1, Volume 1, Westinghouse Savannah River Company, Aiken, South Carolina.

Kim D-S, P Hrma, SE Palmer, DE Smith, and MJ Schweiger. 1995. "Effect of B_2O_3, CaO, and Al_2O_3 on the Chemical Durability of Silicate Glasses for Hanford Low-Level Waste Glass Immobilization," *Ceram. Trans*., 61, 531–538.

Langowski, MH. 1996. *The Incorporation of P, S, Cr, F, Cl, I, Mn, Ti, U, and Bi into Simulated Nuclear Waste Glasses: Literature Study*, PNNL-10980, Pacific Northwest National Laboratory, Richland, Washington.

Li, H, MH Langowski, P Hrma, MJ Schweiger, JD Vienna, and DE Smith. 1995. Minor Component Study for Simulated High-Level Nuclear Waste Glasses, PNNL-10996, Pacific Northwest National Laboratory, Richland, Washington.

Marra SL, and CM Jantzen. 1993. *Characterization of Projected DWPF Glasses Heat Treated to Simulate Canister Centerline Cooling (U),* WSRC-TR-92-142, Revision 1, Westinghouse Savannah River Company, Aiken, South Carolina.

Peeler, DK, TB Edwards, and KG Brown. 2001. *Technical Status Report on the Applicability of the Homogeneity Constraint for Sludge-Only Processing*, WSRC-TR-2001-00538, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Peeler DK and TB Edwards. 2002a. *Frit Development for Sludge Batch 3*, WSRC-TR-2002-00491, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Peeler DK, KG Brown, TB Edwards, DR Best, RJ Workman, and IA Reamer. 2002b. *Reduction of Constraints: Phase 1 Experimental Assessment of Centroid-Based Sludge-Only Glasses*, WSRC-TR-2002-00120, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Plodinec MJ, KG Brown, SL Marra, CM Jantzen, and TB Edwards. 1995. "Technical Bases for the DWPF Glass Product Control Program." In: *Waste Qualification Report (WQR),* WSRC-IM-91-116-5, Revision 1, Volume 5, Westinghouse Savannah River Company, Aiken, South Carolina.

Savannah River Technology Center (SRTC). 2002a. "Glass Batching," SRTC Procedure Manual, L29, ITS-0001, Westinghouse Savannah River Company, Aiken, SC.

Savannah River Technology Center (SRTC). 2002b. "Glass Melting," SRTC Procedure Manual, L29, ITS-0003, Westinghouse Savannah River Company, Aiken, SC.

Schumacher, RF and DK Peeler. 1998. *Establishment of Harrop, High Temperature Viscometer*, WSRC-RP-98-00737, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Vienna, JD, P Hrma, MJ Schweiger, MH Langowski, P Redgate, and DS Kim. 1995. Effect of Composition and Temperature on the Properties of High-Level Waste Glasses above 1200°C, PNNL-10987, Richland, Washington.

Appendix A:

ANALYTICAL PLAN FOR THE MEASUREMENT OF CHEMICAL COMPOSITIONS

SRT-SCS-2002-00015

March 1, 2002

To: D. K. Peeler

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K. G. Brown, I. A. Reamer
S. P. Harris R. C. Tuckfield
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From: T. B. Edwards
Statistical Consulting Section

AN ANALYTICAL PLAN FOR MEASURING THE CHEMICAL COMPOSITIONS OF GLASSES CONTAINING U AND TH (U)

1.0 EXECUTIVE SUMMARY

A study is being conducted by the Savannah River Technology Center (SRTC) for the Defense Waste Processing Facility (DWPF) that involves investigating the impact of uranium and thorium on glass properties of interest. Several glass compositions have been selected for batching and testing to support this effort.

The chemical compositions of these study glasses are to be determined by the Savannah River Technology Center – Mobile Laboratory (SRTC-ML). This memorandum provides an analytical plan to direct and support these measurements at the SRTC-ML.

2.0 INTRODUCTION

A study of the impact of uranium and thorium on glass properties is being conducted by the Savannah River Technology Center (SRTC) for the Defense Waste Processing Facility (DWPF). Several glass compositions have been selected for batching and testing to support this effort. The chemical compositions of these glasses are to be determined by the Savannah River Technology Center – Mobile Laboratory (SRTC-ML). This memorandum provides an analytical plan to direct and support these measurements at the SRTC-ML.

3.0 ANALYTICAL PLAN

The analytical procedures used by the SRTC-ML to determine cation concentrations for a glass sample include steps for sample preparation and for instrument calibration. Each glass is to be prepared in duplicate by each of two dissolution methods: lithium metaborate (LM) and sodium peroxide (SP).

The primary measurements of interest are to be acquired as follows: the samples prepared by lithium metaborate (LM) are to be measured for aluminum (Al), calcium (Ca), chromium (Cr), iron (Fe), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), phosphorous (P), silicon (Si), thorium (Th), uranium (U), and zirconium (Zr) concentrations. Samples prepared by sodium peroxide (SP) are to be measured for boron (B) and lithium (Li). Samples dissolved by either of these two preparation methods are to be measured using Inductively Coupled Plasma (ICP) – Atomic Emission Spectrometry (AES). It should be noted that there are minor components associated with these glasses that will not be measured since their concentrations are projected to be below the detection limits of the ICP. These minor components include Ba, Cd, Co, Cu, La, Mo, Pb, Ru, Sn, Sr, Ti, V, and Zn.

Randomizing the preparation steps and blocking and randomizing the measurements for the ICP are of primary concern in the development of this analytical plan. The sources of uncertainty for the analytical procedure used by the SRTC-ML to determine the cation concentrations for the submitted glass samples primarily involve the dissolution step in the preparation of the sample and the calibrations of the ICP.

Samples of two standard glasses will be included in the analytical plan to provide an opportunity for checking the performance of the instrumentation over the course of the analyses and for potential bias correction. Specifically, several samples of Waste Compliance Plan (WCP) Batch 1 (BCH) [1] and a glass containing uranium (UST) are included in this analytical plan. The reference compositions of these glasses are provided in Table 1. These standards will be referred to using the short identifier provided in Table 1 in the remainder of this memo.

Table 1: Oxide Compositions of WCP Batch 1 (BCH) and Uranium Standard (UST) Glasses (wt%).

Oxide/ Anion	BCH (wt%)	UST (wt%)
Al_2O_3	4.877	4.1
B_2O_3	7.777	9.209
BaO	0.151	0.00
CaO	1.220	1.301
CdO	0.00	0.00
Cl	0.00	0.00
Cr_2O_3	0.107	0.00
Cs_2O	0.060	0.00
CuO	0.399	0.00
F	0.00	0.00
Fe_2O_3	12.839	13.196
K_2O	3.327	2.999
Li_2O	4.429	3.057
MgO	1.419	1.21
MnO	1.726	2.892
MoO_3	0.00	0.00
Na_2O	9.003	11.795
Nd_2O_3	0.147	0.00
NiO	0.751	1.12
P_2O_5	0.00	0.00
PbO	0.00	0.00
RuO_2	0.0214	0.00
SiO_2	50.22	45.353
SnO_2	0.00	0.00
SO_3	0.00	0.00
TiO_2	0.677	1.049
U_3O_8	0.00	2.406
ZrO_2	0.098	0.00

Each glass sample submitted to the SRTC-ML will be prepared in duplicate by the LM and SP dissolution methods. Each sample prepared using LM or SP will be read twice by ICP-AES, with the instrument being calibrated before each of these two sets of readings. This will lead to four measurements for each cation of interest for each submitted glass.

Table 2 presents identifying codes, D01 through D13, for the 13 glasses being considered as part of this study. The table provides a naming convention that is to be used in analyzing the glasses and reporting the measurements of their compositions.[8] It should be noted that RC-38U is included in this analytical plan although it is not of primary interest to this study. It is being evaluated due to the high concentration of uranium in this glass, to provide insight into the effects of uranium on various glass properties.

[8] Renaming these samples helps to ensure that they will be processed as blind samples within the SRTC-ML. Table 2 is not shown in its entirety in those copies going to the SRTC-ML.

Table 2: Identifiers to Establish Blind Samples for the SRTC-ML

Glass ID	Sample ID	Glass ID	Sample ID
rcth-30	D13	rchwl-05	D08
rcth-40	D04	rchwl-06	D03
rcth-50	D10	tk40-01-new	D11
rchwl-01	D07	tk40-02-new	D01
rchwl-02	D02	tk40-03-new	D12
rchwl-03	D05	RC-38U	D09
rchwl-04	D06		

3.1 Preparation of the Samples

Each of the 13 study glasses included in this analytical plan is to be prepared in duplicate by the LM and SP dissolution methods. Thus, the total number of prepared glass samples is determined by $13 \cdot 2 \cdot 2 = 52$, not including the samples of the BCH and UST glass standards that are to be prepared.

Tables 3a-3b provide blocking and (random) sequencing schema for conducting the preparation steps of the analytical procedures. A block of preparation work is provided for each preparation method to facilitate the scheduling of activities by work shift. The identifier for each of the prepared samples indicates the sample identifier (ID), preparation method, and duplicate number.

Table 3a: LM (Lithium Metaborate) Preparation Block

1
D03LM1
D01LM1
D06LM1
D07LM1
D05LM1
D13LM1
D11LM1
D07LM2
D12LM1
D12LM2
D11LM2
D06LM2
D08LM1
D05LM2
D03LM2
D01LM2
D09LM1
D10LM1
D13LM2
D09LM2
D02LM1
D04LM1
D08LM2
D02LM2
D10LM2
D04LM2

Table 3b: SP (Sodium Peroxide) Preparation Block

1
D01SP1
D04SP1
D07SP1
D12SP1
D06SP1
D09SP1
D08SP1
D01SP2
D03SP1
D08SP2
D04SP2
D02SP1
D03SP2
D07SP2
D05SP1
D09SP2
D02SP2
D12SP2
D13SP1
D06SP2
D10SP1
D11SP1
D13SP2
D11SP2
D05SP2
D10SP2

3.2 ICP Calibration Blocks

The glass samples prepared by LM and SP dissolution methods are to be analyzed using ICP instrumentation calibrated for the particular preparation method. After the initial set of cation concentration measurements, the ICP instrumentation is to be recalibrated and a second set of concentration measurements for the cations determined.

Randomized plans for measuring cation concentrations in the LM-prepared and SP-prepared samples are provided in Tables 4 and 5, respectively. The cations to be measured are specified in the header of each of these tables. In these tables, the sample identifiers for the study glasses have been modified by the addition of a suffix (a "1" or a "2") to indicate whether the measurement are to be made during the first or second (respectively) ICP calibration group. The identifiers for the BCH and UST samples have been modified to indicate that each of these prepared samples is to be read 3 and 2 times, respectively, (mirrored in the corresponding suffix of 1, 2, or 3) per calibration block.

Table 4: ICP Block and Calibration Groups for Samples Prepared Using LM
(Used to Measure Elemental Al, Ca, Cr, Fe, Mg, Mn, Na, Ni, P, Si, Th, U, and Zr)

ICP Block 1	
Calibration 1	Calibration 2
BCHLM11	BCHLM21
D02LM11	D07LM12
D06LM21	D06LM12
D07LM21	D05LM12
D02LM21	D12LM22
D11LM21	D01LM22
D09LM11	D09LM22
USTLM11	USTLM21
D13LM11	D06LM22
D01LM21	D05LM22
D04LM11	D11LM22
D06LM11	D02LM22
D10LM21	D10LM12
D09LM21	D08LM12
D08LM11	D12LM12
BCHLM12	BCHLM22
D07LM11	D04LM22
D04LM21	D03LM12
D05LM11	D09LM12
D08LM21	D03LM22
D13LM21	D08LM22
D03LM11	D07LM22
D01LM11	D01LM12
USTLM12	USTLM22
D03LM21	D10LM22
D10LM11	D13LM12
D11LM11	D11LM12
D12LM21	D04LM12
D12LM11	D02LM12
D05LM21	D13LM22
BCHLM13	BCHLM23

Table 5: ICP Block and Calibration Groups for Samples Prepared Using SP
(Used to Measure Elemental B and Li)

ICP Block 1	
Calibration 1	Calibration 2
BCHSP11	BCHSP21
D03SP11	D09SP22
D13SP21	D04SP22
D05SP11	D01SP22
D01SP11	D03SP22
D09SP21	D12SP22
D07SP11	D03SP12
USTSP11	USTSP21
D03SP21	D02SP12
D07SP21	D07SP22
D09SP11	D13SP12
D11SP11	D11SP12
D13SP11	D05SP22
D01SP21	D07SP12
D11SP21	D06SP12
BCHSP12	BCHSP22
D05SP21	D02SP22
D02SP11	D06SP22
D06SP21	D11SP22
D04SP11	D08SP22
D10SP11	D10SP12
D02SP21	D04SP12
D12SP21	D05SP12
USTSP12	USTSP22
D08SP11	D09SP12
D10SP21	D12SP12
D08SP21	D13SP22
D12SP11	D08SP12
D06SP11	D01SP12
D04SP21	D10SP22
BCHSP13	BCHSP23

4.0 CONCLUDING COMMENTS

In summary, this analytical plan identifies several ICP calibration blocks in Tables 4 – 5 as well as two preparation blocks in Tables 3a-3b for use by the SRTC-ML. The sequencing of the activities associated with each of the steps in the analytical procedures has been randomized. The size of each of the blocks was selected so that it could be completed in a single work shift.

If a problem is discovered while measuring samples in a calibration block, the instrument should be re-calibrated and the block of samples re-measured in its entirety. If for some reason the measurements are not conducted in the sequences presented in this report, a record should be made of the actual order used along with any explanative comments.

The analytical plan indicated in the preceding tables should be modified by the personnel of SRTC-ML to include any calibration check standards and/or other standards that are part of their routine operating procedures. It is also recommended that the solutions resulting from each of the prepared samples be archived for some period, considering the "shelf-life" of the solutions, in case questions arise during data analysis. This would allow for the solutions to be rerun without additional preparations, thus minimizing cost.

5.0 REFERENCES

[1] Jantzen, C. M., J. B. Pickett, K. G. Brown, T. B. Edwards, and D. C. Beam, "Process/Product Models for the Defense Waste Processing Facility (DWPF): Part I. Predicting Glass Durability from Composition Using a Thermodynamic Hydration Energy Reaction Model (THERMO™) (U)," WSRC-TR-93-673, Rev. 1, Volume 2, Table B.1, pp. B.9, 1995.

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Appendix B:

ANALYTICAL PLAN FOR THE MEASUREMENT OF PCT LEACHATES

SRT-SCS-2002-00017

March 6, 2002

To: D. K. Peeler, 999-W

cc: R. A. Baker, 773-42A
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K. G. Brown, 773-42A
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I. A. Reamer, 773-A
R. C. Tuckfield, 773-42A
R. J. Workman, 773-A

From: T. B. Edwards, 773-42A (5-5148)
Statistical Consulting Section

wo – without glass identifiers
es – executive summary only

R. A. Baker, Technical Reviewer — 3/11/2002 **Date**

R. C. Tuckfield, Manager
Statistical Consulting Section — 3/11/02 **Date**

AN ANALYTICAL PLAN FOR MEASURING PCT SOLUTIONS FOR THE U/TH GLASSES (U)

1.0 EXECUTIVE SUMMARY

A study is being conducted by the Savannah River Technology Center (SRTC) for the Defense Waste Processing Facility (DWPF) that involves investigating the impact of uranium and thorium on glass properties of interest. Several glass compositions were selected for batching and testing to support this effort.

The 13 study glasses were cooled both by quenching and centerline-cooling, and the durabilities of the resulting twenty-six glasses are to be measured in triplicate using the Product Consistency Test, or PCT. Its requirements are described in ASTM C1285-97 (Method A).

The Savannah River Technology Center-Mobile Laboratory (SRTC-ML) is to be used to measure elemental concentrations of the resulting leachate solutions from these PCTs. This memorandum provides an analytical plan for the SRTC-ML to follow in measuring the compositions of the leachate solutions resulting from the PCT procedures for the glasses.

2.0 INTRODUCTION

A study is being conducted by the Savannah River Technology Center (SRTC) for the Defense Waste Processing Facility (DWPF) that involves investigating the impact of uranium and thorium on glass properties on interest. Several glass compositions were selected for batching and testing to support this effort.

The thirteen study glasses were cooled both by quenching and by centerline canister cooling, and the durabilities of the resulting twenty-six glasses are to be measured in triplicate using the Product Consistency Test, or PCT. Its requirements are described in ASTM C1285-97 (Method A) [1].

The identifiers for the study glasses are presented in Table 1. The centerline canister-cooled glasses are denoted by a "ccc" suffix.

Table 1: Identifiers for the U/Th Study Glasses

Quenched	Centerline Canister Cooled
rcth-30	rcth-30ccc
rcth-40	rcth-40ccc
rcth-50	rcth-50ccc
rchwl-01	rchwl-01ccc
rchwl-02	rchwl-02ccc
rchwl-03	rchwl-03ccc
rchwl-04	rchwl-04ccc
rchwl-05	rchwl-05ccc
rchwl-06	rchwl-06ccc
tk40-01-new	tk40-01-newccc
tk40-02-new	tk40-02-newccc
tk40-03-new	tk40-03-newccc
RC-38U	RC-38Uccc

This memorandum provides an analytical plan for the Savannah River Technology Center's Mobile Laboratory (SRTC-ML) to follow in measuring the compositions of the PCT leachate solutions for these glasses.

3.0 DISCUSSION

The quenched and centerline-cooled versions of the study glasses are to be subjected to the PCT. The 2 different thermal histories for each of the 13 glasses lead to 26 glasses that are to be measured (in triplicate) using the PCT. In addition to those for the study glasses, triplicate PCTs are to be conducted on a sample of the Approved Reference Material (ARM) glass and a sample of the Environmental Assessment (EA) glass. Two reagent blank samples are also to be included in these tests. This results in 86 sample solutions being required to complete these PCTs.

The leachates from these tests will be diluted by adding 4 mL of 0.4 M HNO_3 to 6 mL of the leachate (a 6:10 volume to volume, v:v, dilution) before being submitted to the SRTC-ML. The EA leachates will be further diluted (1:10 v:v) with deionized water prior to submission to the SRTC-ML in order to prevent problems with the nebulizer.

Table 2 presents identifying codes, P01 through P86, for the individual solutions required for the PCTs of the study glasses and of the standards (EA, ARM, and blanks). This provides a naming convention that is to be used by the SRTC-ML in analyzing the solutions and reporting the relevant concentration measurements.[9]

Table 2: Solution Identifiers for the Study Glasses

Original Sample	Solution Identifier	Original Sample	Solution Identifier	Original Sample	Solution Identifier
RC-38U	P70	rchwl-05	P59	tk40-01-new	P06
RC-38U	P76	rchwl-05	P57	tk40-01-new	P53
RC-38U	P02	rchwl-05	P44	tk40-01-new	P45
RC-38Uccc	P49	rchwl-05ccc	P64	tk40-01-newccc	P34
RC-38Uccc	P11	rchwl-05ccc	P17	tk40-01-newccc	P78
RC-38Uccc	P08	rchwl-05ccc	P46	tk40-01-newccc	P42
rchwl-01	P09	rchwl-06	P30	tk40-02-new	P79
rchwl-01	P12	rchwl-06	P77	tk40-02-new	P32
rchwl-01	P04	rchwl-06	P80	tk40-02-new	P16
rchwl-01ccc	P86	rchwl-06ccc	P85	tk40-02-newccc	P68
rchwl-01ccc	P31	rchwl-06ccc	P35	tk40-02-newccc	P50
rchwl-01ccc	P21	rchwl-06ccc	P51	tk40-02-newccc	P48
rchwl-02	P55	rcth-30	P24	tk40-03-new	P20
rchwl-02	P40	rcth-30	P54	tk40-03-new	P84
rchwl-02	P83	rcth-30	P56	tk40-03-new	P19
rchwl-02ccc	P39	rcth-30ccc	P61	tk40-03-newccc	P23
rchwl-02ccc	P14	rcth-30ccc	P18	tk40-03-newccc	P27
rchwl-02ccc	P38	rcth-30ccc	P29	tk40-03-newccc	P05
rchwl-03	P73	rcth-40	P25	ARM	P58
rchwl-03	P43	rcth-40	P52	ARM	P13
rchwl-03	P65	rcth-40	P26	ARM	P62
rchwl-03ccc	P75	rcth-40ccc	P28	EA	P37
rchwl-03ccc	P03	rcth-40ccc	P63	EA	P01
rchwl-03ccc	P81	rcth-40ccc	P36	EA	P15
rchwl-04	P71	rcth-50	P74	blank	P41
rchwl-04	P22	rcth-50	P47	blank	P33
rchwl-04	P60	rcth-50	P82		
rchwl-04ccc	P67	rcth-50ccc	P69		
rchwl-04ccc	P66	rcth-50ccc	P72		
rchwl-04ccc	P10	rcth-50ccc	P07		

4.0 ANALYTICAL PLAN

The analytical plan for the SRTC-ML is provided in this section. Each of the solution samples submitted to the SRTC-ML is to be analyzed only once for each of the following: aluminum, (Al), boron (B), calcium (Ca), chromium (Cr), iron (Fe), magnesium (Mg), manganese (Mn), lithium (Li), sodium (Na), nickel (Ni), phosphorous (P), silicon (Si), thorium (Th), uranium (U), and zirconium (Zr). The measurements are to be made in parts per million (ppm). The analytical procedure used by the SRTC-ML to determine the concentrations utilizes an Inductively Coupled Plasma (ICP) – Atomic Emission Spectrometer (AES). The PCT solutions (as identified in Table 2) are grouped in six ICP blocks for processing by the SRTC-ML in Table 3. Each block requires a different calibration of the ICP.

9 Renaming these samples ensures that they will be processed as blind samples by the SRTC-ML. This table does not contain the solution identifiers for those on the distribution list with a "wo" following their names.

Table 3: ICP Calibration Blocks for Leachate Measurements

1	2	3	4	5	6
std-b1-1	std-b2-1	std-b3-1	std-b4-1	std-b5-1	std-b6-1
P30	P63	P51	P09	P57	P07
P70	P11	P02	P74	P12	P16
P49	P27	P60	P24	P13	P29
P71	P40	P45	P86	P31	P81
P85	P22	P08	P61	P47	P56
P41	P84	P83	P69	P43	P46
P55	P35	P10	P64	P01	P62
std-b1-2	std-b2-2	std-b3-2	std-b4-2	std-b5-2	std-b6-2
P34	P66	P26	P68	P18	P82
P25	P52	P05	P73	P72	P04
P39	P14	P36	P37	P17	P44
P23	P77	P80	P59	P03	P48
P67	P33	P42	P79	P50	P21
P06	P78	P38	P58	P32	P65
P20	P53	P19	P75	P54	P15
P28	P76	std-b3-3	std-b4-3	std-b5-3	std-b6-3
std-b1-3	std-b2-3				

A multi-element solution standard (denoted by "std-bi-j" where i=1 to 6 represents the block number and j=1, 2, and 3 represents the position in the block) was added at the beginning, middle, and end of each of the three blocks. This standard may be useful in checking and correcting for bias in the concentration measurements arising from the ICP calibrations.

5.0 SUMMARY

In summary, this analytical plan provides identifiers for the PCT solutions in Table 2 and six ICP calibration blocks in Table 3 for the SRTC-ML to use in conducting the aluminum, (Al), boron (B), calcium (Ca), chromium (Cr), iron (Fe), magnesium (Mg), manganese (Mn), lithium (Li), sodium (Na), nickel (Ni), phosphorous (P), silicon (Si), thorium (Th), uranium (U), and zirconium (Zr) concentration measurements for this PCT study. The sequencing of the activities associated with each of the steps in the analytical procedure has been randomized. The size of the blocks was selected so that the block could be completed in a single work shift. If for some reason the measurements are not conducted in the sequence presented in this memorandum, the actual order should be recorded along with any explanative comments.

The analytical plan indicated in the preceding tables should be modified by the personnel of the SRTC-ML to include any calibration check standards and/or other standards that are part of their standard operating procedures.

6.0 REFERENCE

[1] ASTM C1285-97, "Standard Test Methods for Determining Chemical Durability of Nuclear Waste Glasses: The Product Consistency Test (PCT)," 1997.

Appendix C:

Tables and Exhibits Supporting the Analysis of the Chemical Composition Measurements of the Study Glasses

Table C.1: Targeted Oxide Concentrations (as wt%'s) for the Study Glasses

Glass	Al2O3	B2O3	CaO	Cr2O3	Fe2O3	Li2O	MgO	MnO	Na2O	NiO	P2O5	SiO2	ThO2	U3O8	ZrO2	Total
RC-38U	2.731	6.488	0.987	0.083	10.475	2.746	1.381	1.328	8.757	0.593	0.314	38.306	0.012	25.563	0.028	99.792
rchwl-01	4.496	6.205	1.630	0.136	17.246	4.409	1.113	2.187	12.911	0.976	0.517	42.932	0.020	4.209	0.668	99.656
rchwl-02	4.806	5.857	1.686	0.149	17.403	4.171	1.341	4.117	12.932	0.849	0.565	41.521	0.022	3.568	0.638	99.625
rchwl-03	3.929	8.017	1.424	0.119	15.073	3.401	1.765	1.911	11.588	0.853	0.452	47.424	0.018	3.679	0.043	99.696
rchwl-04	4.206	7.647	1.475	0.130	15.227	3.253	1.934	3.602	11.668	0.743	0.494	46.103	0.019	3.122	0.047	99.671
rchwl-05	4.755	4.792	1.724	0.144	18.242	4.856	0.522	2.313	12.308	1.032	0.547	43.873	0.022	4.452	0.052	99.634
rchwl-06	5.072	4.506	1.779	0.157	18.365	4.575	0.799	4.344	12.367	0.896	0.596	42.301	0.023	3.766	0.057	99.603
rcth-30	3.115	6.514	0.613	0.126	12.040	4.620	1.663	3.973	12.939	2.938	0.478	44.534	2.891	2.541	0.696	99.681
rcth-40	3.115	7.814	0.613	0.126	12.040	3.320	2.313	3.973	11.639	2.938	0.478	45.834	2.891	2.541	0.046	99.681
rcth-50	3.115	5.214	0.613	0.126	12.040	5.270	1.013	3.973	12.289	2.938	0.478	47.134	2.891	2.541	0.046	99.681
tk40-01	4.877	6.425	1.503	0.129	15.765	4.559	2.112	1.942	12.510	0.708	0.490	43.909	0.019	4.037	0.688	99.673
tk40-02	4.252	8.257	1.310	0.113	13.745	3.498	2.656	1.693	11.199	0.617	0.428	48.370	0.017	3.519	0.041	99.715
tk40-03	5.176	4.967	1.595	0.137	16.732	5.028	1.561	2.061	11.861	0.751	0.520	44.909	0.020	4.284	0.050	99.652

Table C.2: Measured Elemental Concentrations (wt%) for the Study Glasses Prepared Using Lithium Metaborate

Glass ID	SRTC-ML ID	Block	Sub-Block	Analytical Sequence	Al	Ca	Cr	Fe	Mg	Mn	Na	Ni	P	Si	Th	U	Zr
Batch 1	BCHLM11	1	1	1	2.51	0.919	0.069	8.91	0.914	1.36	6.94	0.582	<0.010	23.6	<0.100	0.04	0.062
rchwl-06	D03LM11	1	1	2	2.75	1.35	0.086	11.8	0.501	3.12	9.38	0.619	0.187	20.3	<0.100	3.12	0.033
rcth-30	D13LM21	1	1	3	1.87	0.501	0.066	7.52	1.04	2.97	9.92	2.13	0.131	20.9	2.46	2.10	0.421
rchwl-03	D05LM11	1	1	4	2.14	1.07	0.071	9.40	1.08	1.48	8.69	0.624	0.154	22.2	<0.100	3.05	0.028
tk40-02	D01LM11	1	1	5	2.37	1.00	0.066	8.53	1.60	1.33	8.46	0.465	0.138	22.9	<0.100	2.94	0.024
RC-38U	D09LM21	1	1	6	1.45	0.782	0.094	6.88	0.829	1.05	6.52	0.442	0.106	17.8	0.202	20.6	0.024
rchwl-01	D07LM11	1	1	7	2.46	1.23	0.079	11.5	0.683	1.65	9.70	0.705	0.142	20.3	<0.100	3.44	0.363
u-std	USTLM11	1	1	8	1.95	0.903	0.160	8.43	0.723	2.01	8.09	0.780	<0.010	22.2	<0.100	1.82	0.002
rchwl-06	D03LM21	1	1	9	2.78	1.35	0.085	11.84	0.488	3.08	9.23	0.601	0.188	20.3	<0.100	3.11	0.031
rchwl-01	D07LM21	1	1	10	2.49	1.24	0.077	11.57	0.688	1.67	9.66	0.690	0.143	20.3	<0.100	3.43	0.374
RC-38U	D09LM11	1	1	11	1.47	0.752	0.093	7.11	0.838	1.06	6.50	0.442	0.108	18.0	0.202	20.8	0.025
tk40-01	D11LM11	1	1	12	2.59	1.14	0.080	10.5	1.28	1.48	9.24	0.517	0.164	21.0	<0.100	3.28	0.476
rcth-30	D13LM11	1	1	13	1.74	0.490	0.065	7.71	1.03	2.97	9.72	2.14	0.145	21.3	2.48	2.10	0.431
tk40-02	D01LM21	1	1	14	2.36	1.00	0.064	8.68	1.61	1.32	8.32	0.453	0.133	23.0	<0.100	2.94	0.027
tk40-01	D11LM21	1	1	15	2.62	1.13	0.077	10.4	1.29	1.52	9.24	0.517	0.165	20.9	<0.100	3.26	0.477
Batch 1	BCHLM12	1	1	16	2.57	0.916	0.070	9.00	0.946	1.39	6.86	0.592	<0.010	23.7	<0.100	0.05	0.065
rchwl-03	D05LM21	1	1	17	2.22	1.11	0.069	9.53	1.11	1.49	8.79	0.623	0.148	22.6	<0.100	3.07	0.027
rchwl-02	D02LM11	1	1	18	2.57	1.26	0.084	11.7	0.816	2.97	9.91	0.596	0.159	19.1	<0.100	2.99	0.365
rchwl-04	D06LM21	1	1	19	2.30	1.12	0.073	10.1	1.18	2.69	8.77	0.515	0.159	21.9	<0.100	2.61	0.036
rcth-40	D04LM11	1	1	20	1.82	0.507	0.096	7.73	1.32	2.90	8.50	2.10	0.155	22.1	2.35	2.37	0.043
rcth-50	D10LM11	1	1	21	1.75	0.489	0.081	7.90	0.629	2.95	9.09	2.16	0.166	22.2	2.44	2.09	0.049
rchwl-02	D02LM21	1	1	22	2.66	1.29	0.088	11.2	0.829	3.06	9.34	0.598	0.188	18.6	<0.100	2.84	0.413
tk40-03	D12LM21	1	1	23	2.86	1.22	0.087	10.4	1.00	1.67	8.97	0.576	0.184	21.9	<0.100	3.60	0.032
u-std	USTLM12	1	1	24	1.97	0.909	0.167	8.56	0.765	2.10	8.09	0.809	<0.010	22.3	<0.100	1.84	0.001
rchwl-05	D08LM11	1	1	25	2.62	1.31	0.093	11.6	0.344	1.88	9.26	0.744	0.190	20.8	<0.100	3.74	0.033
rcth-50	D10LM21	1	1	26	1.77	0.495	0.086	7.98	0.656	3.06	9.30	2.23	0.174	22.5	2.45	2.14	0.054
rchwl-05	D08LM21	1	1	27	2.62	1.31	0.091	11.9	0.331	1.82	9.34	0.759	0.189	21.0	<0.100	3.77	0.032
tk40-03	D12LM11	1	1	28	2.84	1.20	0.087	10.5	0.985	1.62	8.99	0.568	0.184	21.8	<0.100	3.61	0.031
rchwl-04	D06LM11	1	1	29	2.32	1.11	0.079	10.2	1.25	2.80	8.80	0.548	0.158	22.0	<0.100	2.63	0.037
rcth-40	D04LM21	1	1	30	1.77	0.489	0.076	7.75	1.42	3.04	8.46	2.21	0.163	22.0	2.36	2.35	0.031
Batch 1	BCHLM13	1	1	31	2.56	0.917	0.071	9.11	0.936	1.38	6.89	0.598	<0.010	23.9	<0.100	0.05	0.063
Batch 1	BCHLM21	1	2	1	2.52	0.930	0.068	8.97	0.880	1.33	6.72	0.655	<0.010	23.5	<0.100	0.02	0.065
RC-38U	D09LM22	1	2	2	1.45	0.790	0.092	6.91	0.788	1.03	6.52	0.494	0.109	17.8	0.202	20.7	0.027
rcth-40	D04LM22	1	2	3	1.75	0.501	0.070	7.61	1.26	2.75	8.47	2.08	0.160	21.6	2.32	2.31	0.032
tk40-02	D01LM22	1	2	4	2.34	1.01	0.062	8.59	1.46	1.26	8.39	0.509	0.137	22.9	<0.100	2.90	0.026
rchwl-06	D03LM22	1	2	5	2.74	1.34	0.083	11.7	0.459	3.06	9.43	0.655	0.188	20.4	<0.100	3.10	0.033
tk40-03	D12LM22	1	2	6	2.82	1.22	0.083	10.4	0.926	1.56	9.01	0.619	0.180	21.8	<0.100	3.56	0.033

Table C.2: Measured Elemental Concentrations (wt%) for the Study Glasses Prepared Using Lithium Metaborate *(continued)*

Glass ID	SRTC-ML ID	Block	Sub-Block	Analytical Sequence	Al	Ca	Cr	Fe	Mg	Mn	Na	Ni	P	Si	Th	U	Zr
rchwl-06	D03LM12	1	2	7	2.73	1.36	0.085	11.9	0.477	3.16	9.43	0.681	0.192	20.6	<0.100	3.13	0.036
u-std	USTLM21	1	2	8	1.94	0.905	0.158	8.55	0.692	1.99	8.15	0.846	<0.010	22.4	<0.100	1.82	0.003
rchwl-02	D02LM12	1	2	9	2.55	1.26	0.083	11.6	0.781	2.92	9.93	0.649	0.154	19.1	<0.100	2.96	0.360
rchwl-01	D07LM22	1	2	10	2.47	1.25	0.074	11.6	0.634	1.59	9.85	0.731	0.139	20.3	<0.100	3.45	0.356
rcth-30	D13LM12	1	2	11	1.72	0.497	0.062	7.66	0.972	2.83	10.05	2.12	0.145	21.3	2.46	2.11	0.415
tk40-01	D11LM12	1	2	12	2.61	1.16	0.076	10.5	1.17	1.39	9.51	0.563	0.164	21.0	<0.100	3.26	0.464
rchwl-03	D05LM22	1	2	13	2.19	1.12	0.065	9.60	0.996	1.36	9.05	0.658	0.153	22.7	<0.100	3.08	0.030
rchwl-01	D07LM12	1	2	14	2.44	1.24	0.076	11.4	0.630	1.59	10.04	0.740	0.144	20.2	<0.100	3.46	0.355
rchwl-04	D06LM12	1	2	15	2.29	1.13	0.072	9.99	1.11	2.58	9.00	0.573	0.155	21.6	<0.100	2.59	0.041
Batch 1	BCHLM22	1	2	16	2.51	0.914	0.066	9.02	0.837	1.28	7.01	0.632	<0.010	23.7	<0.100	0.03	0.064
rchwl-02	D02LM22	1	2	17	2.62	1.30	0.082	11.6	0.751	2.84	10.01	0.622	0.180	19.3	<0.100	2.94	0.396
rchwl-04	D06LM22	1	2	18	2.28	1.12	0.071	10.1	1.12	2.58	8.95	0.563	0.159	21.9	<0.100	2.60	0.039
tk40-01	D11LM22	1	2	19	2.58	1.14	0.072	10.4	1.17	1.42	9.40	0.552	0.161	20.9	<0.100	3.23	0.458
rchwl-05	D08LM22	1	2	20	2.56	1.30	0.085	11.7	0.300	1.68	9.57	0.773	0.184	21.0	<0.100	3.74	0.035
rcth-50	D10LM12	1	2	21	1.71	0.485	0.077	7.79	0.583	2.81	9.45	2.11	0.165	22.2	2.38	2.10	0.051
rcth-40	D04LM12	1	2	22	1.78	0.506	0.092	7.67	1.25	2.76	8.83	2.08	0.158	22.0	2.32	2.35	0.044
rchwl-03	D05LM12	1	2	23	2.10	1.06	0.069	9.58	1.03	1.43	8.91	0.673	0.151	22.5	<0.100	3.06	0.029
u-std	USTLM22	1	2	24	1.93	0.908	0.153	8.60	0.674	1.96	8.47	0.834	<0.010	22.6	<0.100	1.85	0.004
RC-38U	D09LM12	1	2	25	1.46	0.743	0.091	7.07	0.788	1.04	6.74	0.493	0.111	18.2	0.201	20.97	0.027
tk40-03	D12LM12	1	2	26	2.80	1.20	0.085	10.5	0.945	1.60	9.20	0.629	0.180	21.9	<0.100	3.60	0.034
rcth-30	D13LM22	1	2	27	1.84	0.495	0.067	7.77	1.01	2.99	10.13	2.19	0.130	21.6	2.44	2.11	0.409
rchwl-05	D08LM12	1	2	28	2.56	1.32	0.086	11.6	0.311	1.71	9.59	0.761	0.192	21.0	<0.100	3.76	0.038
tk40-02	D01LM12	1	2	29	2.35	1.01	0.065	8.71	1.52	1.29	8.80	0.524	0.136	23.4	<0.100	3.02	0.027
rcth-50	D10LM22	1	2	30	1.75	0.501	0.080	7.88	0.583	2.84	9.62	2.15	0.166	22.4	2.41	2.12	0.055
Batch 1	BCHLM23	1	2	31	2.50	0.924	0.066	8.96	0.828	1.27	7.19	0.628	<0.010	24.0	<0.100	0.04	0.063

**Table C.3: Measured Elemental Concentrations (wt%)
for the Study Glasses Prepared Using Sodium Peroxide Fusion**

Glass ID	SRTC-ML ID	Block	Sub-Block	Analytical Sequence	B	Li
Batch 1	BCHSP11	1	1	1	2.40	1.97
rchwl-02	D02SP11	1	1	2	1.82	1.84
rchwl-04	D06SP21	1	1	3	2.31	1.42
rchwl-01	D07SP21	1	1	4	1.85	1.91
rchwl-02	D02SP21	1	1	5	1.79	1.79
tk40-01	D11SP21	1	1	6	1.90	1.98
RC-38U	D09SP11	1	1	7	1.91	1.17
u-std	USTSP11	1	1	8	2.63	1.23
rcth-30	D13SP11	1	1	9	1.96	2.03
tk40-02	D01SP21	1	1	10	2.51	1.53
rcth-40	D04SP11	1	1	11	2.17	1.33
rchwl-04	D06SP11	1	1	12	2.35	1.43
rcth-50	D10SP21	1	1	13	1.59	2.32
RC-38U	D09SP21	1	1	14	1.91	1.17
rchwl-05	D08SP11	1	1	15	1.41	2.13
Batch 1	BCHSP12	1	1	16	2.41	1.97
rchwl-01	D07SP11	1	1	17	1.88	1.92
rcth-40	D04SP21	1	1	18	2.10	1.28
rchwl-03	D05SP11	1	1	19	2.46	1.49
rchwl-05	D08SP21	1	1	20	1.47	2.16
rcth-30	D13SP21	1	1	21	2.01	2.07
rchwl-06	D03SP11	1	1	22	1.38	2.02
tk40-02	D01SP11	1	1	23	2.56	1.53
u-std	USTSP112	1	1	24	2.73	1.26
rchwl-06	D03SP21	1	1	25	1.37	2.02
rcth-50	D10SP11	1	1	26	1.60	2.34
tk40-01	D11SP11	1	1	27	1.94	1.99
tk40-03	D12SP21	1	1	28	1.51	2.23
tk40-03	D12SP11	1	1	29	1.56	2.31
rchwl-03	D05SP21	1	1	30	2.49	1.51
Batch 1	BCHSP13	1	1	31	2.51	2.02
Batch 1	BCHSP21	1	2	1	2.40	1.99
rchwl-01	D07SP12	1	2	2	1.88	1.95
rchwl-04	D06SP12	1	2	3	2.32	1.45
rchwl-03	D05SP12	1	2	4	2.47	1.54
tk40-03	D12SP22	1	2	5	1.48	2.23
tk40-02	D01SP22	1	2	6	2.49	1.56
RC-38U	D09SP22	1	2	7	1.91	1.20
u-std	USTSP21	1	2	8	2.65	1.28
rchwl-04	D06SP22	1	2	9	2.31	1.44
rchwl-03	D05SP22	1	2	10	2.40	1.50
tk40-01	D11SP22	1	2	11	1.87	1.99
rchwl-02	D02SP22	1	2	12	1.77	1.78
rcth-50	D10SP12	1	2	13	1.55	2.32
rchwl-05	D08SP12	1	2	14	1.41	2.18
tk40-03	D12SP12	1	2	15	1.49	2.27
Batch 1	BCHSP22	1	2	16	2.41	2.02
rcth-40	D04SP22	1	2	17	2.10	1.32
rchwl-06	D03SP12	1	2	18	1.35	2.03
RC-38U	D09SP12	1	2	19	1.77	1.16
rchwl-06	D03SP22	1	2	20	1.30	1.97
rchwl-05	D08SP22	1	2	21	1.42	2.16
rchwl-01	D07SP22	1	2	22	1.82	1.94
tk40-02	D01SP12	1	2	23	2.47	1.56
u-std	USTSP22	1	2	24	2.62	1.28
rcth-50	D10SP22	1	2	25	1.56	2.37
rcth-30	D13SP12	1	2	26	1.97	2.10
tk40-01	D11SP12	1	2	27	1.91	2.03

Table C.3: Measured Elemental Concentrations (wt%) for the Study Glasses Prepared Using Sodium Peroxide Fusion *(continued)*

Glass ID	SRTC-ML ID	Block	Sub-Block	Analytical Sequence	B	Li
rcth-40	D04SP12	1	2	28	2.14	1.38
rchwl-02	D02SP12	1	2	29	1.81	1.84
rcth-30	D13SP22	1	2	30	2.00	2.16
Batch 1	BCHSP23	1	2	31	2.43	2.07

Table C.4: Average Measured and Bias-Corrected Chemical Compositions Versus Targeted Compositions by Oxide by Study Glass

Glass ID		Measured (wt%)	Measured Bias-Corrected (wt%)	Targeted (wt%)	Diff of Measured	Diff of Meas BC	% Diff of Measured	% Diff of Meas BC
Batch 1	Al2O3 (wt%)	4.7773	4.8770	4.8770	-0.0997	0.0000	-2.0%	0.0%
Batch 1	B2O3 (wt%)	7.8136	7.7770	7.7770	0.0366	0.0000	0.5%	0.0%
Batch 1	CaO (wt%)	1.2873	1.2200	1.2200	0.0673	0.0000	5.5%	0.0%
Batch 1	Cr2O3 (wt%)	0.0999	0.1070	0.1070	-0.0071	0.0000	-6.7%	0.0%
Batch 1	Fe2O3 (wt%)	12.8602	12.8390	12.8390	0.0212	0.0000	0.2%	0.0%
Batch 1	Li2O (wt%)	4.3202	4.4290	4.4290	-0.1088	0.0000	-2.5%	0.0%
Batch 1	MgO (wt%)	1.4760	1.4190	1.4190	0.0570	0.0000	4.0%	0.0%
Batch 1	MnO (wt%)	1.7238	1.7260	1.7260	-0.0022	0.0000	-0.1%	0.0%
Batch 1	Na2O (wt%)	9.3484	9.0030	9.0030	0.3454	0.0000	3.8%	0.0%
Batch 1	NiO (wt%)	0.7820	0.7510	0.7510	0.0310	0.0000	4.1%	0.0%
Batch 1	P2O5 (wt%)	0.0115	0.0115	0.0000	0.0115	0.0115		
Batch 1	SiO2 (wt%)	50.7727	50.2200	50.2200	0.5527	0.0000	1.1%	0.0%
Batch 1	ThO2 (wt%)	0.0569	0.0569	0.0000	0.0569	0.0569		
Batch 1	U3O8 (wt%)	0.0452	0.0503	0.0000	0.0452	0.0503		
Batch 1	ZrO2 (wt%)	0.0860	0.0860	0.0980	-0.0120	-0.0120	-12.2%	-12.2%
Batch 1	Sum of Oxides (wt%)	95.4607	94.5727	94.4660	0.9947	0.1067	1.1%	0.1%
tk40-02	Al2O3 (wt%)	4.4498	4.5428	4.2519	0.1979	0.2909	4.7%	6.8%
tk40-02	B2O3 (wt%)	8.0739	8.0358	8.2567	-0.1828	-0.2208	-2.2%	-2.7%
tk40-02	CaO (wt%)	1.4062	1.3327	1.3100	0.0962	0.0227	7.3%	1.7%
tk40-02	Cr2O3 (wt%)	0.0939	0.1006	0.1127	-0.0188	-0.0121	-16.7%	-10.7%
tk40-02	Fe2O3 (wt%)	12.3347	12.3145	13.7454	-1.4106	-1.4309	-10.3%	-10.4%
tk40-02	Li2O (wt%)	3.3262	3.4100	3.4978	-0.1716	-0.0878	-4.9%	-2.5%
tk40-02	MgO (wt%)	2.5659	2.4680	2.6565	-0.0906	-0.1885	-3.4%	-7.1%
tk40-02	MnO (wt%)	1.6786	1.6814	1.6929	-0.0144	-0.0115	-0.8%	-0.7%
tk40-02	Na2O (wt%)	11.4479	11.0245	11.1989	0.2490	-0.1744	2.2%	-1.6%
tk40-02	NiO (wt%)	0.6207	0.5956	0.6170	0.0036	-0.0214	0.6%	-3.5%
tk40-02	P2O5 (wt%)	0.3116	0.3116	0.4276	-0.1160	-0.1160	-27.1%	-27.1%
tk40-02	SiO2 (wt%)	49.3109	48.7741	48.3703	0.9406	0.4038	1.9%	0.8%
tk40-02	ThO2 (wt%)	0.0569	0.0569	0.0168	0.0401	0.0401	239.1%	239.1%
tk40-02	U3O8 (wt%)	3.4786	3.8732	3.5193	-0.0407	0.3539	-1.2%	10.1%
tk40-02	ZrO2 (wt%)	0.0351	0.0351	0.0408	-0.0057	-0.0057	-14.0%	-14.0%
tk40-02	Sum of Oxides (wt%)	99.1909	98.5570	99.7146	-0.5237	-1.1577	-0.5%	-1.2%
rchwl-02	Al2O3 (wt%)	4.9127	5.0153	4.8060	0.1067	0.2093	2.2%	4.4%
rchwl-02	B2O3 (wt%)	5.7878	5.7607	5.8570	-0.0692	-0.0963	-1.2%	-1.6%
rchwl-02	CaO (wt%)	1.7875	1.6941	1.6860	0.1015	0.0081	6.0%	0.5%
rchwl-02	Cr2O3 (wt%)	0.1231	0.1319	0.1487	-0.0256	-0.0168	-17.2%	-11.3%
rchwl-02	Fe2O3 (wt%)	16.4773	16.4504	17.4030	-0.9257	-0.9526	-5.3%	-5.5%
rchwl-02	Li2O (wt%)	3.9021	4.0009	4.1710	-0.2689	-0.1701	-6.4%	-4.1%
rchwl-02	MgO (wt%)	1.3169	1.2668	1.3410	-0.0241	-0.0742	-1.8%	-5.5%
rchwl-02	MnO (wt%)	3.8058	3.8118	4.1170	-0.3112	-0.3052	-7.6%	-7.4%
rchwl-02	Na2O (wt%)	13.2070	12.7182	12.9320	0.2750	-0.2138	2.1%	-1.7%
rchwl-02	NiO (wt%)	0.7842	0.7534	0.8491	-0.0649	-0.0957	-7.6%	-11.3%
rchwl-02	P2O5 (wt%)	0.3901	0.3901	0.5645	-0.1744	-0.1744	-30.9%	-30.9%
rchwl-02	SiO2 (wt%)	40.7002	40.2571	41.5210	-0.8208	-1.2639	-2.0%	-3.0%
rchwl-02	ThO2 (wt%)	0.0569	0.0569	0.0222	0.0347	0.0347	156.3%	156.3%
rchwl-02	U3O8 (wt%)	3.4580	3.8502	3.5684	-0.1104	0.2818	-3.1%	7.9%
rchwl-02	ZrO2 (wt%)	0.5180	0.5180	0.6379	-0.1199	-0.1199	-18.8%	-18.8%
rchwl-02	Sum of Oxides (wt%)	97.2277	96.6758	99.6248	-2.3971	-2.9490	-2.4%	-3.0%
rchwl-06	Al2O3 (wt%)	5.1961	5.3047	5.0720	0.1241	0.2327	2.4%	4.6%
rchwl-06	B2O3 (wt%)	4.3469	4.3262	4.5060	-0.1591	-0.1798	-3.5%	-4.0%
rchwl-06	CaO (wt%)	1.8889	1.7902	1.7790	0.1099	0.0112	6.2%	0.6%
rchwl-06	Cr2O3 (wt%)	0.1239	0.1328	0.1569	-0.0330	-0.0241	-21.1%	-15.4%
rchwl-06	Fe2O3 (wt%)	16.8848	16.8570	18.3650	-1.4802	-1.5080	-8.1%	-8.2%
rchwl-06	Li2O (wt%)	4.3273	4.4370	4.5750	-0.2477	-0.1380	-5.4%	-3.0%
rchwl-06	MgO (wt%)	0.7980	0.7679	0.7990	-0.0010	-0.0311	-0.1%	-3.9%

Table C.4: Average Measured and Bias-Corrected Chemical Compositions Versus Targeted Compositions by Oxide by Study Glass

Glass ID		Measured (wt%)	Measured Bias-Corrected (wt%)	Targeted (wt%)	Diff of Measured	Diff of Meas BC	% Diff of Measured	% Diff of Meas BC
rchwl-06	MnO (wt%)	4.0092	4.0185	4.3440	-0.3348	-0.3255	-7.7%	-7.5%
rchwl-06	Na2O (wt%)	12.6274	12.1608	12.3670	0.2604	-0.2062	2.1%	-1.7%
rchwl-06	NiO (wt%)	0.8131	0.7807	0.8961	-0.0830	-0.1154	-9.3%	-12.9%
rchwl-06	P2O5 (wt%)	0.4325	0.4325	0.5957	-0.1632	-0.1632	-27.4%	-27.4%
rchwl-06	SiO2 (wt%)	43.6417	43.1666	42.3010	1.3407	0.8656	3.2%	2.0%
rchwl-06	ThO2 (wt%)	0.0569	0.0569	0.0234	0.0335	0.0335	143.1%	143.1%
rchwl-06	U3O8 (wt%)	3.6732	4.0899	3.7657	-0.0925	0.3242	-2.5%	8.6%
rchwl-06	ZrO2 (wt%)	0.0449	0.0449	0.0569	-0.0120	-0.0120	-21.1%	-21.1%
rchwl-06	Sum of Oxides (wt%)	98.8648	98.3666	99.6027	-0.7379	-1.2361	-0.7%	-1.2%
rcth-40	Al2O3 (wt%)	3.3633	3.4335	3.1150	0.2483	0.3185	8.0%	10.2%
rcth-40	B2O3 (wt%)	6.8503	6.8183	7.8140	-0.9637	-0.9957	-12.3%	-12.7%
rcth-40	CaO (wt%)	0.7006	0.6640	0.6130	0.0876	0.0510	14.3%	8.3%
rcth-40	Cr2O3 (wt%)	0.1220	0.1307	0.1260	-0.0040	0.0047	-3.1%	3.8%
rcth-40	Fe2O3 (wt%)	10.9944	10.9762	12.0400	-1.0456	-1.0638	-8.7%	-8.8%
rcth-40	Li2O (wt%)	2.8580	2.9298	3.3200	-0.4620	-0.3902	-13.9%	-11.8%
rcth-40	MgO (wt%)	2.1763	2.0925	2.3130	-0.1367	-0.2205	-5.9%	-9.5%
rcth-40	MnO (wt%)	3.6961	3.7002	3.9730	-0.2769	-0.2728	-7.0%	-6.9%
rcth-40	Na2O (wt%)	11.5456	11.1188	11.6390	-0.0934	-0.5202	-0.8%	-4.5%
rcth-40	NiO (wt%)	2.6945	2.5935	2.9380	-0.2435	-0.3445	-8.3%	-11.7%
rcth-40	P2O5 (wt%)	0.3643	0.3643	0.4782	-0.1139	-0.1139	-23.8%	-23.8%
rcth-40	SiO2 (wt%)	46.9042	46.3936	45.8340	1.0702	0.5596	2.3%	1.2%
rcth-40	ThO2 (wt%)	2.6598	2.6598	2.8914	-0.2316	-0.2316	-8.0%	-8.0%
rcth-40	U3O8 (wt%)	2.7652	3.0789	2.5412	0.2240	0.5377	8.8%	21.2%
rcth-40	ZrO2 (wt%)	0.0507	0.0507	0.0457	0.0050	0.0050	10.8%	10.8%
rcth-40	Sum of Oxides (wt%)	97.7454	97.0049	99.6815	-1.9361	-2.6766	-1.9%	-2.7%
rchwl-03	Al2O3 (wt%)	4.0860	4.1713	3.9290	0.1570	0.2423	4.0%	6.2%
rchwl-03	B2O3 (wt%)	7.9049	7.8677	8.0170	-0.1121	-0.1493	-1.4%	-1.9%
rchwl-03	CaO (wt%)	1.5251	1.4454	1.4240	0.1011	0.0214	7.1%	1.5%
rchwl-03	Cr2O3 (wt%)	0.1001	0.1073	0.1191	-0.0190	-0.0118	-15.9%	-9.9%
rchwl-03	Fe2O3 (wt%)	13.6215	13.5992	15.0730	-1.4515	-1.4738	-9.6%	-9.8%
rchwl-03	Li2O (wt%)	3.2509	3.3329	3.4010	-0.1501	-0.0681	-4.4%	-2.0%
rchwl-03	MgO (wt%)	1.7476	1.6808	1.7650	-0.0174	-0.0842	-1.0%	-4.8%
rchwl-03	MnO (wt%)	1.8593	1.8618	1.9110	-0.0517	-0.0492	-2.7%	-2.6%
rchwl-03	Na2O (wt%)	11.9433	11.5015	11.5880	0.3553	-0.0865	3.1%	-0.7%
rchwl-03	NiO (wt%)	0.8201	0.7879	0.8529	-0.0328	-0.0650	-3.8%	-7.6%
rchwl-03	P2O5 (wt%)	0.3471	0.3471	0.4520	-0.1049	-0.1049	-23.2%	-23.2%
rchwl-03	SiO2 (wt%)	48.1343	47.6103	47.4240	0.7103	0.1863	1.5%	0.4%
rchwl-03	ThO2 (wt%)	0.0569	0.0569	0.0177	0.0392	0.0392	221.4%	221.4%
rchwl-03	U3O8 (wt%)	3.6142	4.0242	3.6789	-0.0647	0.3453	-1.8%	9.4%
rchwl-03	ZrO2 (wt%)	0.0385	0.0385	0.0432	-0.0047	-0.0047	-10.9%	-10.9%
rchwl-03	Sum of Oxides (wt%)	99.0499	98.4328	99.6958	-0.6459	-1.2630	-0.6%	-1.3%
rchwl-04	Al2O3 (wt%)	4.3411	4.4318	4.2060	0.1351	0.2258	3.2%	5.4%
rchwl-04	B2O3 (wt%)	7.4782	7.4433	7.6470	-0.1688	-0.2037	-2.2%	-2.7%
rchwl-04	CaO (wt%)	1.5671	1.4852	1.4750	0.0921	0.0102	6.2%	0.7%
rchwl-04	Cr2O3 (wt%)	0.1078	0.1155	0.1301	-0.0223	-0.0146	-17.1%	-11.2%
rchwl-04	Fe2O3 (wt%)	14.4364	14.4126	15.2270	-0.7906	-0.8144	-5.2%	-5.3%
rchwl-04	Li2O (wt%)	3.0894	3.1673	3.2530	-0.1636	-0.0857	-5.0%	-2.6%
rchwl-04	MgO (wt%)	1.9317	1.8575	1.9340	-0.0023	-0.0765	-0.1%	-4.0%
rchwl-04	MnO (wt%)	3.4378	3.4423	3.6020	-0.1642	-0.1597	-4.6%	-4.4%
rchwl-04	Na2O (wt%)	11.9702	11.5277	11.6680	0.3022	-0.1403	2.6%	-1.2%
rchwl-04	NiO (wt%)	0.6996	0.6720	0.7430	-0.0434	-0.0710	-5.8%	-9.6%
rchwl-04	P2O5 (wt%)	0.3615	0.3615	0.4940	-0.1325	-0.1325	-26.8%	-26.8%
rchwl-04	SiO2 (wt%)	46.7437	46.2349	46.1030	0.6407	0.1319	1.4%	0.3%
rchwl-04	ThO2 (wt%)	0.0569	0.0569	0.0194	0.0375	0.0375	193.3%	193.3%
rchwl-04	U3O8 (wt%)	3.0748	3.4236	3.1223	-0.0475	0.3013	-1.5%	9.6%

Table C.4: Average Measured and Bias-Corrected Chemical Compositions Versus Targeted Compositions by Oxide by Study Glass

Glass ID		Measured (wt%)	Measured Bias-Corrected (wt%)	Targeted (wt%)	Diff of Measured	Diff of Meas BC	% Diff of Measured	% Diff of Meas BC
rchwl-04	ZrO2 (wt%)	0.0517	0.0517	0.0472	0.0045	0.0045	9.5%	9.5%
rchwl-04	Sum of Oxides (wt%)	99.3479	98.6836	99.6710	-0.3231	-0.9874	-0.3%	-1.0%
rchwl-01	Al2O3 (wt%)	4.6576	4.7549	4.4960	0.1616	0.2589	3.6%	5.8%
rchwl-01	B2O3 (wt%)	5.9810	5.9530	6.2050	-0.2240	-0.2520	-3.6%	-4.1%
rchwl-01	CaO (wt%)	1.7350	1.6443	1.6300	0.1050	0.0143	6.4%	0.9%
rchwl-01	Cr2O3 (wt%)	0.1118	0.1198	0.1363	-0.0245	-0.0165	-18.0%	-12.1%
rchwl-01	Fe2O3 (wt%)	16.4666	16.4395	17.2460	-0.7794	-0.8065	-4.5%	-4.7%
rchwl-01	Li2O (wt%)	4.1551	4.2599	4.4090	-0.2539	-0.1491	-5.8%	-3.4%
rchwl-01	MgO (wt%)	1.0923	1.0504	1.1130	-0.0207	-0.0626	-1.9%	-5.6%
rchwl-01	MnO (wt%)	2.0982	2.1016	2.1870	-0.0888	-0.0854	-4.1%	-3.9%
rchwl-01	Na2O (wt%)	13.2273	12.7380	12.9110	0.3163	-0.1730	2.4%	-1.3%
rchwl-01	NiO (wt%)	0.9117	0.8761	0.9759	-0.0642	-0.0998	-6.6%	-10.2%
rchwl-01	P2O5 (wt%)	0.3254	0.3254	0.5172	-0.1918	-0.1918	-37.1%	-37.1%
rchwl-01	SiO2 (wt%)	43.3743	42.9021	42.9320	0.4423	-0.0299	1.0%	-0.1%
rchwl-01	ThO2 (wt%)	0.0569	0.0569	0.0203	0.0366	0.0366	180.3%	180.3%
rchwl-01	U3O8 (wt%)	4.0623	4.5231	4.2092	-0.1469	0.3139	-3.5%	7.5%
rchwl-01	ZrO2 (wt%)	0.4890	0.4890	0.6684	-0.1794	-0.1794	-26.8%	-26.8%
rchwl-01	Sum of Oxides (wt%)	98.7445	98.2340	99.6563	-0.9118	-1.4223	-0.9%	-1.4%
rchwl-05	Al2O3 (wt%)	4.8938	4.9958	4.7550	0.1388	0.2408	2.9%	5.1%
rchwl-05	B2O3 (wt%)	4.5964	4.5748	4.7920	-0.1956	-0.2172	-4.1%	-4.5%
rchwl-05	CaO (wt%)	1.8330	1.7372	1.7240	0.1090	0.0132	6.3%	0.8%
rchwl-05	Cr2O3 (wt%)	0.1297	0.1389	0.1441	-0.0144	-0.0052	-10.0%	-3.6%
rchwl-05	Fe2O3 (wt%)	16.7275	16.6999	18.2420	-1.5145	-1.5421	-8.3%	-8.5%
rchwl-05	Li2O (wt%)	4.6449	4.7621	4.8560	-0.2111	-0.0939	-4.3%	-1.9%
rchwl-05	MgO (wt%)	0.5331	0.5124	0.5220	0.0111	-0.0096	2.1%	-1.8%
rchwl-05	MnO (wt%)	2.2887	2.2907	2.3130	-0.0243	-0.0223	-1.1%	-1.0%
rchwl-05	Na2O (wt%)	12.7251	12.2544	12.3080	0.4171	-0.0536	3.4%	-0.4%
rchwl-05	NiO (wt%)	0.9661	0.9289	1.0322	-0.0661	-0.1033	-6.4%	-10.0%
rchwl-05	P2O5 (wt%)	0.4325	0.4325	0.5471	-0.1146	-0.1146	-20.9%	-20.9%
rchwl-05	SiO2 (wt%)	44.8183	44.3305	43.8730	0.9453	0.4575	2.2%	1.0%
rchwl-05	ThO2 (wt%)	0.0569	0.0569	0.0215	0.0354	0.0354	164.6%	164.6%
rchwl-05	U3O8 (wt%)	4.4249	4.9269	4.4522	-0.0273	0.4747	-0.6%	10.7%
rchwl-05	ZrO2 (wt%)	0.0466	0.0466	0.0523	-0.0057	-0.0057	-10.9%	-10.9%
rchwl-05	Sum of Oxides (wt%)	99.1175	98.6885	99.6344	-0.5169	-0.9459	-0.5%	-0.9%
RC-38U	Al2O3 (wt%)	2.7539	2.8115	2.7305	0.0234	0.0810	0.9%	3.0%
RC-38U	B2O3 (wt%)	6.0373	6.0086	6.4880	-0.4507	-0.4794	-6.9%	-7.4%
RC-38U	CaO (wt%)	1.0728	1.0168	0.9873	0.0855	0.0295	8.7%	3.0%
RC-38U	Cr2O3 (wt%)	0.1352	0.1449	0.0826	0.0526	0.0623	63.6%	75.3%
RC-38U	Fe2O3 (wt%)	9.9972	9.9807	10.4748	-0.4776	-0.4940	-4.6%	-4.7%
RC-38U	Li2O (wt%)	2.5297	2.5935	2.7460	-0.2163	-0.1525	-7.9%	-5.6%
RC-38U	MgO (wt%)	1.3443	1.2936	1.3807	-0.0364	-0.0871	-2.6%	-6.3%
RC-38U	MnO (wt%)	1.3493	1.3520	1.3282	0.0211	0.0237	1.6%	1.8%
RC-38U	Na2O (wt%)	8.8564	8.5290	8.7573	0.0991	-0.2283	1.1%	-2.6%
RC-38U	NiO (wt%)	0.5952	0.5713	0.5934	0.0018	-0.0221	0.3%	-3.7%
RC-38U	P2O5 (wt%)	0.2486	0.2486	0.3137	-0.0651	-0.0651	-20.8%	-20.8%
RC-38U	SiO2 (wt%)	38.4004	37.9824	38.3063	0.0942	-0.3239	0.2%	-0.8%
RC-38U	ThO2 (wt%)	0.2296	0.2296	0.0123	0.2173	0.2173	1767.9%	1767.9%
RC-38U	U3O8 (wt%)	24.4890	27.2668	25.5632	-1.0742	1.7036	-4.2%	6.7%
RC-38U	ZrO2 (wt%)	0.0348	0.0348	0.0276	0.0072	0.0072	26.0%	26.0%
RC-38U	Sum of Oxides (wt%)	98.0738	100.0641	99.7921	-1.7183	0.2720	-1.7%	0.3%
rcth-50	Al2O3 (wt%)	3.2972	3.3660	3.1150	0.1822	0.2510	5.8%	8.1%
rcth-50	B2O3 (wt%)	5.0713	5.0474	5.2140	-0.1427	-0.1666	-2.7%	-3.2%
rcth-50	CaO (wt%)	0.6891	0.6531	0.6130	0.0761	0.0401	12.4%	6.5%
rcth-50	Cr2O3 (wt%)	0.1184	0.1268	0.1260	-0.0076	0.0008	-6.0%	0.6%
rcth-50	Fe2O3 (wt%)	11.2768	11.2581	12.0400	-0.7632	-0.7819	-6.3%	-6.5%

Table C.4: Average Measured and Bias-Corrected Chemical Compositions Versus Targeted Compositions by Oxide by Study Glass

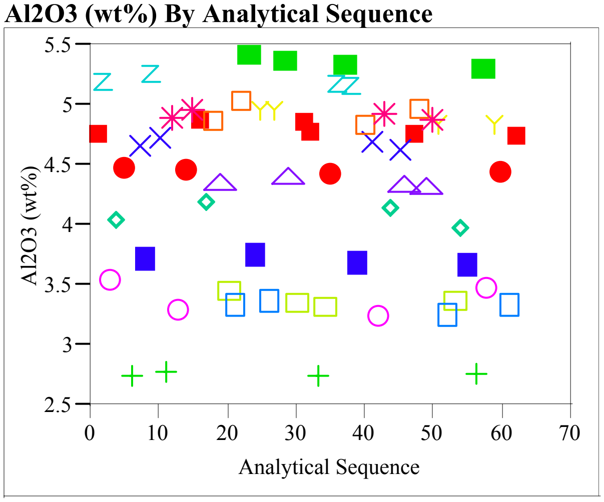
Glass ID		Measured (wt%)	Measured Bias-Corrected (wt%)	Targeted (wt%)	Diff of Measured	Diff of Meas BC	% Diff of Measured	% Diff of Meas BC
rcth-50	Li2O (wt%)	5.0324	5.1595	5.2700	-0.2376	-0.1105	-4.5%	-2.1%
rcth-50	MgO (wt%)	1.0160	0.9767	1.0130	0.0030	-0.0363	0.3%	-3.6%
rcth-50	MnO (wt%)	3.7638	3.7688	3.9730	-0.2092	-0.2042	-5.3%	-5.1%
rcth-50	Na2O (wt%)	12.6240	12.1568	12.2890	0.3350	-0.1322	2.7%	-1.1%
rcth-50	NiO (wt%)	2.7518	2.6484	2.9380	-0.1862	-0.2896	-6.3%	-9.9%
rcth-50	P2O5 (wt%)	0.3844	0.3844	0.4782	-0.0938	-0.0938	-19.6%	-19.6%
rcth-50	SiO2 (wt%)	47.7599	47.2400	47.1340	0.6259	0.1060	1.3%	0.2%
rcth-50	ThO2 (wt%)	2.7537	2.7537	2.8914	-0.1377	-0.1377	-4.8%	-4.8%
rcth-50	U3O8 (wt%)	2.4911	2.7736	2.5412	-0.0501	0.2324	-2.0%	9.1%
rcth-50	ZrO2 (wt%)	0.0706	0.0706	0.0457	0.0249	0.0249	54.4%	54.4%
rcth-50	Sum of Oxides (wt%)	99.1004	98.3839	99.6815	-0.5811	-1.2976	-0.6%	-1.3%
tk40-01	Al2O3 (wt%)	4.9127	5.0154	4.8768	0.0359	0.1387	0.7%	2.8%
tk40-01	B2O3 (wt%)	6.1339	6.1051	6.4245	-0.2906	-0.3194	-4.5%	-5.0%
tk40-01	CaO (wt%)	1.5986	1.5150	1.5026	0.0960	0.0125	6.4%	0.8%
tk40-01	Cr2O3 (wt%)	0.1114	0.1194	0.1292	-0.0178	-0.0098	-13.7%	-7.6%
tk40-01	Fe2O3 (wt%)	14.9404	14.9158	15.7655	-0.8251	-0.8496	-5.2%	-5.4%
tk40-01	Li2O (wt%)	4.3004	4.4089	4.5590	-0.2586	-0.1501	-5.7%	-3.3%
tk40-01	MgO (wt%)	2.0353	1.9568	2.1120	-0.0766	-0.1552	-3.6%	-7.3%
tk40-01	MnO (wt%)	1.8755	1.8778	1.9417	-0.0663	-0.0639	-3.4%	-3.3%
tk40-01	Na2O (wt%)	12.6004	12.1345	12.5101	0.0903	-0.3756	0.7%	-3.0%
tk40-01	NiO (wt%)	0.6837	0.6566	0.7077	-0.0241	-0.0511	-3.4%	-7.2%
tk40-01	P2O5 (wt%)	0.3746	0.3746	0.4904	-0.1158	-0.1158	-23.6%	-23.6%
tk40-01	SiO2 (wt%)	44.8183	44.3305	43.9095	0.9088	0.4210	2.1%	1.0%
tk40-01	ThO2 (wt%)	0.0569	0.0569	0.0192	0.0377	0.0377	195.7%	195.7%
tk40-01	U3O8 (wt%)	3.8412	4.2770	4.0366	-0.1953	0.2404	-4.8%	6.0%
tk40-01	ZrO2 (wt%)	0.6332	0.6332	0.6878	-0.0547	-0.0547	-7.9%	-7.9%
tk40-01	Sum of Oxides (wt%)	98.9166	98.3776	99.6726	-0.7560	-1.2950	-0.8%	-1.3%
tk40-03	Al2O3 (wt%)	5.3473	5.4589	5.1756	0.1717	0.2833	3.3%	5.5%
tk40-03	B2O3 (wt%)	4.8620	4.8390	4.9674	-0.1054	-0.1284	-2.1%	-2.6%
tk40-03	CaO (wt%)	1.6930	1.6046	1.5946	0.0984	0.0099	6.2%	0.6%
tk40-03	Cr2O3 (wt%)	0.1250	0.1339	0.1371	-0.0121	-0.0032	-8.8%	-2.3%
tk40-03	Fe2O3 (wt%)	14.9404	14.9158	16.7316	-1.7912	-1.8158	-10.7%	-10.9%
tk40-03	Li2O (wt%)	4.8656	4.9889	5.0284	-0.1629	-0.0396	-3.2%	-0.8%
tk40-03	MgO (wt%)	1.5984	1.5380	1.5611	0.0373	-0.0231	2.4%	-1.5%
tk40-03	MnO (wt%)	2.0821	2.0855	2.0607	0.0214	0.0248	1.0%	1.2%
tk40-03	Na2O (wt%)	12.1893	11.7389	11.8611	0.3282	-0.1223	2.8%	-1.0%
tk40-03	NiO (wt%)	0.7610	0.7307	0.7511	0.0099	-0.0204	1.3%	-2.7%
tk40-03	P2O5 (wt%)	0.4170	0.4170	0.5205	-0.1035	-0.1035	-19.9%	-19.9%
tk40-03	SiO2 (wt%)	46.7437	46.2349	44.9092	1.8345	1.3257	4.1%	3.0%
tk40-03	ThO2 (wt%)	0.0569	0.0569	0.0204	0.0365	0.0365	178.6%	178.6%
tk40-03	U3O8 (wt%)	4.2363	4.7168	4.2839	-0.0477	0.4329	-1.1%	10.1%
tk40-03	ZrO2 (wt%)	0.0439	0.0439	0.0497	-0.0058	-0.0058	-11.7%	-11.7%
tk40-03	Sum of Oxides (wt%)	99.9618	99.5036	99.6525	0.3092	-0.1490	0.3%	-0.1%
rcth-30	Al2O3 (wt%)	3.3869	3.4576	3.1150	0.2719	0.3426	8.7%	11.0%
rcth-30	B2O3 (wt%)	6.3915	6.3617	6.5140	-0.1225	-0.1523	-1.9%	-2.3%
rcth-30	CaO (wt%)	0.6937	0.6574	0.6130	0.0807	0.0444	13.2%	7.2%
rcth-30	Cr2O3 (wt%)	0.0950	0.1018	0.1260	-0.0310	-0.0242	-24.6%	-19.2%
rcth-30	Fe2O3 (wt%)	10.9587	10.9407	12.0400	-1.0813	-1.0993	-9.0%	-9.1%
rcth-30	Li2O (wt%)	4.4996	4.6125	4.6200	-0.1204	-0.0075	-2.6%	-0.2%
rcth-30	MgO (wt%)	1.6797	1.6167	1.6630	0.0167	-0.0463	1.0%	-2.8%
rcth-30	MnO (wt%)	3.7961	3.8036	3.9730	-0.1769	-0.1694	-4.5%	-4.3%
rcth-30	Na2O (wt%)	13.4193	12.9230	12.9390	0.4803	-0.0160	3.7%	-0.1%
rcth-30	NiO (wt%)	2.7295	2.6249	2.9380	-0.2085	-0.3131	-7.1%	-10.7%
rcth-30	P2O5 (wt%)	0.3156	0.3156	0.4782	-0.1626	-0.1626	-34.0%	-34.0%
rcth-30	SiO2 (wt%)	45.5136	45.0182	44.5340	0.9796	0.4842	2.2%	1.1%

Table C.4: Average Measured and Bias-Corrected Chemical Compositions Versus Targeted Compositions by Oxide by Study Glass

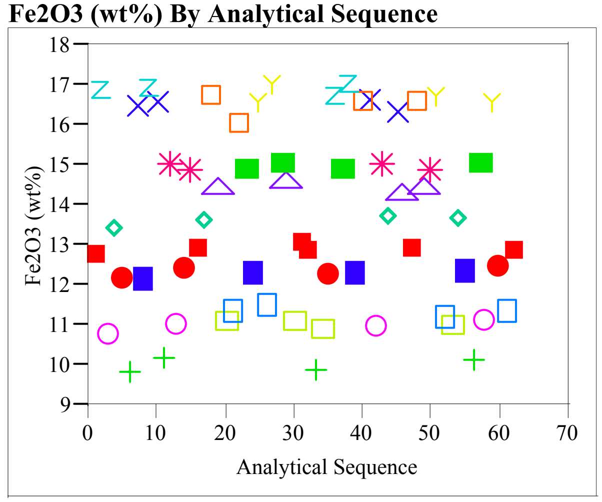
Glass ID		Measured (wt%)	Measured Bias-Corrected (wt%)	Targeted (wt%)	Diff of Measured	Diff of Meas BC	% Diff of Measured	% Diff of Meas BC
rcth-30	ThO2 (wt%)	2.7992	2.7992	2.8914	-0.0922	-0.0922	-3.2%	-3.2%
rcth-30	U3O8 (wt%)	2.4822	2.7638	2.5412	-0.0590	0.2226	-2.3%	8.8%
rcth-30	ZrO2 (wt%)	0.5660	0.5660	0.6957	-0.1297	-0.1297	-18.6%	-18.6%
rcth-30	Sum of Oxides (wt%)	99.3266	98.5629	99.6815	-0.3549	-1.1186	-0.4%	-1.1%
u-std	Al2O3 (wt%)	3.6798	3.7566	4.1000	-0.4202	-0.3434	-10.2%	-8.4%
u-std	B2O3 (wt%)	8.5569	8.5166	9.2090	-0.6521	-0.6924	-7.1%	-7.5%
u-std	CaO (wt%)	1.2680	1.2018	1.3010	-0.0330	-0.0992	-2.5%	-7.6%
u-std	Cr2O3 (wt%)	0.2331	0.2497	0.0000	0.2331	0.2497		
u-std	Fe2O3 (wt%)	12.2025	12.1825	13.1960	-0.9935	-1.0135	-7.5%	-7.7%
u-std	Li2O (wt%)	2.7180	2.7864	3.0570	-0.3390	-0.2706	-11.1%	-8.9%
u-std	MgO (wt%)	1.1831	1.1376	1.2100	-0.0269	-0.0724	-2.2%	-6.0%
u-std	MnO (wt%)	2.6018	2.6061	2.8920	-0.2902	-0.2859	-10.0%	-9.9%
u-std	Na2O (wt%)	11.0536	10.6448	11.7950	-0.7414	-1.1502	-6.3%	-9.8%
u-std	NiO (wt%)	1.0400	0.9992	1.1200	-0.0800	-0.1208	-7.1%	-10.8%
u-std	P2O5 (wt%)	0.0115	0.0115	0.0000	0.0115	0.0115		
u-std	SiO2 (wt%)	47.8668	47.3458	45.3530	2.5138	1.9928	5.5%	4.4%
u-std	ThO2 (wt%)	0.0569	0.0569	0.0000	0.0569	0.0569		
u-std	U3O8 (wt%)	2.1609	2.4060	2.4060	-0.2451	0.0000	-10.2%	0.0%
u-std	ZrO2 (wt%)	0.0034	0.0034	0.0000	0.0034	0.0034		
u-std	Sum of Oxides (wt%)	94.6362	93.9049	95.6390	-1.0028	-1.7341	-1.0%	-1.8%

Exhibit C.1: SRTC-ML Measurements for Samples of the Study Glasses Prepared Using the LM Method

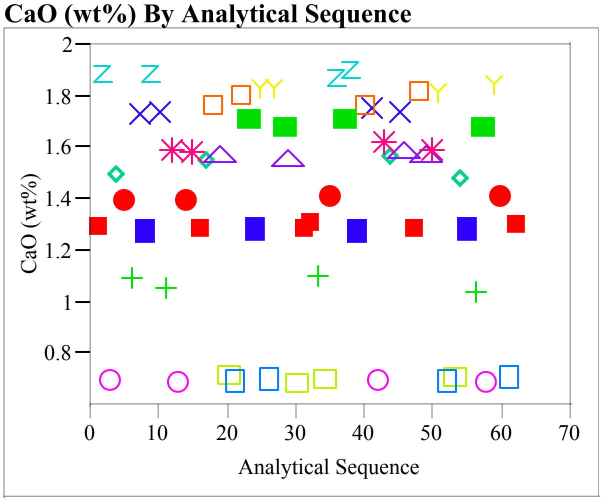
Al2O3 (wt%) By Analytical Sequence



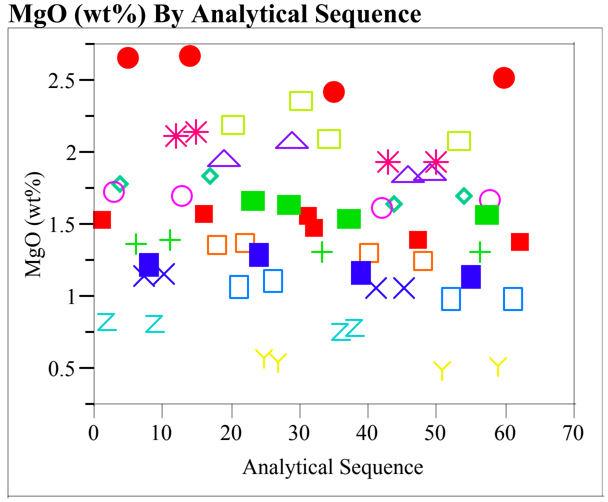
Fe2O3 (wt%) By Analytical Sequence



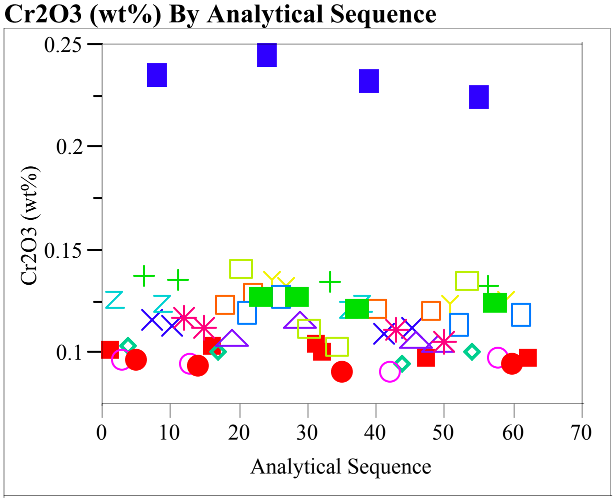
CaO (wt%) By Analytical Sequence



MgO (wt%) By Analytical Sequence



Cr2O3 (wt%) By Analytical Sequence



MnO (wt%) By Analytical Sequence

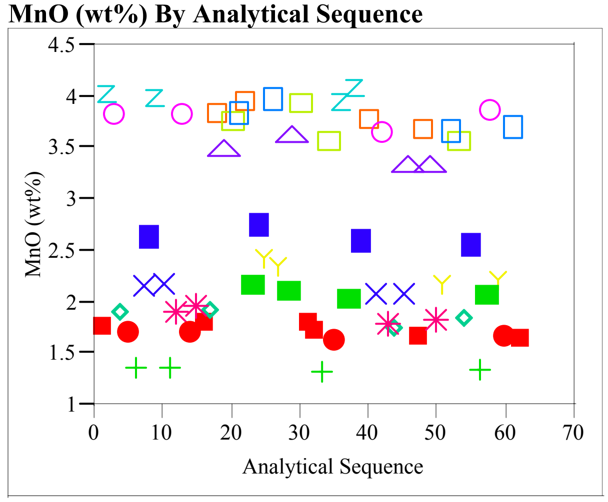
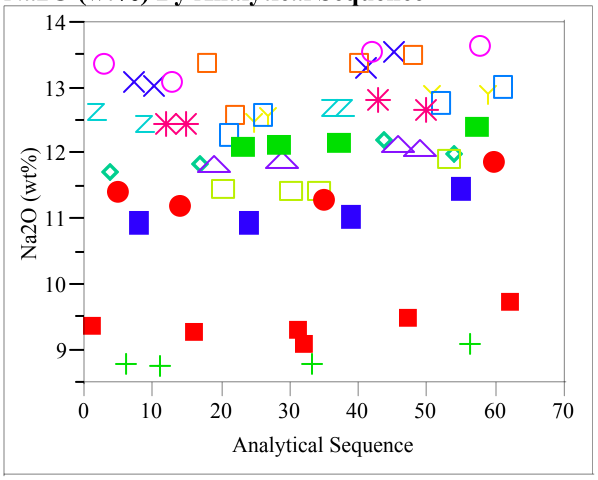
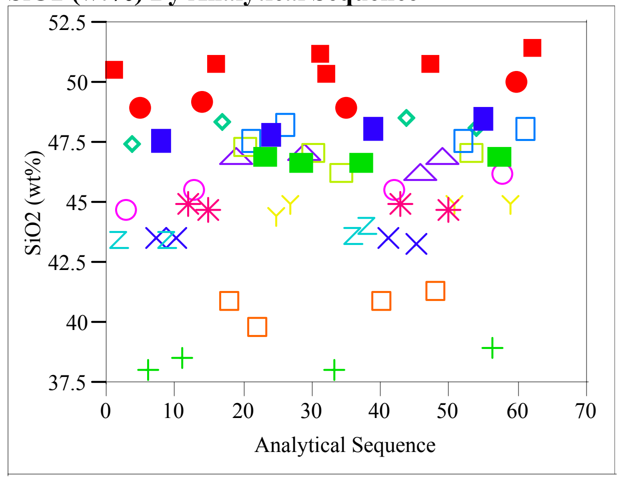


Exhibit C.1: SRTC-ML Measurements for Samples of the Study Glasses Prepared Using the LM Method *(continued)*

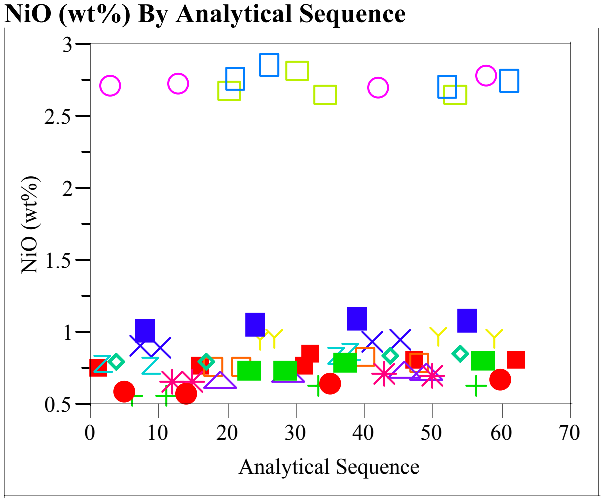
Na2O (wt%) By Analytical Sequence



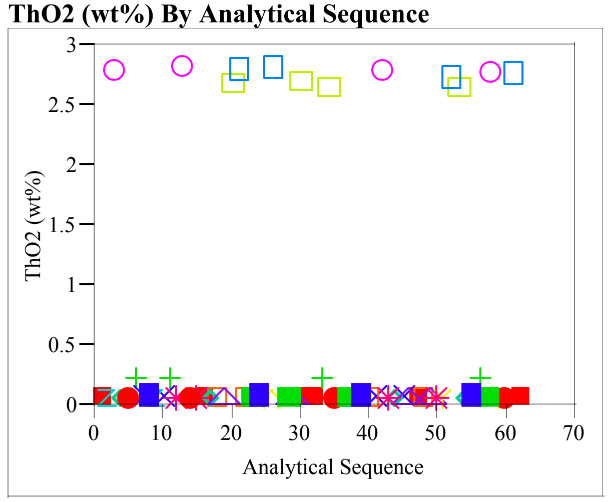
SiO2 (wt%) By Analytical Sequence



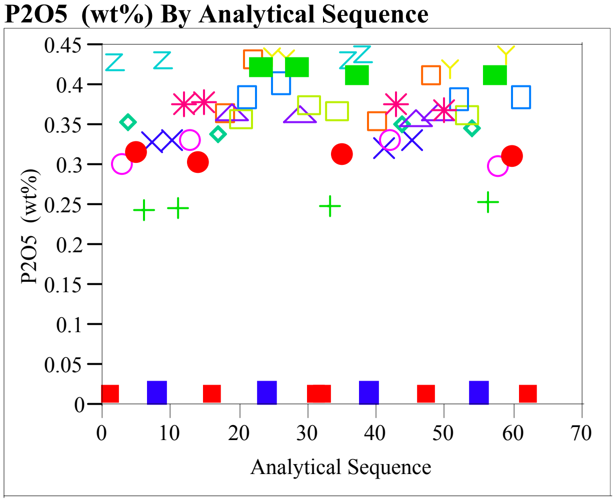
NiO (wt%) By Analytical Sequence



ThO2 (wt%) By Analytical Sequence



P2O5 (wt%) By Analytical Sequence



U3O8 (wt%) By Analytical Sequence

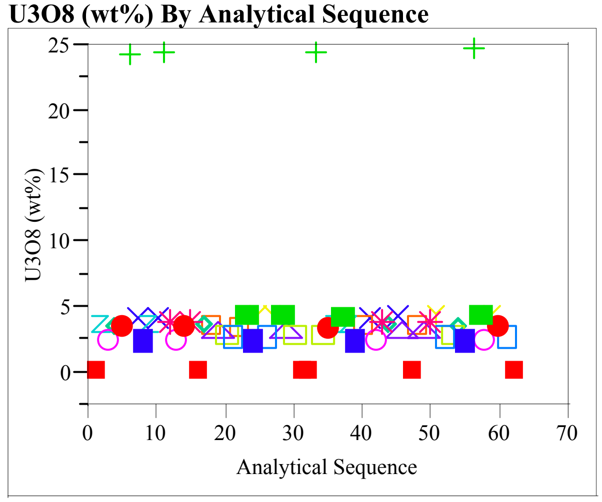


Exhibit C.1: SRTC-ML Measurements for Samples of the Study Glasses Prepared Using the LM Method *(continued)*

ZrO2 (wt%) By Analytical Sequence

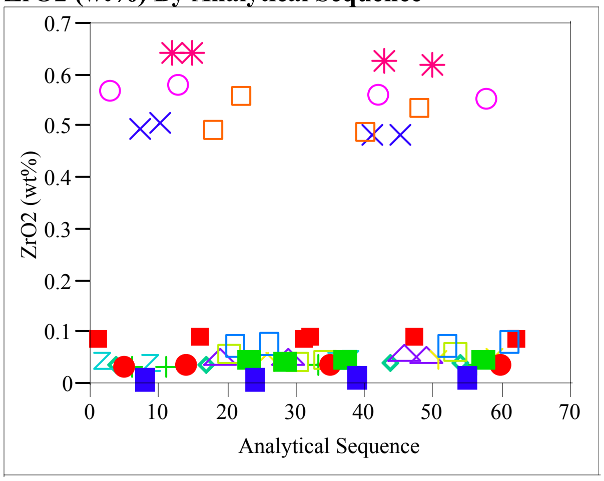
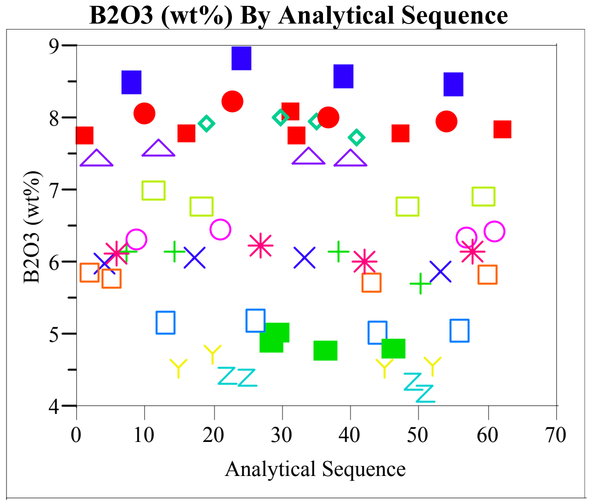


Exhibit C.2: SRTC-ML Measurements for Samples of the Study Glasses Prepared Using the SP Method



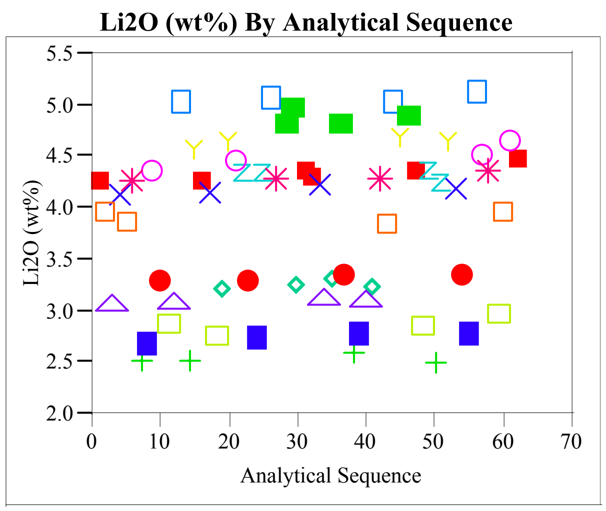
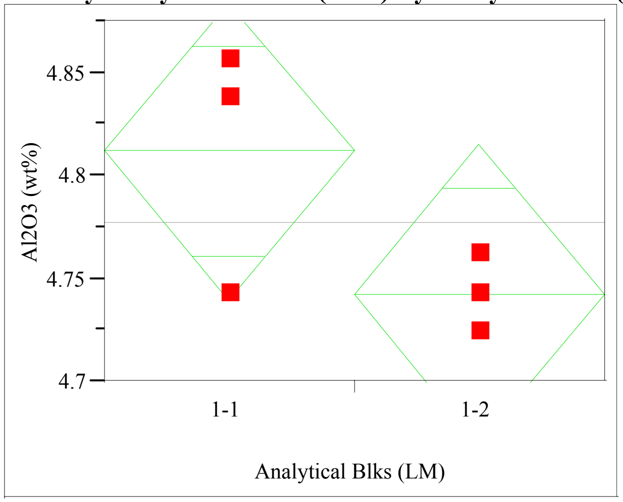


Exhibit C.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method

Batch 1 – Al2O3 reference value 4.877 wt%
Oneway Analysis of Al2O3 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.470817
Adj Rsquare	0.338521
Root Mean Square Error	0.044979
Mean of Response	4.777286
Observations (or Sum Wgts)	6

Analysis of Variance

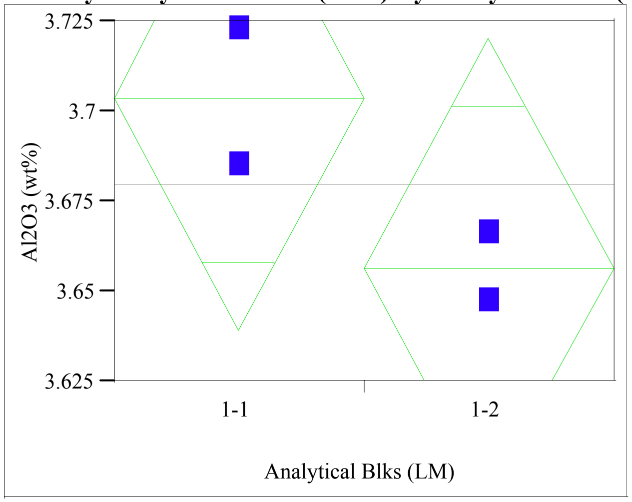
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00719992	0.007200	3.5588	0.1323
Error	4	0.00809248	0.002023		
C. Total	5	0.01529240			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	4.81193	0.02597	4.7398	4.8840
1-2	3	4.74264	0.02597	4.6705	4.8147

Std Error uses a pooled estimate of error variance

U std – Al2O3 reference value 4.1 wt%
Oneway Analysis of Al2O3 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.714286
Adj Rsquare	0.571429
Root Mean Square Error	0.021125
Mean of Response	3.679801
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00223138	0.002231	5.0000	0.1548
Error	2	0.00089255	0.000446		
C. Total	3	0.00312393			

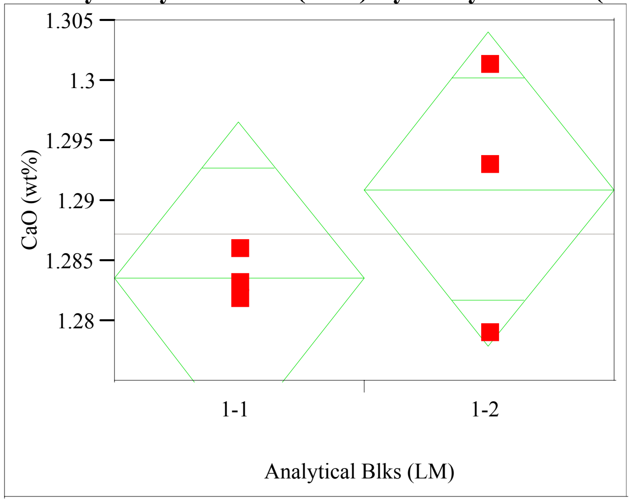
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	3.70342	0.01494	3.6391	3.7677
1-2	2	3.65618	0.01494	3.5919	3.7205

Std Error uses a pooled estimate of error variance

Exhibit C.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method

Batch 1 – CaO reference value 1.22 wt%
Oneway Analysis of CaO (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.2397
Adj Rsquare	0.049625
Root Mean Square Error	0.008139
Mean of Response	1.287264
Observations (or Sum Wgts)	6

Analysis of Variance

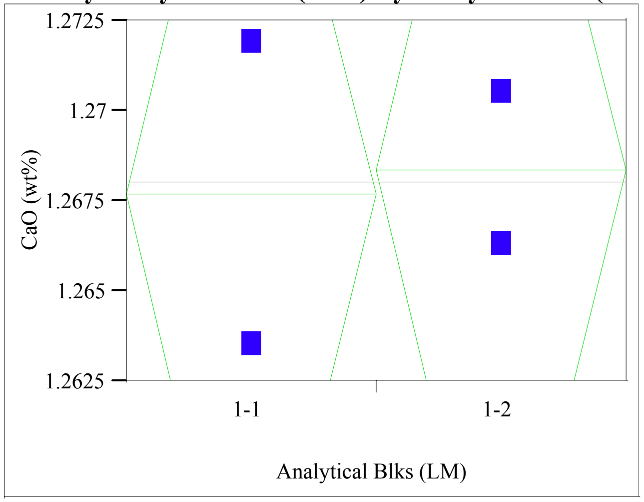
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00008353	0.000084	1.2611	0.3243
Error	4	0.00026495	0.000066		
C. Total	5	0.00034848			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	1.28353	0.00470	1.2705	1.2966
1-2	3	1.29100	0.00470	1.2779	1.3040

Std Error uses a pooled estimate of error variance

U std – CaO reference value 1.301 wt%
Oneway Analysis of CaO (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.010989
Adj Rsquare	-0.48352
Root Mean Square Error	0.004693
Mean of Response	1.268025
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00000049	0.000000	0.0222	0.8952
Error	2	0.00004405	0.000022		
C. Total	3	0.00004454			

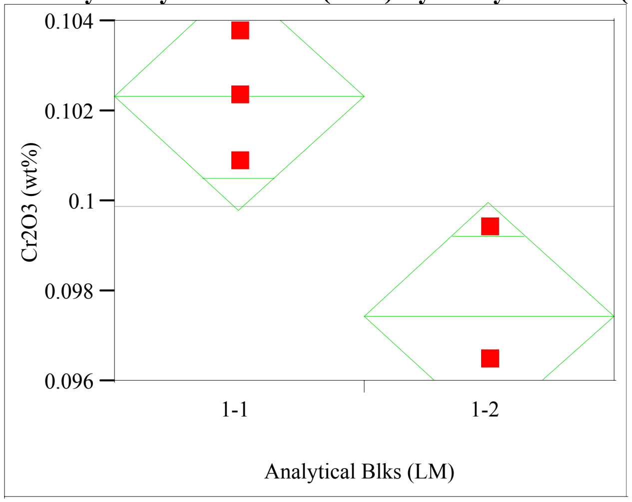
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	1.26768	0.00332	1.2534	1.2820
1-2	2	1.26837	0.00332	1.2541	1.2827

Std Error uses a pooled estimate of error variance

Exhibit C.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method *(continued)*

Batch 1 – Cr2O3 reference 0.107 wt%
Oneway Analysis of Cr2O3 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.78125
Adj Rsquare	0.726562
Root Mean Square Error	0.001579
Mean of Response	0.099876
Observations (or Sum Wgts)	6

Analysis of Variance

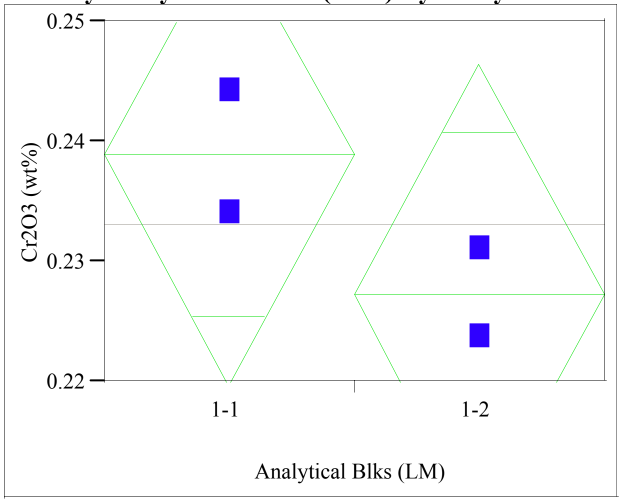
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00003560	0.000036	14.2857	0.0194
Error	4	0.00000997	0.000002		
C. Total	5	0.00004557			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	0.102312	0.00091	0.09978	0.10484
1-2	3	0.097440	0.00091	0.09491	0.09997

Std Error uses a pooled estimate of error variance

U std – Cr2O3 reference value ~0 wt%
Oneway Analysis of Cr2O3 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.633663
Adj Rsquare	0.450495
Root Mean Square Error	0.006287
Mean of Response	0.233125
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00013672	0.000137	3.4595	0.2040
Error	2	0.00007904	0.000040		
C. Total	3	0.00021576			

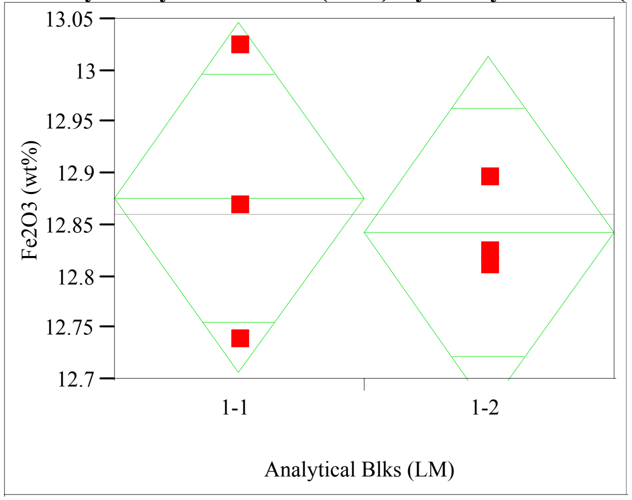
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	0.238972	0.00445	0.21985	0.25810
1-2	2	0.227279	0.00445	0.20815	0.24641

Std Error uses a pooled estimate of error variance

Exhibit C.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method *(continued)*

Batch 1 – Fe2O3 reference value 12.839 wt%
Oneway Analysis of Fe2O3 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.035585
Adj Rsquare	-0.20552
Root Mean Square Error	0.10635
Mean of Response	12.86015
Observations (or Sum Wgts)	6

Analysis of Variance

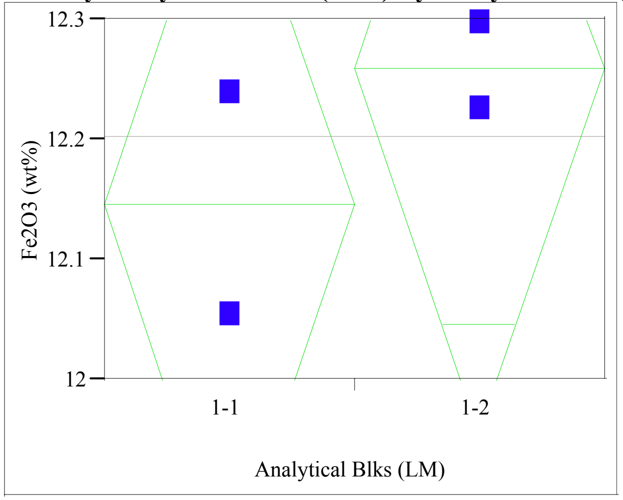
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00166930	0.001669	0.1476	0.7204
Error	4	0.04524146	0.011310		
C. Total	5	0.04691077			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	12.8768	0.06140	12.706	13.047
1-2	3	12.8435	0.06140	12.673	13.014

Std Error uses a pooled estimate of error variance

U std – Fe2O3 reference value 13.196 wt%
Oneway Analysis of Fe2O3 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.397516
Adj Rsquare	0.096273
Root Mean Square Error	0.099567
Mean of Response	12.20249
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.01308187	0.013082	1.3196	0.3695
Error	2	0.01982721	0.009914		
C. Total	3	0.03290908			

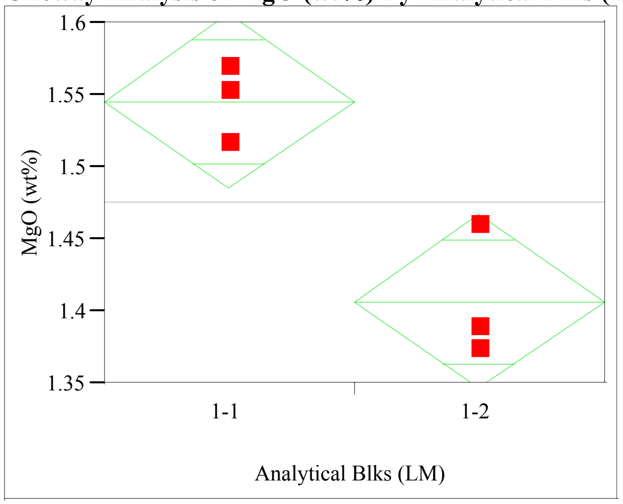
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	12.1453	0.07040	11.842	12.448
1-2	2	12.2597	0.07040	11.957	12.563

Std Error uses a pooled estimate of error variance

Exhibit C.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method *(continued)*

Batch 1 – MgO reference value 1.419 wt %
Oneway Analysis of MgO (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.834616
Adj Rsquare	0.79327
Root Mean Square Error	0.037817
Mean of Response	1.475985
Observations (or Sum Wgts)	6

Analysis of Variance

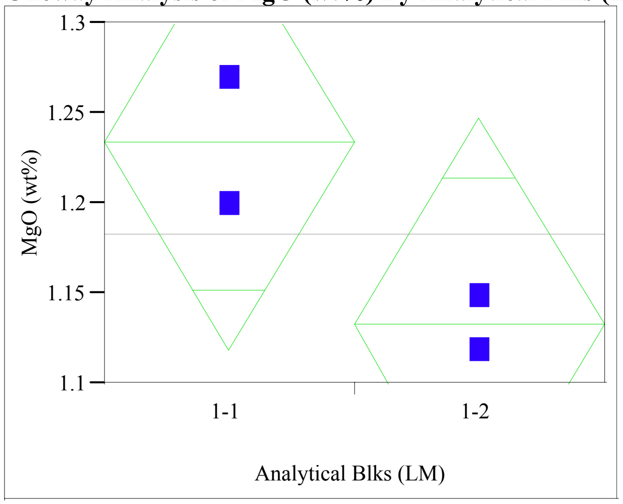
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.02886806	0.028868	20.1862	0.0109
Error	4	0.00572037	0.001430		
C. Total	5	0.03458843			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	1.54535	0.02183	1.4847	1.6060
1-2	3	1.40662	0.02183	1.3460	1.4672

Std Error uses a pooled estimate of error variance

U std – MgO reference value 1.21 wt%
Oneway Analysis of MgO (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.780902
Adj Rsquare	0.671354
Root Mean Square Error	0.037883
Mean of Response	1.183054
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.01023013	0.010230	7.1284	0.1163
Error	2	0.00287026	0.001435		
C. Total	3	0.01310039			

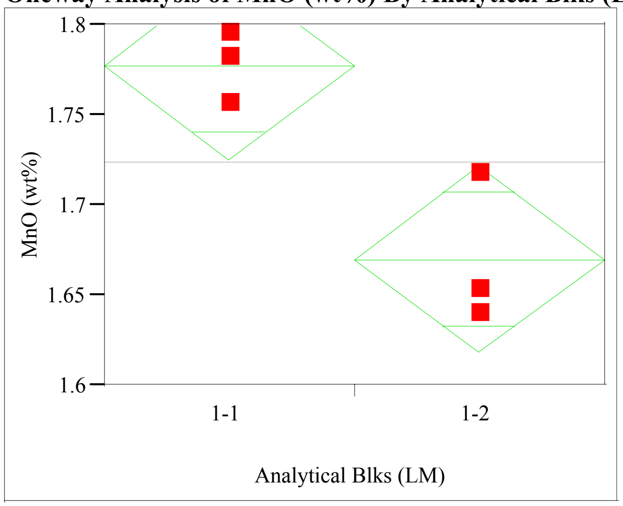
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	1.23363	0.02679	1.1184	1.3489
1-2	2	1.13248	0.02679	1.0172	1.2477

Std Error uses a pooled estimate of error variance

Exhibit C.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method *(continued)*

Batch 1 – MnO reference value 1.726 wt%
Oneway Analysis of MnO (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.804376
Adj Rsquare	0.75547
Root Mean Square Error	0.032494
Mean of Response	1.723752
Observations (or Sum Wgts)	6

Analysis of Variance

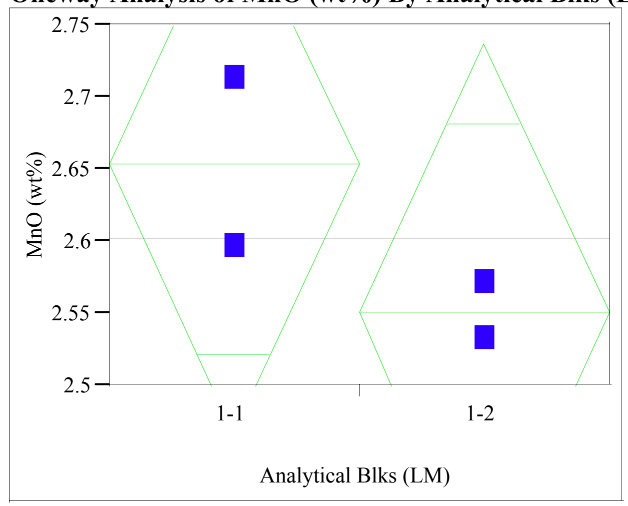
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.01736664	0.017367	16.4474	0.0154
Error	4	0.00422357	0.001056		
C. Total	5	0.02159021			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	1.77755	0.01876	1.7255	1.8296
1-2	3	1.66995	0.01876	1.6179	1.7220

Std Error uses a pooled estimate of error variance

U std – MnO reference value 2.892 wt%
Oneway Analysis of MnO (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.587156
Adj Rsquare	0.380734
Root Mean Square Error	0.061247
Mean of Response	2.601768
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.01067006	0.010670	2.8444	0.2337
Error	2	0.00750239	0.003751		
C. Total	3	0.01817245			

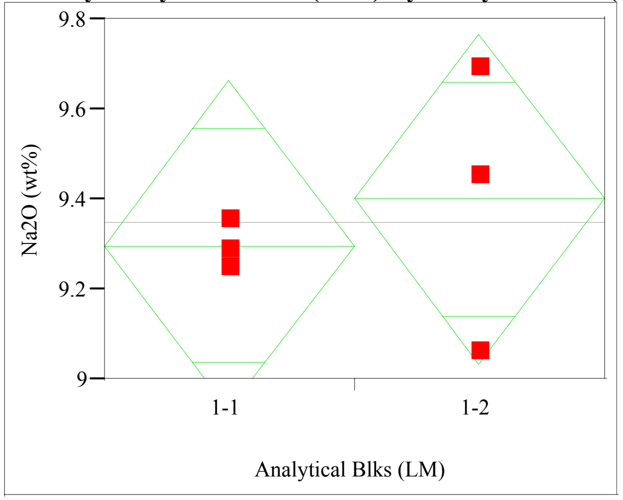
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	2.65342	0.04331	2.4671	2.8398
1-2	2	2.55012	0.04331	2.3638	2.7365

Std Error uses a pooled estimate of error variance

Exhibit C.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method *(continued)*

Batch 1 – Na2O reference value 9.003 wt%
Oneway Analysis of Na2O (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.070788
Adj Rsquare	-0.16151
Root Mean Square Error	0.229292
Mean of Response	9.34838
Observations (or Sum Wgts)	6

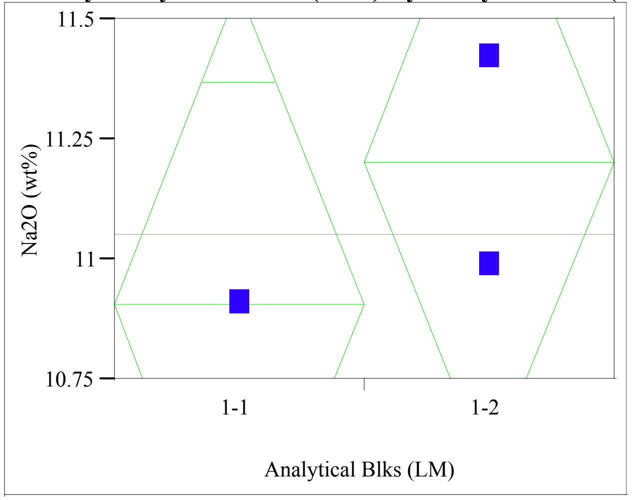
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.01602080	0.016021	0.3047	0.6103
Error	4	0.21029950	0.052575		
C. Total	5	0.22632030			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	9.29671	0.13238	8.9292	9.6643
1-2	3	9.40005	0.13238	9.0325	9.7676

U std – Na2O reference value 11.795 wt%
Oneway Analysis of Na2O (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.485944
Adj Rsquare	0.228916
Root Mean Square Error	0.21568
Mean of Response	11.0536
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.08794783	0.087948	1.8906	0.3029
Error	2	0.09303572	0.046518		
C. Total	3	0.18098356			

Means for Oneway Anova

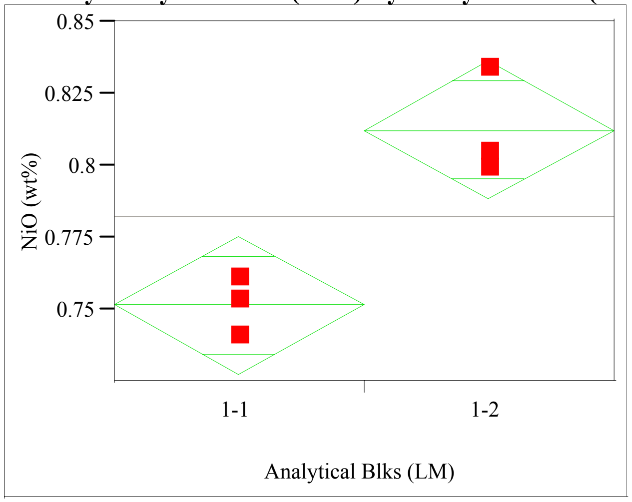
Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	10.9053	0.15251	10.249	11.562
1-2	2	11.2019	0.15251	10.546	11.858

Std Error uses a pooled estimate of error variance

Exhibit C.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method *(continued)*

Batch 1 – NiO reference value 0.751 wt%

Oneway Analysis of NiO (wt%) By Analytical Blks (LM)



Oneway Anova

Summary of Fit

Rsquare	0.859888
Adj Rsquare	0.82486
Root Mean Square Error	0.014994
Mean of Response	0.781951
Observations (or Sum Wgts)	6

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00551870	0.005519	24.5486	0.0077
Error	4	0.00089923	0.000225		
C. Total	5	0.00641792			

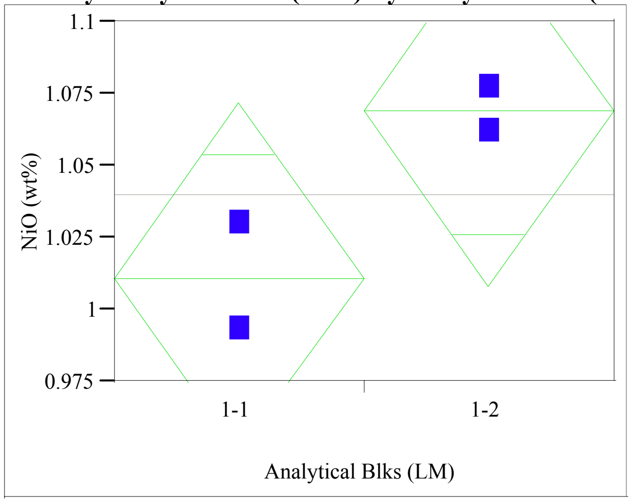
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	0.751623	0.00866	0.72759	0.77566
1-2	3	0.812279	0.00866	0.78824	0.83631

Std Error uses a pooled estimate of error variance

U std – NiO reference value 1.12 wt%

Oneway Analysis of NiO (wt%) By Analytical Blks (LM)



Oneway Anova

Summary of Fit

Rsquare	0.807824
Adj Rsquare	0.711735
Root Mean Square Error	0.019969
Mean of Response	1.039951
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00335227	0.003352	8.4071	0.1012
Error	2	0.00079748	0.000399		
C. Total	3	0.00414975			

Means for Oneway Anova

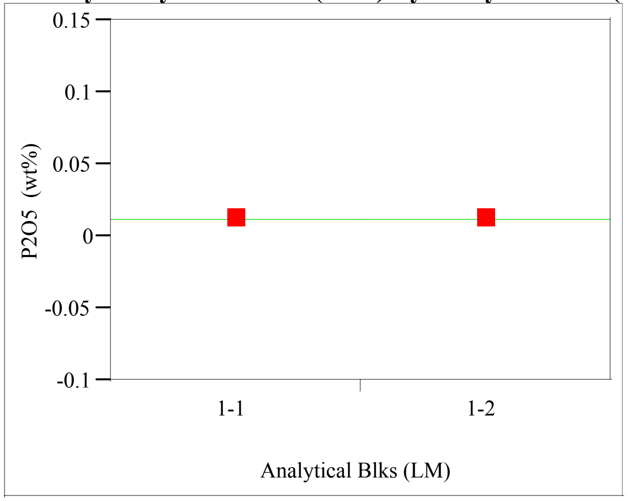
Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	1.01100	0.01412	0.9502	1.0718
1-2	2	1.06890	0.01412	1.0081	1.1297

Std Error uses a pooled estimate of error variance

Exhibit C.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method *(continued)*

Batch 1 – P2O5 reference value ~0 wt%

Oneway Analysis of P2O5 (wt%) By Analytical Blks (LM)



Oneway Anova

Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.011457
Observations (or Sum Wgts)	6

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0	0	.	.
Error	4	0	0		
C. Total	5	0			

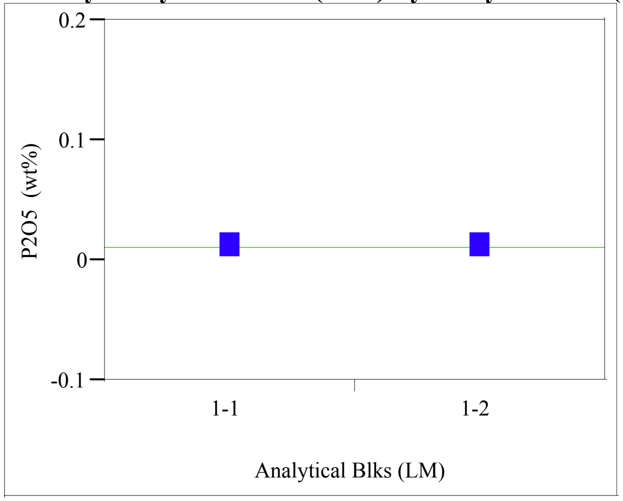
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	0.011457	0	0.01146	0.01146
1-2	3	0.011457	0	0.01146	0.01146

Std Error uses a pooled estimate of error variance

U std – P2O5 reference value ~0 wt%

Oneway Analysis of P2O5 (wt%) By Analytical Blks (LM)



Oneway Anova

Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.011457
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0	0	.	.
Error	2	0	0		
C. Total	3	0			

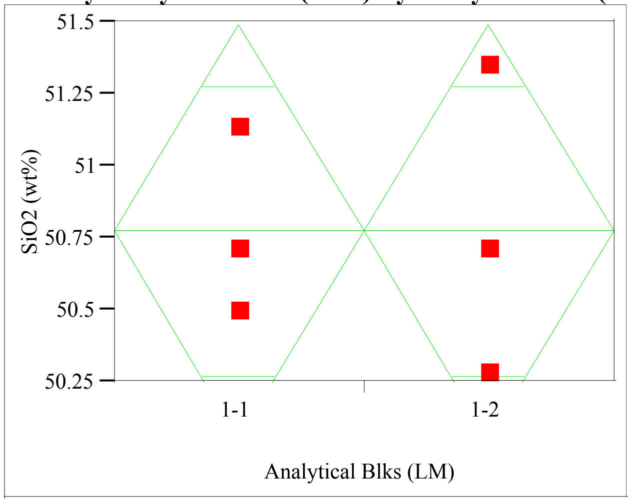
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	0.011457	0	0.01146	0.01146
1-2	2	0.011457	0	0.01146	0.01146

Std Error uses a pooled estimate of error variance

Exhibit C.7: Exhibit A.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method *(continued)*

Batch 1 – SiO2 reference value 50.22 wt%
Oneway Analysis of SiO2 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0
Adj Rsquare	-0.25
Root Mean Square Error	0.445331
Mean of Response	50.77272
Observations (or Sum Wgts)	6

Analysis of Variance

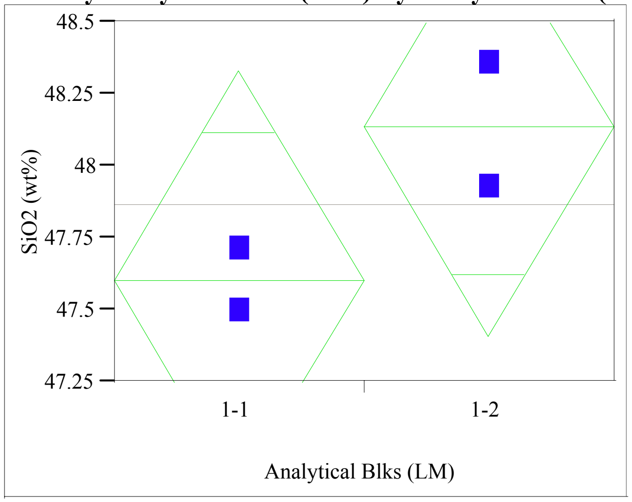
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00000000	0.000000	0.0000	1.0000
Error	4	0.79327811	0.198320		
C. Total	5	0.79327811			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	50.7727	0.25711	50.059	51.487
1-2	3	50.7727	0.25711	50.059	51.487

Std Error uses a pooled estimate of error variance

U std – SiO2 reference value 45.353 wt%
Oneway Analysis of SiO2 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.714286
Adj Rsquare	0.571429
Root Mean Square Error	0.239181
Mean of Response	47.86684
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.28603778	0.286038	5.0000	0.1548
Error	2	0.11441511	0.057208		
C. Total	3	0.40045289			

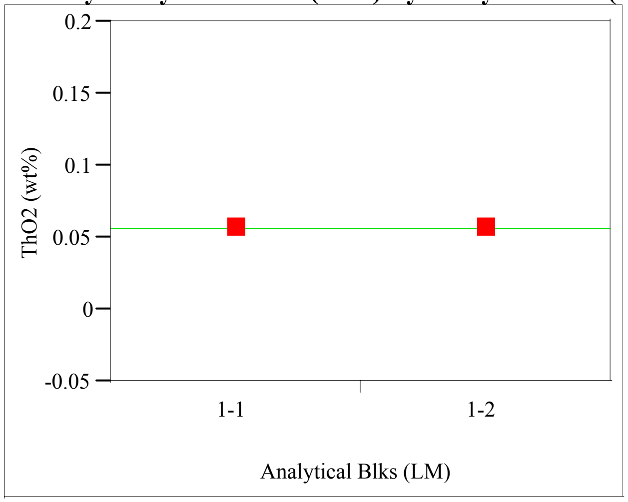
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	47.5994	0.16913	46.872	48.327
1-2	2	48.1342	0.16913	47.407	48.862

Std Error uses a pooled estimate of error variance

Exhibit C.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method *(continued)*

Batch 1 – ThO2 reference value ~0 wt%
Oneway Analysis of ThO2 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.056895
Observations (or Sum Wgts)	6

Analysis of Variance

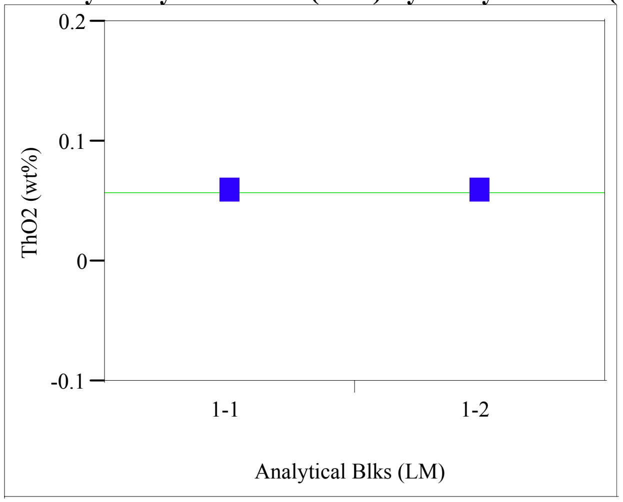
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0	0	.	.
Error	4	0	0		
C. Total	5	0			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	0.056895	0	0.05690	0.05690
1-2	3	0.056895	0	0.05690	0.05690

Std Error uses a pooled estimate of error variance

U std – ThO2 reference value ~0 wt%
Oneway Analysis of ThO2 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.056895
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0	0	.	.
Error	2	0	0		
C. Total	3	0			

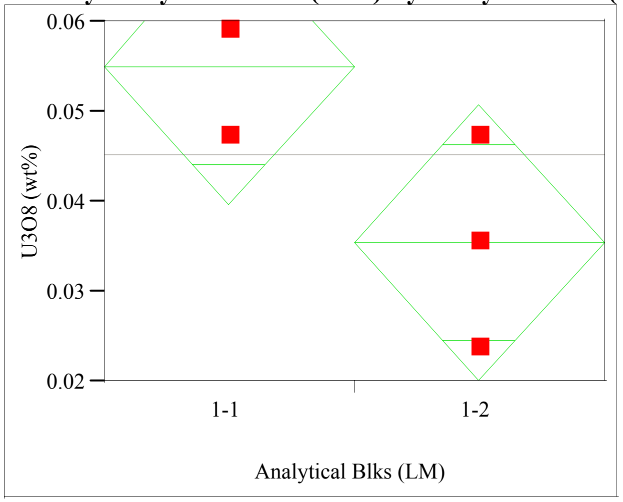
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	0.056895	0	0.05690	0.05690
1-2	2	0.056895	0	0.05690	0.05690

Std Error uses a pooled estimate of error variance

Exhibit C.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method *(continued)*

Batch 1 – U3O8 reference value ~0 wt%
Oneway Analysis of U3O8 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.609756
Adj Rsquare	0.512195
Root Mean Square Error	0.009628
Mean of Response	0.045203
Observations (or Sum Wgts)	6

Analysis of Variance

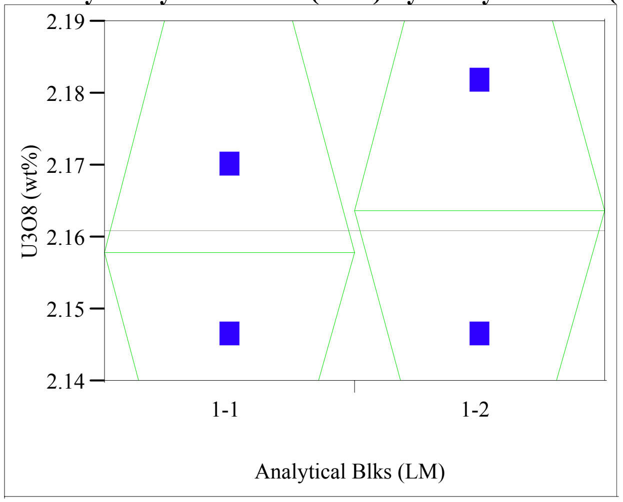
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00057938	0.000579	6.2500	0.0668
Error	4	0.00037080	0.000093		
C. Total	5	0.00095018			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	0.055029	0.00556	0.03960	0.07046
1-2	3	0.035376	0.00556	0.01994	0.05081

Std Error uses a pooled estimate of error variance

U std – U3O8 reference value 2.406 wt%
Oneway Analysis of U3O8 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.037037
Adj Rsquare	-0.44444
Root Mean Square Error	0.021258
Mean of Response	2.160884
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00003476	0.000035	0.0769	0.8075
Error	2	0.00090383	0.000452		
C. Total	3	0.00093860			

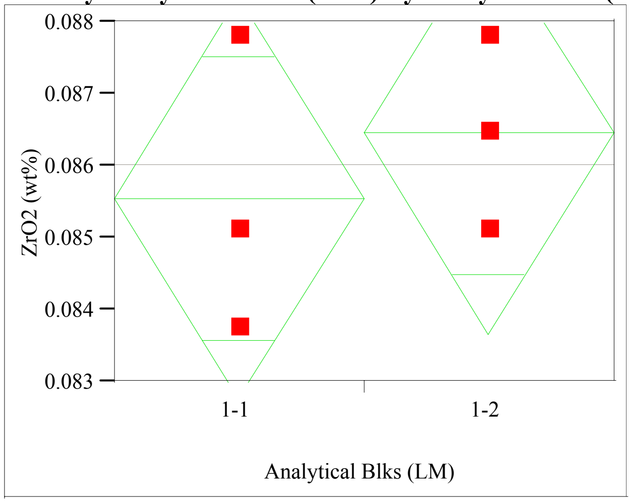
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	2.15794	0.01503	2.0933	2.2226
1-2	2	2.16383	0.01503	2.0992	2.2285

Std Error uses a pooled estimate of error variance

Exhibit C.3: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the LM Method *(continued)*

Batch 1 – ZrO2 reference value ~0.098 wt%
Oneway Analysis of ZrO2 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.090909
Adj Rsquare	-0.13636
Root Mean Square Error	0.001744
Mean of Response	0.086001
Observations (or Sum Wgts)	6

Analysis of Variance

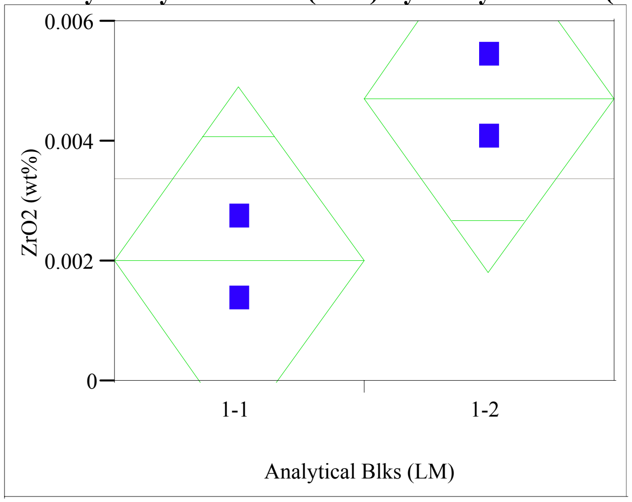
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.00000122	0.0000012	0.4000	0.5614
Error	4	0.00001216	0.000003		
C. Total	5	0.00001338			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	0.085551	0.00101	0.08276	0.08835
1-2	3	0.086451	0.00101	0.08366	0.08925

Std Error uses a pooled estimate of error variance

U std – ZrO2 reference value 0 wt%
Oneway Analysis of ZrO2 (wt%) By Analytical Blks (LM)



Oneway Anova
Summary of Fit

Rsquare	0.8
Adj Rsquare	0.7
Root Mean Square Error	0.000955
Mean of Response	0.003377
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (LM)	1	0.0000073	0.0000073	8.0000	0.1056
Error	2	0.00000182	9.1233e-7		
C. Total	3	0.00000912			

Means for Oneway Anova

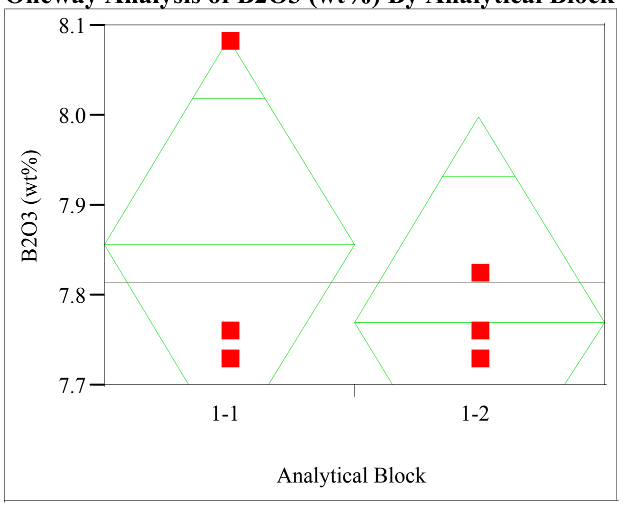
Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	0.002026	0.00068	-0.0009	0.00493
1-2	2	0.004728	0.00068	0.0018	0.00763

Std Error uses a pooled estimate of error variance

Exhibit C.4: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the SP Method

Batch 1 – B2O3 reference value 7.777wt%

Oneway Analysis of B2O3 (wt%) By Analytical Block



Oneway Anova

Summary of Fit

Rsquare	0.119403
Adj Rsquare	-0.10075
Root Mean Square Error	0.142793
Mean of Response	7.813624
Observations (or Sum Wgts)	6

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Block	1	0.01105894	0.011059	0.5424	0.5023
Error	4	0.08155968	0.020390		
C. Total	5	0.09261862			

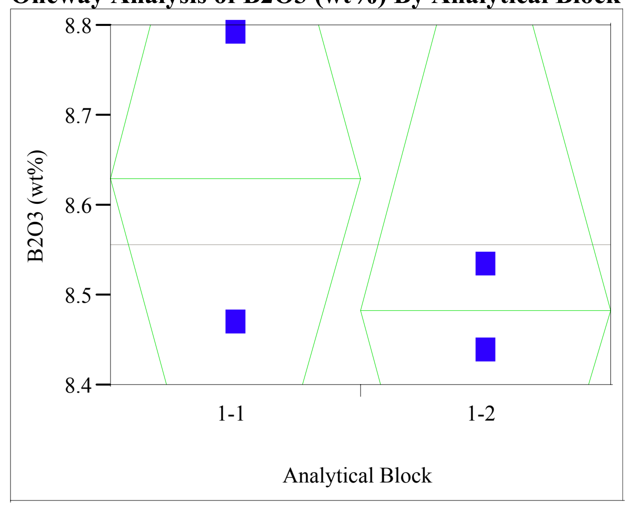
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	7.85656	0.08244	7.6277	8.0855
1-2	3	7.77069	0.08244	7.5418	7.9996

Std Error uses a pooled estimate of error variance

U std – B2O3 reference value 9.209 wt%

Oneway Analysis of B2O3 (wt%) By Analytical Block



Oneway Anova

Summary of Fit

Rsquare	0.270903
Adj Rsquare	-0.09365
Root Mean Square Error	0.168084
Mean of Response	8.556884
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Block	1	0.02099471	0.020995	0.7431	0.4795
Error	2	0.05650427	0.028252		
C. Total	3	0.07749898			

Means for Oneway Anova

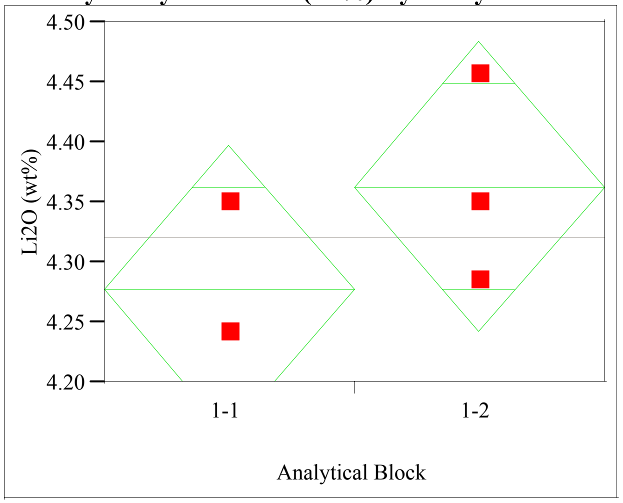
Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	8.62933	0.11885	8.1179	9.1407
1-2	2	8.48444	0.11885	7.9731	8.9958

Std Error uses a pooled estimate of error variance

Exhibit C.4: SRTC-ML Measurements by Analytical Block for Samples of the Standard Glasses Prepared Using the SP Method *(continued)*

Batch 1 – Li2O reference value 4.429 wt %

Oneway Analysis of Li2O (wt%) By Analytical Block



Oneway Anova

Summary of Fit

Rsquare	0.327273
Adj Rsquare	0.159091
Root Mean Square Error	0.075607
Mean of Response	4.320153
Observations (or Sum Wgts)	6

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Block	1	0.01112395	0.011124	1.9459	0.2355
Error	4	0.02286589	0.005716		
C. Total	5	0.03398984			

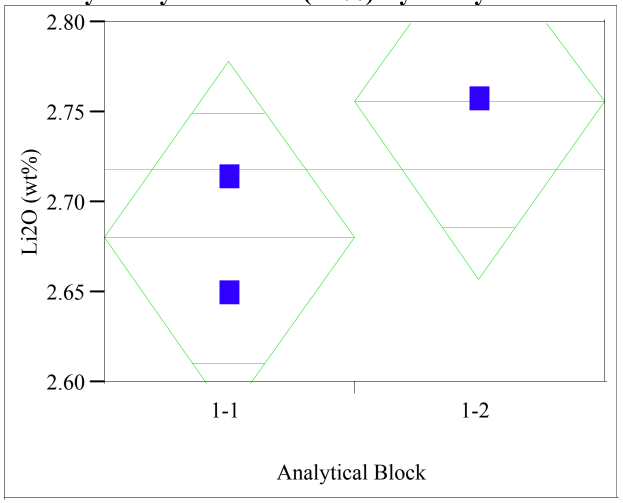
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	4.27709	0.04365	4.1559	4.3983
1-2	3	4.36321	0.04365	4.2420	4.4844

Std Error uses a pooled estimate of error variance

U std – Li2Oreference value 3.057 wt%

Oneway Analysis of Li2O (wt%) By Analytical Block



Oneway Anova

Summary of Fit

Rsquare	0.731343
Adj Rsquare	0.597015
Root Mean Square Error	0.032294
Mean of Response	2.718036
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Block	1	0.00567785	0.005678	5.4444	0.1448
Error	2	0.00208574	0.001043		
C. Total	3	0.00776359			

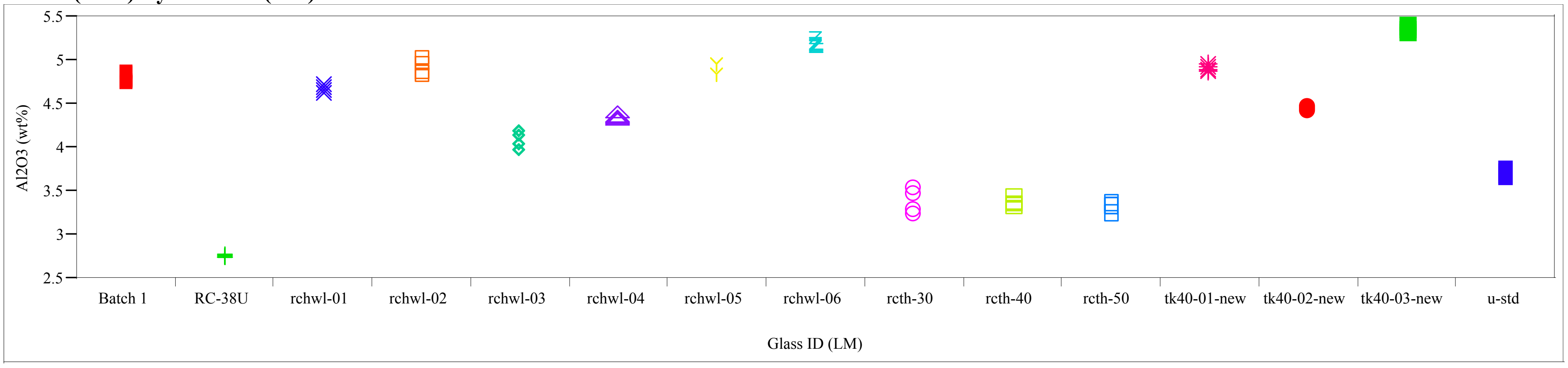
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	2.68036	0.02283	2.5821	2.7786
1-2	2	2.75571	0.02283	2.6575	2.8540

Std Error uses a pooled estimate of error variance

Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method

Al2O3 (wt%) By Glass ID (LM)



Al2O3 bc (wt%) By Glass ID (LM)

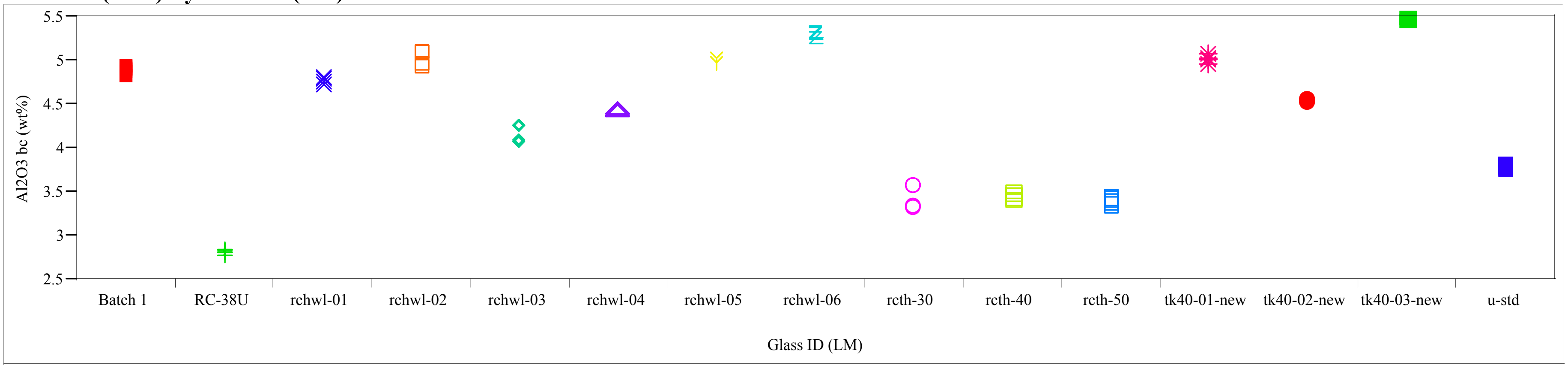
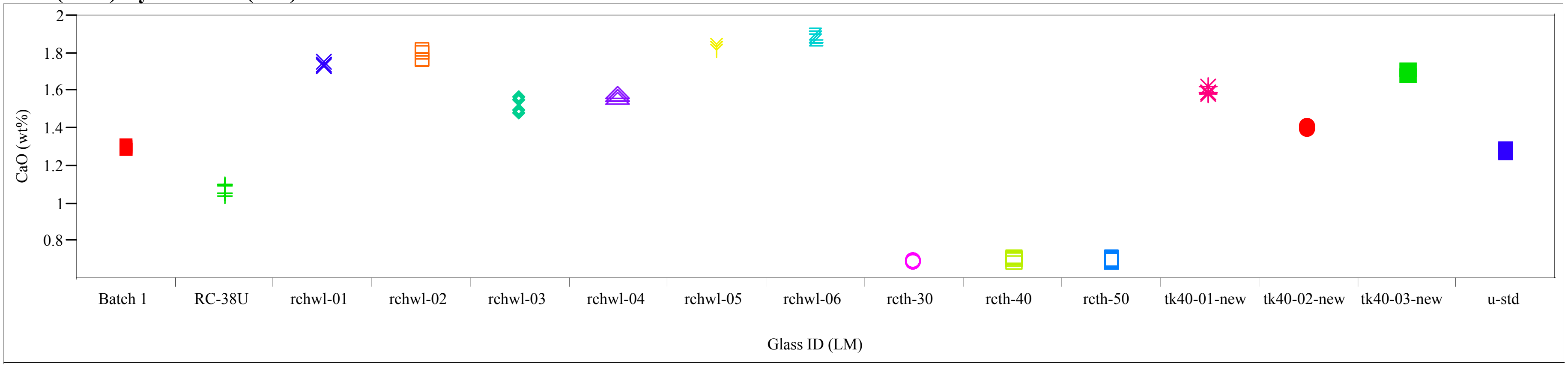


Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method *(continued)*

CaO (wt%) By Glass ID (LM)



CaO bc (wt%) By Glass ID (LM)

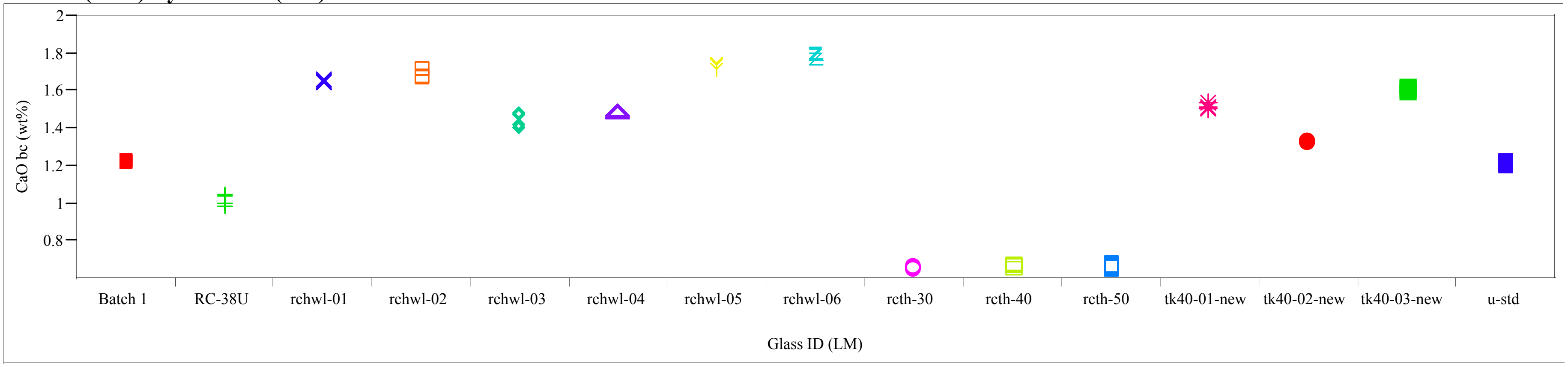
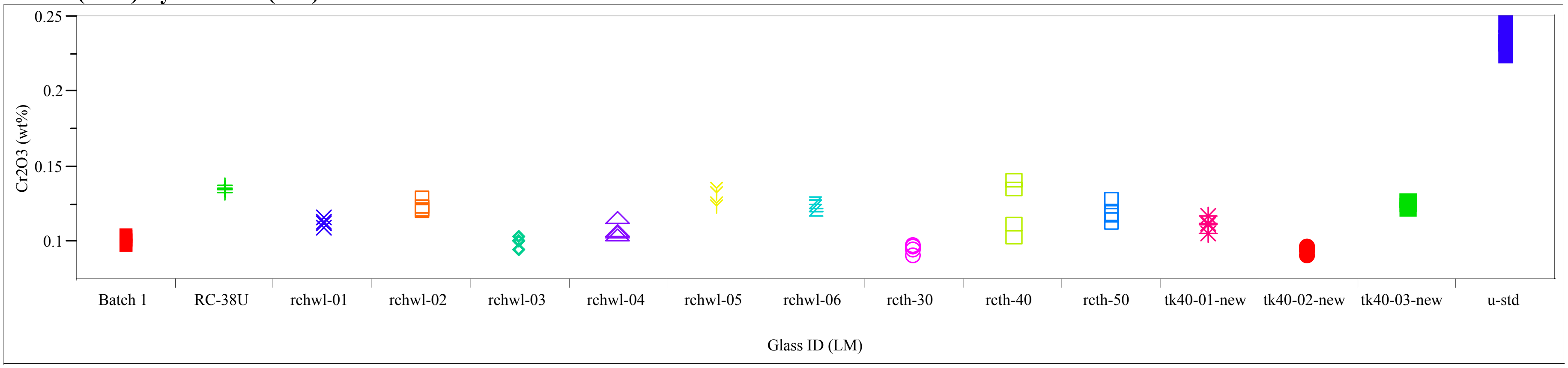


Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method *(continued)*

Cr2O3 (wt%) By Glass ID (LM)



Cr2O3 bc (wt%) By Glass ID (LM)

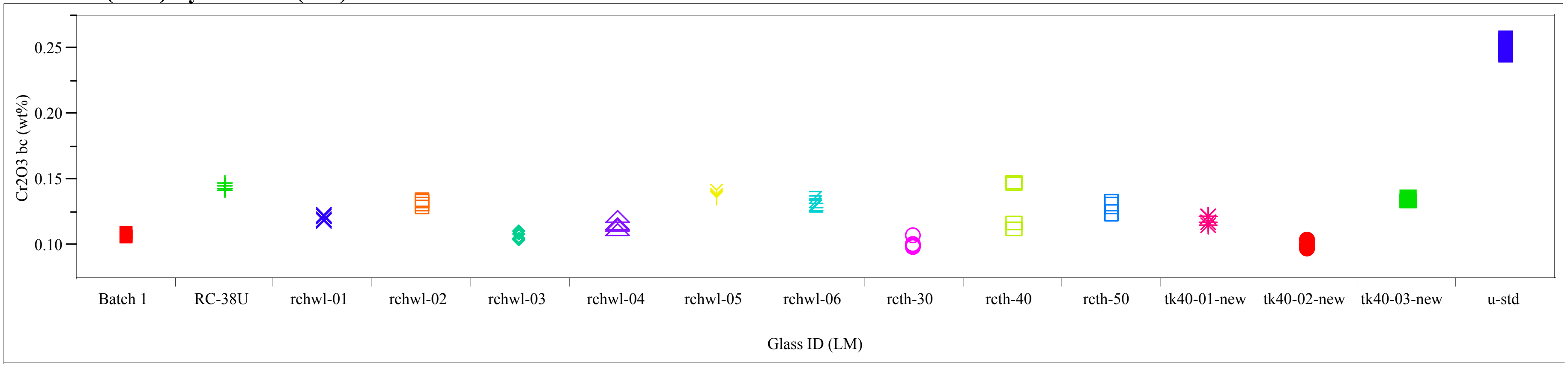
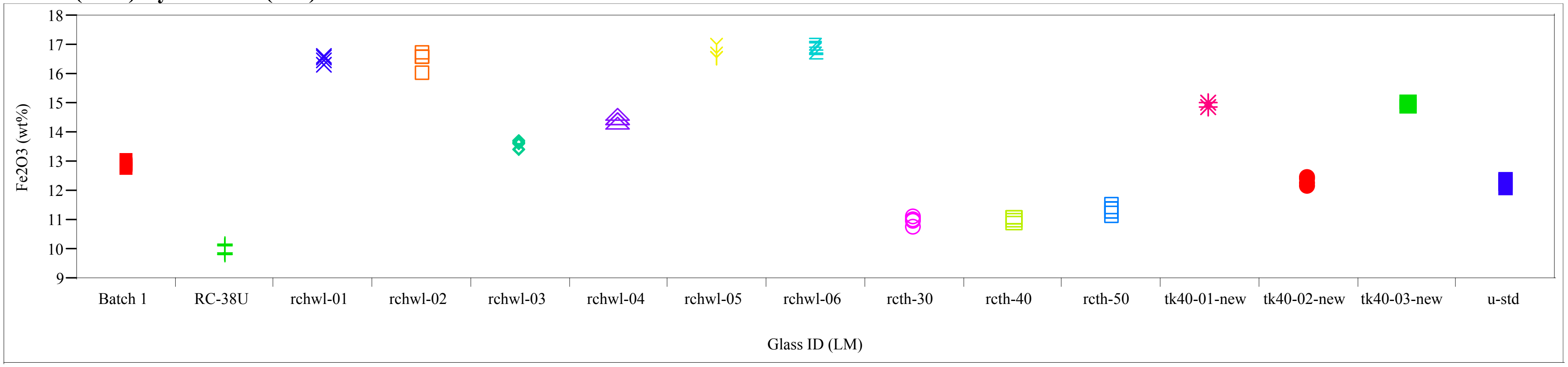


Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method *(continued)*

Fe2O3 (wt%) By Glass ID (LM)



Fe2O3 bc (wt%) By Glass ID (LM)

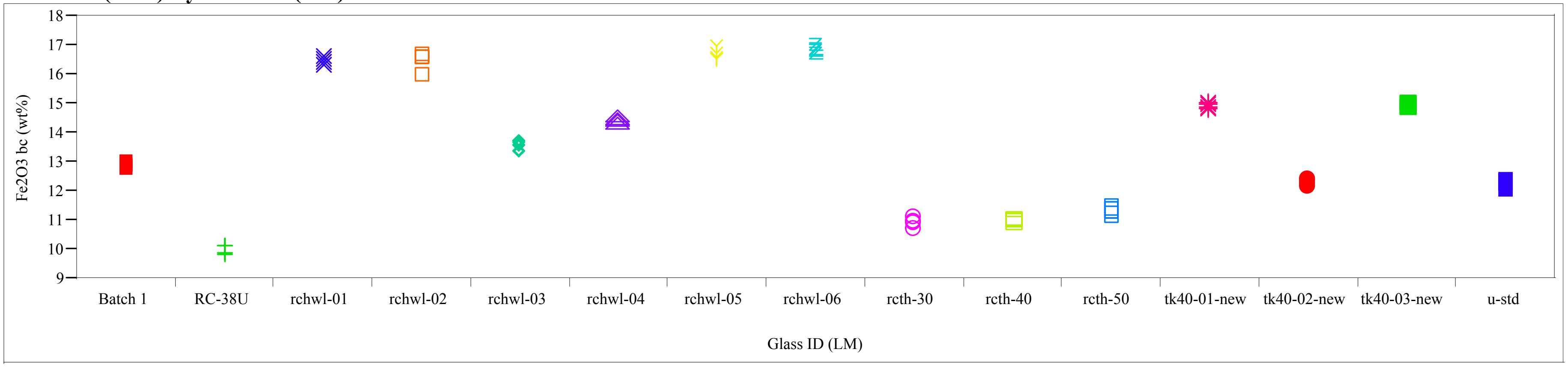
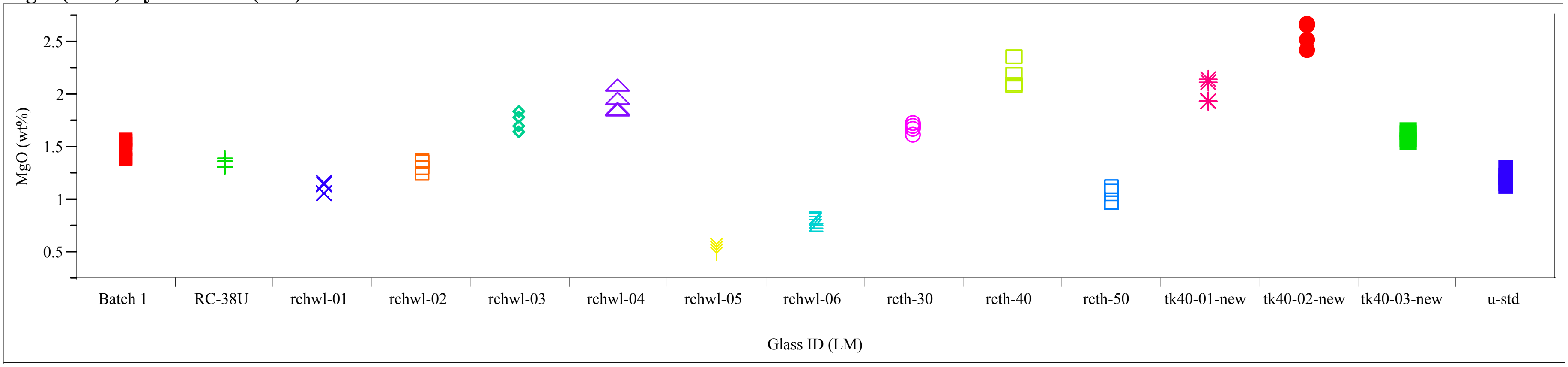


Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method *(continued)*

MgO (wt%) By Glass ID (LM)



MgO bc (wt%) By Glass ID (LM)

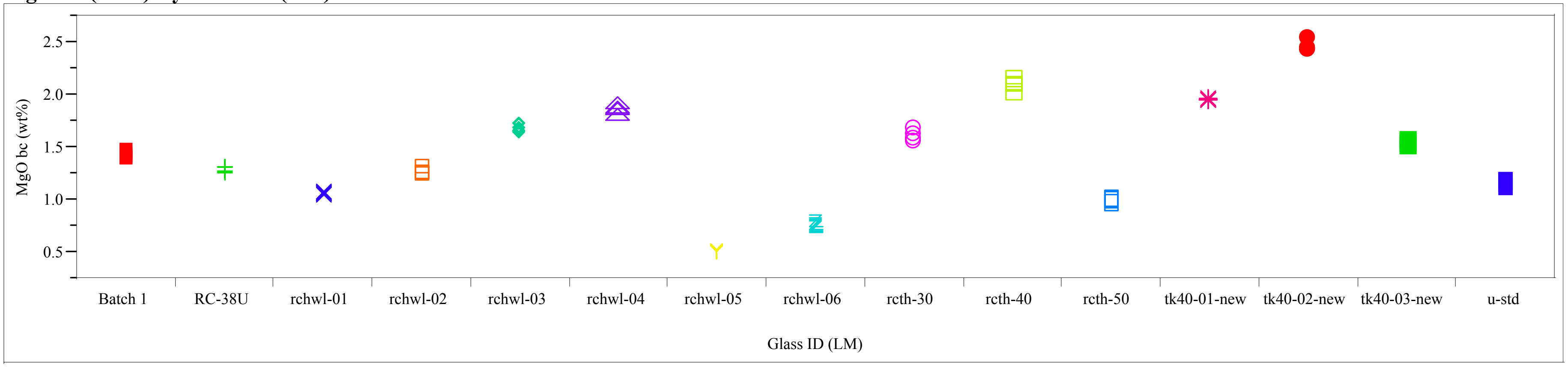
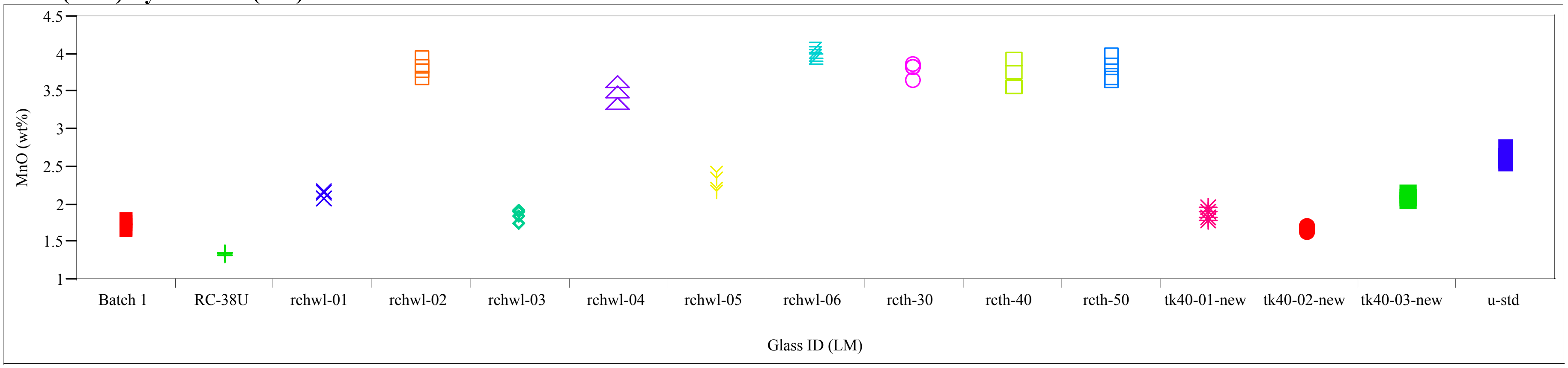


Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method *(continued)*

MnO (wt%) By Glass ID (LM)



MnO bc (wt%) By Glass ID (LM)

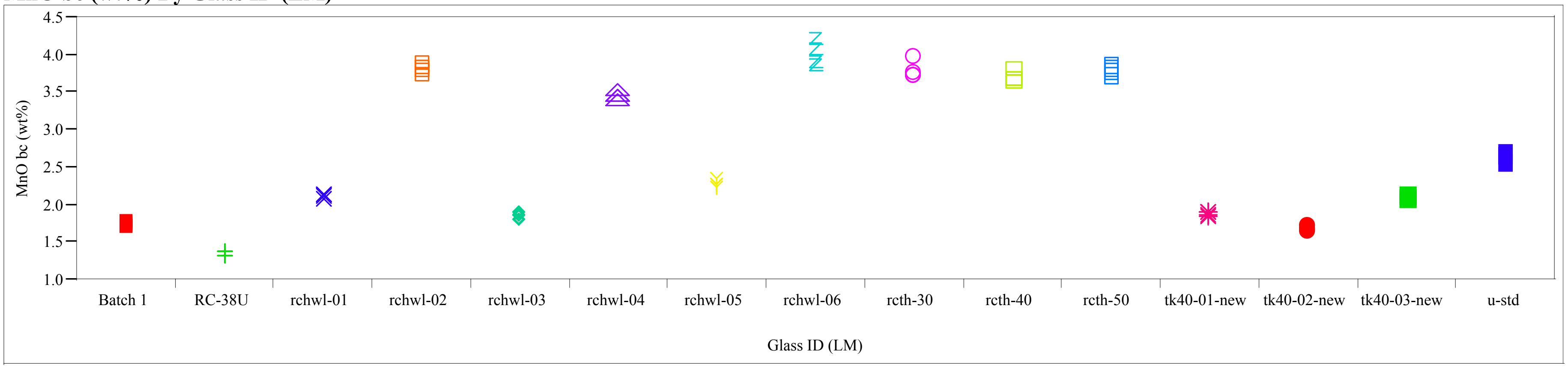
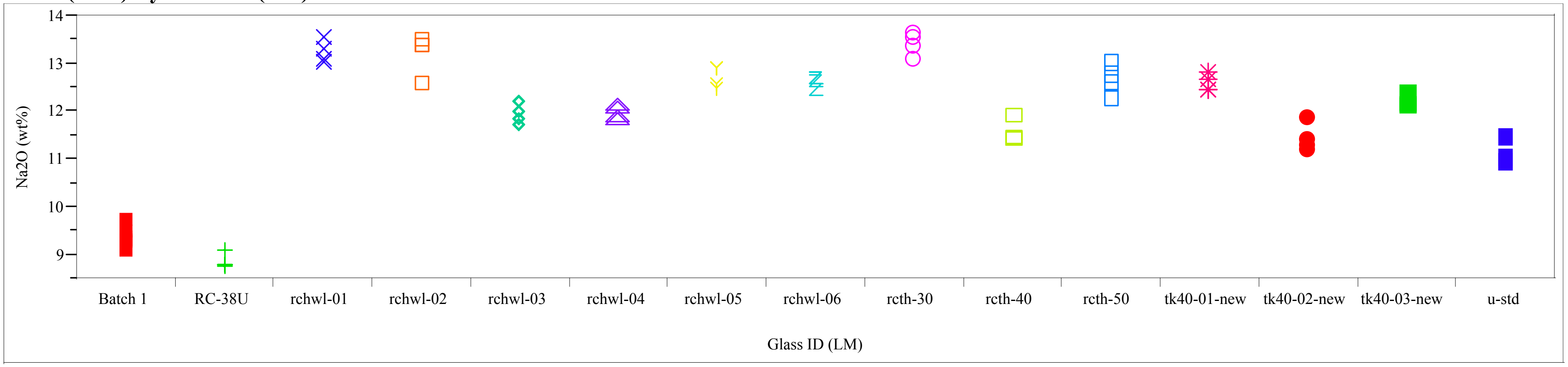


Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method *(continued)*

Na2O (wt%) By Glass ID (LM)



Na2O bc (wt%) By Glass ID (LM)

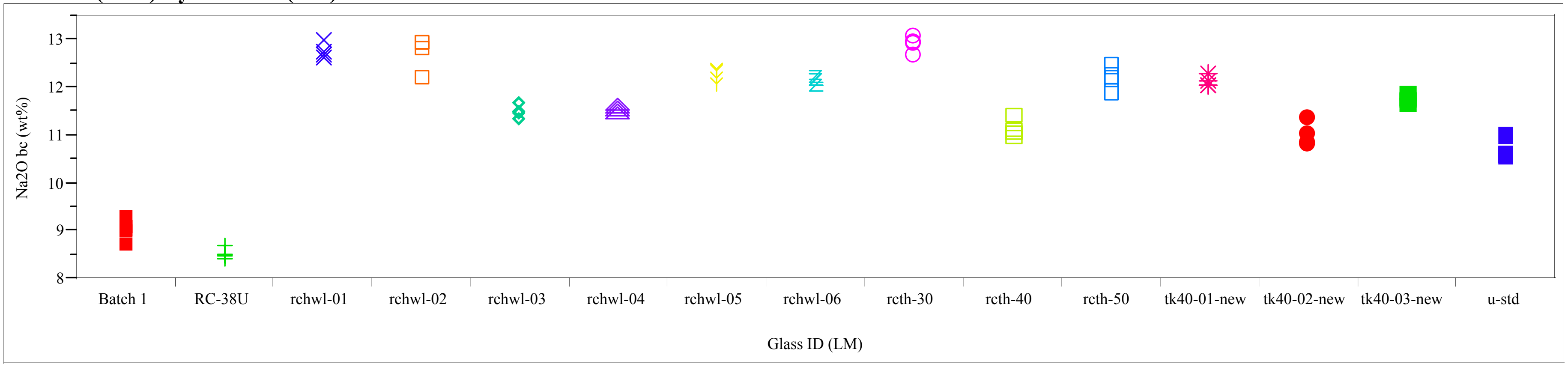
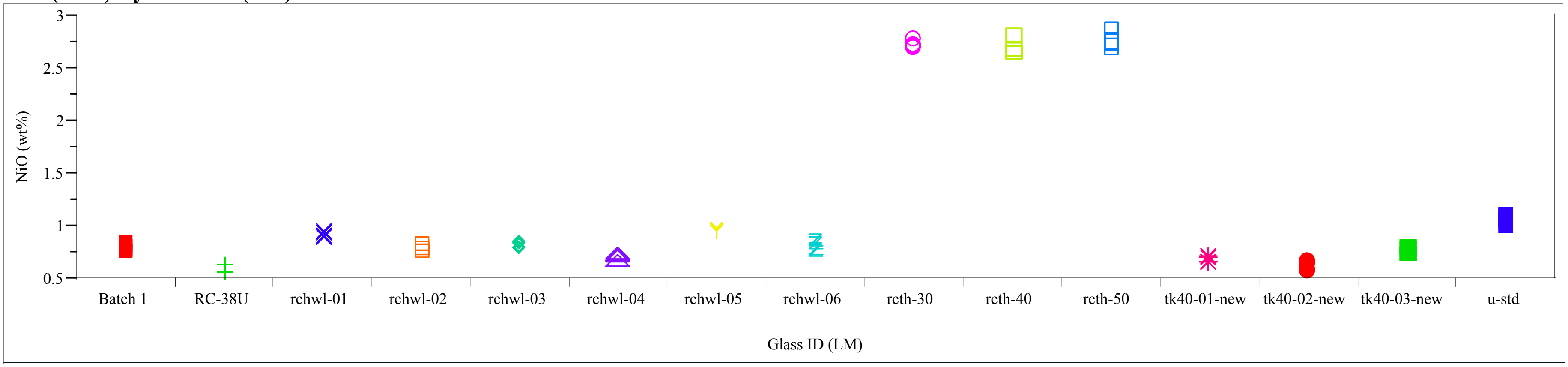


Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method *(continued)*

NiO (wt%) By Glass ID (LM)



NiO bc (wt%) By Glass ID (LM)

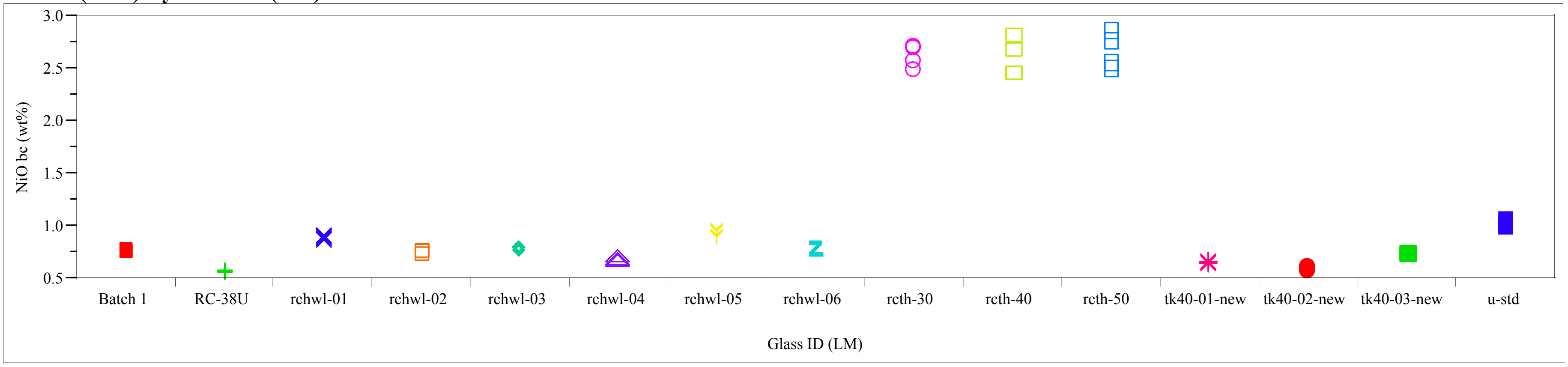
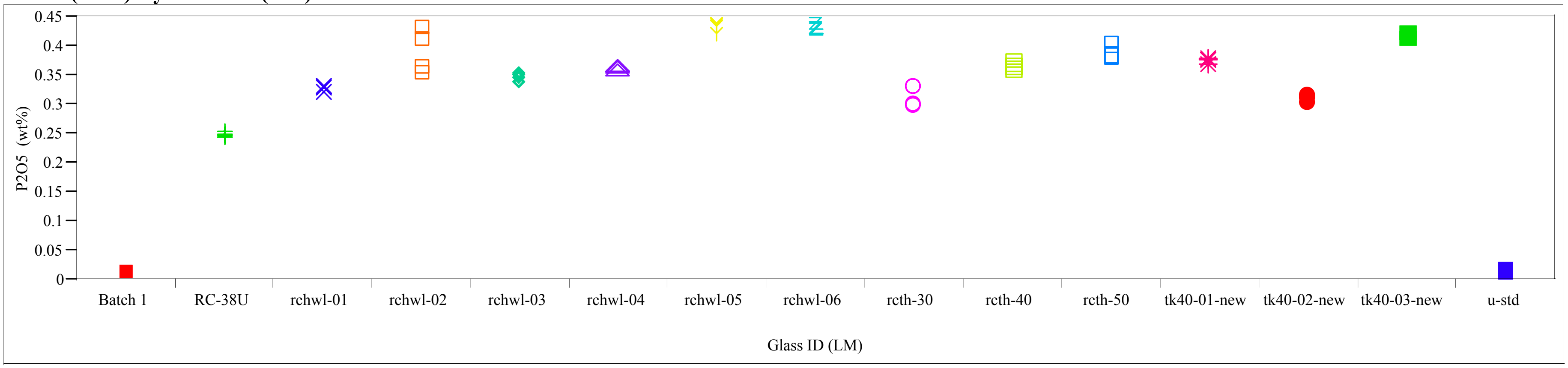


Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method *(continued)*

P2O5 (wt%) By Glass ID (LM)



P2O5 bc (wt%) By Glass ID (LM)

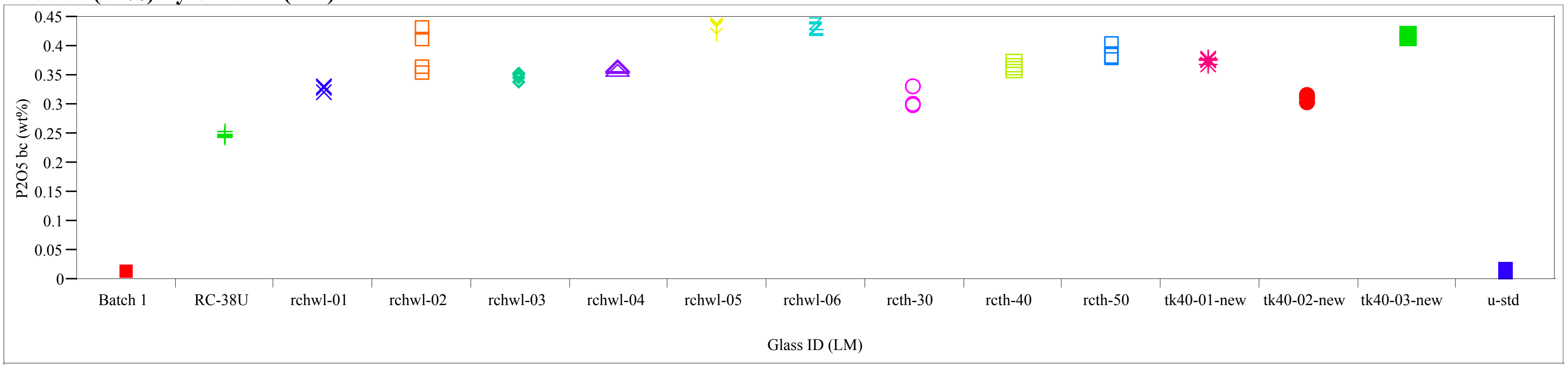
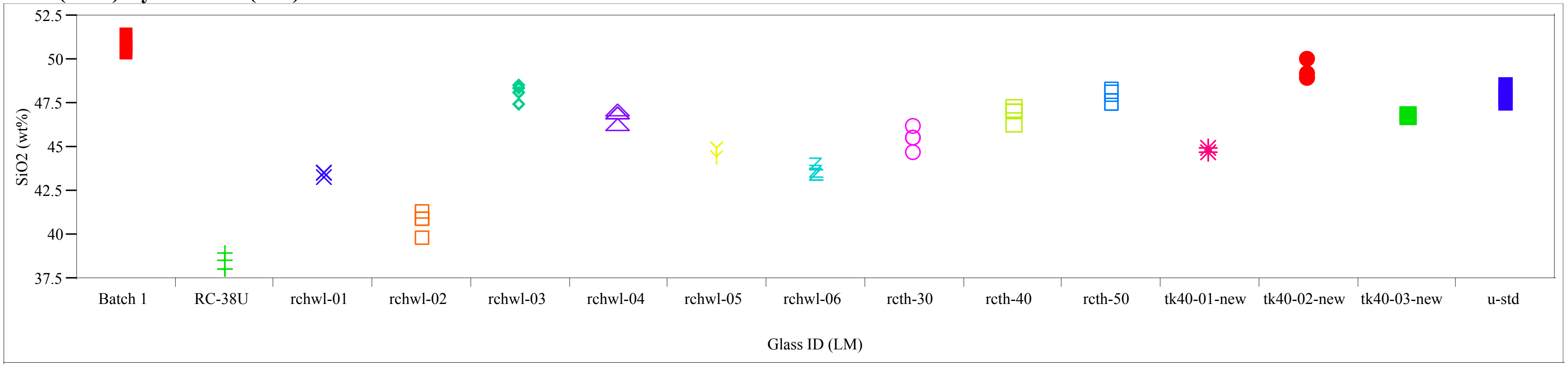


Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method *(continued)*

SiO2 (wt%) By Glass ID (LM)



SiO2 bc (wt%) By Glass ID (LM)

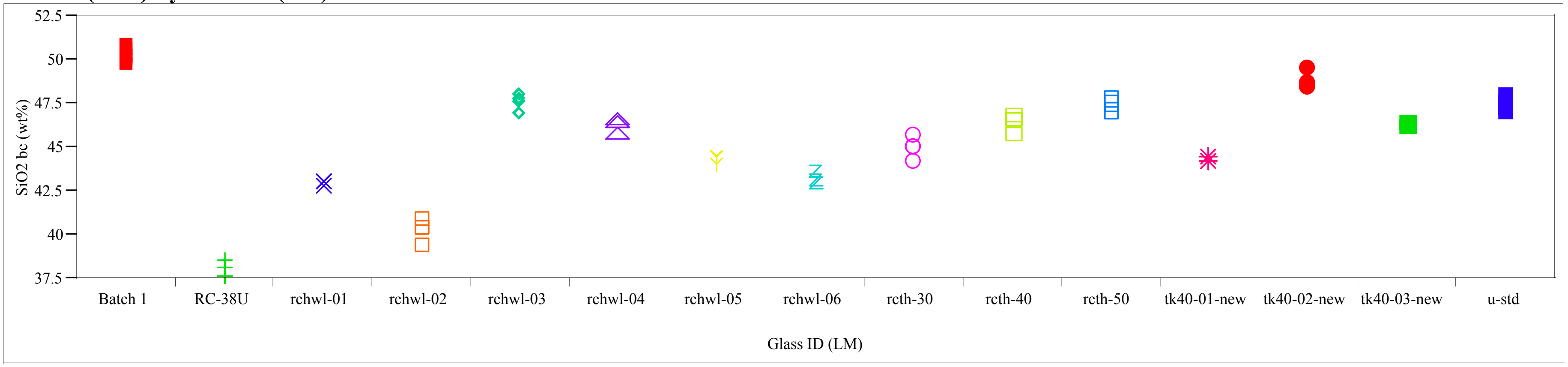
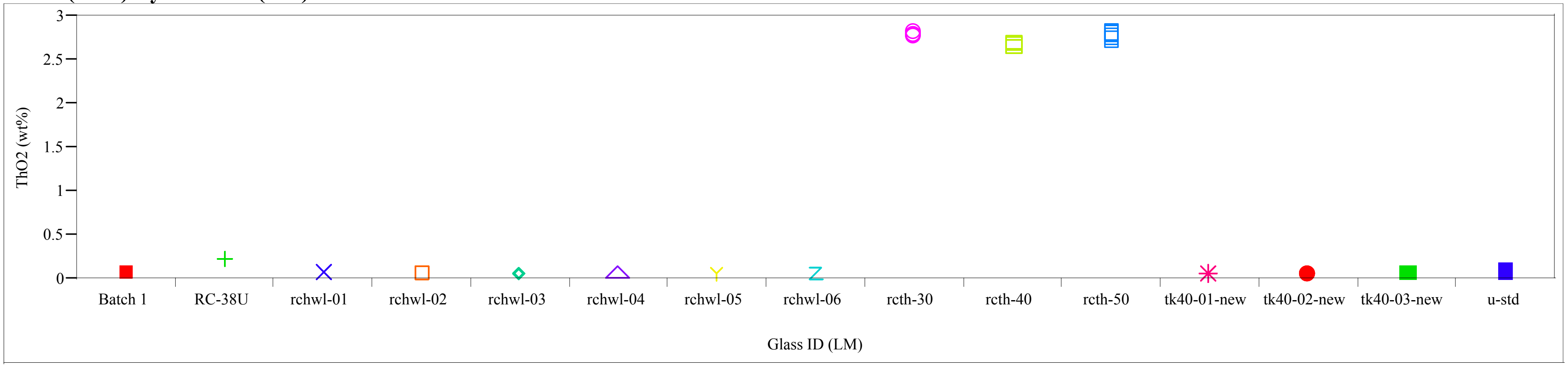


Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method *(continued)*

ThO2 (wt%) By Glass ID (LM)



ThO2 bc (wt%) By Glass ID (LM)

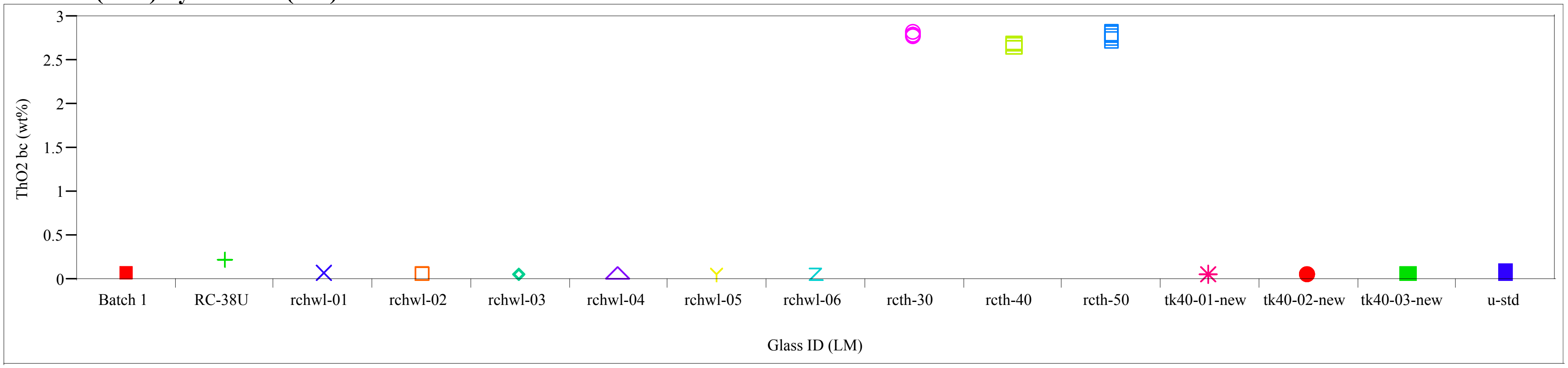
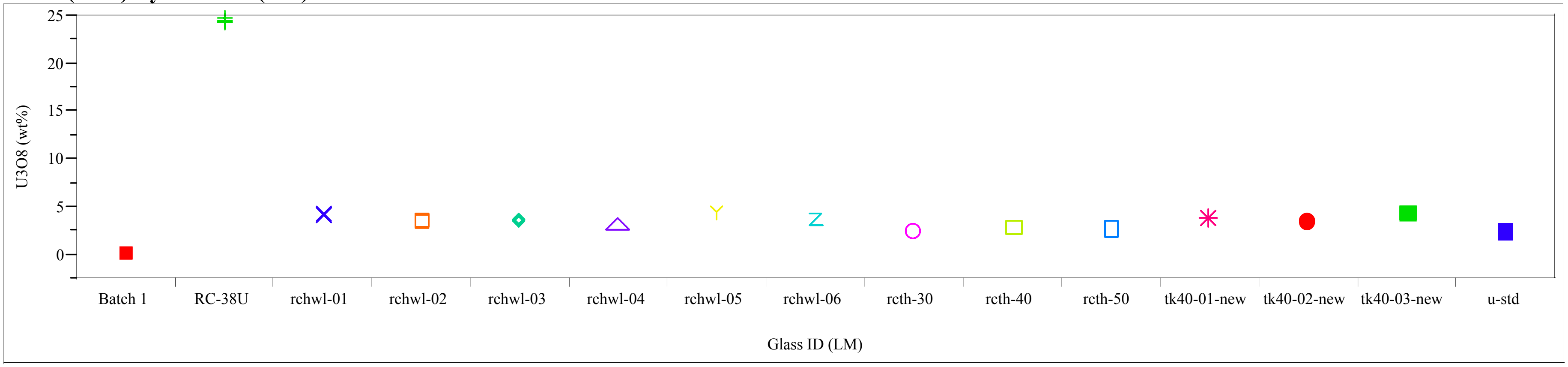


Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method *(continued)*

U3O8 (wt%) By Glass ID (LM)



U3O8 bc (wt%) By Glass ID (LM)

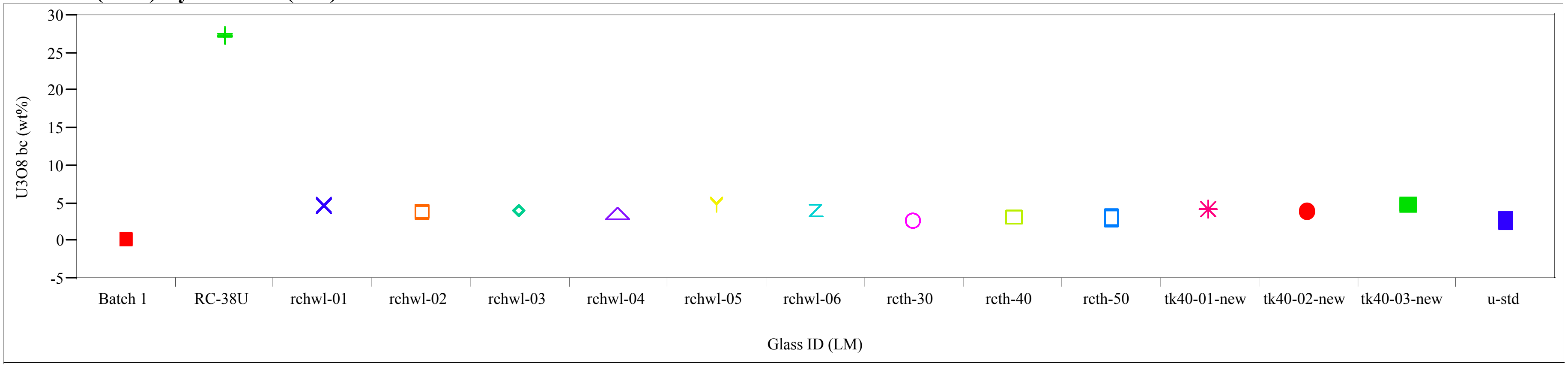
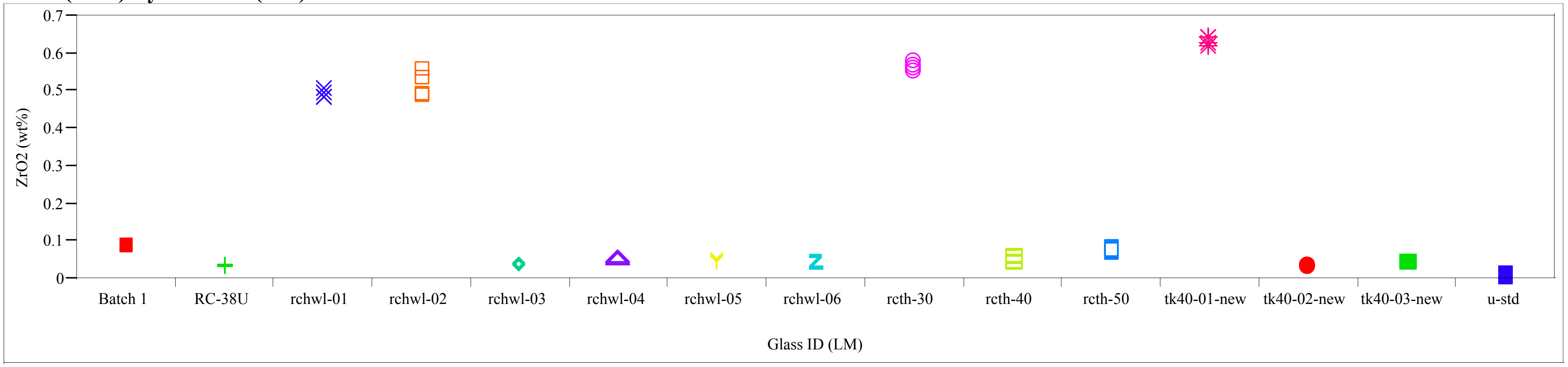


Exhibit C.5: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the LM Method *(continued)*

ZrO2 (wt%) By Glass ID (LM)



ZrO2 bc (wt%) By Glass ID (LM)

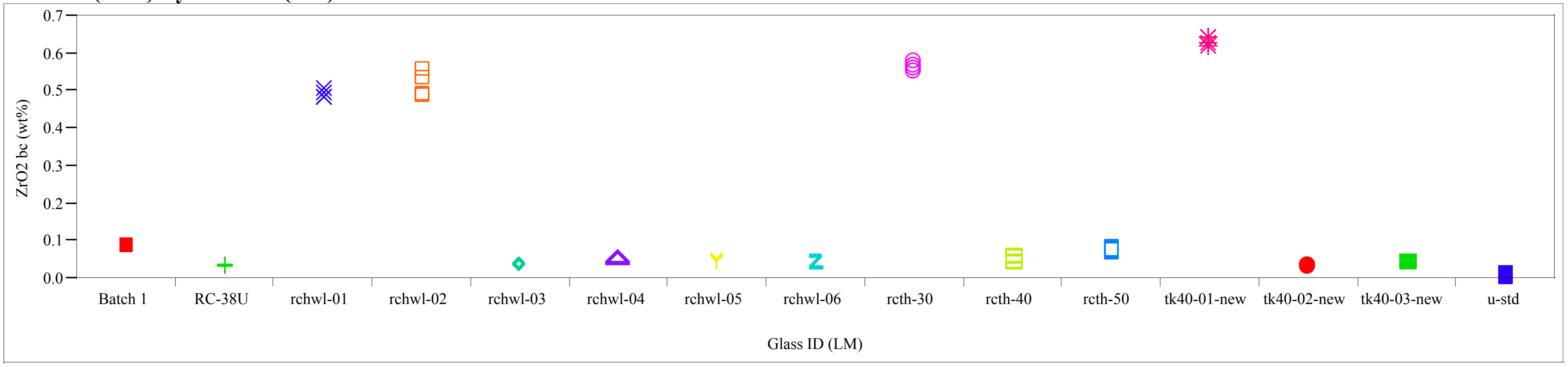
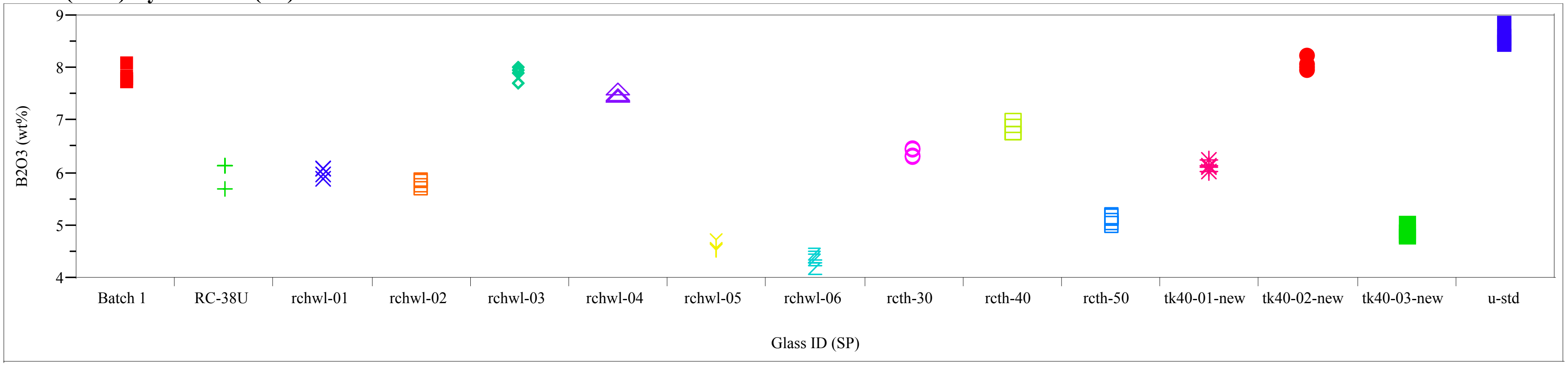


Exhibit C.6: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the SP Method

B2O3 (wt%) By Glass ID (SP)



B2O3 bc (wt%) By Glass ID (SP)

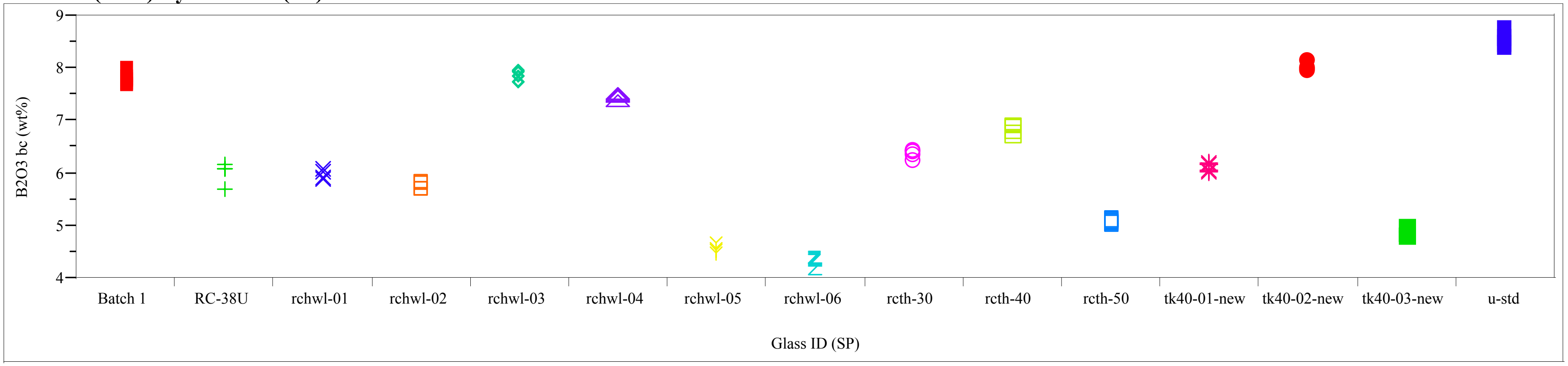


Exhibit C.6: SRTC-ML Measurements by Study Glass ID for Samples Prepared Using the SP Method *(continued)*

Li2O (wt%) By Glass ID (SP)

Li2O bc (wt%) By Glass ID (SP)

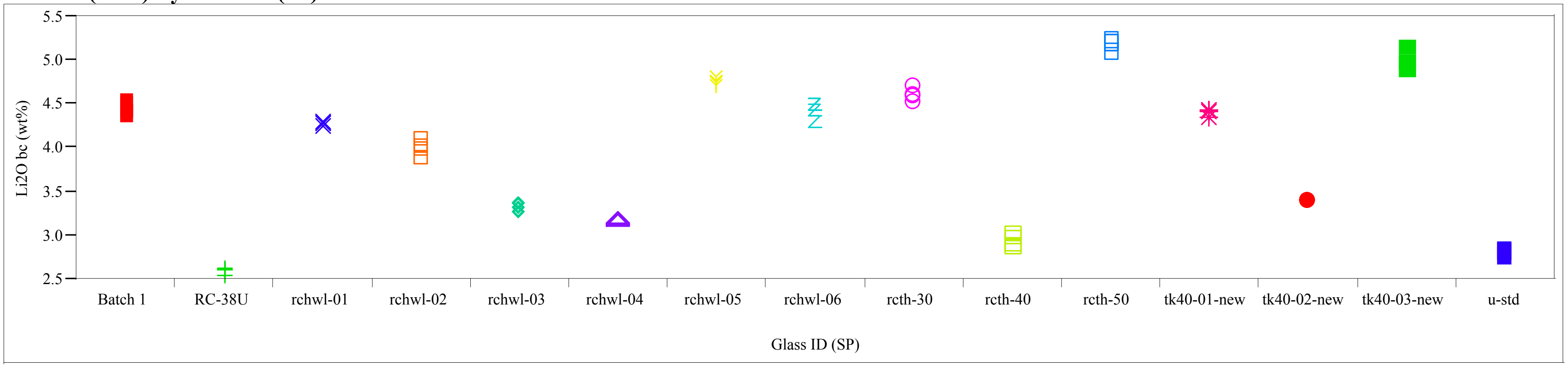
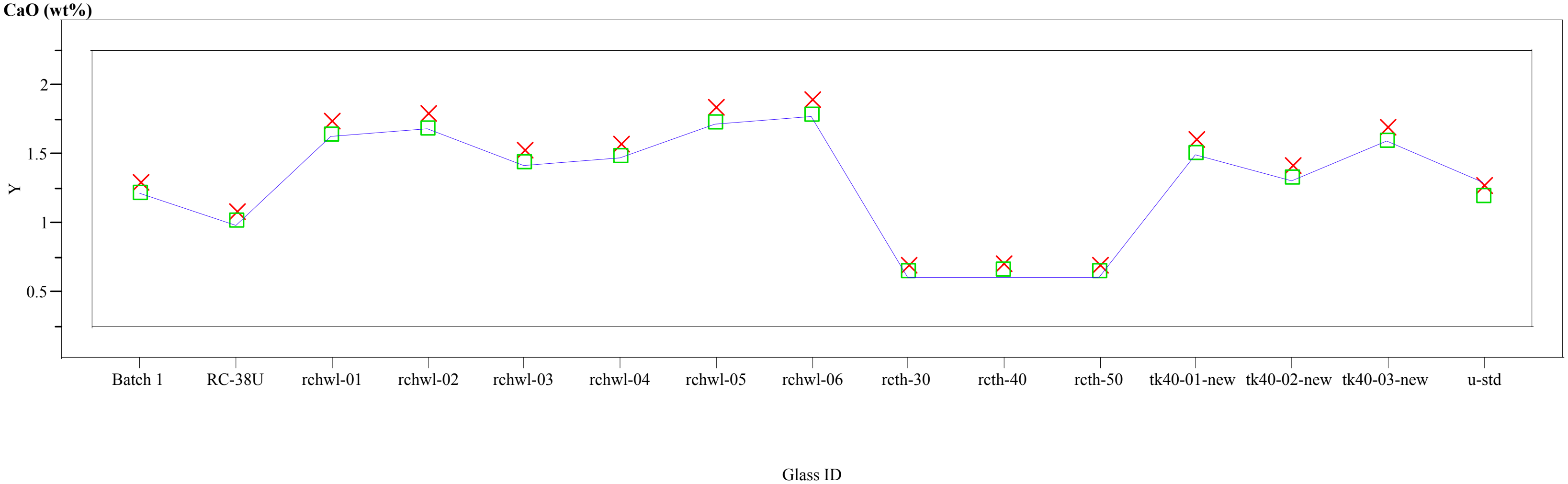


Exhibit C.7: Average Measured and Bias-Corrected (bc) Versus Targeted Compositions by Study Glass ID by Oxide

Exhibit C.7: Average Measured and Bias-Corrected (bc) Versus Targeted Compositions by Study Glass ID by Oxide *(continued)*

CaO (wt%)



Cr2O3 (wt%)

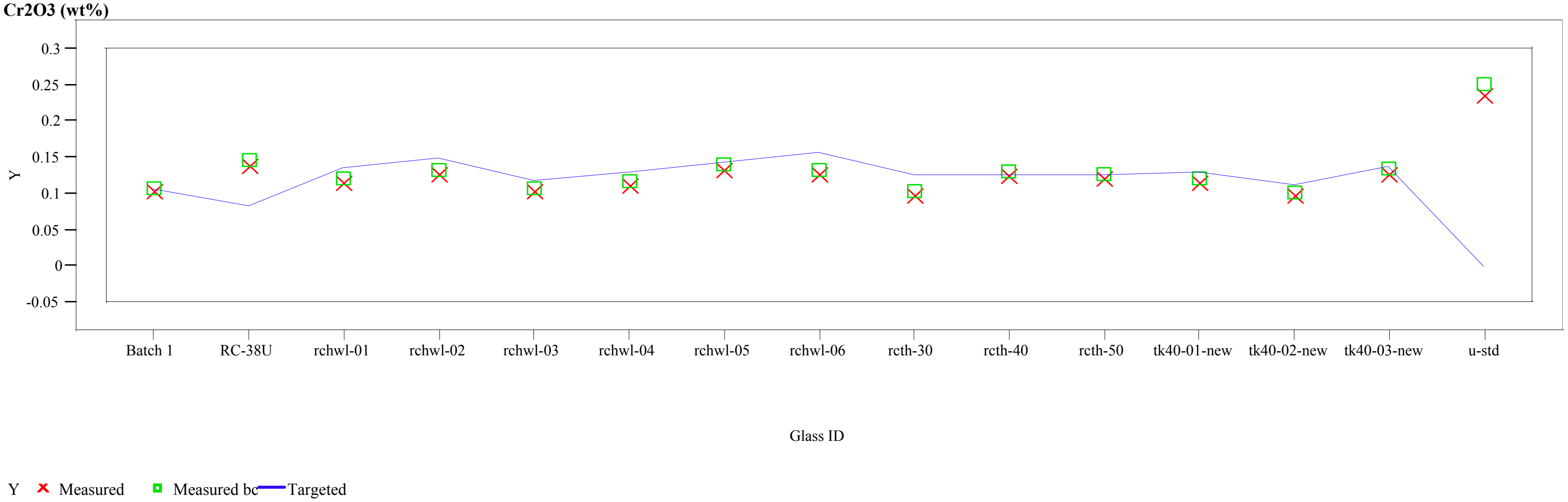
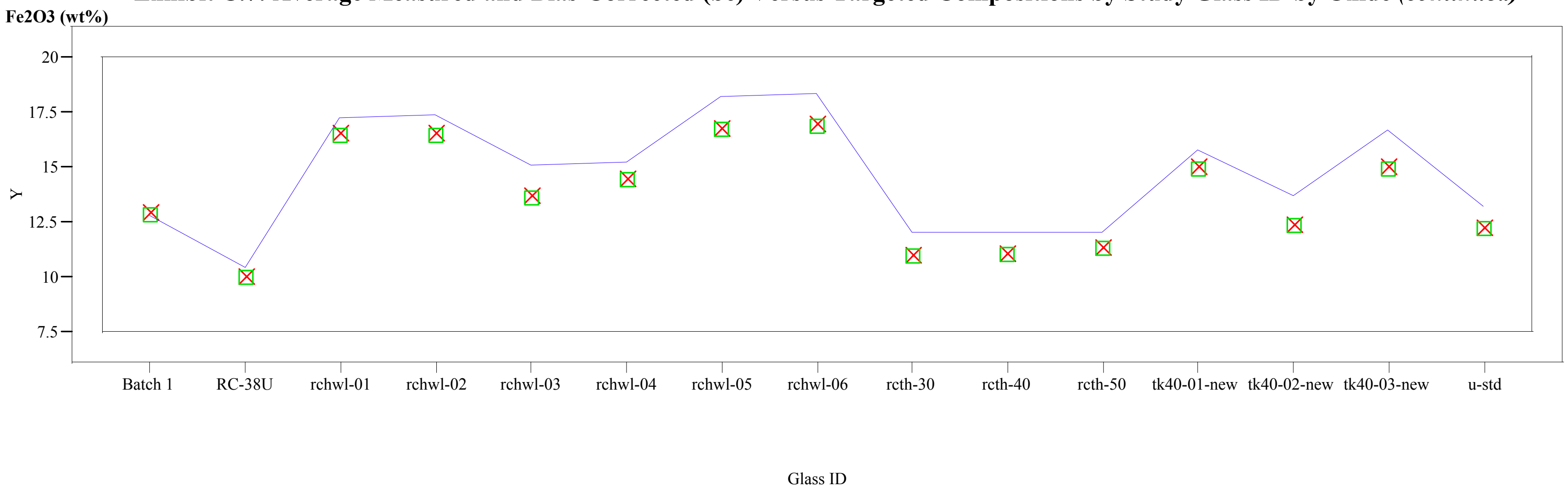


Exhibit C.7: Average Measured and Bias-Corrected (bc) Versus Targeted Compositions by Study Glass ID by Oxide *(continued)*



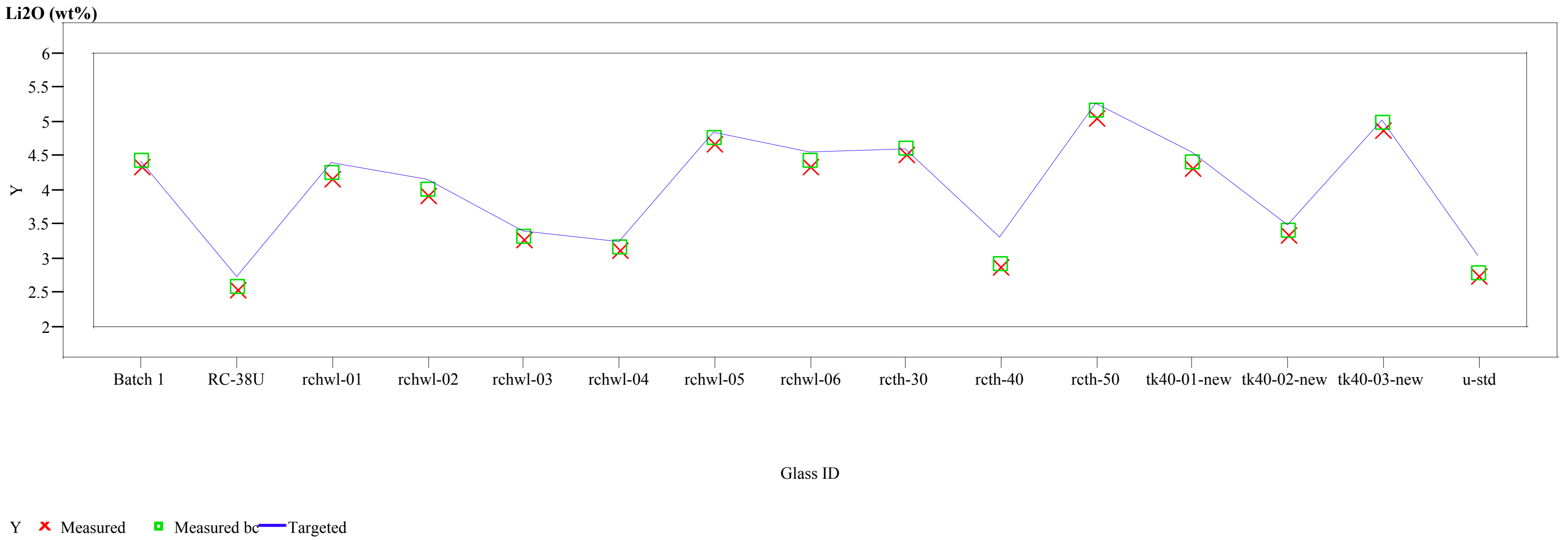
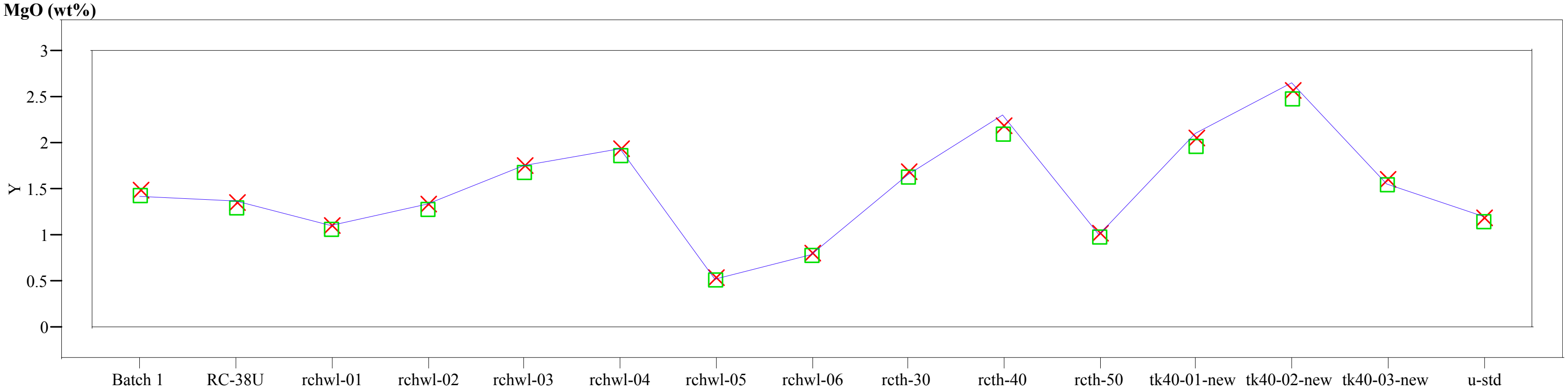


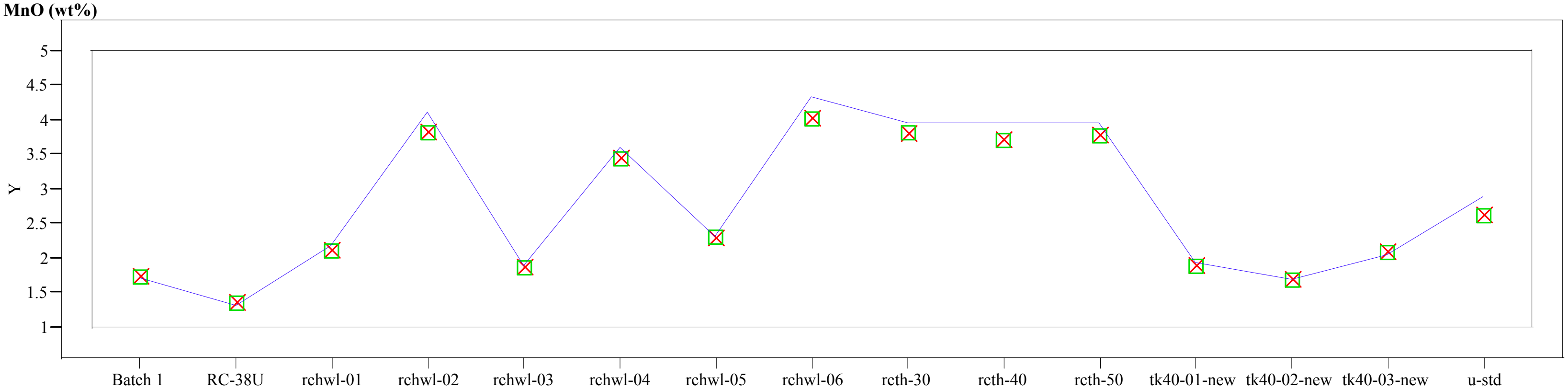
Exhibit C.7: Average Measured and Bias-Corrected (bc) Versus Targeted Compositions by Study Glass ID by Oxide *(continued)*

MgO (wt%)



Glass ID

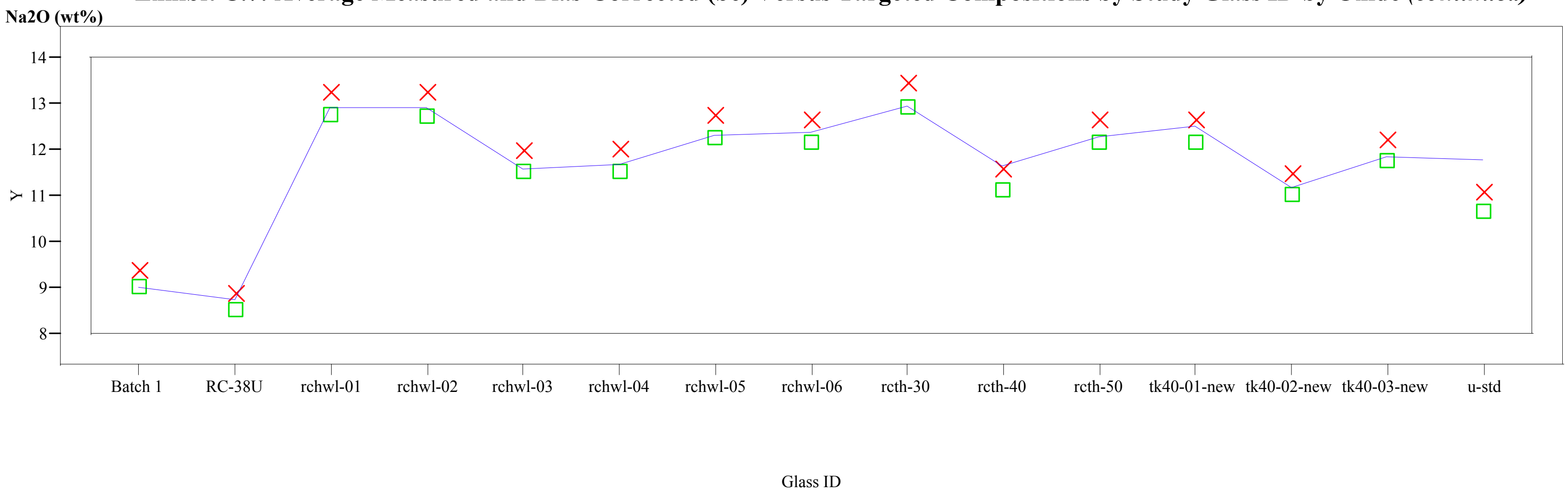
MnO (wt%)

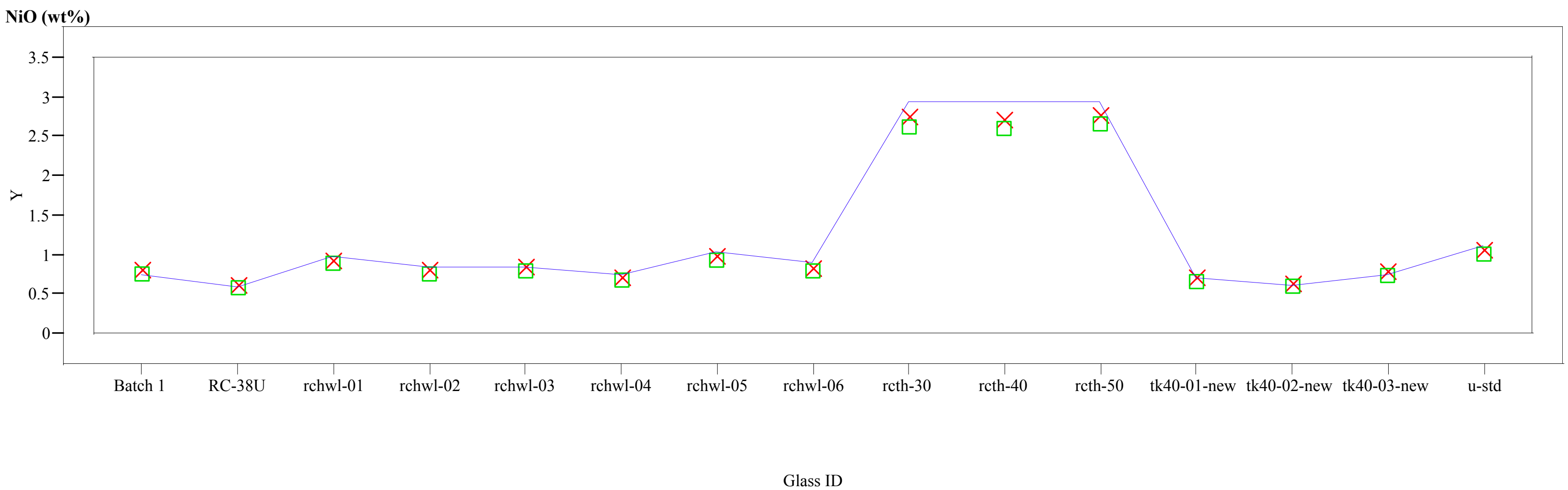


Glass ID

Y × Measured ▫ Measured bc — Targeted

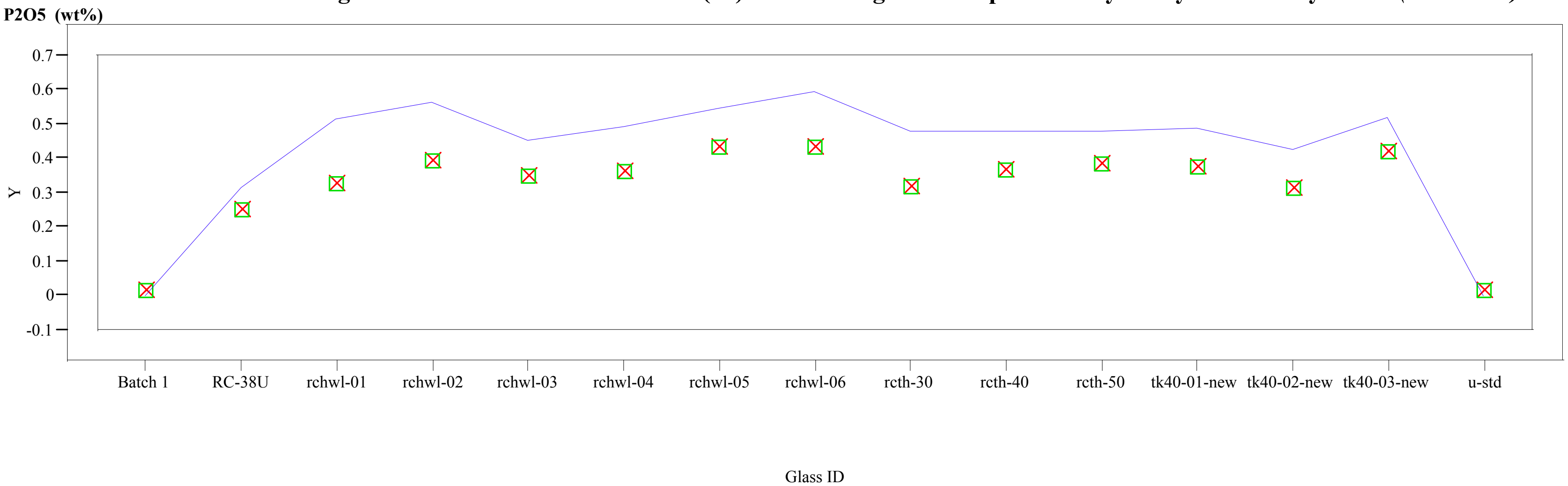
Exhibit C.7: Average Measured and Bias-Corrected (bc) Versus Targeted Compositions by Study Glass ID by Oxide *(continued)*





Y ✕ Measured ▫ Measured bc — Targeted

Exhibit C.7: Average Measured and Bias-Corrected (bc) Versus Targeted Compositions by Study Glass ID by Oxide *(continued)*



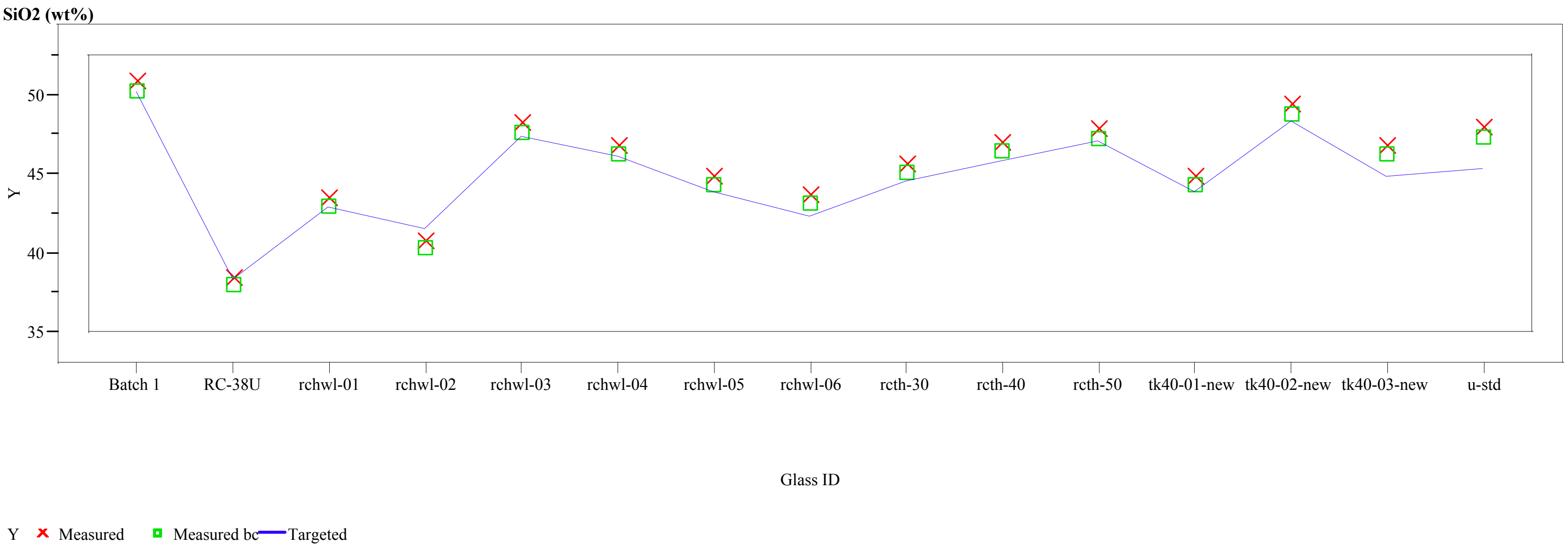
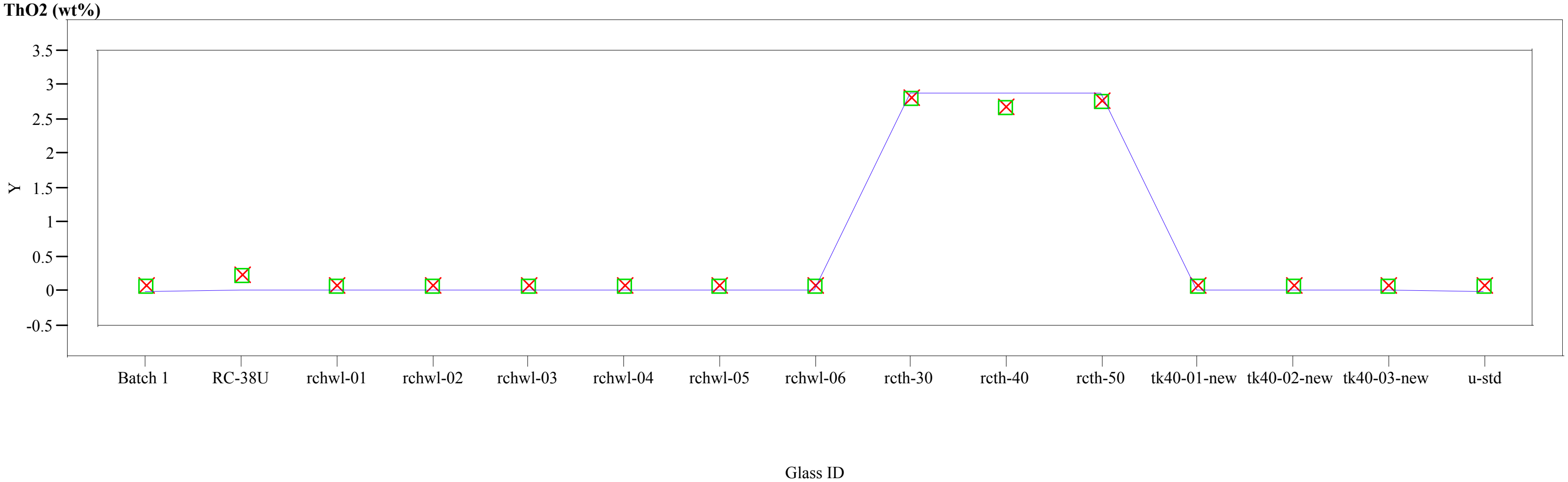


Exhibit C.7: Average Measured and Bias-Corrected (bc) Versus Targeted Compositions by Study Glass ID by Oxide *(continued)*



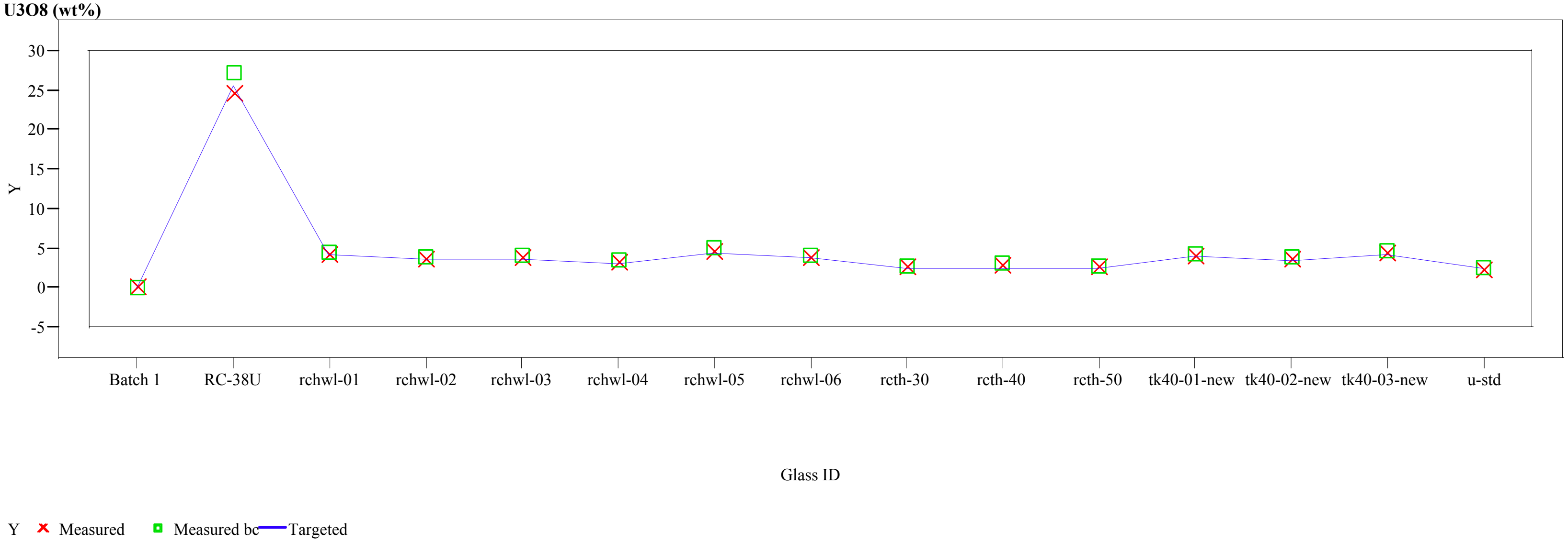
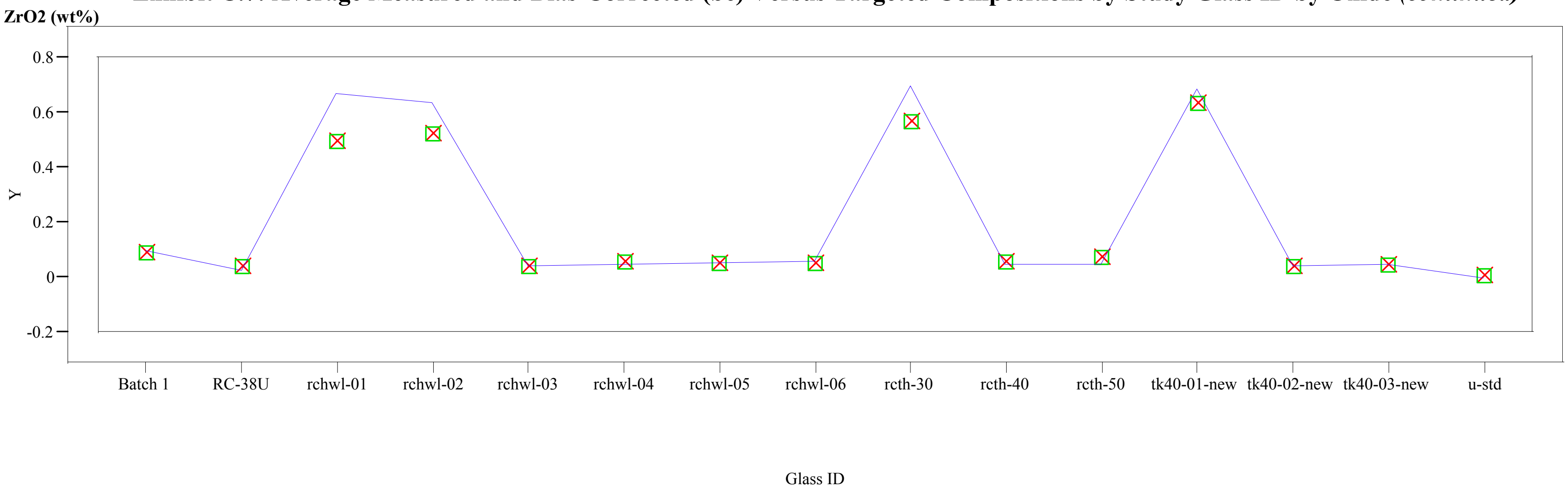
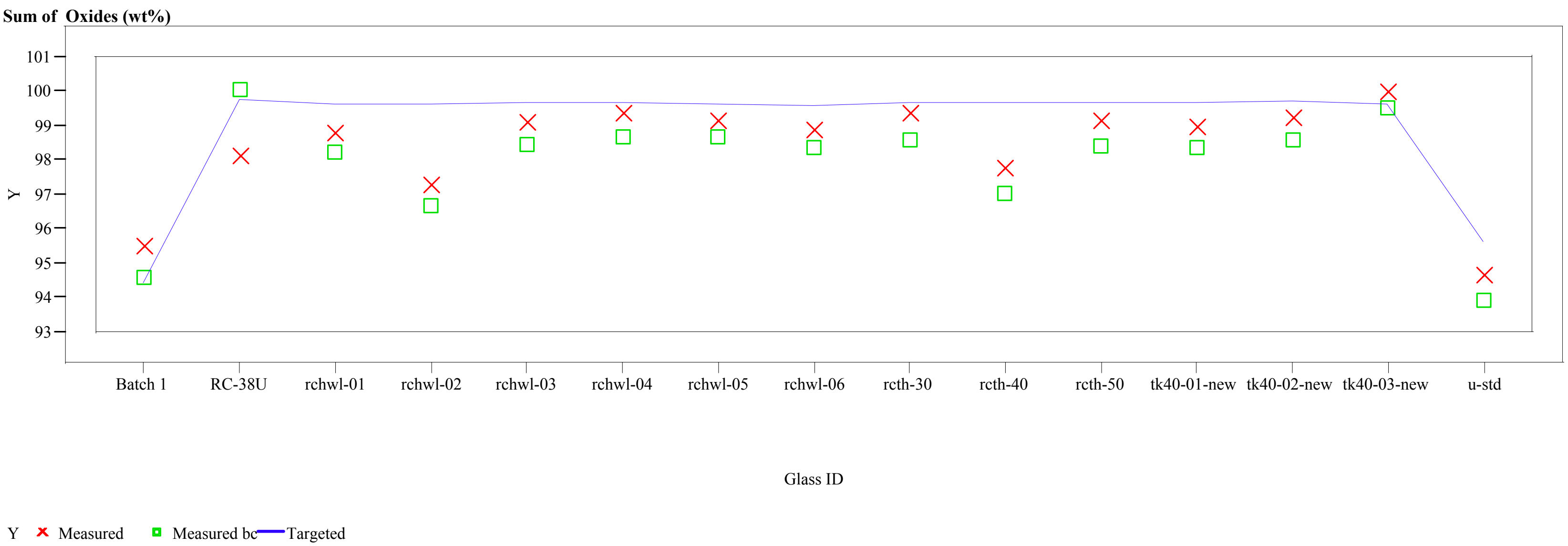


Exhibit C.7: Average Measured and Bias-Corrected (bc) Versus Targeted Compositions by Study Glass ID by Oxide *(continued)*





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Appendix D:

Tables and Exhibits Supporting the Analysis of the PCT Results for the Study Glasses

Table D.1: SRTC-ML Measurements of the PCT Solutions for the Study Glasses and Standards

ID	Block	#	ID	Al	B	Ca	Cr	Fe	Li	Mg	Mn	Na	Ni	P	Th	Si	U	Zr
soln std	1	1	std-b1-1	3.85	19.7	<0.006	<0.002	3.89	9.73	<0.004	<0.001	83.6	<0.010	<0.100	49.6	<0.100	<0.087	<0.001
rchwl-06	1	2	p30	8.26	12.6	0.232	<0.002	6.73	18.6	0.084	1.25	78.1	<0.010	1.75	97.1	0.108	2.31	<0.001
RC-38U	1	3	p70	2.38	30.7	0.062	<0.002	3.80	18.6	0.324	0.224	58.4	<0.010	1.45	94.4	<0.100	2.40	<0.001
RC-38Uccc	1	4	p49	4.29	18.2	0.062	<0.002	4.99	13.3	0.559	0.449	38.0	<0.010	0.884	84.5	0.093	2.32	<0.001
rchwl-04	1	5	p71	3.23	17.1	0.056	<0.002	2.30	9.83	0.108	0.292	55.6	<0.010	1.16	74.9	<0.100	2.44	<0.001
rchwl-06ccc	1	6	p85	9.64	10.0	0.526	<0.002	5.53	17.2	0.238	1.63	70.7	<0.010	1.41	92.9	<0.100	1.86	<0.001
blank	1	7	p41	0.017	0.215	<0.006	<0.002	<0.004	0.064	<0.004	<0.001	<0.100	<0.010	<0.100	<0.790	<0.100	<0.087	<0.001
rchwl-02	1	8	p55	6.17	17.0	0.142	<0.002	5.00	16.8	0.310	1.13	82.9	<0.010	1.72	86.7	0.112	2.95	0.034
soln std	1	9	std-bl-2	3.85	20.0	<0.006	<0.002	3.86	9.77	<0.004	<0.001	85.8	<0.010	<0.100	50.4	<0.100	<0.087	<0.001
tk40-01-newccc	1	10	p34	6.35	15.6	0.134	<0.002	5.19	15.6	0.405	0.431	64.1	<0.010	1.32	81.3	0.141	1.75	0.081
rcth-40	1	11	p25	0.889	56.5	<0.006	<0.002	1.14	31.7	0.260	0.575	146	0.182	3.57	142	<0.100	2.01	<0.001
rchwl-02ccc	1	12	p39	7.51	11.2	0.294	<0.002	4.61	12.0	0.533	1.55	60.5	<0.010	1.15	72.1	0.101	2.23	0.105
tk40-03-newccc	1	13	p23	11.3	11.9	0.689	0.013	14.3	18.5	1.59	2.61	62.5	0.130	1.41	97.4	0.115	2.38	0.006
rchwl-04ccc	1	14	p67	7.59	30.3	0.051	<0.002	5.04	14.9	1.07	3.35	67.3	<0.010	1.17	71.6	0.100	2.08	<0.001
tk40-01-new	1	15	p06	5.23	18.1	0.147	<0.002	5.06	17.1	0.483	0.488	73.8	0.024	1.48	86.2	<0.100	1.94	0.036
tk40-03-new	1	16	p20	6.51	14.4	0.188	<0.002	5.22	20.0	0.182	0.403	73.0	<0.010	1.63	101	<0.100	1.94	<0.001
rcth-40ccc	1	17	p28	0.521	70.0	<0.006	<0.002	0.324	41.0	<0.004	0.146	178	<0.010	4.42	191	0.258	2.43	<0.001
soln std	1	18	std-bl-3	3.82	19.9	<0.006	<0.002	3.84	9.69	<0.004	<0.001	82.4	<0.010	<0.100	49.7	<0.100	<0.087	<0.001
soln std	2	1	std-b2-1	3.84	19.9	<0.006	<0.002	3.86	9.72	<0.004	<0.001	86.3	<0.010	<0.100	50.1	<0.100	<0.087	<0.001
rcth-40ccc	2	2	p63	0.663	67.5	<0.006	<0.002	0.694	39.3	0.131	0.473	174	<0.010	4.20	179	0.259	2.64	<0.001
RC-38Uccc	2	3	p11	4.32	18.0	0.053	<0.002	5.07	12.9	0.595	0.470	37.7	<0.010	0.833	83.1	<0.100	2.34	<0.001
tk40-03-newccc	2	4	p27	11.4	11.9	0.682	<0.002	14.2	18.5	1.61	2.63	64.0	0.134	1.35	97.9	0.100	2.49	<0.001
rchwl-02	2	5	p40	6.1	16.4	0.120	<0.002	4.77	16.5	0.287	1.08	80.2	<0.010	1.65	83.2	<0.100	2.79	0.005
rchwl-04	2	6	p22	3.26	17.1	0.070	<0.002	2.51	9.88	0.143	0.346	56.0	<0.010	1.14	75.4	<0.100	2.47	<0.001
tk40-03-new	2	7	p84	6.61	14.7	0.207	<0.002	5.53	20.4	0.245	0.440	75.0	0.005	1.64	102.0	<0.100	1.84	<0.001
rchwl-06ccc	2	8	p35	9.91	9.75	0.531	<0.002	6.04	17.1	0.302	1.91	70.8	<0.010	1.38	93.1	<0.100	1.86	<0.001
soln std	2	9	std-b2-2	3.84	19.9	<0.006	<0.002	3.79	9.72	<0.004	<0.001	85.1	<0.010	<0.100	49.9	<0.100	<0.087	<0.001
rchwl-04ccc	2	10	p66	7.57	30.8	0.046	<0.002	4.97	15.0	1.07	3.24	67.8	<0.010	1.18	70.3	0.137	2.10	<0.001
rcth-40	2	11	p52	0.712	54.2	<0.006	<0.002	0.451	30.6	<0.004	0.129	140	<0.010	3.36	141	<0.100	2.01	<0.001

Table D.1: SRTC-ML Measurements of the PCT Solutions for the Study Glasses and Standards

ID	Block	#	ID	Al	B	Ca	Cr	Fe	Li	Mg	Mn	Na	Ni	P	Th	Si	U	Zr
rchwl-02ccc	2	12	p14	7.65	11.3	0.301	<0.002	4.80	12.5	0.554	1.60	62.2	<0.010	1.15	74.5	<0.100	2.28	0.067
rchwl-06	2	13	p77	8.17	12.0	0.240	<0.002	6.90	18.2	0.094	1.30	76.3	<0.010	1.67	94.8	<0.100	2.49	<0.001
blank	2	14	p33	0.015	<0.150	<0.006	<0.002	<0.004	0.055	<0.004	<0.001	<0.100	<0.010	<0.100	<0.790	<0.100	<0.087	<0.001
tk40-01-newccc	2	15	p78	6.42	15.3	0.114	<0.002	4.86	15.6	0.363	0.383	64.0	<0.010	1.26	80.5	<0.100	1.83	0.016
tk40-01-new	2	16	p53	4.97	16.3	0.105	<0.002	4.28	15.7	0.369	0.385	67.2	<0.010	1.32	79.4	<0.100	2.02	<0.001
RC-38U	2	17	p76	2.47	29.6	0.071	<0.002	4.06	18.1	0.357	0.242	56.3	<0.010	1.36	92.9	<0.100	2.45	<0.001
soln std	2	18	std-b2-3	3.85	20.0	<0.006	<0.002	3.80	9.75	<0.004	<0.001	85.0	<0.010	<0.100	49.7	<0.100	<0.087	<0.001
soln std	3	1	std-b3-1	3.88	19.9	<0.006	<0.002	3.98	9.74	<0.004	<0.001	82.2	<0.010	<0.100	49.0	<0.100	<0.087	<0.001
rchwl-06ccc	3	2	p51	10.1	9.87	0.706	<0.002	7.55	16.9	0.564	2.73	67.4	<0.010	1.36	91.0	<0.100	2.21	<0.001
RC-38U	3	3	p02	2.49	30.0	0.062	<0.002	3.48	18.3	0.251	0.185	56.1	<0.010	1.38	92.3	<0.100	2.35	<0.001
rchwl-04	3	4	p60	3.29	17.7	0.064	<0.002	2.53	10.3	0.123	0.335	55.9	<0.010	1.18	75.4	<0.100	2.33	<0.001
tk40-01-new	3	5	p45	5.3	17.5	0.168	<0.002	4.94	16.9	0.479	0.473	70.2	0.014	1.41	82.8	<0.100	2.23	<0.001
RC-38Uccc	3	6	p08	4.32	18.0	0.048	<0.002	5.15	13.4	0.608	0.490	36.9	<0.010	0.831	82.4	<0.100	2.36	<0.001
rchwl-02	3	7	p83	6.1	16.8	0.112	<0.002	5.02	16.9	0.314	1.15	79.4	<0.010	1.70	84.1	<0.100	2.90	<0.001
rchwl-04ccc	3	8	p10	7.36	30.1	0.036	<0.002	3.65	14.7	0.642	2.04	65.2	<0.010	1.12	67.3	<0.100	1.79	<0.001
soln std	3	9	std-b3-2	3.84	20.2	<0.006	<0.002	3.82	9.76	<0.004	<0.001	83.6	<0.010	<0.100	49.6	<0.100	<0.087	<0.001
rcth-40	3	10	p26	0.702	53.6	<0.006	<0.002	0.508	30.4	<0.004	0.144	137	<0.010	3.37	139	0.109	2.07	<0.001
tk40-03-newccc	3	11	p05	10.4	12.2	0.384	<0.002	9.10	19.0	0.740	1.26	61.5	<0.010	1.38	93.3	<0.100	1.89	<0.001
rcth-40ccc	3	12	p36	0.815	70.3	0.009	<0.002	1.58	41.4	0.647	1.42	175	<0.010	4.44	183	0.228	2.70	<0.001
rchwl-06	3	13	p80	8.27	12.8	0.241	<0.002	7.00	18.7	0.104	1.33	76.6	<0.010	1.74	95.7	<0.100	2.27	<0.001
tk40-01-newccc	3	14	p42	6.47	14.8	0.129	<0.002	5.13	15.6	0.410	0.422	59.2	<0.010	1.26	76.5	<0.100	1.74	0.015
rchwl-02ccc	3	15	p38	7.64	11.5	0.284	<0.002	4.69	12.5	0.534	1.57	62.2	<0.010	1.15	73.5	<0.100	2.23	0.092
tk40-03-new	3	16	p19	6.52	14.6	0.223	<0.002	5.17	20.2	0.212	0.396	72.7	<0.010	1.63	99.1	<0.100	1.82	<0.001
soln std	3	17	std-b3-3	3.84	20.5	<0.006	<0.002	3.80	9.76	<0.004	<0.001	85.5	<0.010	<0.100	49.9	<0.100	<0.087	<0.001
soln std	4	1	std-b4-1	3.83	19.6	<0.006	<0.002	3.93	9.69	<0.004	<0.001	84.5	<0.010	<0.100	50.0	<0.100	<0.087	<0.001
rchwl-01	4	2	p09	4.89	21.3	0.042	<0.002	3.94	20.0	<0.004	0.232	92.1	<0.010	1.82	100	<0.100	2.13	<0.001
rcth-50	4	3	p74	2.09	30.8	0.027	0.054	2.16	40.7	<0.004	0.586	137.7	0.065	2.83	182	0.138	4.83	<0.001
rcth-30	4	4	p24	1.35	85.3	0.021	0.004	1.70	83.5	0.263	0.872	279	0.212	7.53	242	<0.100	0.93	<0.001
rchwl-01ccc	4	5	p86	6.18	14.1	0.220	<0.002	6.60	14.6	0.468	0.867	64.6	<0.010	1.20	79.2	<0.100	2.55	0.092
rcth-30ccc	4	6	p61	1.84	67.6	0.006	0.034	4.34	62.5	0.417	1.68	230	0.122	5.04	239	0.112	2.92	<0.001

Table D.1: SRTC-ML Measurements of the PCT Solutions for the Study Glasses and Standards

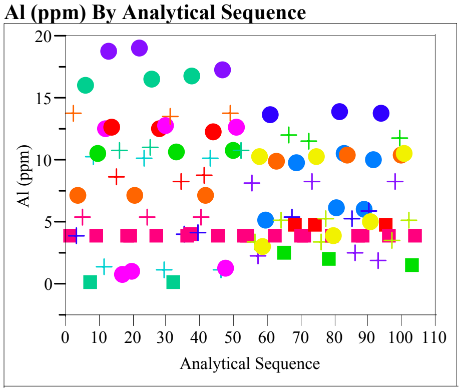
ID	Block	#	ID	Al	B	Ca	Cr	Fe	Li	Mg	Mn	Na	Ni	P	Th	Si	U	Zr
rcth-50ccc	4	7	p69	3.1	25.5	0.043	0.039	5.45	36.2	0.287	1.90	116	0.276	2.38	165	1.07	4.30	<0.001
rchwl-05ccc	4	8	p64	8.24	9.90	0.398	<0.002	6.40	16.2	0.088	0.771	62.9	<0.010	1.15	91.4	0.065	1.78	<0.001
soln std	4	9	std-b4-2	3.82	19.8	<0.006	<0.002	3.82	9.66	<0.004	<0.001	86.1	<0.010	<0.100	50.6	<0.100	<0.087	<0.001
tk40-02-newccc	4	10	p68	5.99	24.8	0.011	<0.002	2.98	12.7	0.623	0.457	55.0	<0.010	0.918	72.4	0.124	1.72	0.011
rchwl-03	4	11	p73	3.13	17.2	0.127	<0.002	3.76	9.90	0.409	0.382	53.2	0.038	1.11	77.3	<0.100	1.89	<0.001
EA	4	12	p37	0.145	35.7	0.006	<0.002	<0.004	11.0	<0.004	<0.001	99.9	<0.010	<0.100	53.2	<0.100	<0.087	<0.001
rchwl-05	4	13	p59	7.22	14.1	0.282	<0.002	9.46	20.4	0.250	1.30	78.0	0.272	1.69	103	<0.100	3.09	<0.001
tk40-02-new	4	14	p79	3.24	15.0	0.109	<0.002	2.74	8.90	0.351	0.148	45.3	<0.010	0.820	72.0	<0.100	1.56	<0.001
ARM	4	15	p58	2.84	11.2	0.053	<0.002	<0.004	8.45	<0.004	<0.001	23.1	<0.010	0.565	38.5	<0.100	<0.087	<0.001
rchwl-03ccc	4	16	p75	5.9	39.4	0.025	<0.002	3.93	21.4	0.734	1.54	83.5	<0.010	1.33	87.8	<0.100	2.19	<0.001
soln std	4	17	std-b4-3	3.82	20.1	<0.006	<0.002	3.80	9.65	<0.004	<0.001	87.8	<0.010	<0.100	51.4	<0.100	<0.087	<0.001
soln std	5	1	std-b5-1	3.85	20.5	<0.006	<0.002	3.93	9.72	<0.004	<0.001	87.6	<0.010	<0.100	50.8	<0.100	<0.087	<0.001
rchwl-05	5	2	p57	6.95	14.4	0.187	<0.002	7.02	20.7	<0.004	0.554	80.3	0.013	1.75	105	0.110	2.30	<0.001
rchwl-01	5	3	p12	4.96	21.6	0.107	<0.002	4.96	20.8	0.191	0.505	91.5	0.043	1.87	97.4	0.103	2.52	0.012
ARM	5	4	p13	2.84	11.0	0.061	<0.002	<0.004	8.37	<0.004	<0.001	22.8	<0.010	0.581	37.7	<0.100	<0.087	<0.001
rchwl-01ccc	5	5	p31	6.21	13.8	0.234	<0.002	6.78	15.0	0.504	0.906	65.3	<0.010	1.26	79.4	0.123	2.76	0.090
rcth-50	5	6	p47	2.06	28.4	0.006	0.061	1.65	39.1	<0.004	0.389	128	<0.010	2.72	169	0.175	4.97	<0.001
rchwl-03	5	7	p43	3.18	16.5	0.123	<0.002	3.74	9.91	0.401	0.363	51.1	0.038	1.00	75.3	<0.100	2.07	<0.001
EA	5	8	p01	0.115	36.0	<0.006	<0.002	<0.004	10.6	<0.004	<0.001	97.8	<0.010	<0.100	52.1	<0.100	<0.087	<0.001
soln std	5	9	std-b5-2	3.84	20.0	<0.006	<0.002	3.90	9.73	<0.004	<0.001	85.8	<0.010	<0.100	50.4	<0.100	<0.087	<0.001
rcth-30ccc	5	10	p18	2.33	66.9	0.113	0.047	7.08	62.9	0.989	3.03	226	0.342	5.05	239	0.217	3.45	0.040
rcth-50ccc	5	11	p72	3.71	25.5	0.079	0.047	8.29	36.2	0.746	3.33	115	0.648	2.36	170	1.47	3.63	<0.001
rchwl-05ccc	5	12	p17	8.39	9.53	0.430	<0.002	6.56	16.3	0.139	0.835	61.1	<0.010	1.20	89.7	0.113	2.02	<0.001
rchwl-03ccc	5	13	p03	6.31	40.7	0.054	<0.002	4.63	21.3	0.909	1.84	83.2	<0.010	1.35	89.2	0.118	2.20	0.007
tk40-02-newccc	5	14	p50	6.23	24.8	0.047	<0.002	3.35	12.8	0.781	0.597	53.2	<0.010	0.893	72.3	<0.100	1.78	<0.001
tk40-02-new	5	15	p32	3.19	15.4	0.117	<0.002	2.49	8.97	0.307	0.110	45.5	<0.010	0.854	73.3	<0.100	1.46	<0.001
rcth-30	5	16	p54	1.5	99.3	<0.006	0.009	2.25	83.6	0.468	1.25	312	0.330	7.49	278	<0.100	1.03	<0.001
soln std	5	17	std-b5-3	3.87	21.2	<0.006	<0.002	3.91	9.80	<0.004	<0.001	88.4	<0.010	<0.100	52.4	<0.100	<0.087	<0.001
soln std	6	1	std-b6-1	3.87	20.5	<0.006	<0.002	3.86	9.79	<0.004	<0.001	87.2	<0.010	<0.100	50.9	<0.100	<0.087	<0.001
rcth-50ccc	6	2	p07	3.67	23.5	0.077	0.035	7.88	35.7	0.662	3.16	109	0.577	2.32	155	1.29	4.03	<0.001

Table D.1: SRTC-ML Measurements of the PCT Solutions for the Study Glasses and Standards

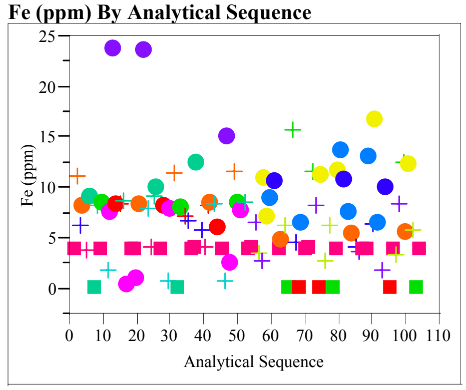
ID	Block	#	ID	Al	B	Ca	Cr	Fe	Li	Mg	Mn	Na	Ni	P	Th	Si	U	Zr
tk40-02-new	6	3	p16	3.55	15.0	0.169	<0.002	3.88	9.23	0.639	0.363	45.0	<0.010	0.840	71.2	<0.100	1.64	<0.001
rcth-30ccc	6	4	p29	3.02	68.7	0.054	0.015	10.1	65.8	1.91	5.00	234	0.556	5.45	238	0.160	3.92	<0.001
rchwl-03ccc	6	5	p81	6.01	40.1	0.017	<0.002	3.93	21.3	0.740	1.51	81.7	<0.010	1.30	86.1	<0.100	2.22	<0.001
rcth-30	6	6	p56	1.14	85.3	<0.006	0.027	1.08	75.6	0.066	0.586	272	0.070	6.34	262	<0.100	0.971	<0.001
rchwl-05ccc	6	7	p46	8.28	8.89	0.375	<0.002	6.09	16.4	0.066	0.723	57.8	<0.010	1.17	85.0	<0.100	1.88	<0.001
ARM	6	8	p62	2.79	11.8	0.044	<0.002	<0.004	9.02	<0.004	<0.001	23.0	<0.010	0.615	39.0	<0.100	<0.087	<0.001
soln std	6	9	std-b6-2	3.84	19.9	<0.006	<0.002	3.80	9.76	<0.004	<0.001	84.1	<0.010	<0.100	50.4	<0.100	<0.087	<0.001
rcth-50	6	10	p82	2.1	31.3	<0.006	0.056	2.06	40.8	<0.004	0.536	136	0.023	2.88	181	0.216	4.91	<0.001
rchwl-01	6	11	p04	5.01	22.2	0.080	<0.002	5.07	21.0	0.170	0.487	92.5	0.032	1.91	101	<0.100	2.59	<0.001
rchwl-05	6	12	p44	7.09	14.7	0.245	<0.002	7.56	20.8	0.003	0.693	80.1	0.042	1.72	104	<0.100	2.48	<0.001
tk40-02-newccc	6	13	p48	6.23	24.5	0.016	<0.002	3.41	12.9	0.796	0.604	52.5	<0.010	0.862	71.1	<0.100	1.76	<0.001
rchwl-01ccc	6	14	p21	6.34	14.9	0.255	<0.002	7.48	15.3	0.540	1.03	68.5	<0.010	1.25	82.9	0.103	2.74	0.030
rchwl-03	6	15	p65	3.12	16.9	0.083	<0.002	3.45	9.72	0.339	0.323	50.7	0.019	0.957	74.9	<0.100	2.30	<0.001
EA	6	16	p15	0.087	35.6	<0.006	<0.002	<0.004	10.6	<0.004	<0.001	96.5	<0.010	<0.100	51.8	<0.100	<0.087	<0.001
soln std	6	17	std-b6-3	3.85	19.7	<0.006	<0.002	3.82	9.80	<0.004	<0.001	84.8	<0.010	<0.100	50.3	<0.100	<0.087	<0.001

Exhibit D.1: SRTC-ML PCT Measurements in Analytical Sequence for the Study Glasses, EA, ARM, Blanks, and Solution Standards

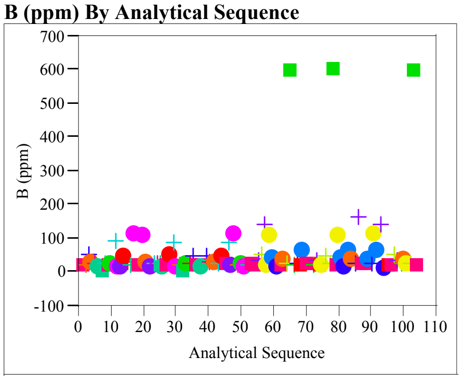
Al (ppm) By Analytical Sequence



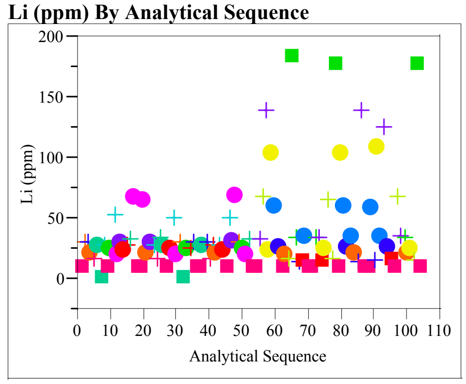
Fe (ppm) By Analytical Sequence



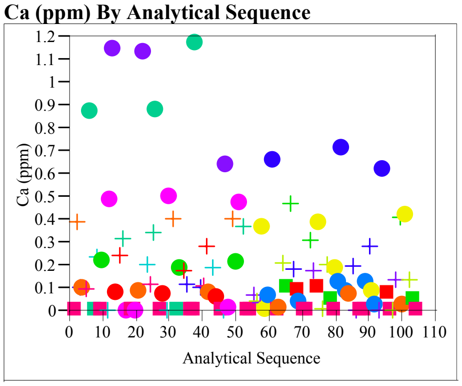
B (ppm) By Analytical Sequence



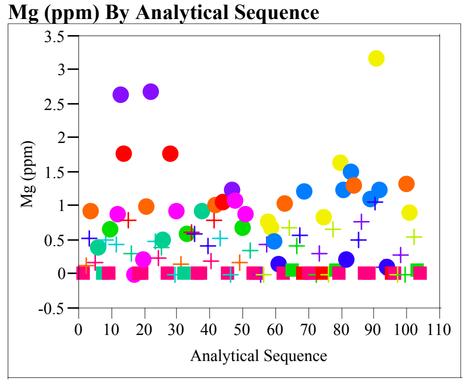
Li (ppm) By Analytical Sequence



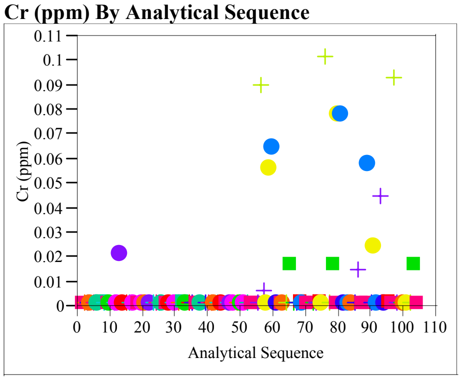
Ca (ppm) By Analytical Sequence



Mg (ppm) By Analytical Sequence



Cr (ppm) By Analytical Sequence



Mn (ppm) By Analytical Sequence

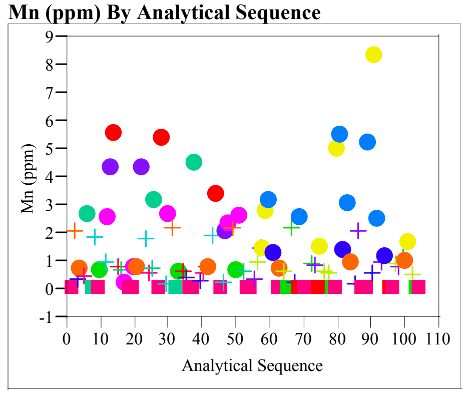
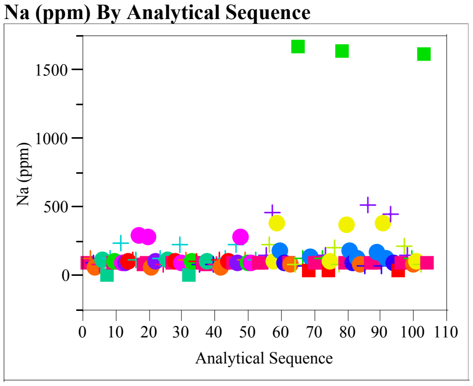
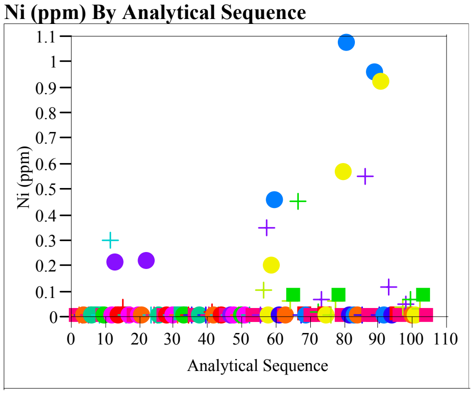


Exhibit D.1: SRTC-ML PCT Measurements in Analytical Sequence for the Study Glasses, EA, ARM, Blanks, and Solution Standards *(continued)*

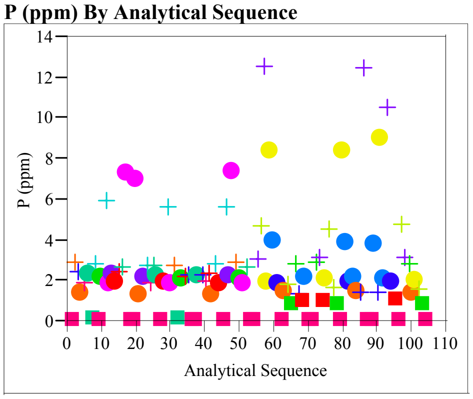
Na (ppm) By Analytical Sequence



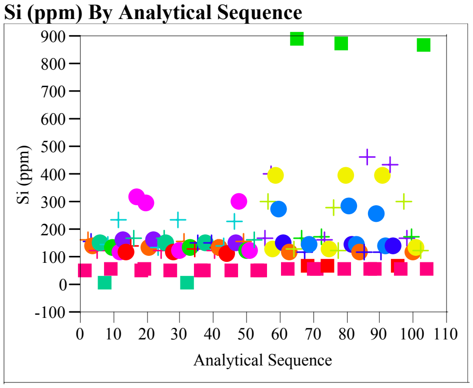
Ni (ppm) By Analytical Sequence



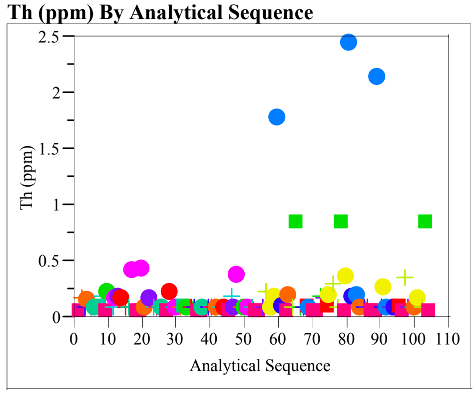
P (ppm) By Analytical Sequence



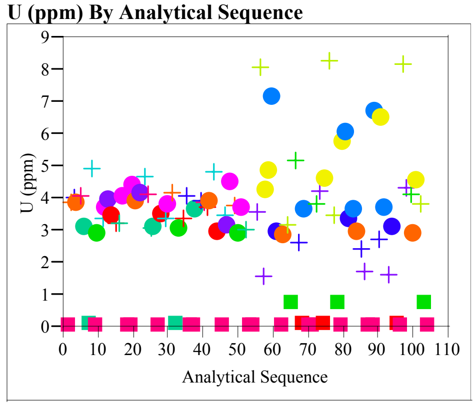
Si (ppm) By Analytical Sequence



Th (ppm) By Analytical Sequence



U (ppm) By Analytical Sequence



Zr (ppm) By Analytical Sequence

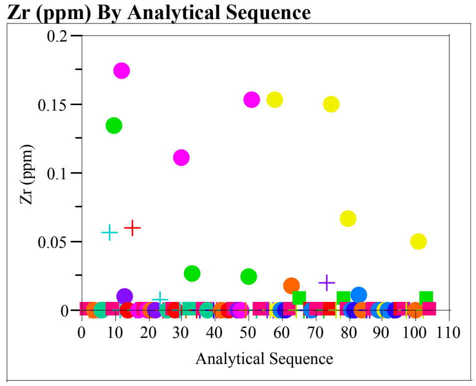
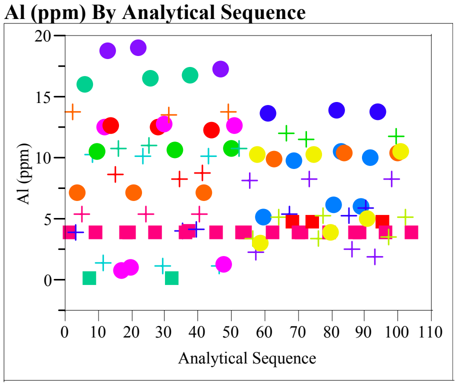
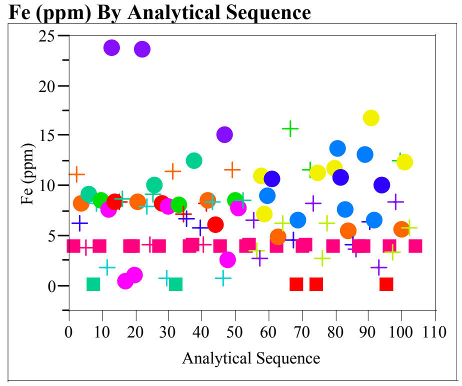


Exhibit D.2: SRTC-ML PCT Measurements in Analytical Sequence for the Study Glasses, ARM, Blanks, and Solution Standards But Without EA

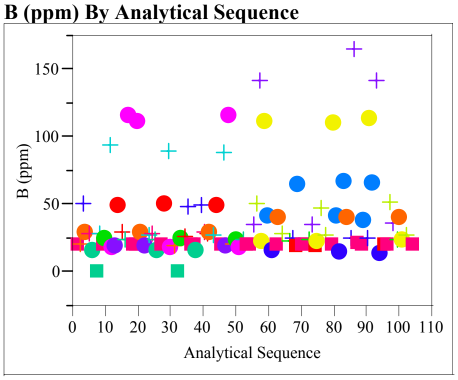
Al (ppm) By Analytical Sequence



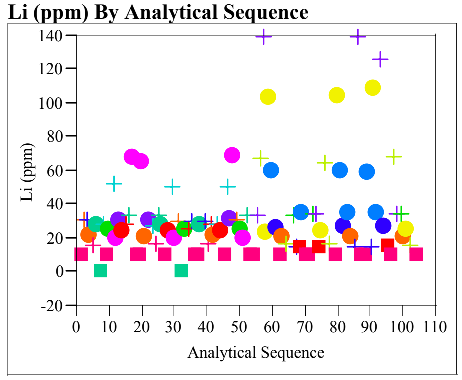
Fe (ppm) By Analytical Sequence



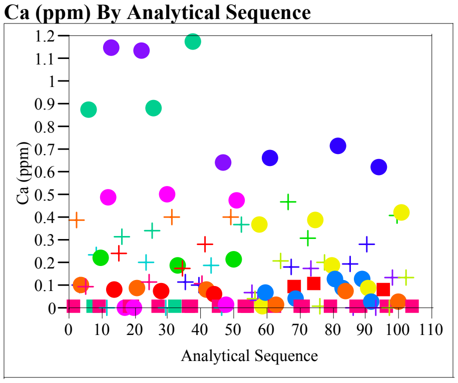
B (ppm) By Analytical Sequence



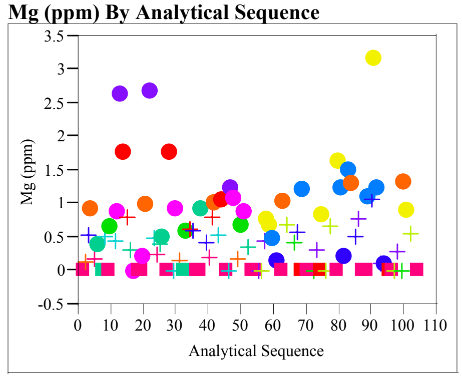
Li (ppm) By Analytical Sequence



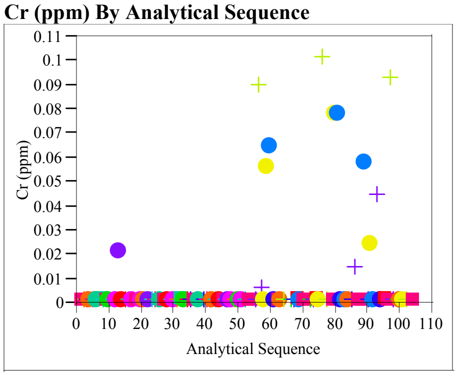
Ca (ppm) By Analytical Sequence



Mg (ppm) By Analytical Sequence



Cr (ppm) By Analytical Sequence



Mn (ppm) By Analytical Sequence

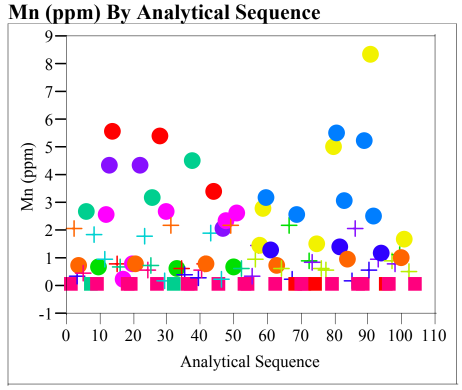
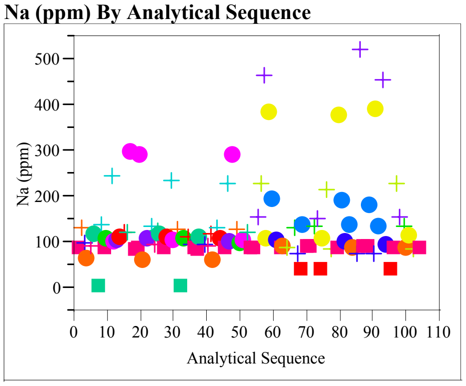
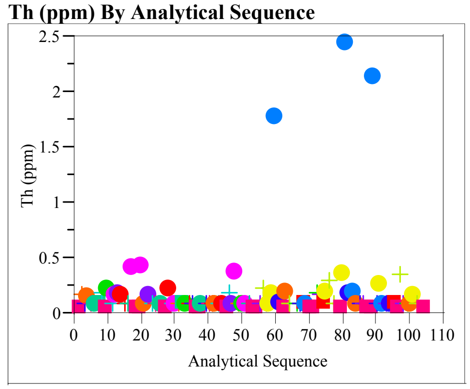


Exhibit D.2: SRTC-ML PCT Measurements in Analytical Sequence for the Study Glasses, ARM, Blanks, and Solution Standards But Without EA *(continued)*

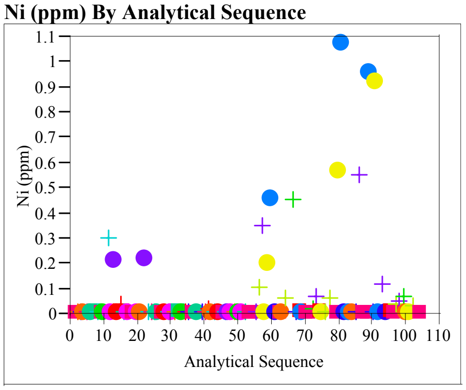
Na (ppm) By Analytical Sequence



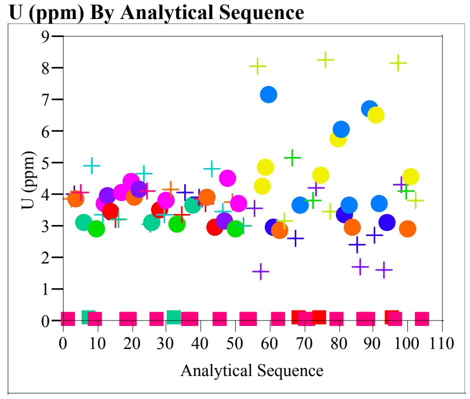
Th (ppm) By Analytical Sequence



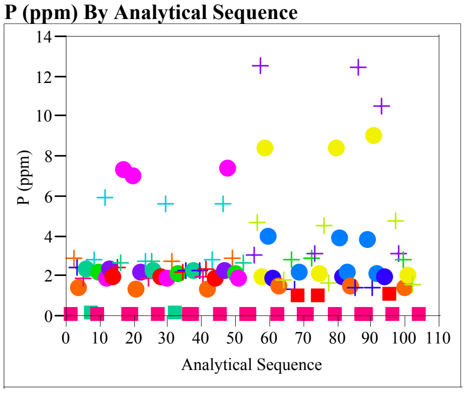
Ni (ppm) By Analytical Sequence



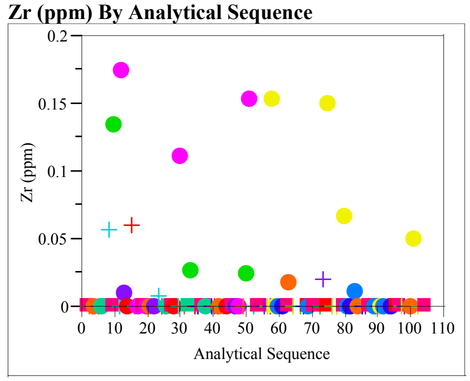
U (ppm) By Analytical Sequence



P (ppm) By Analytical Sequence



Zr (ppm) By Analytical Sequence



Si (ppm) By Analytical Sequence

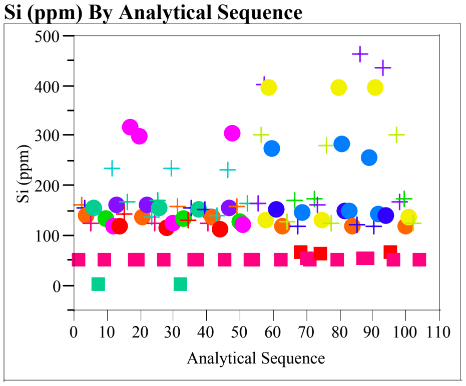
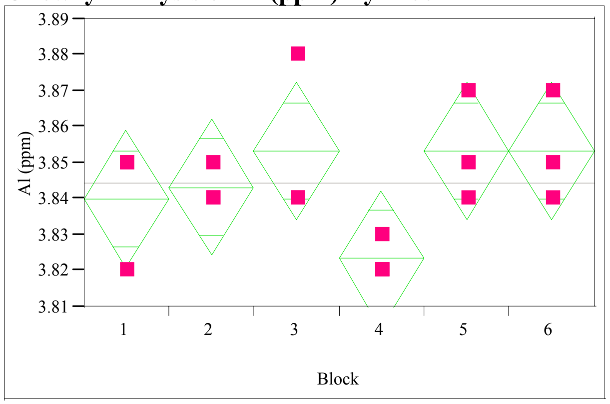


Exhibit D.3: Measurements of the Multi-Element Solution Standard by ICP Block

Oneway Analysis of Al (ppm) By Block



Oneway Anova
Summary of Fit

Rsquare	0.43578
Adj Rsquare	0.200688
Root Mean Square Error	0.015092
Mean of Response	3.844444
Observations (or Sum Wgts)	18

Analysis of Variance

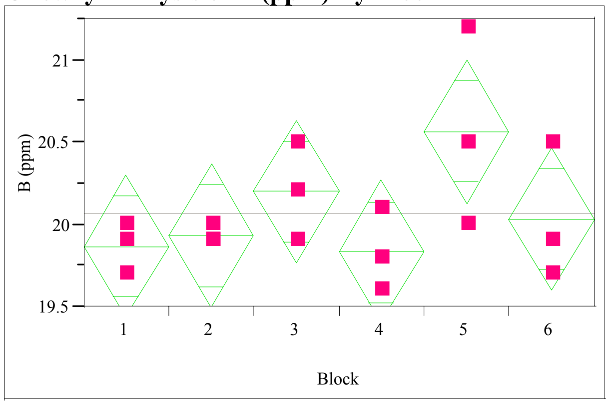
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0.00211111	0.000422	1.8537	0.1767
Error	12	0.00273333	0.000228		
C. Total	17	0.00484444			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	3.84000	0.00871	3.8210	3.8590
2	3	3.84333	0.00871	3.8243	3.8623
3	3	3.85333	0.00871	3.8343	3.8723
4	3	3.82333	0.00871	3.8043	3.8423
5	3	3.85333	0.00871	3.8343	3.8723
6	3	3.85333	0.00871	3.8343	3.8723

Std Error uses a pooled estimate of error variance

Oneway Analysis of B (ppm) By Block



Oneway Anova
Summary of Fit

Rsquare	0.443606
Adj Rsquare	0.211775
Root Mean Square Error	0.345607
Mean of Response	20.07222
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	1.1427778	0.228556	1.9135	0.1656
Error	12	1.4333333	0.119444		
C. Total	17	2.5761111			

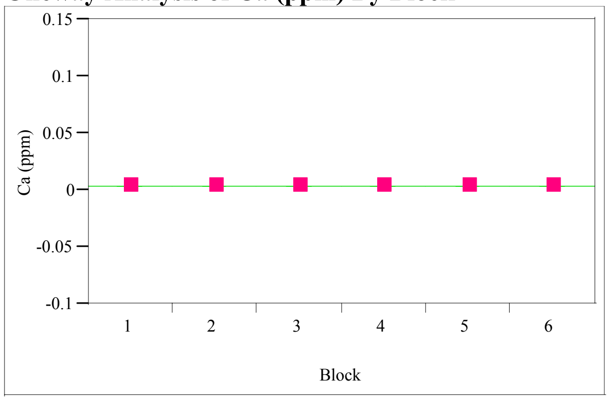
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	19.8667	0.19954	19.432	20.301
2	3	19.9333	0.19954	19.499	20.368
3	3	20.2000	0.19954	19.765	20.635
4	3	19.8333	0.19954	19.399	20.268
5	3	20.5667	0.19954	20.132	21.001
6	3	20.0333	0.19954	19.599	20.468

Std Error uses a pooled estimate of error variance

Exhibit D.3: Measurements of the Multi-Element Solution Standard by ICP Block *(continued)*

Oneway Analysis of Ca (ppm) By Block



Oneway Anova
Summary of Fit

Rsquare	0
Adj Rsquare	-0.41667
Root Mean Square Error	5.31e-19
Mean of Response	0.003
Observations (or Sum Wgts)	18

Analysis of Variance

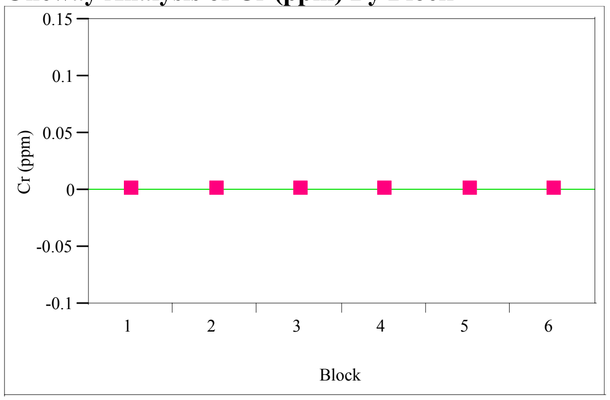
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0	0	0.0000	1.0000
Error	12	3.3854e-36	2.821e-37		
C. Total	17	3.3854e-36			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	0.003000	3.067e-19	0.00300	0.00300
2	3	0.003000	3.067e-19	0.00300	0.00300
3	3	0.003000	3.067e-19	0.00300	0.00300
4	3	0.003000	3.067e-19	0.00300	0.00300
5	3	0.003000	3.067e-19	0.00300	0.00300
6	3	0.003000	3.067e-19	0.00300	0.00300

Std Error uses a pooled estimate of error variance

Oneway Analysis of Cr (ppm) By Block



Oneway Anova
Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.001
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0	0	.	.
Error	12	0	0		
C. Total	17	0			

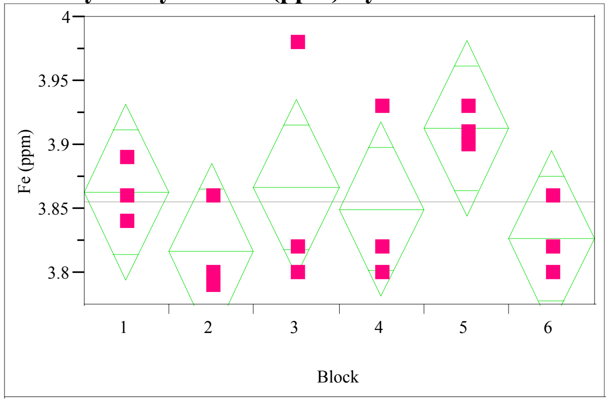
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	0.001000	0	0.00100	0.00100
2	3	0.001000	0	0.00100	0.00100
3	3	0.001000	0	0.00100	0.00100
4	3	0.001000	0	0.00100	0.00100
5	3	0.001000	0	0.00100	0.00100
6	3	0.001000	0	0.00100	0.00100

Std Error uses a pooled estimate of error variance

Exhibit D.3: Measurements of the Multi-Element Solution Standard by ICP Block *(continued)*

Oneway Analysis of Fe (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	0.331184
Adj Rsquare	0.052511
Root Mean Square Error	0.054569
Mean of Response	3.856111
Observations (or Sum Wgts)	18

Analysis of Variance

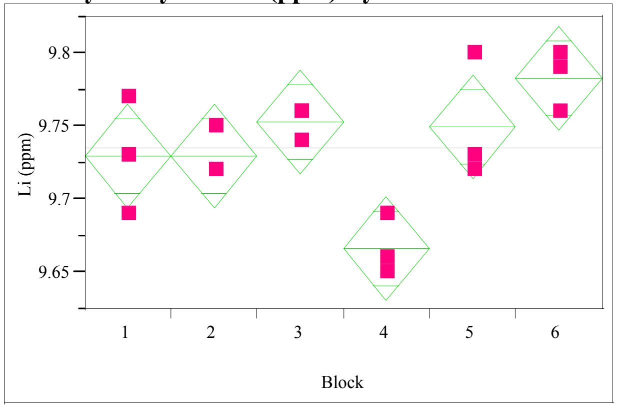
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0.01769444	0.003539	1.1884	0.3708
Error	12	0.03573333	0.002978		
C. Total	17	0.05342778			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	3.86333	0.03151	3.7947	3.9320
2	3	3.81667	0.03151	3.7480	3.8853
3	3	3.86667	0.03151	3.7980	3.9353
4	3	3.85000	0.03151	3.7814	3.9186
5	3	3.91333	0.03151	3.8447	3.9820
6	3	3.82667	0.03151	3.7580	3.8953

Std Error uses a pooled estimate of error variance

Oneway Analysis of Li (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	0.70411
Adj Rsquare	0.580822
Root Mean Square Error	0.028284
Mean of Response	9.735556
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0.02284444	0.004569	5.7111	0.0064
Error	12	0.00960000	0.000800		
C. Total	17	0.03244444			

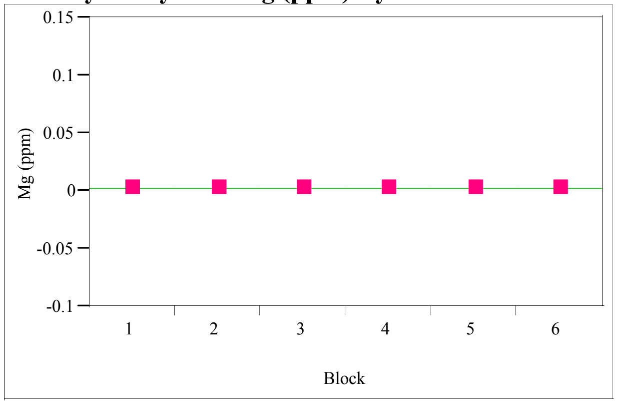
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	9.73000	0.01633	9.6944	9.7656
2	3	9.73000	0.01633	9.6944	9.7656
3	3	9.75333	0.01633	9.7178	9.7889
4	3	9.66667	0.01633	9.6311	9.7022
5	3	9.75000	0.01633	9.7144	9.7856
6	3	9.78333	0.01633	9.7478	9.8189

Std Error uses a pooled estimate of error variance

Exhibit D.3: Measurements of the Multi-Element Solution Standard by ICP Block *(continued)*

Oneway Analysis of Mg (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.002
Observations (or Sum Wgts)	18

Analysis of Variance

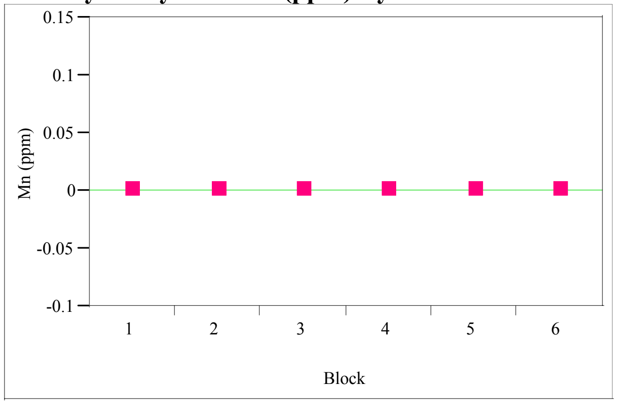
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0	0	.	.
Error	12	0	0		
C. Total	17	0			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	0.002000	0	0.00200	0.00200
2	3	0.002000	0	0.00200	0.00200
3	3	0.002000	0	0.00200	0.00200
4	3	0.002000	0	0.00200	0.00200
5	3	0.002000	0	0.00200	0.00200
6	3	0.002000	0	0.00200	0.00200

Std Error uses a pooled estimate of error variance

Oneway Analysis of Mn (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.0005
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0	0	.	.
Error	12	0	0		
C. Total	17	0			

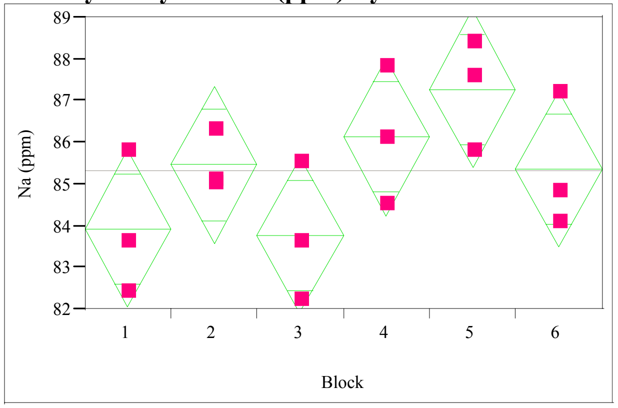
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	0.000500	0	0.00050	0.00050
2	3	0.000500	0	0.00050	0.00050
3	3	0.000500	0	0.00050	0.00050
4	3	0.000500	0	0.00050	0.00050
5	3	0.000500	0	0.00050	0.00050
6	3	0.000500	0	0.00050	0.00050

Std Error uses a pooled estimate of error variance

Exhibit D.3: Measurements of the Multi-Element Solution Standard by ICP Block *(continued)*

Oneway Analysis of Na (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	0.496908
Adj Rsquare	0.287287
Root Mean Square Error	1.493318
Mean of Response	85.32222
Observations (or Sum Wgts)	18

Analysis of Variance

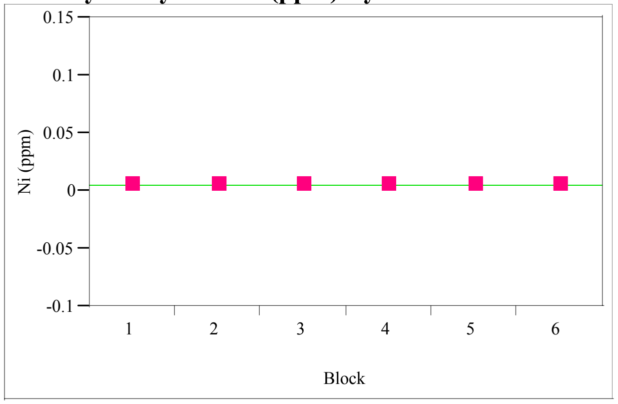
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	26.431111	5.28622	2.3705	0.1024
Error	12	26.760000	2.23000		
C. Total	17	53.191111			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	83.9333	0.86217	82.055	85.812
2	3	85.4667	0.86217	83.588	87.345
3	3	83.7667	0.86217	81.888	85.645
4	3	86.1333	0.86217	84.255	88.012
5	3	87.2667	0.86217	85.388	89.145
6	3	85.3667	0.86217	83.488	87.245

Std Error uses a pooled estimate of error variance

Oneway Analysis of Ni (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.005
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0	0	.	.
Error	12	0	0		
C. Total	17	0			

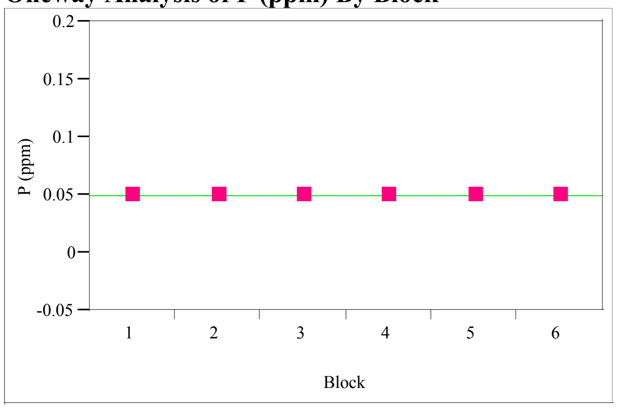
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	0.005000	0	0.00500	0.00500
2	3	0.005000	0	0.00500	0.00500
3	3	0.005000	0	0.00500	0.00500
4	3	0.005000	0	0.00500	0.00500
5	3	0.005000	0	0.00500	0.00500
6	3	0.005000	0	0.00500	0.00500

Std Error uses a pooled estimate of error variance

Exhibit D.3: Measurements of the Multi-Element Solution Standard by ICP Block *(continued)*

Oneway Analysis of P (ppm) By Block



Oneway Anova
Summary of Fit

Rsquare	0
Adj Rsquare	-0.41667
Root Mean Square Error	8.5e-18
Mean of Response	0.05
Observations (or Sum Wgts)	18

Analysis of Variance

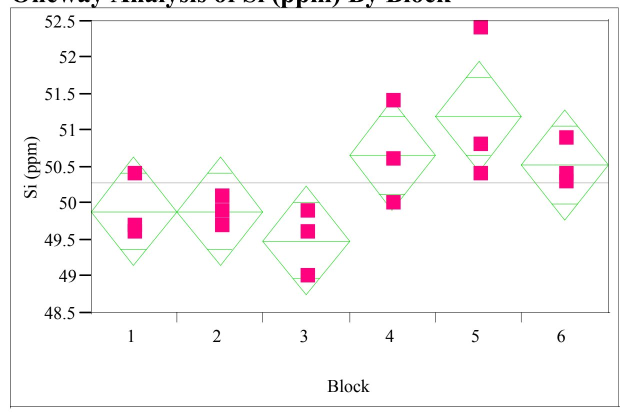
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0	0	0.0000	1.0000
Error	12	8.6667e-34	7.222e-35		
C. Total	17	8.6667e-34			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	0.050000	4.907e-18	0.05000	0.05000
2	3	0.050000	4.907e-18	0.05000	0.05000
3	3	0.050000	4.907e-18	0.05000	0.05000
4	3	0.050000	4.907e-18	0.05000	0.05000
5	3	0.050000	4.907e-18	0.05000	0.05000
6	3	0.050000	4.907e-18	0.05000	0.05000

Std Error uses a pooled estimate of error variance

Oneway Analysis of Si (ppm) By Block



Oneway Anova
Summary of Fit

Rsquare	0.576501
Adj Rsquare	0.400044
Root Mean Square Error	0.599537
Mean of Response	50.28333
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	5.871667	1.17433	3.2671	0.0431
Error	12	4.313333	0.35944		
C. Total	17	10.185000			

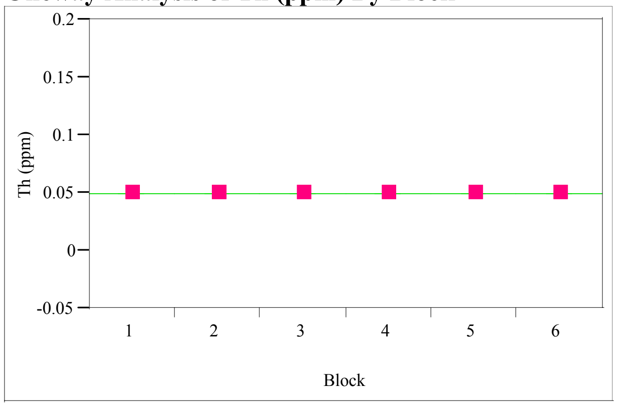
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	49.9000	0.34614	49.146	50.654
2	3	49.9000	0.34614	49.146	50.654
3	3	49.5000	0.34614	48.746	50.254
4	3	50.6667	0.34614	49.912	51.421
5	3	51.2000	0.34614	50.446	51.954
6	3	50.5333	0.34614	49.779	51.288

Std Error uses a pooled estimate of error variance

Exhibit D.3: Measurements of the Multi-Element Solution Standard by ICP Block *(continued)*

Oneway Analysis of Th (ppm) By Block



Oneway Anova
Summary of Fit

Rsquare	0
Adj Rsquare	-0.41667
Root Mean Square Error	8.5e-18
Mean of Response	0.05
Observations (or Sum Wgts)	18

Analysis of Variance

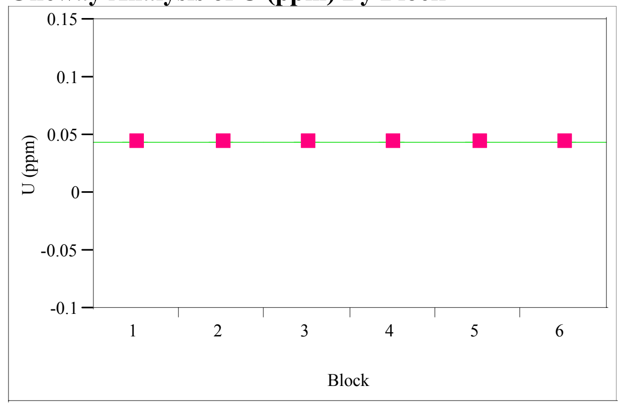
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0	0	0.0000	1.0000
Error	12	8.6667e-34	7.222e-35		
C. Total	17	8.6667e-34			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	0.050000	4.907e-18	0.05000	0.05000
2	3	0.050000	4.907e-18	0.05000	0.05000
3	3	0.050000	4.907e-18	0.05000	0.05000
4	3	0.050000	4.907e-18	0.05000	0.05000
5	3	0.050000	4.907e-18	0.05000	0.05000
6	3	0.050000	4.907e-18	0.05000	0.05000

Std Error uses a pooled estimate of error variance

Oneway Analysis of U (ppm) By Block



Oneway Anova
Summary of Fit

Rsquare	0.25
Adj Rsquare	-0.0625
Root Mean Square Error	1.47e-17
Mean of Response	0.0435
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	8.6667e-34	1.733e-34	0.8000	0.5705
Error	12	2.6e-33	2.167e-34		
C. Total	17	3.4667e-33			

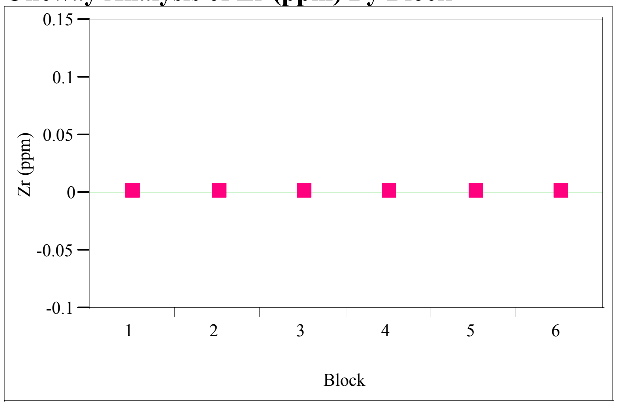
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	0.043500	8.498e-18	0.04350	0.04350
2	3	0.043500	8.498e-18	0.04350	0.04350
3	3	0.043500	8.498e-18	0.04350	0.04350
4	3	0.043500	8.498e-18	0.04350	0.04350
5	3	0.043500	8.498e-18	0.04350	0.04350
6	3	0.043500	8.498e-18	0.04350	0.04350

Std Error uses a pooled estimate of error variance

Exhibit D.3: Measurements of the Multi-Element Solution Standard by ICP Block *(continued)*

Oneway Analysis of Zr (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.0005
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0	0	.	.
Error	12	0	0		
C. Total	17	0			

Means for Oneway Anova

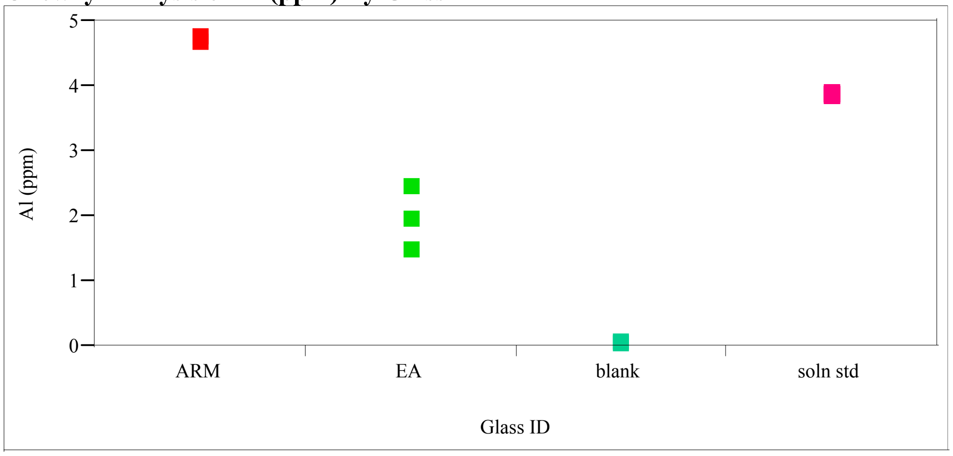
Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	0.000500	0	0.00050	0.00050
2	3	0.000500	0	0.00050	0.00050
3	3	0.000500	0	0.00050	0.00050
4	3	0.000500	0	0.00050	0.00050
5	3	0.000500	0	0.00050	0.00050
6	3	0.000500	0	0.00050	0.00050

Std Error uses a pooled estimate of error variance

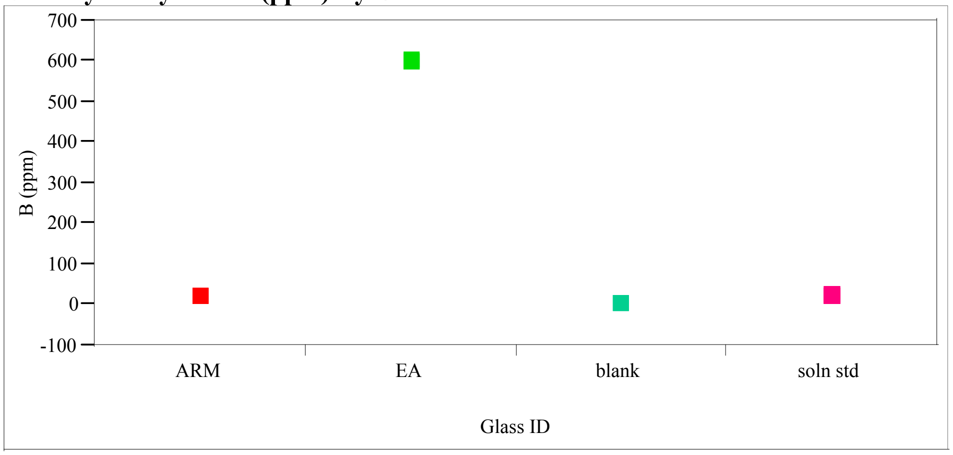
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Standards

Oneway Analysis of Al (ppm) By Glass ID



Oneway Analysis of B (ppm) By Glass ID



Oneway Analysis of Ca (ppm) By Glass ID

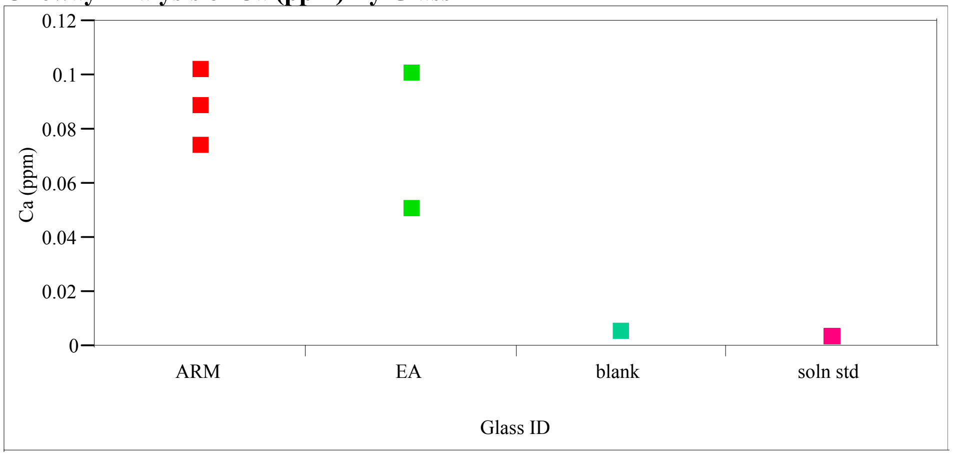
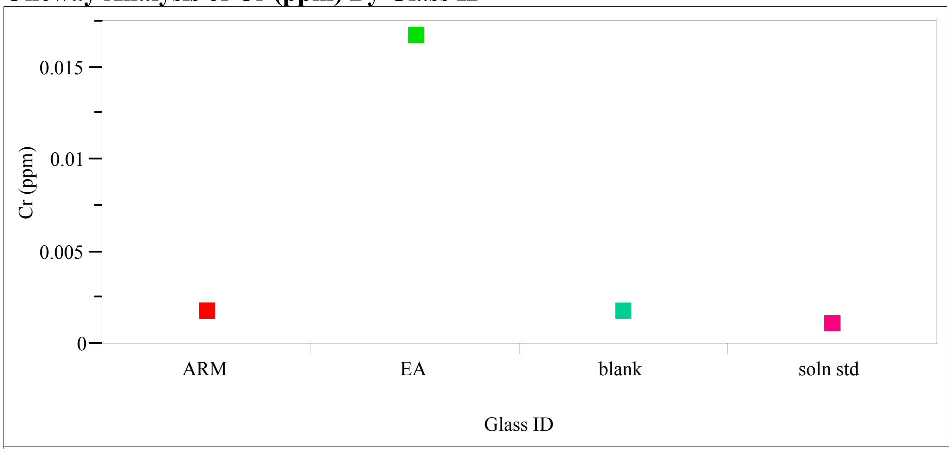


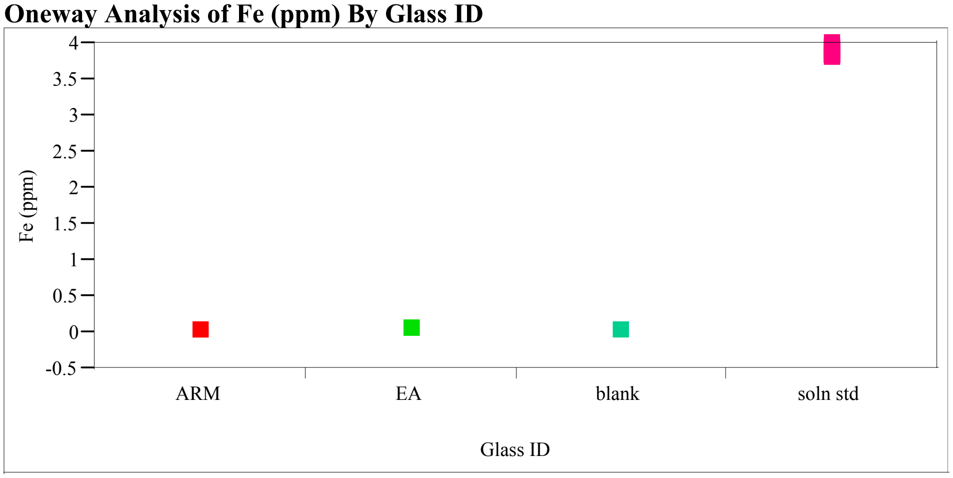
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Standards (continued)

Oneway Analysis of Cr (ppm) By Glass ID



Oneway Analysis of Fe (ppm) By Glass ID



Oneway Analysis of Li (ppm) By Glass ID

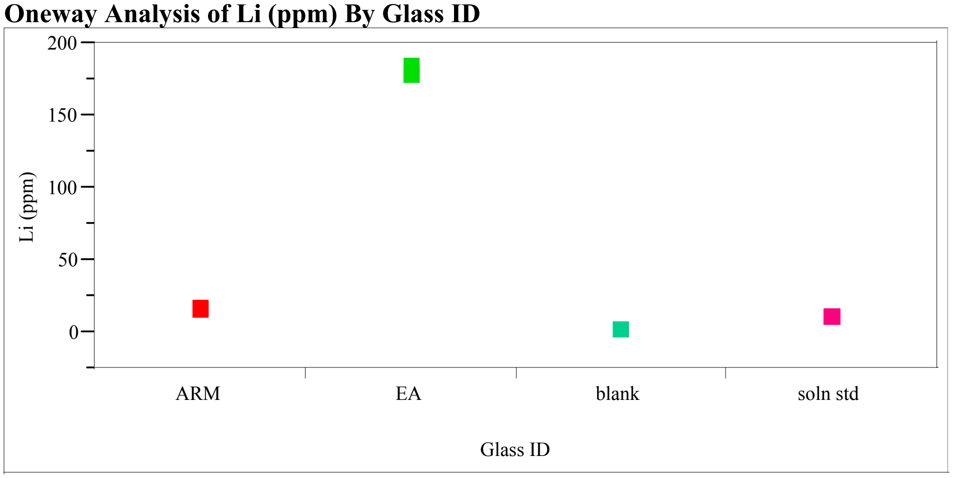
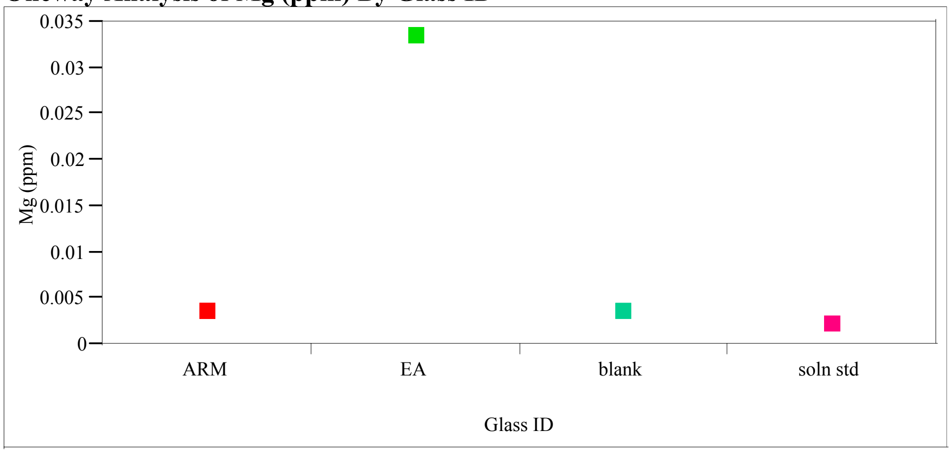


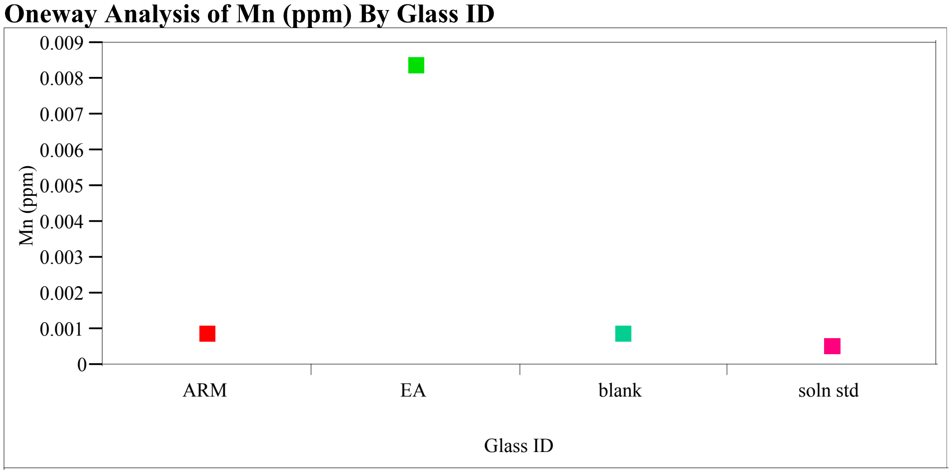
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Standards (continued)

Oneway Analysis of Mg (ppm) By Glass ID



Oneway Analysis of Mn (ppm) By Glass ID



Oneway Analysis of Na (ppm) By Glass ID

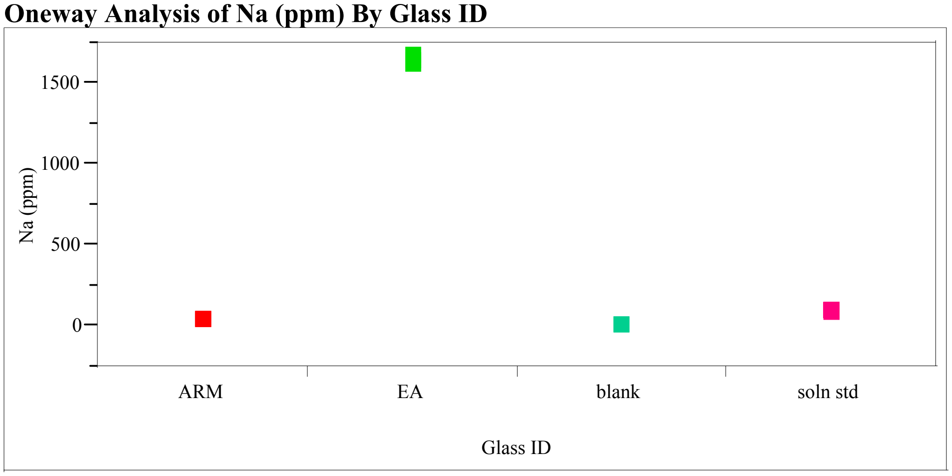
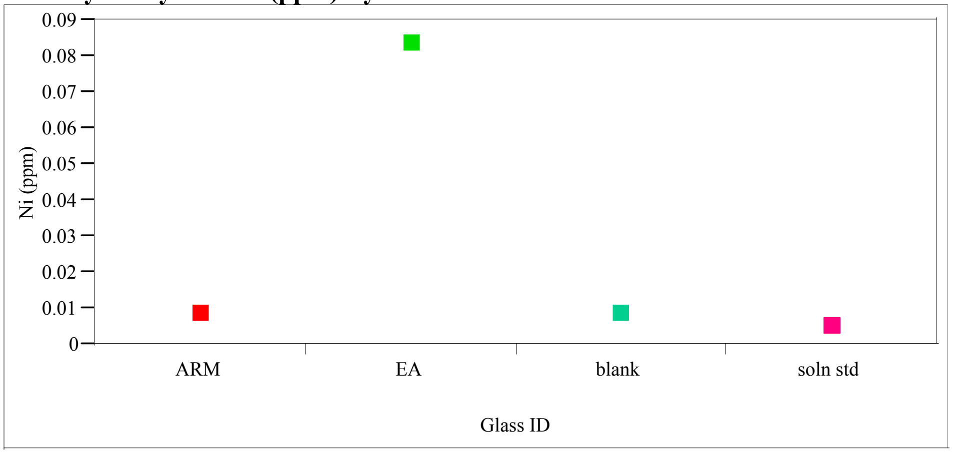


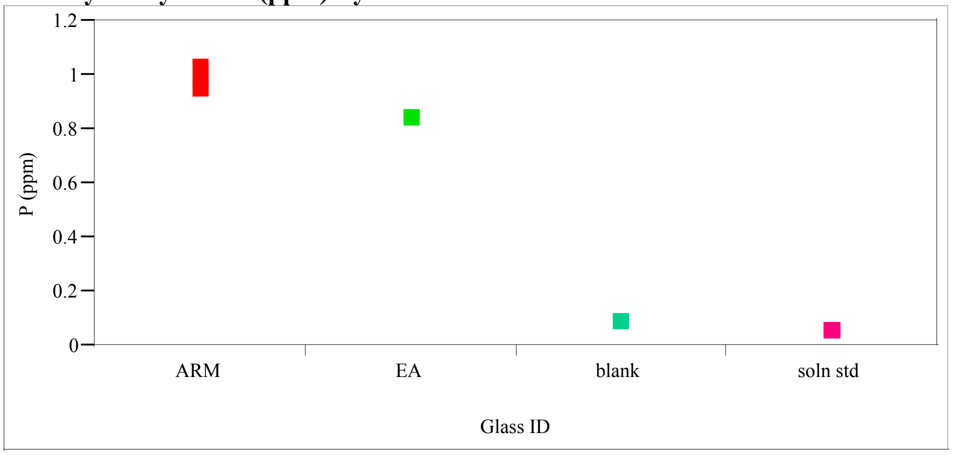
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Standards (continued)

Oneway Analysis of Ni (ppm) By Glass ID



Oneway Analysis of P (ppm) By Glass ID



Oneway Analysis of Si (ppm) By Glass ID

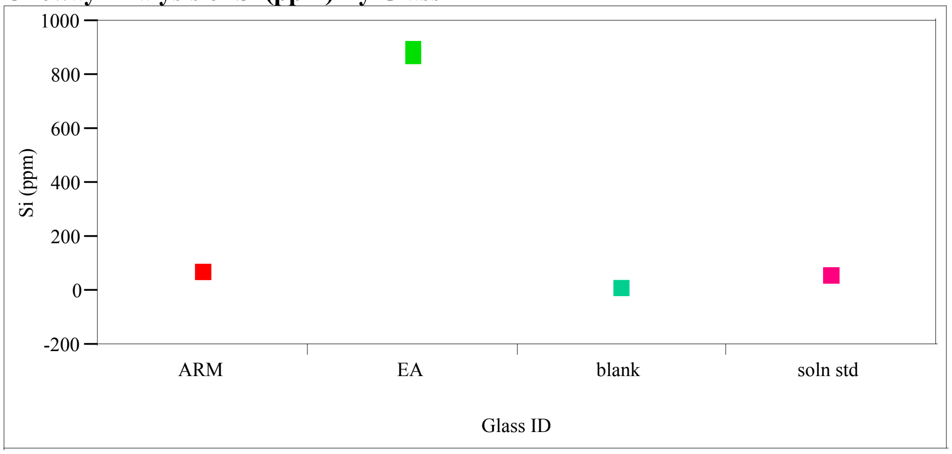
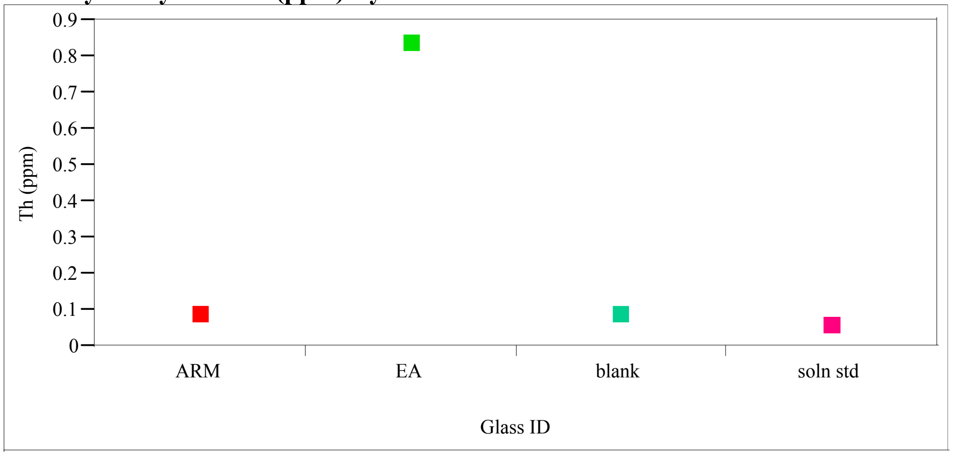


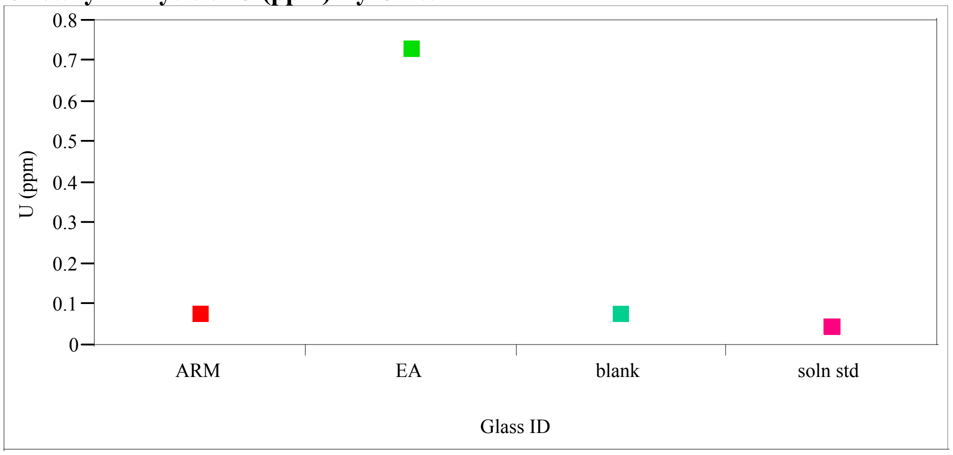
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Standards (continued)

Oneway Analysis of Th (ppm) By Glass ID



Oneway Analysis of U (ppm) By Glass ID



Oneway Analysis of Zr (ppm) By Glass ID

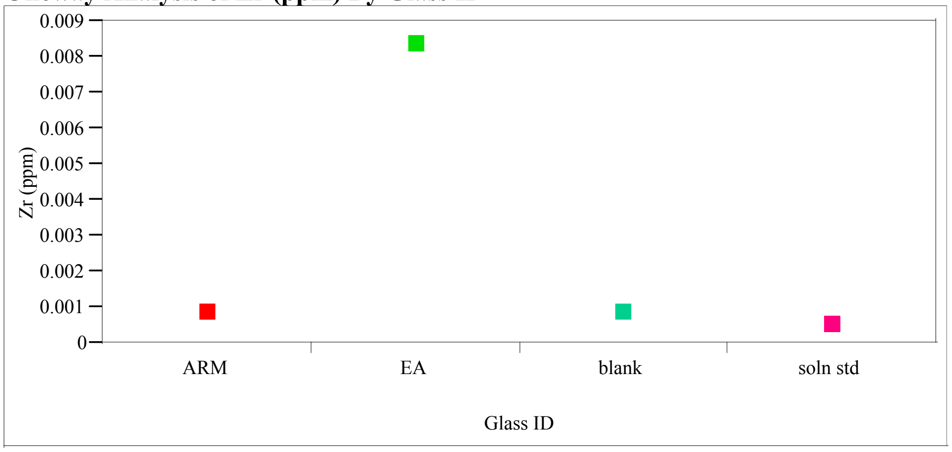
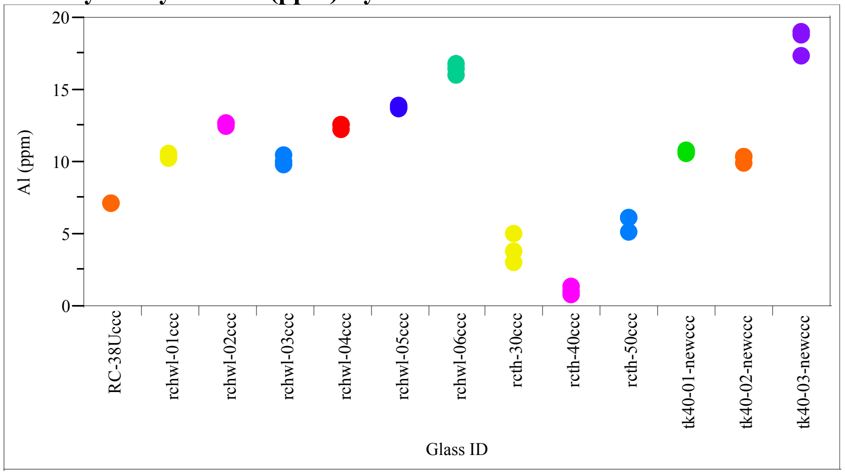


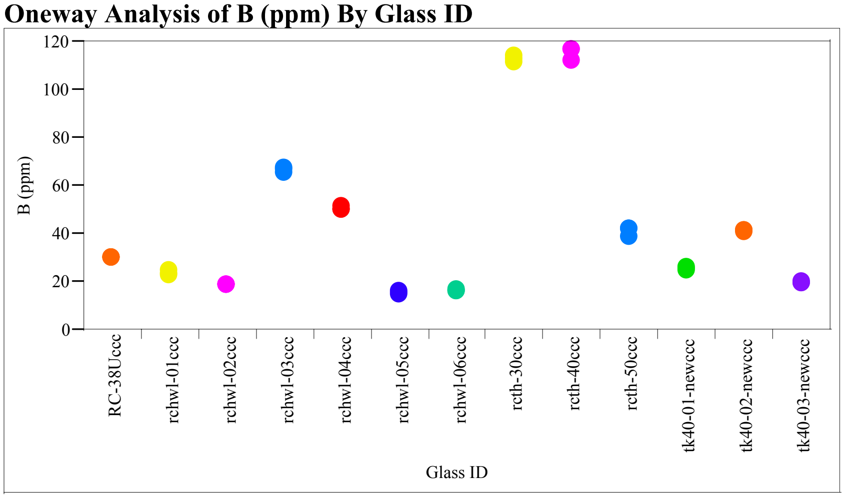
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Study Glasses for Centerline Canister Cooled Heat Treament

Oneway Analysis of Al (ppm) By Glass ID



Oneway Analysis of B (ppm) By Glass ID



Oneway Analysis of Ca (ppm) By Glass ID

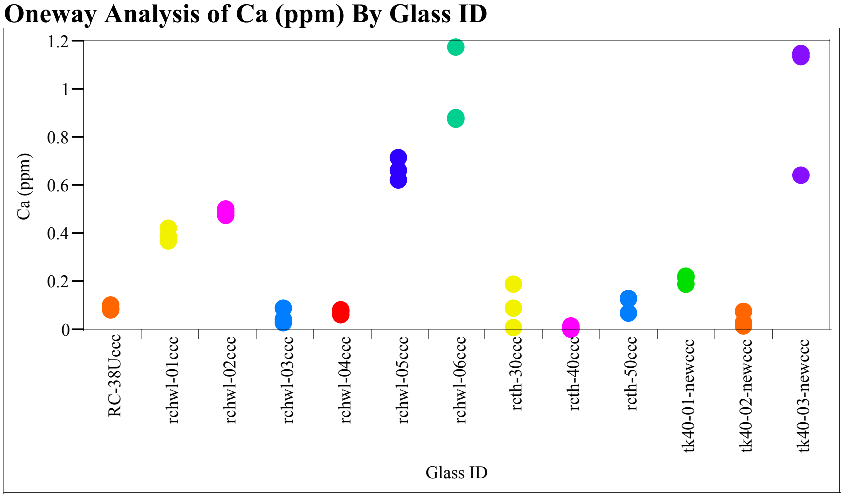
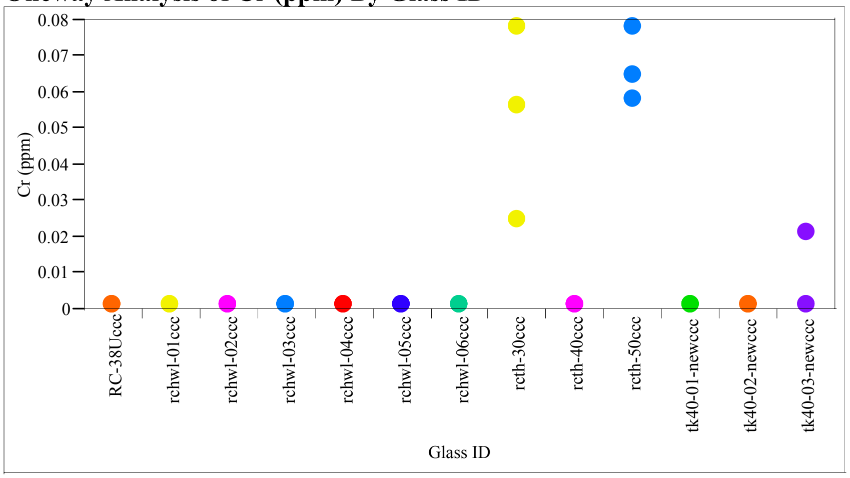


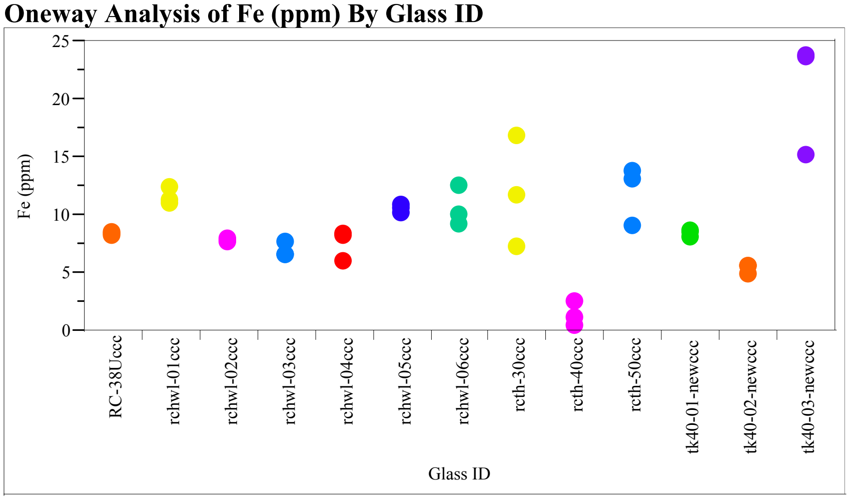
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Study Glasses for Centerline Canister Cooled Heat Treament (continued)

Oneway Analysis of Cr (ppm) By Glass ID



Oneway Analysis of Fe (ppm) By Glass ID



Oneway Analysis of Li (ppm) By Glass ID

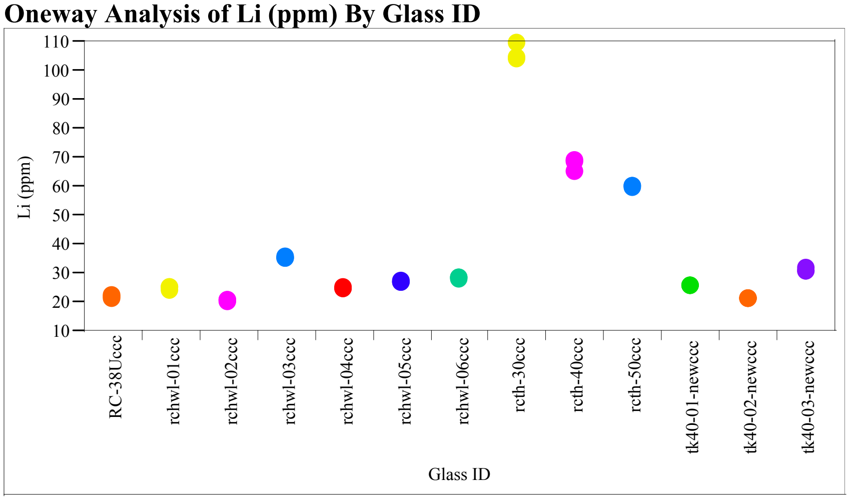
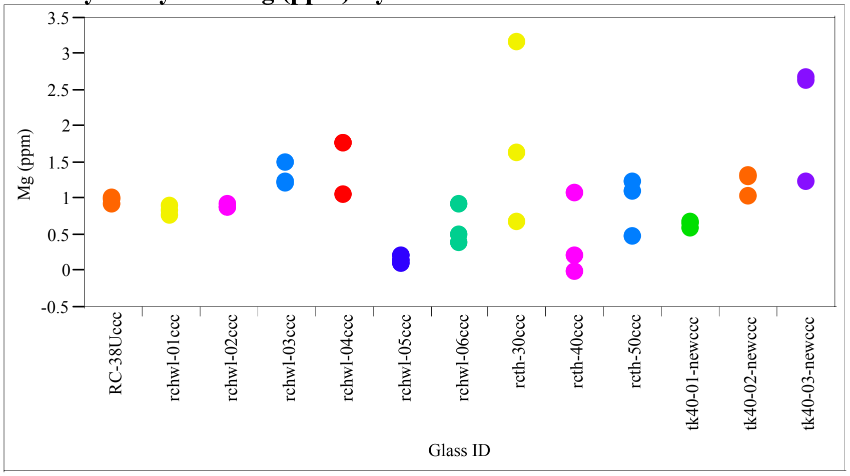


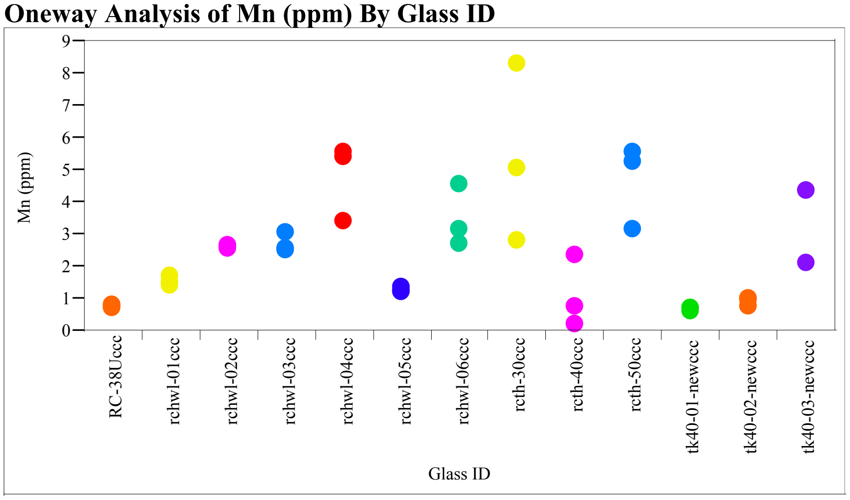
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Study Glasses for Centerline Canister Cooled Heat Treament (continued)

Oneway Analysis of Mg (ppm) By Glass ID



Oneway Analysis of Mn (ppm) By Glass ID



Oneway Analysis of Na (ppm) By Glass ID

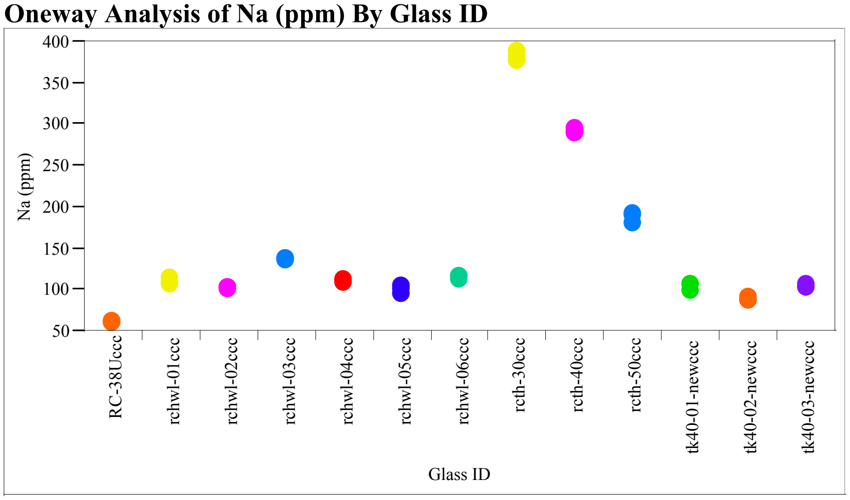
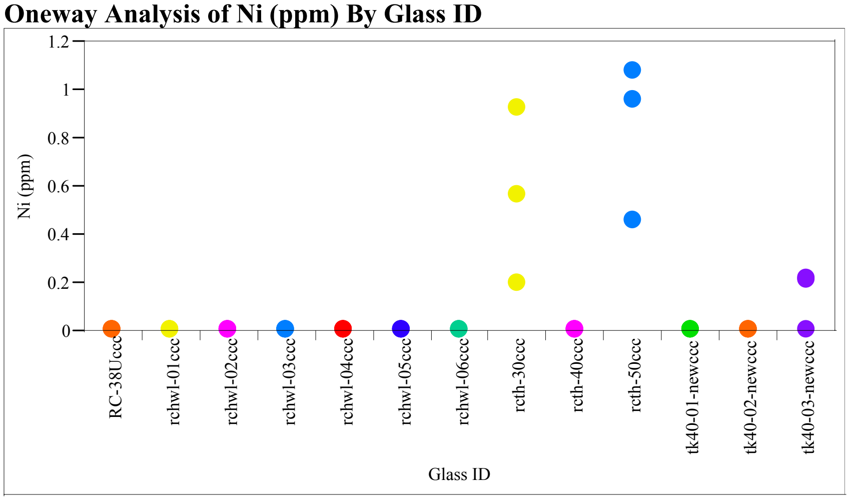


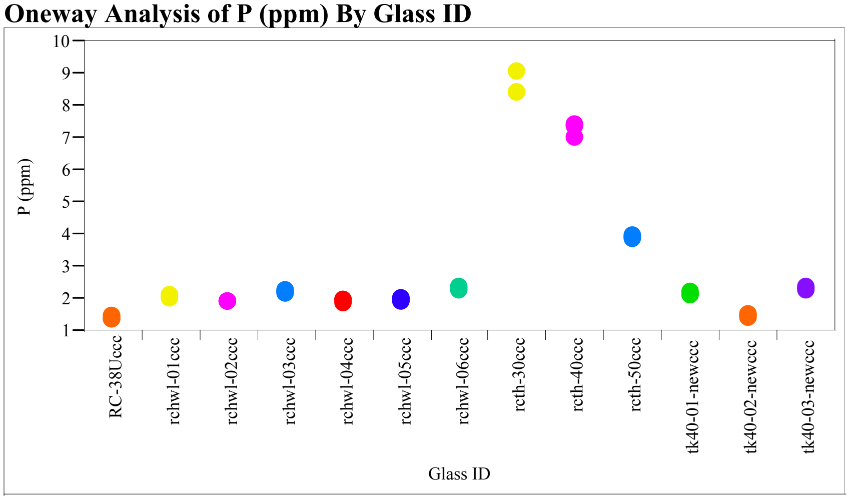
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Study Glasses for Centerline Canister Cooled Heat Treament (continued)

Oneway Analysis of Ni (ppm) By Glass ID



Oneway Analysis of P (ppm) By Glass ID



Oneway Analysis of Si (ppm) By Glass ID

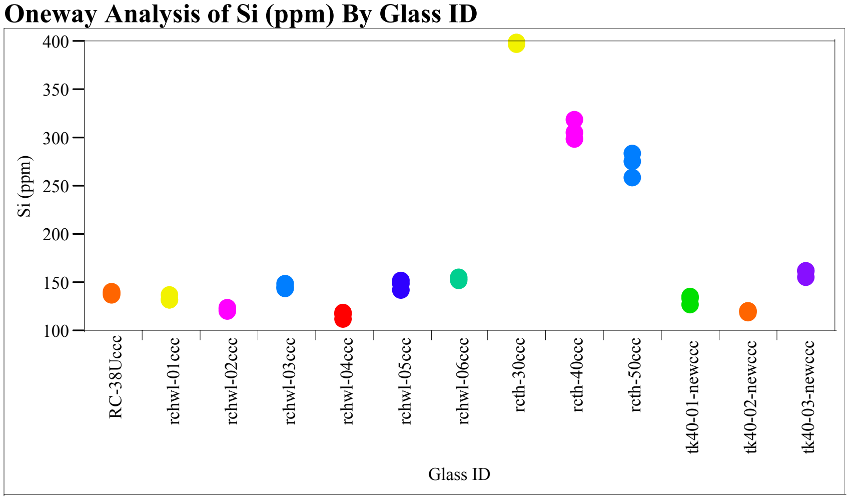
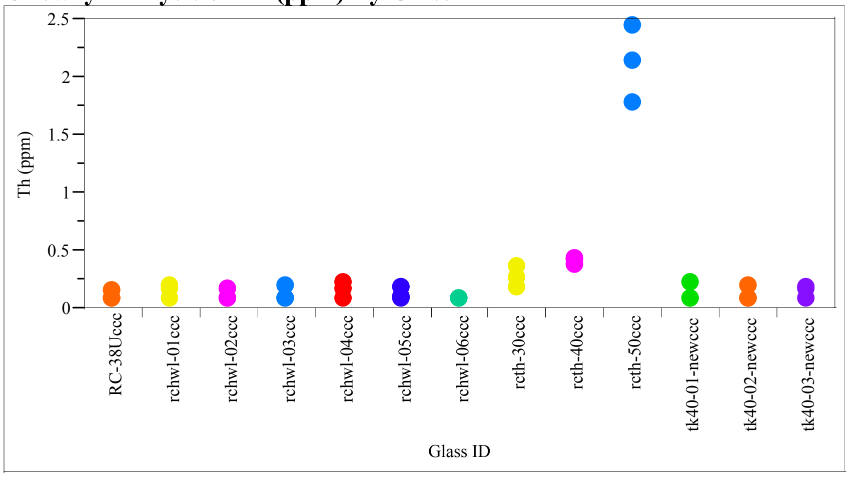


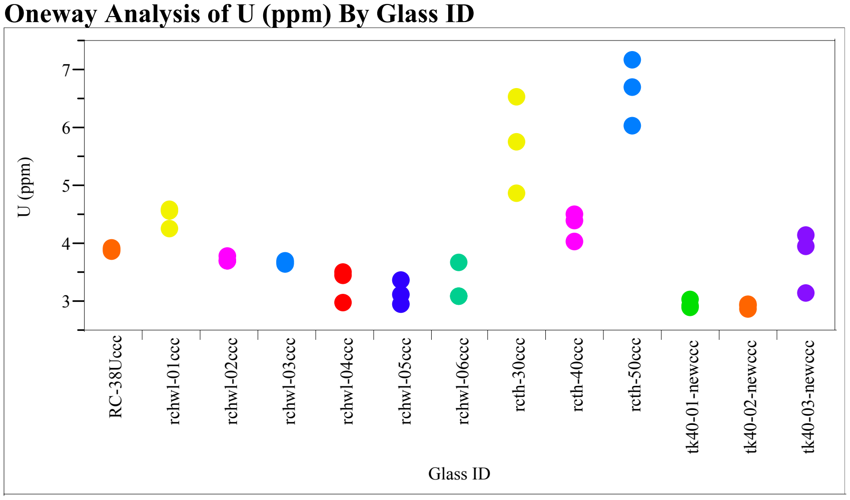
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Study Glasses for Centerline Canister Cooled Heat Treament (continued)

Oneway Analysis of Th (ppm) By Glass ID



Oneway Analysis of U (ppm) By Glass ID



Oneway Analysis of Zr (ppm) By Glass ID

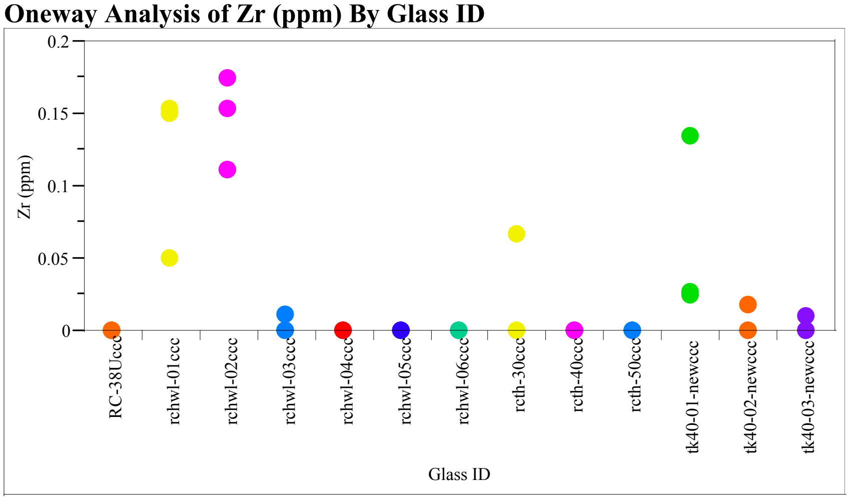
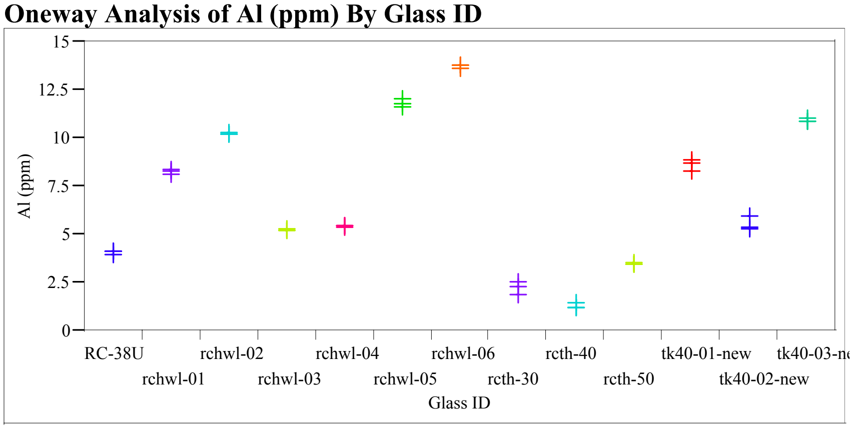


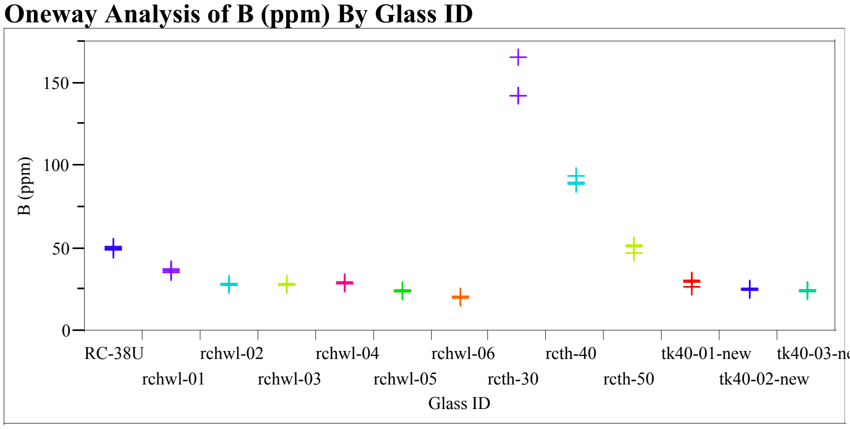
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Study Glasses for Quenched Heat Treament

Oneway Analysis of Al (ppm) By Glass ID



Oneway Analysis of B (ppm) By Glass ID



Oneway Analysis of Ca (ppm) By Glass ID

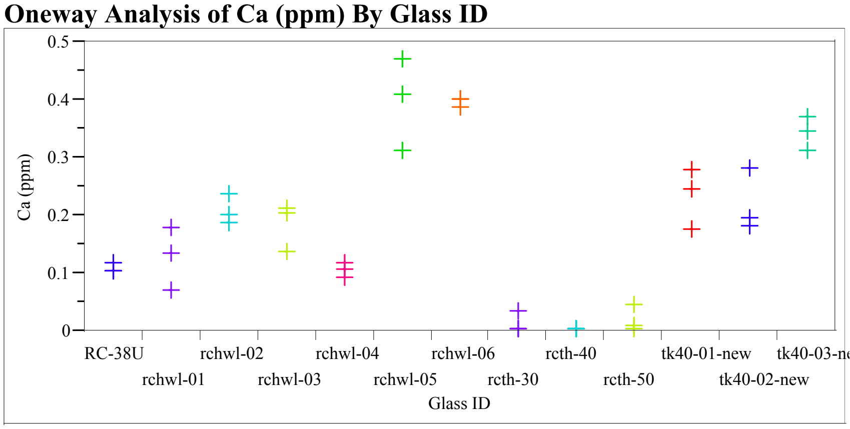
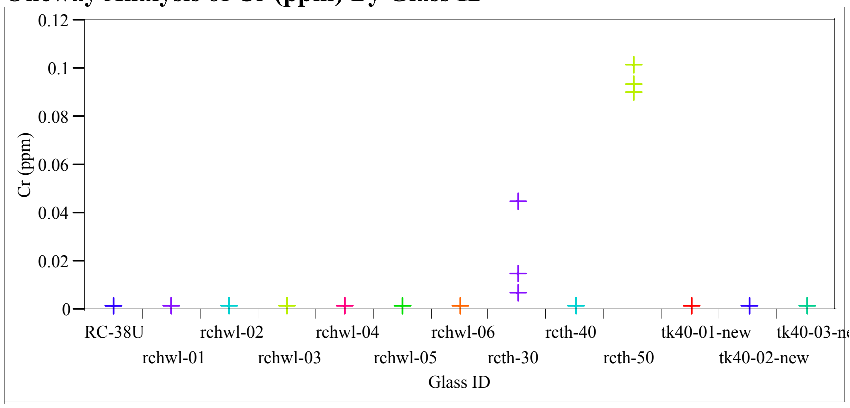


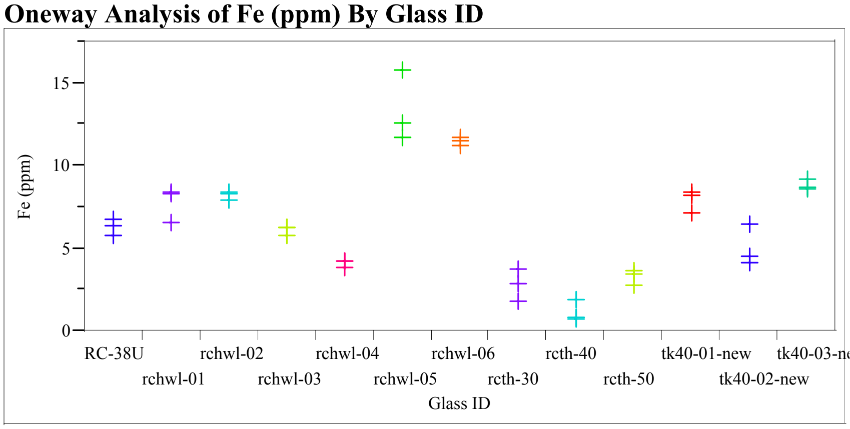
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Study Glasses for Quenched Heat Treament (continued)

Oneway Analysis of Cr (ppm) By Glass ID



Oneway Analysis of Fe (ppm) By Glass ID



Oneway Analysis of Li (ppm) By Glass ID

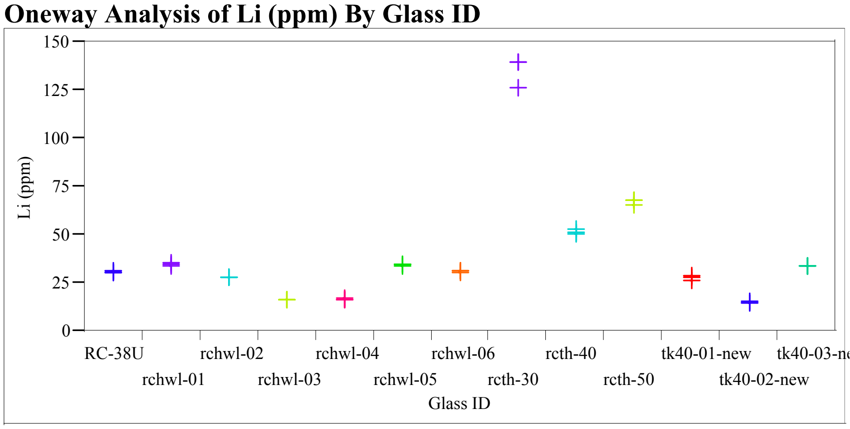
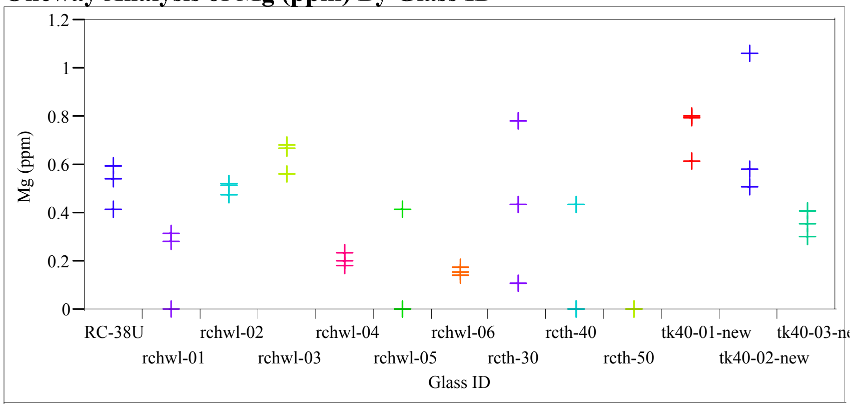


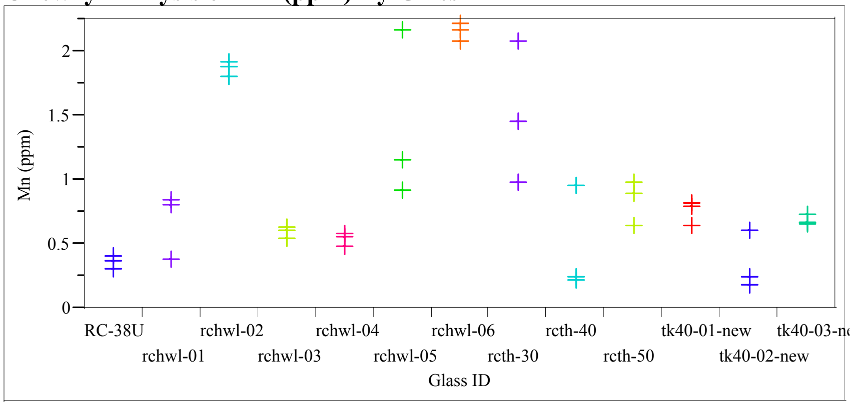
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Study Glasses for Quenched Heat Treament (continued)

Oneway Analysis of Mg (ppm) By Glass ID



Oneway Analysis of Mn (ppm) By Glass ID



Oneway Analysis of Na (ppm) By Glass ID

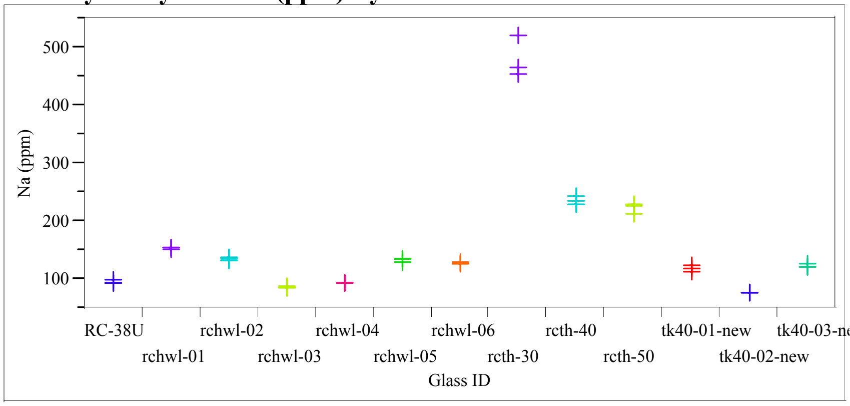
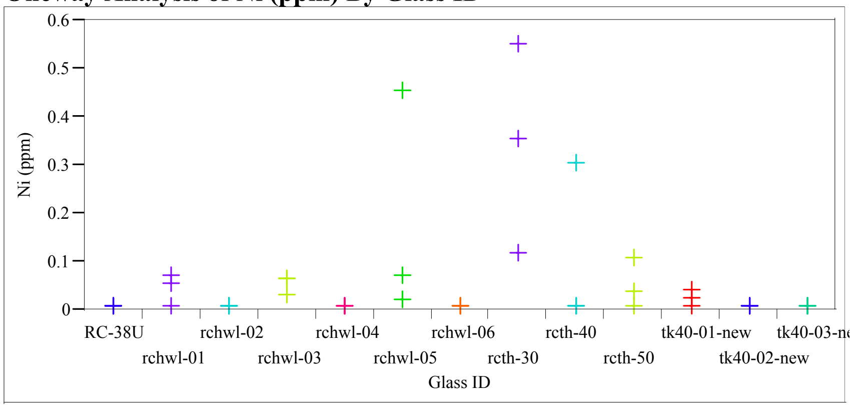


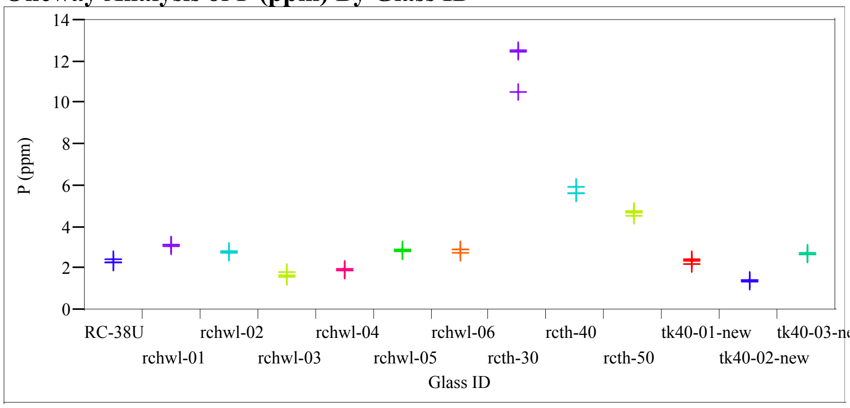
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Study Glasses for Quenched Heat Treament (continued)

Oneway Analysis of Ni (ppm) By Glass ID



Oneway Analysis of P (ppm) By Glass ID



Oneway Analysis of Si (ppm) By Glass ID

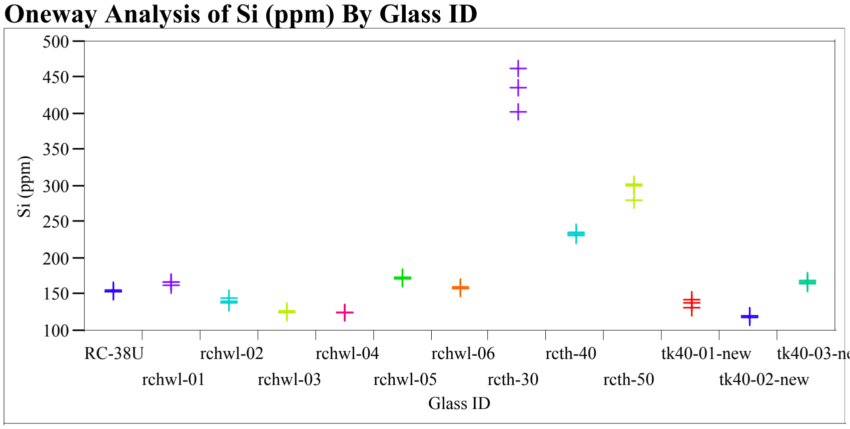
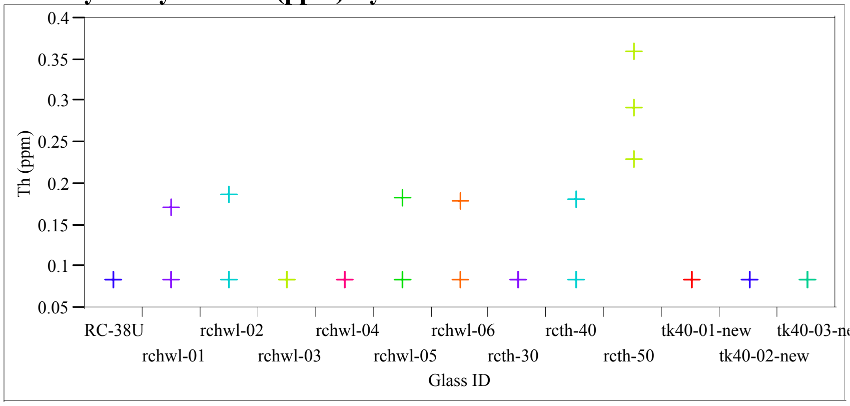


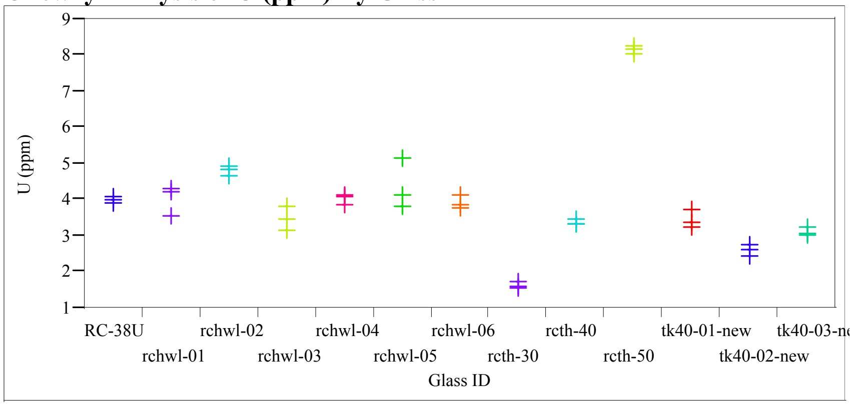
Exhibit D.4: SRTC-ML PCT Results for Each Standard and Study Glass by Heat Treament Group

Study Glasses for Quenched Heat Treament (continued)

Oneway Analysis of Th (ppm) By Glass ID



Oneway Analysis of U (ppm) By Glass ID



Oneway Analysis of Zr (ppm) By Glass ID

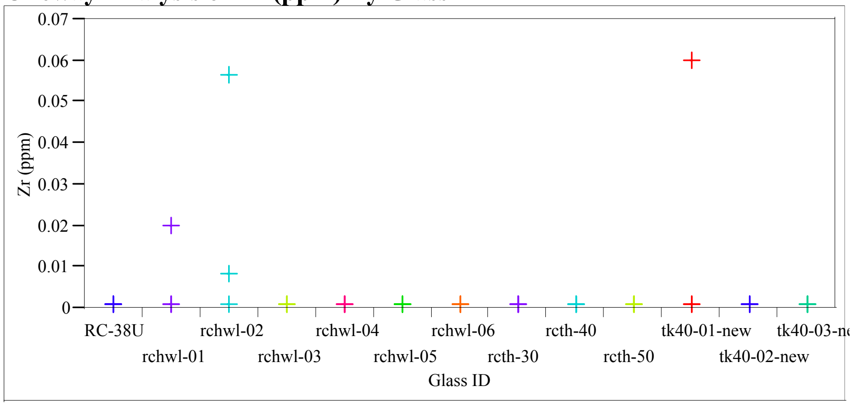
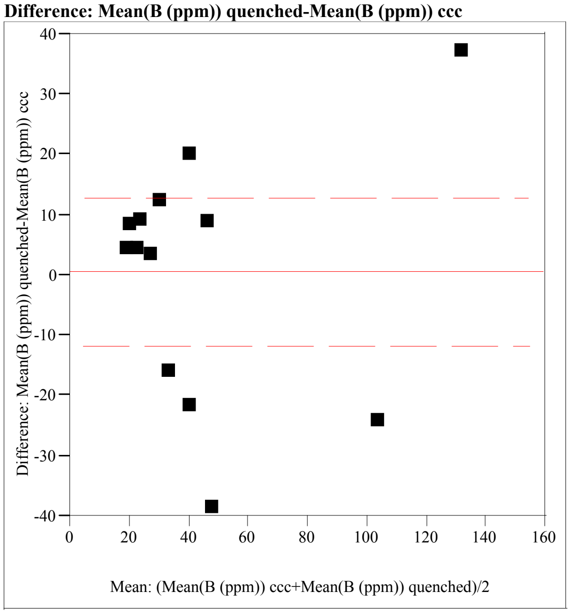


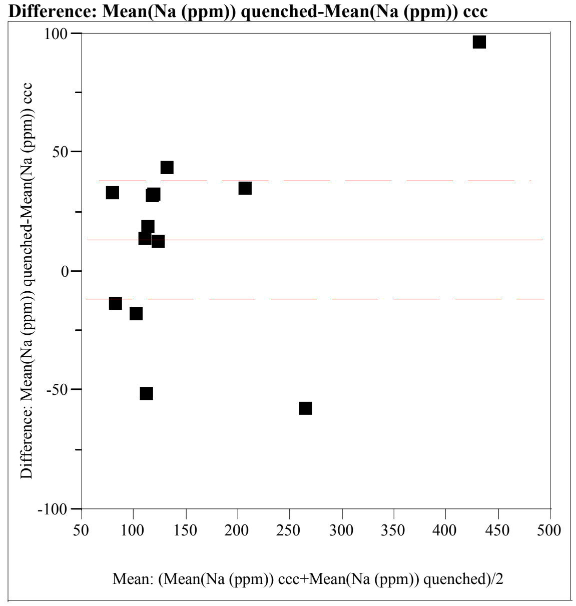
Exhibit D.5: Quenched versus CCC PCTs in ppm

Difference: Mean(B (ppm)) quenched-Mean(B (ppm)) ccc



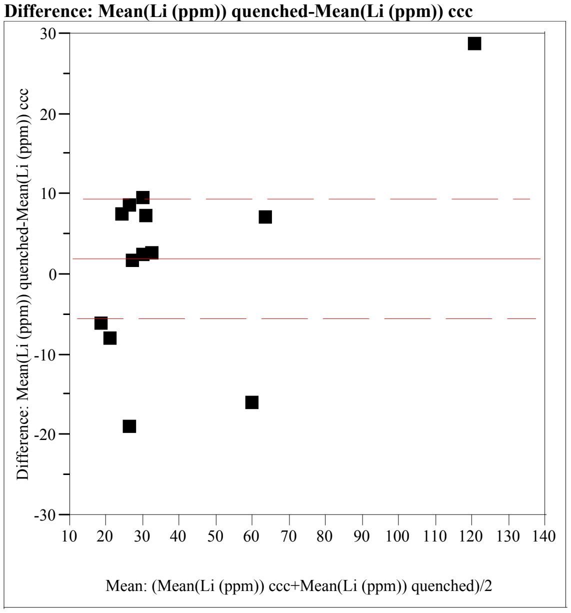
Mean(B (ppm)) quenched	45.0607	t-Ratio	0.096202
Mean(B (ppm)) ccc	44.5154	DF	12
Mean Difference	0.54531	Prob > |t|	0.9249
Std Error	5.66841	Prob > t	0.4625
Upper95%	12.8957	Prob < t	0.5375
Lower95%	-11.805		
N	13		
Correlation	0.83698		

Difference: Mean(Na (ppm)) quenched-Mean(Na (ppm)) ccc



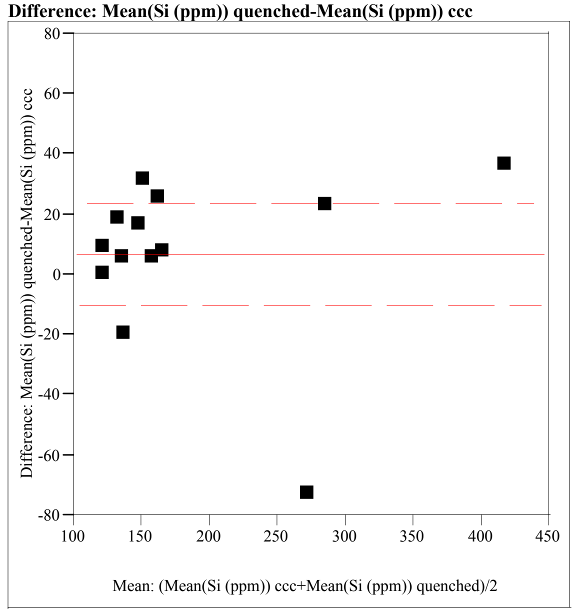
Mean(Na (ppm)) quenched	159.691	t-Ratio	1.155718
Mean(Na (ppm)) ccc	146.511	DF	12
Mean Difference	13.1798	Prob > |t|	0.2703
Std Error	11.4039	Prob > t	0.1351
Upper95%	38.0268	Prob < t	0.8649
Lower95%	-11.667		
N	13		
Correlation	0.92696		

Difference: Mean(Li (ppm)) quenched-Mean(Li (ppm)) ccc



Mean(Li (ppm)) quenched	40.0581	t-Ratio	0.560364
Mean(Li (ppm)) ccc	38.1375	DF	12
Mean Difference	1.92055	Prob > |t|	0.5855
Std Error	3.42733	Prob > t	0.2928
Upper95%	9.38806	Prob < t	0.7072
Lower95%	-5.547		
N	13		
Correlation	0.9323		

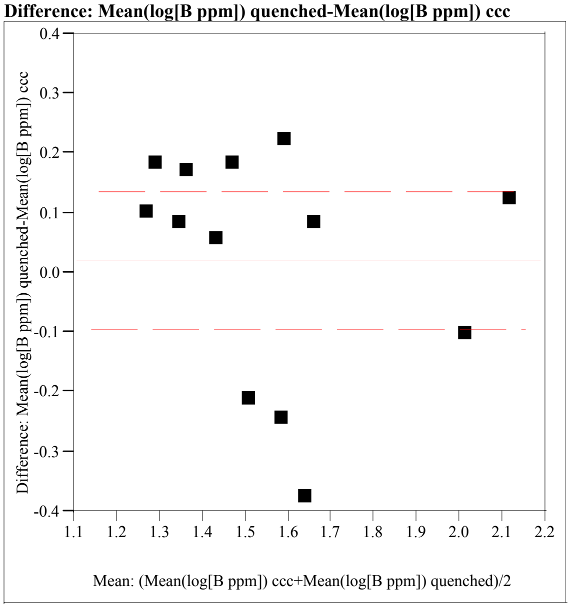
Difference: Mean(Si (ppm)) quenched-Mean(Si (ppm)) ccc



Mean(Si (ppm)) quenched	187.517	t-Ratio	0.873257
Mean(Si (ppm)) ccc	180.717	DF	12
Mean Difference	6.79928	Prob > |t|	0.3997
Std Error	7.78612	Prob > t	0.1998
Upper95%	23.7638	Prob < t	0.8002
Lower95%	-10.165		
N	13		
Correlation	0.94945		

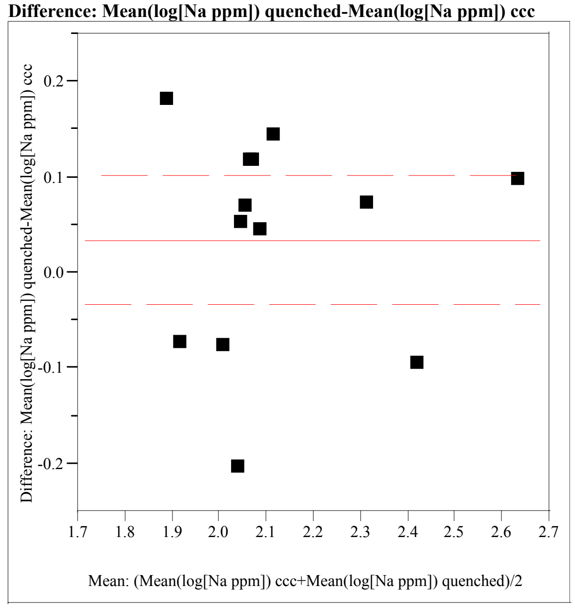
Exhibit D.6: Quenched versus CCC PCTs in log(ppm)

Difference: Mean(log[B ppm]) quenched-Mean(log[B ppm]) ccc



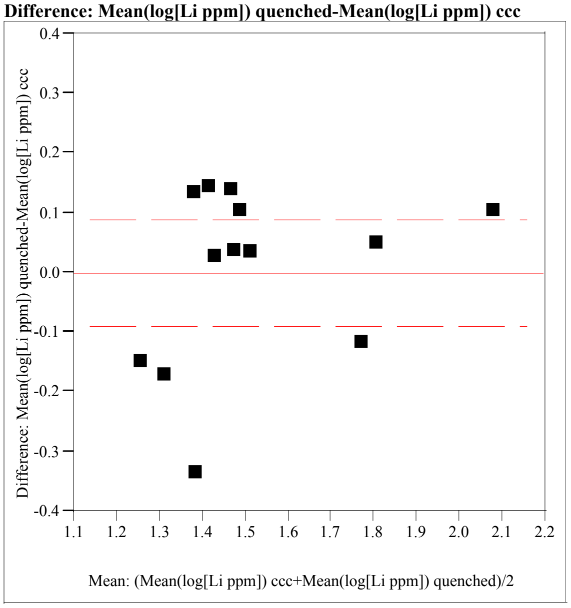
Mean(log[B ppm]) quenched	1.56868	t-Ratio	0.389287
Mean(log[B ppm]) ccc	1.54804	DF	12
Mean Difference	0.02064	Prob > |t|	0.7039
Std Error	0.05302	Prob > t	0.3519
Upper95%	0.13615	Prob < t	0.6481
Lower95%	-0.0949		
N	13		
Correlation	0.76873		

Difference: Mean(log[Na ppm]) quenched-Mean(log[Na ppm]) ccc



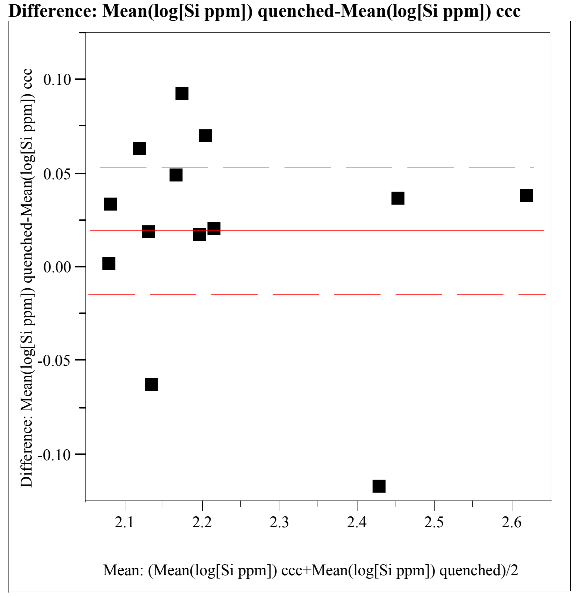
Mean(log[Na ppm]) quenched	2.14315	t-Ratio	1.090992
Mean(log[Na ppm]) ccc	2.10904	DF	12
Mean Difference	0.03411	Prob > |t|	0.2967
Std Error	0.03127	Prob > t	0.1483
Upper95%	0.10224	Prob < t	0.8517
Lower95%	-0.034		
N	13		
Correlation	0.86369		

Difference: Mean(log[Li ppm]) quenched-Mean(log[Li ppm]) ccc



Mean(log[Li ppm]) quenched	1.51855	t-Ratio	-0.02909
Mean(log[Li ppm]) ccc	1.51974	DF	12
Mean Difference	-0.0012	Prob > |t|	0.9773
Std Error	0.04106	Prob > t	0.5114
Upper95%	0.08827	Prob < t	0.4886
Lower95%	-0.0907		
N	13		
Correlation	0.82342		

Difference: Mean(log[Si ppm]) quenched-Mean(log[Si ppm]) ccc



Mean(log[Si ppm]) quenched	2.24038	t-Ratio	1.266198
Mean(log[Si ppm]) ccc	2.22086	DF	12
Mean Difference	0.01951	Prob > |t|	0.2295
Std Error	0.01541	Prob > t	0.1147
Upper95%	0.05309	Prob < t	0.8853
Lower95%	-0.0141		
N	13		
Correlation	0.94627		

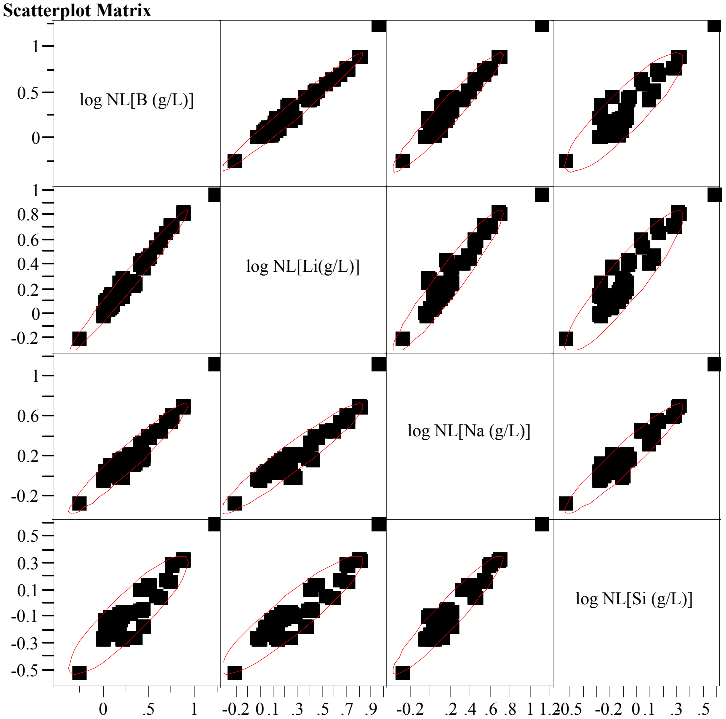
Exhibit D.7: Correlations and Scatter Plots of Normalized PCTs by Compositional View and Heat Treatment

Compositional View = All / Heat Treatment = Both

Multivariate Correlations

	log NL[B (g/L)]	log NL[Li(g/L)]	log NL[Na (g/L)]	log NL[Si (g/L)]
log NL[B (g/L)]	1.0000	0.9862	0.9615	0.8910
log NL[Li(g/L)]	0.9862	1.0000	0.9531	0.9184
log NL[Na (g/L)]	0.9615	0.9531	1.0000	0.9501
log NL[Si (g/L)]	0.8910	0.9184	0.9501	1.0000

Scatterplot Matrix



Compositional View = Measured bc / Heat Treatment = ccc

Multivariate Correlations

	log NL[B (g/L)]	log NL[Li(g/L)]	log NL[Na (g/L)]	log NL[Si (g/L)]
log NL[B (g/L)]	1.0000	0.9785	0.9326	0.7666
log NL[Li(g/L)]	0.9785	1.0000	0.9499	0.8598
log NL[Na (g/L)]	0.9326	0.9499	1.0000	0.8968
log NL[Si (g/L)]	0.7666	0.8598	0.8968	1.0000

Scatterplot Matrix

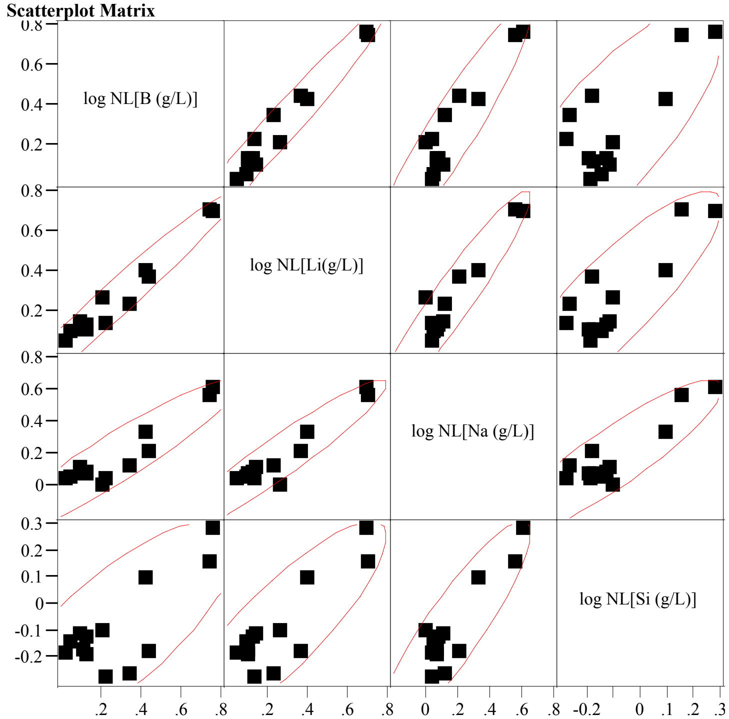


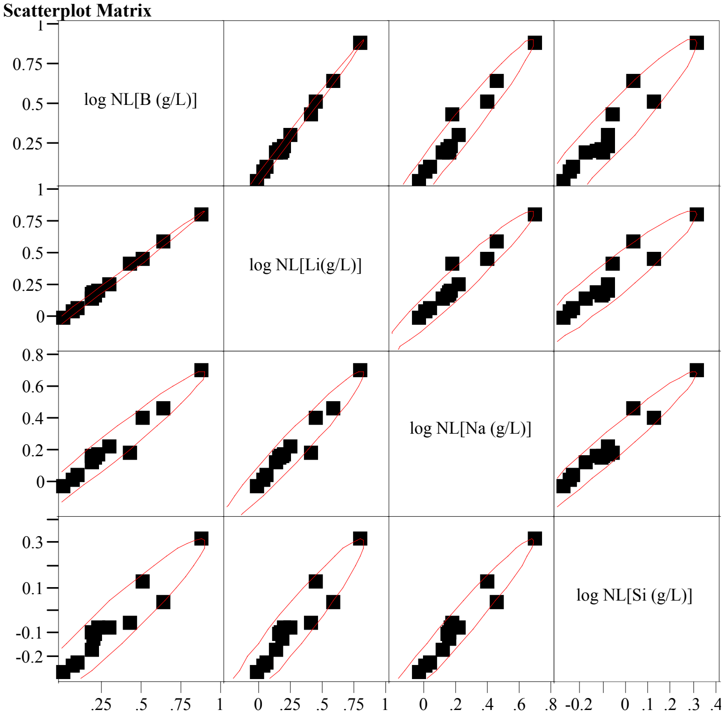
Exhibit D.7: Correlations and Scatter Plots of Normalized PCTs by Compositional View and Heat Treatment

Compositional View = Measured bc / Heat Treatment = quenched

Multivariate Correlations

	log NL[B (g/L)]	log NL[Li(g/L)]	log NL[Na (g/L)]	log NL[Si (g/L)]
log NL[B (g/L)]	1.0000	0.9984	0.9763	0.9559
log NL[Li(g/L)]	0.9984	1.0000	0.9708	0.9536
log NL[Na (g/L)]	0.9763	0.9708	1.0000	0.9751
log NL[Si (g/L)]	0.9559	0.9536	0.9751	1.0000

Scatterplot Matrix



Compositional View = Measured / Heat Treatment = ccc

Multivariate Correlations

	log NL[B (g/L)]	log NL[Li(g/L)]	log NL[Na (g/L)]	log NL[Si (g/L)]
log NL[B (g/L)]	1.0000	0.9785	0.9326	0.7666
log NL[Li(g/L)]	0.9785	1.0000	0.9500	0.8598
log NL[Na (g/L)]	0.9326	0.9500	1.0000	0.8968
log NL[Si (g/L)]	0.7666	0.8598	0.8968	1.0000

Scatterplot Matrix

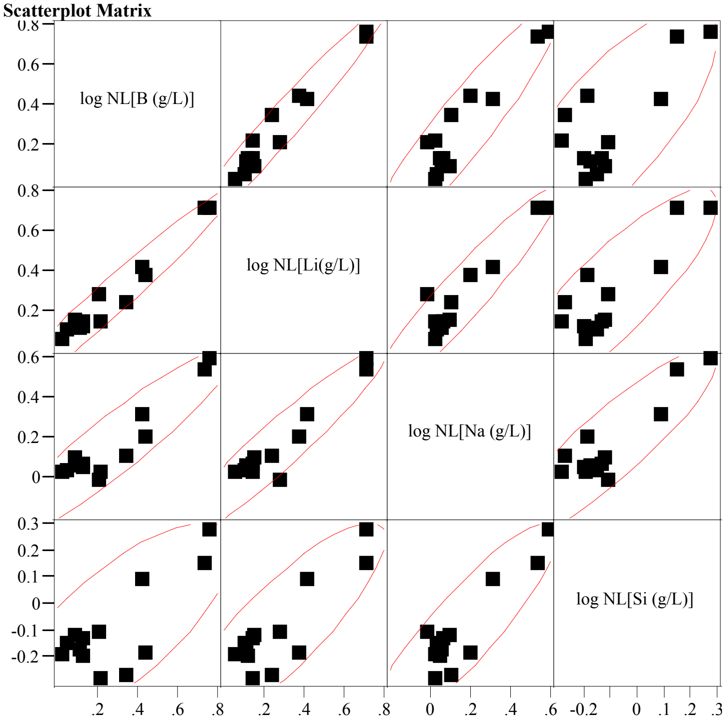


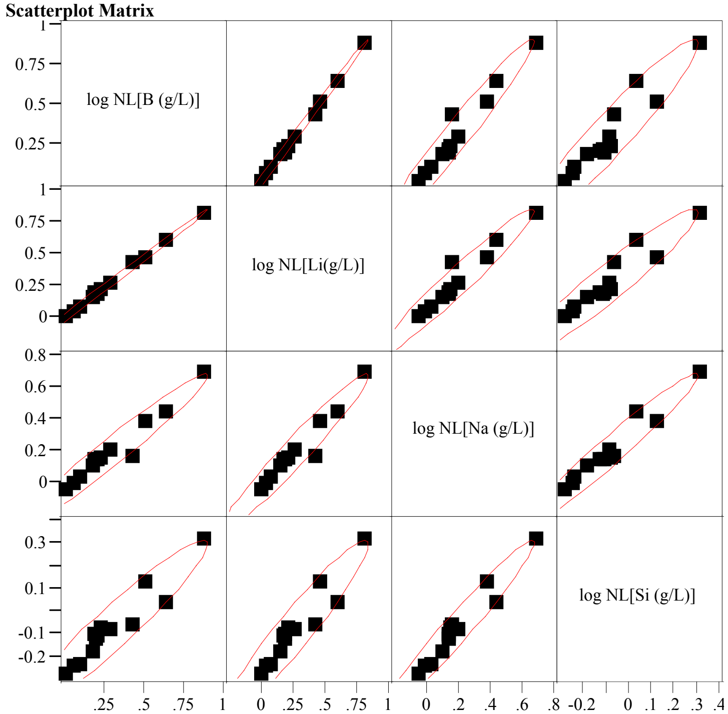
Exhibit D.7: Correlations and Scatter Plots of Normalized PCTs by Compositional View and Heat Treatment

Compositional View = Measured / Heat Treatment = quenched

Multivariate Correlations

	log NL[B (g/L)]	log NL[Li(g/L)]	log NL[Na (g/L)]	log NL[Si (g/L)]
log NL[B (g/L)]	1.0000	0.9984	0.9764	0.9559
log NL[Li(g/L)]	0.9984	1.0000	0.9708	0.9536
log NL[Na (g/L)]	0.9764	0.9708	1.0000	0.9751
log NL[Si (g/L)]	0.9559	0.9536	0.9751	1.0000

Scatterplot Matrix



Compositional View = Targeted / Heat Treatment = ccc

Multivariate Correlations

	log NL[B (g/L)]	log NL[Li(g/L)]	log NL[Na (g/L)]	log NL[Si (g/L)]
log NL[B (g/L)]	1.0000	0.9757	0.9305	0.7610
log NL[Li(g/L)]	0.9757	1.0000	0.9516	0.8648
log NL[Na (g/L)]	0.9305	0.9516	1.0000	0.8988
log NL[Si (g/L)]	0.7610	0.8648	0.8988	1.0000

Scatterplot Matrix

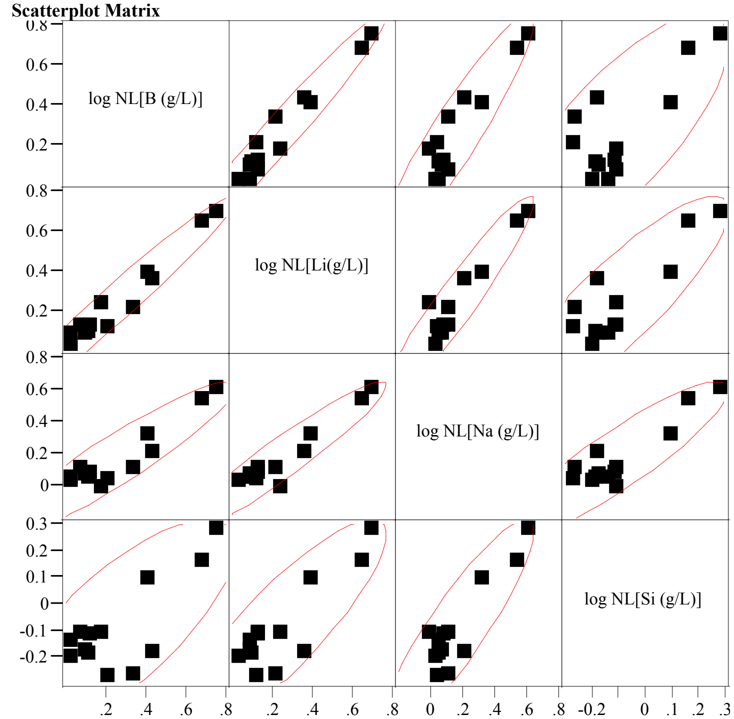


Exhibit D.7: Correlations and Scatter Plots of Normalized PCTs by Compositional View and Heat Treatment

Compositional View = Targeted / Heat Treatment = quenched

Multivariate Correlations

	log NL[B (g/L)]	log NL[Li(g/L)]	log NL[Na (g/L)]	log NL[Si (g/L)]
log NL[B (g/L)]	1.0000	0.9985	0.9790	0.9640
log NL[Li(g/L)]	0.9985	1.0000	0.9732	0.9632
log NL[Na (g/L)]	0.9790	0.9732	1.0000	0.9781
log NL[Si (g/L)]	0.9640	0.9632	0.9781	1.0000

Scatterplot Matrix

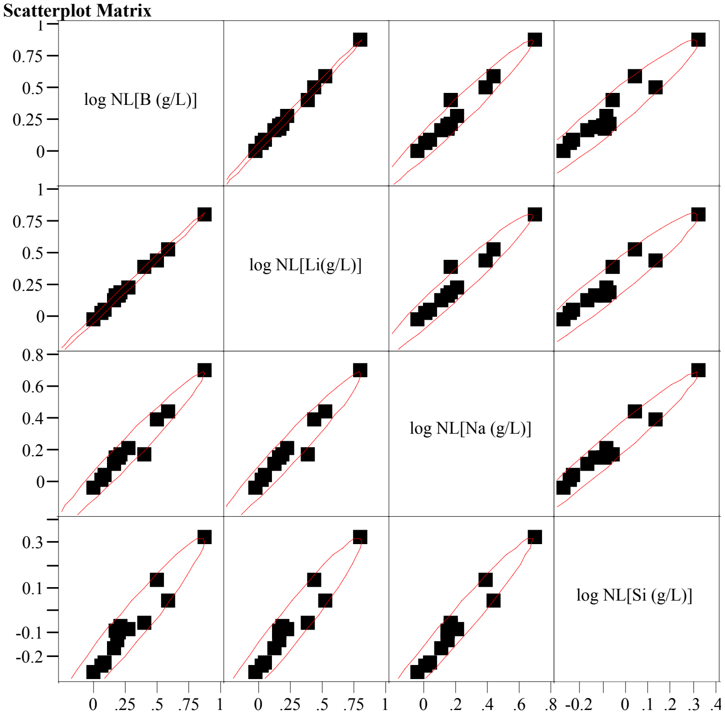
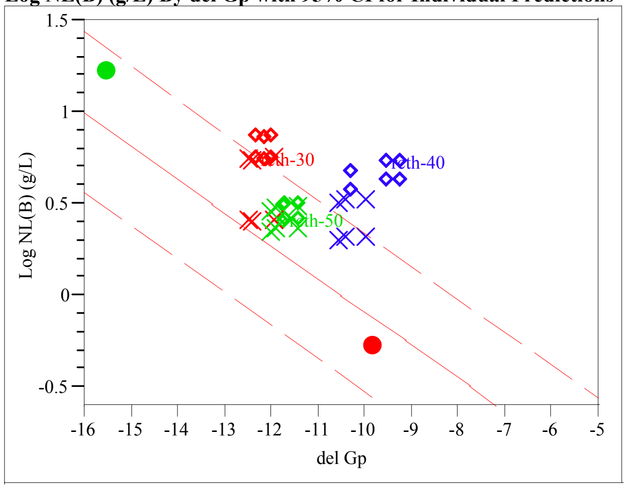


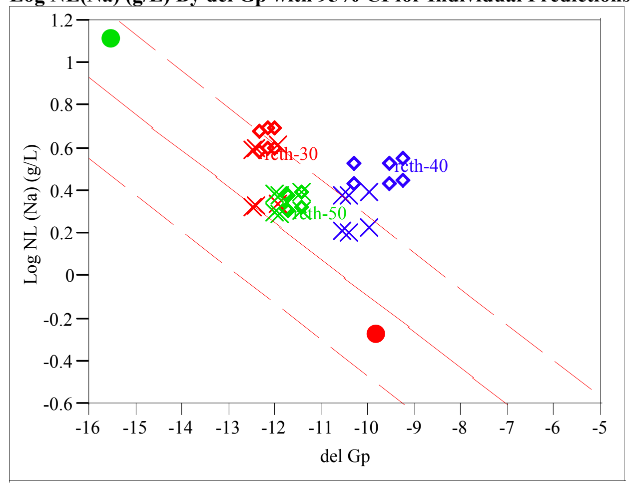
Exhibit D.8: del Gp (ΔG_p) Predictions versus Common Logarithm Normalized Leachate (log NL[.]) for B, Li, Na, and Si by Heat Treatment for RC and rcth Glasses for All Compositional Views

All Data

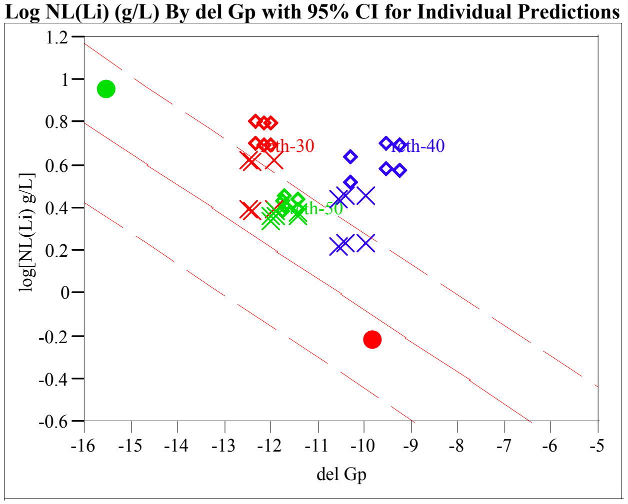
Log NL(B) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Na) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Li) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Si) (g/L) By del Gp with 95% CI for Individual Predictions

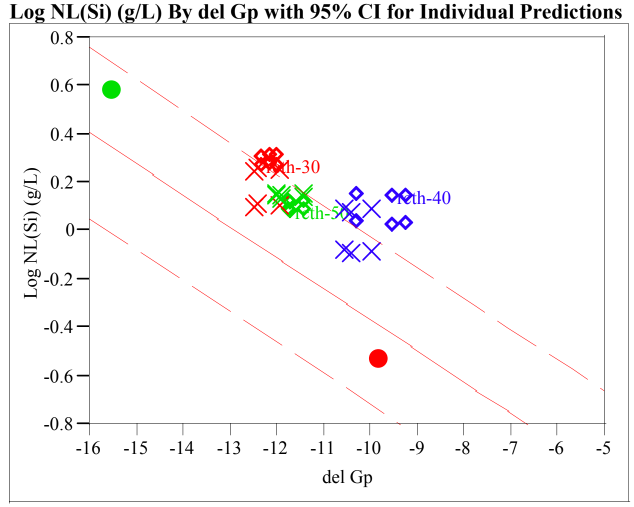
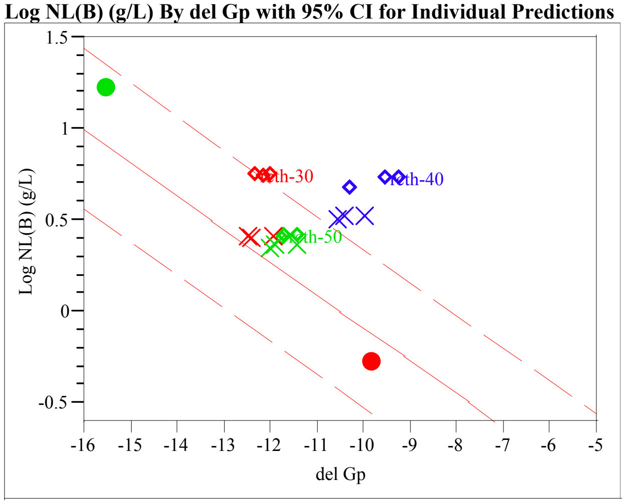


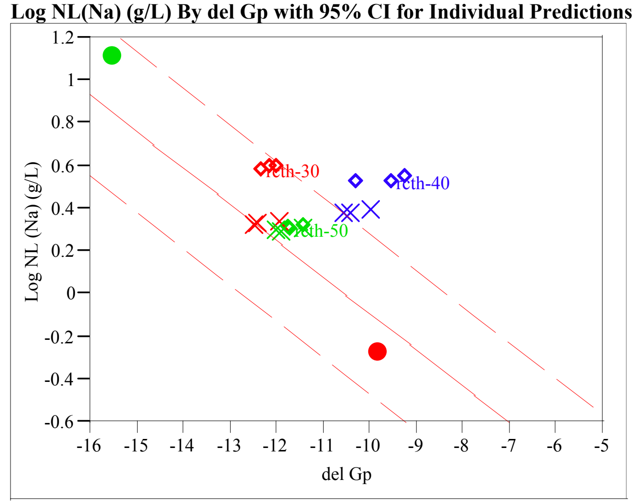
Exhibit D.8: del Gp (ΔG_p) Predictions versus Common Logarithm Normalized Leachate (log NL[.]) for B, Li, Na, and Si by Heat Treatment for RC and rcth Glasses for All Compositional Views

All ccc Data

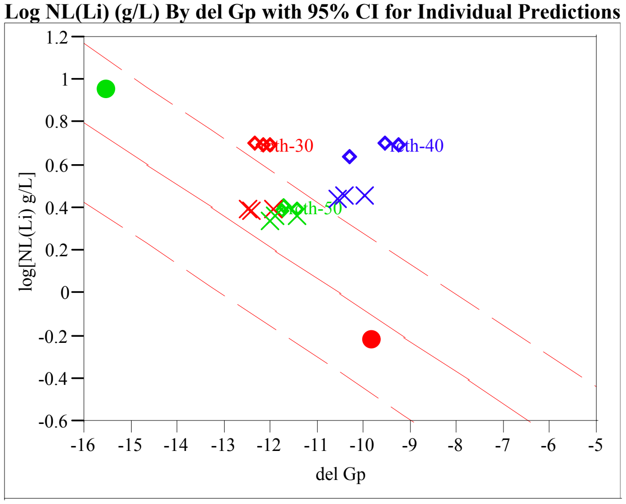
Log NL(B) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Na) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Li) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Si) (g/L) By del Gp with 95% CI for Individual Predictions

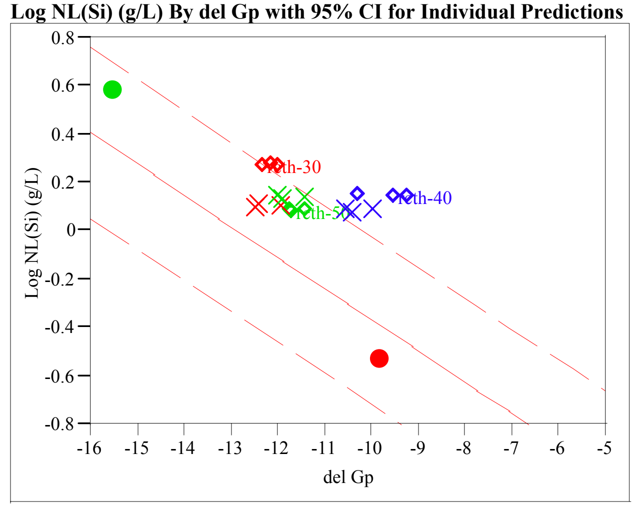
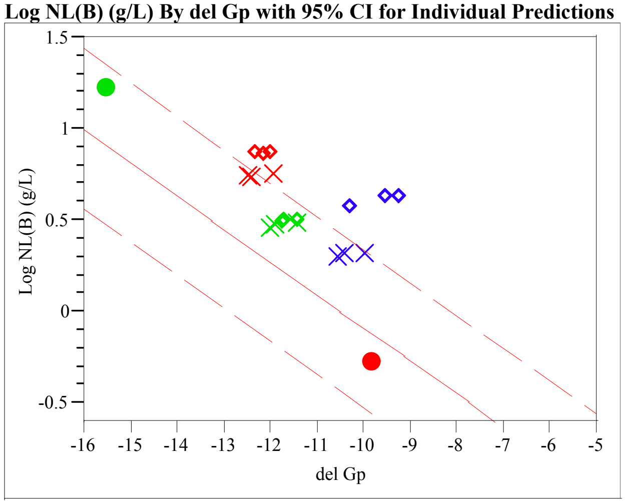


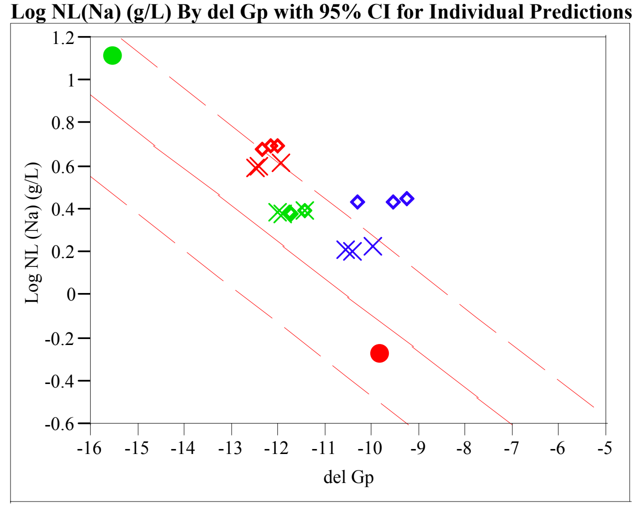
Exhibit D.8: del Gp (ΔG_p) Predictions versus Common Logarithm Normalized Leachate (log NL[.]) for B, Li, Na, and Si by Heat Treatment for RC and rcth Glasses for All Compositional Views

All quenched Data

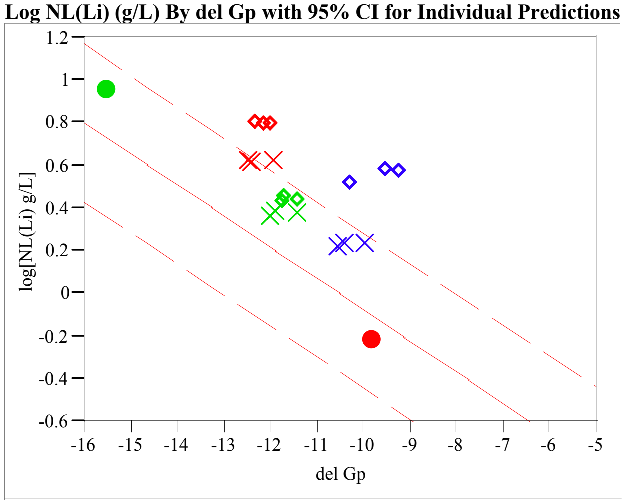
Log NL(B) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Na) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Li) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Si) (g/L) By del Gp with 95% CI for Individual Predictions

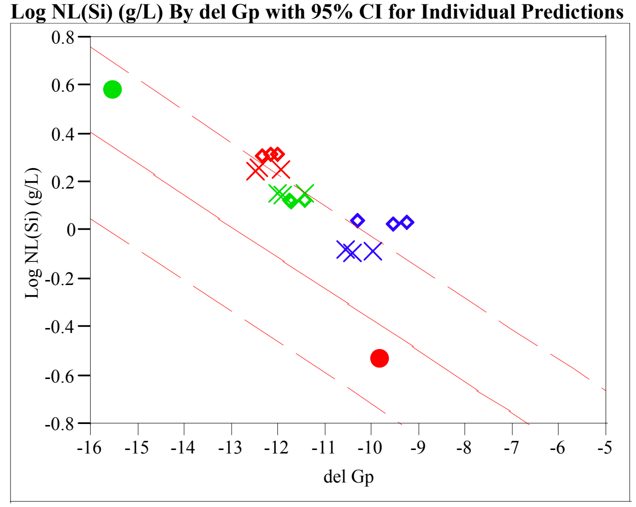
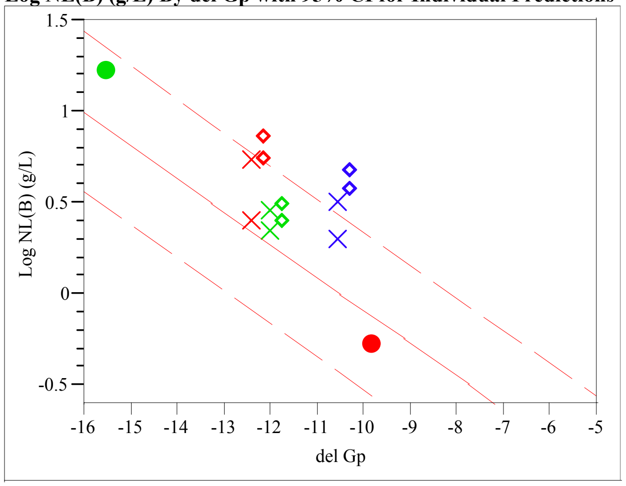


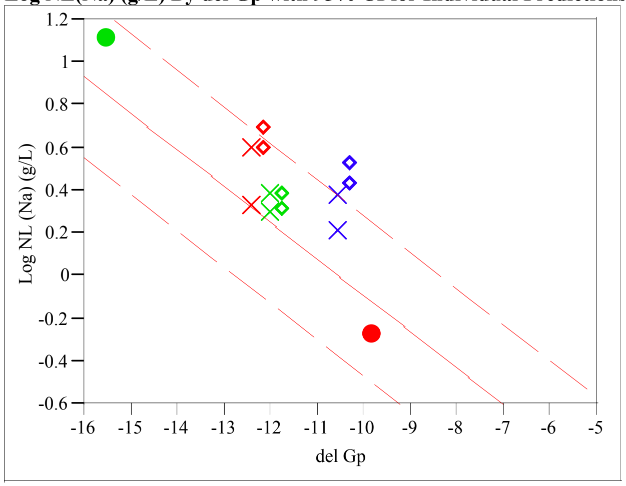
Exhibit D.8: del Gp (ΔG_p) Predictions versus Common Logarithm Normalized Leachate (log NL[.]) for B, Li, Na, and Si by Heat Treatment for RC and rcth Glasses for All Compositional Views

Targeted Compositions for Both Heat Treatments

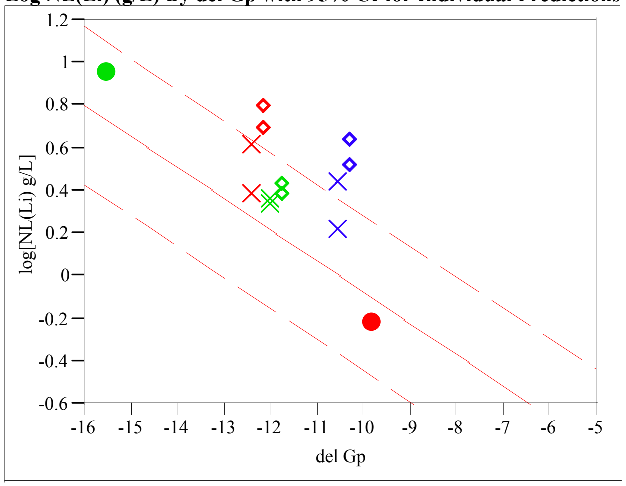
Log NL(B) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Na) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Li) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Si) (g/L) By del Gp with 95% CI for Individual Predictions

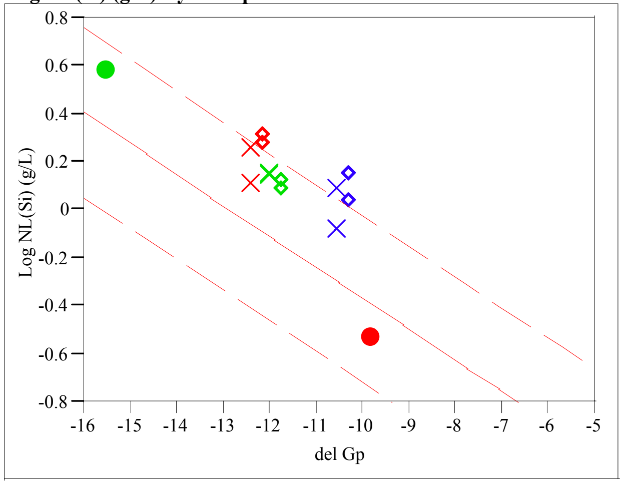
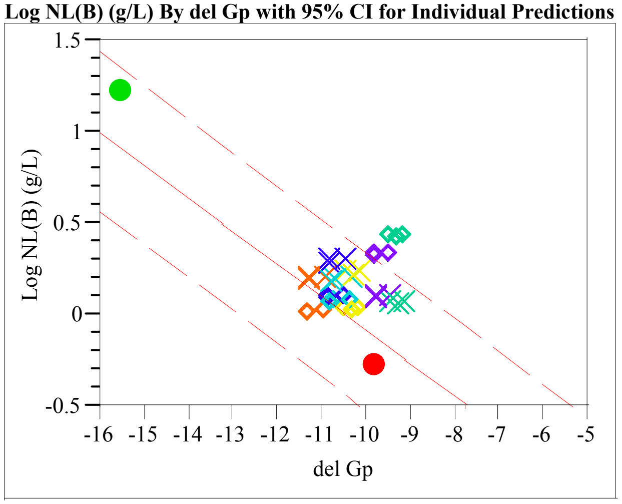


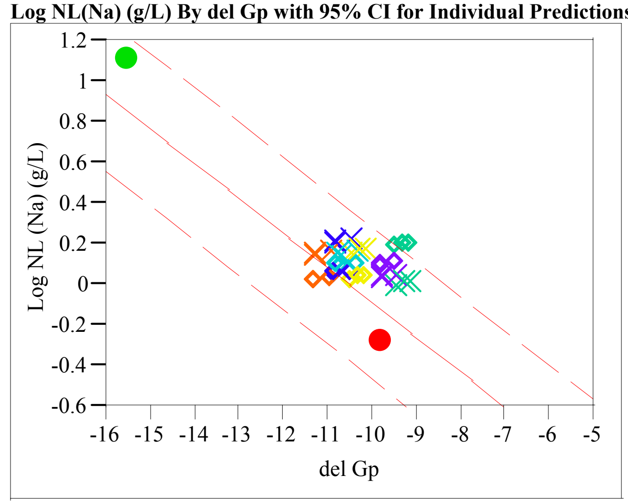
Exhibit D.9: del Gp (ΔG_p) Predictions versus Common Logarithm Normalized Leachate (log NL[.]) for B, Li, Na, and Si by Heat Treatment for HWL Glasses for All Compositional Views

All Data

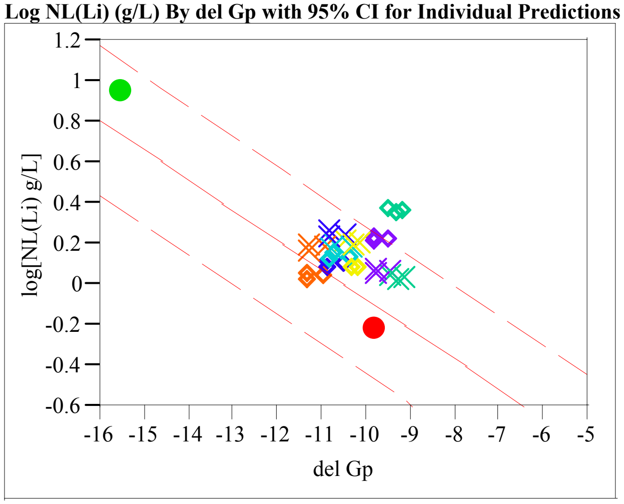
Log NL(B) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Na) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Li) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Si) (g/L) By del Gp with 95% CI for Individual Predictions

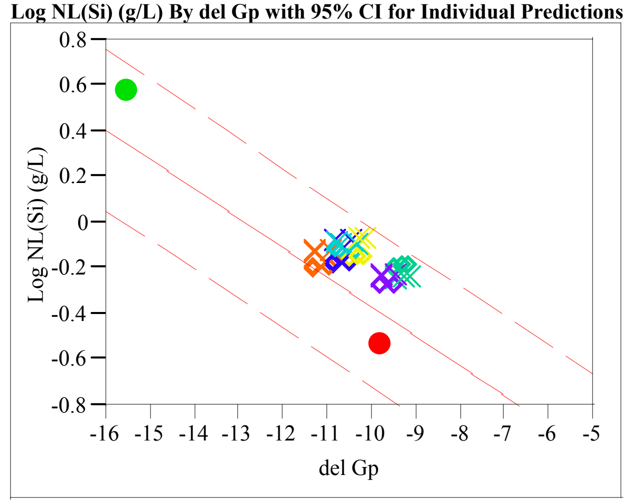
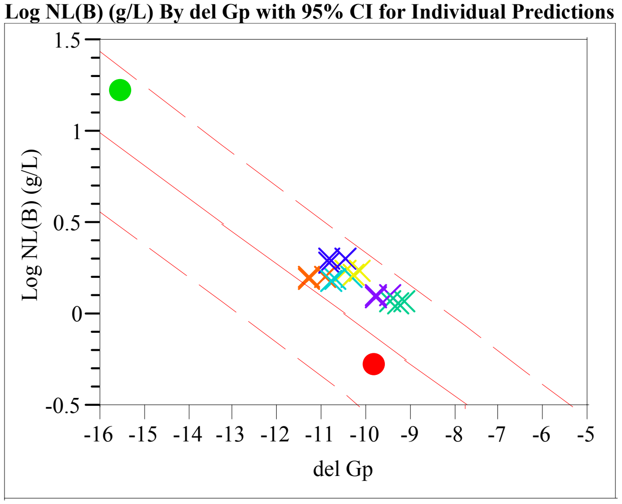


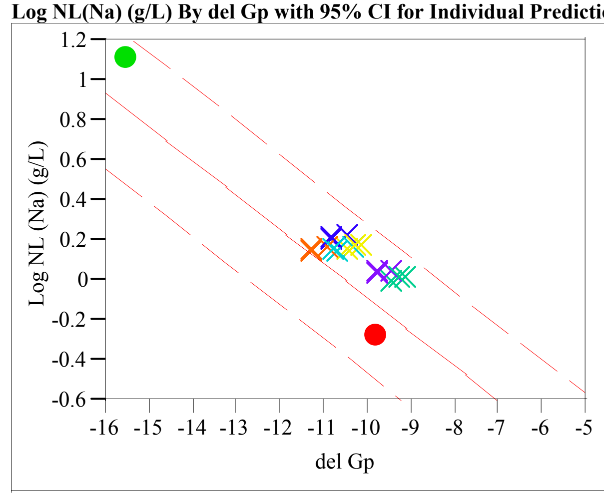
Exhibit D.9: del Gp (ΔG_p) Predictions versus Common Logarithm Normalized Leachate (log NL[.]) for B, Li, Na, and Si by Heat Treatment for HWL Glasses for All Compositional Views

All quenched Data

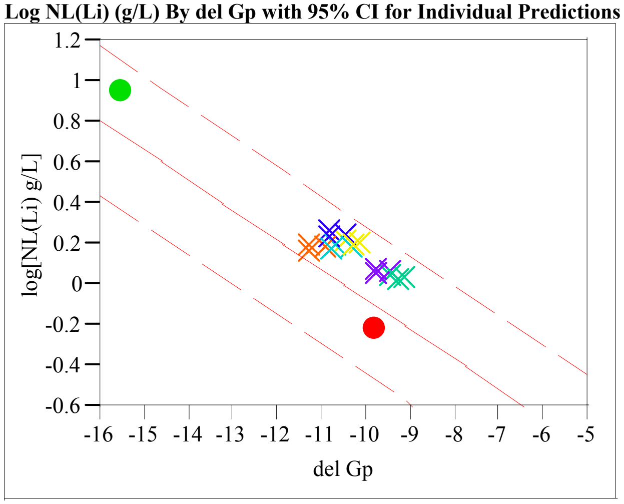
Log NL(B) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Na) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Li) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Si) (g/L) By del Gp with 95% CI for Individual Predictions

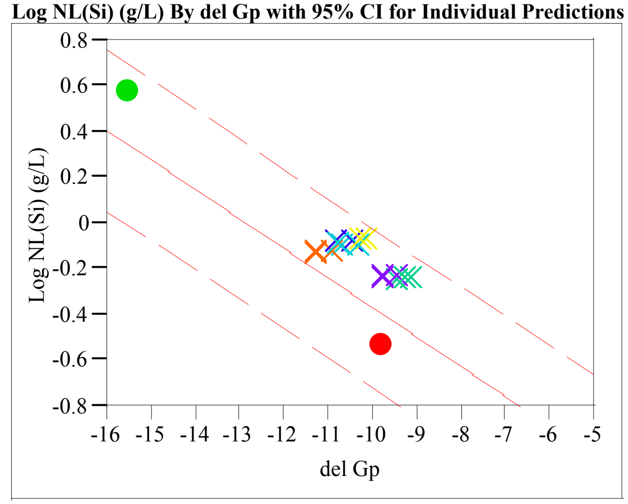
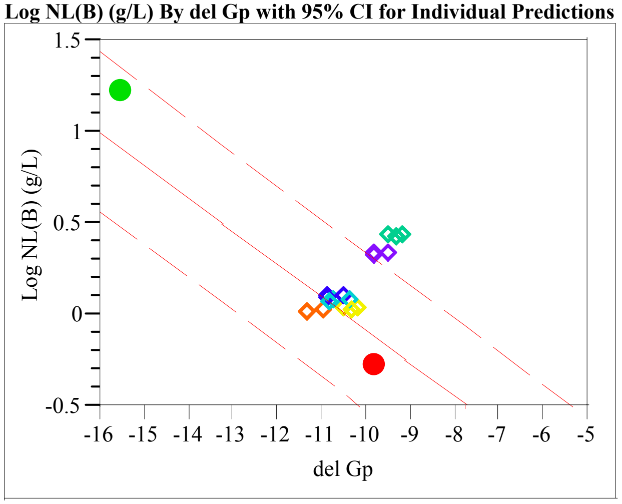


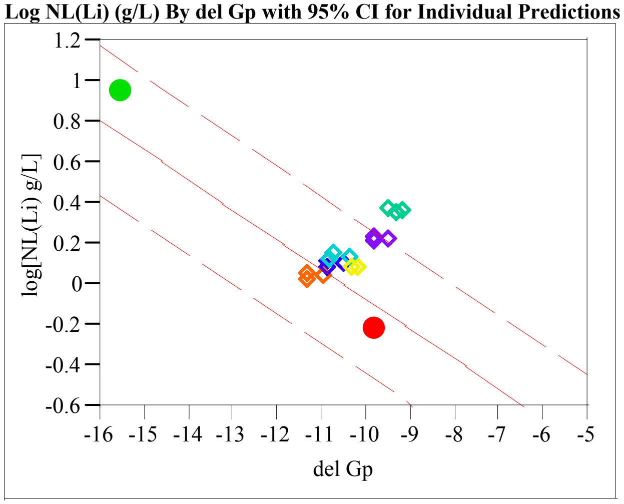
Exhibit D.9: del Gp (ΔG_p) Predictions versus Common Logarithm Normalized Leachate (log NL[.]) for B, Li, Na, and Si by Heat Treatment for HWL Glasses for All Compositional Views

All ccc Data

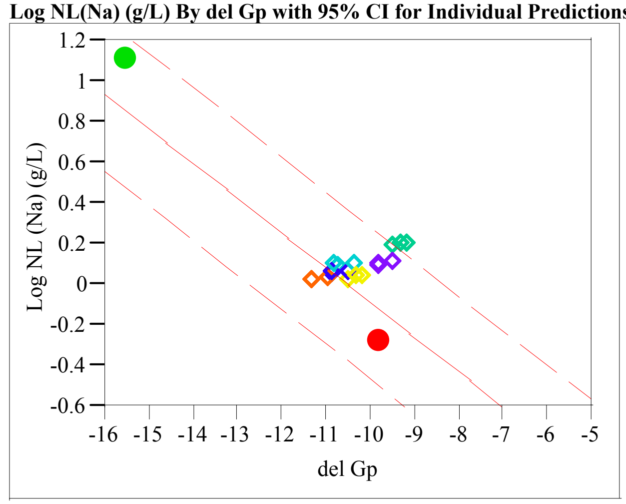
Log NL(B) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Li) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Na) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Si) (g/L) By del Gp with 95% CI for Individual Predictions

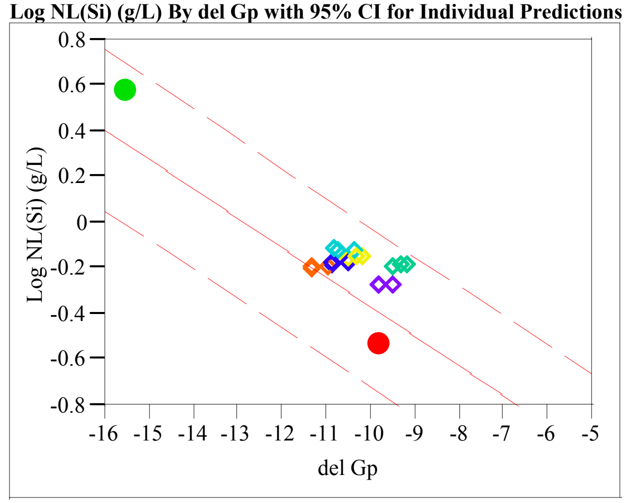
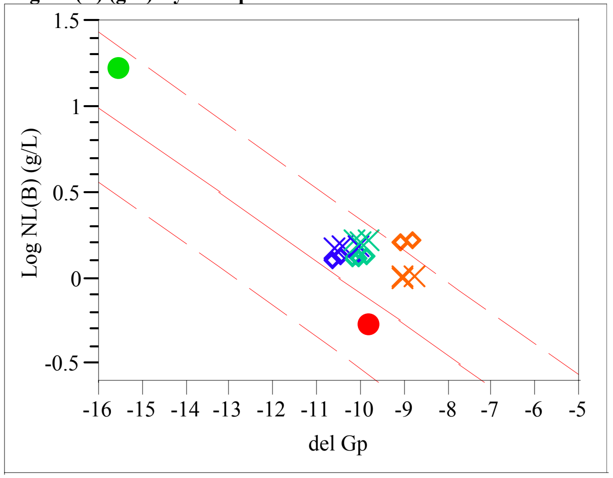


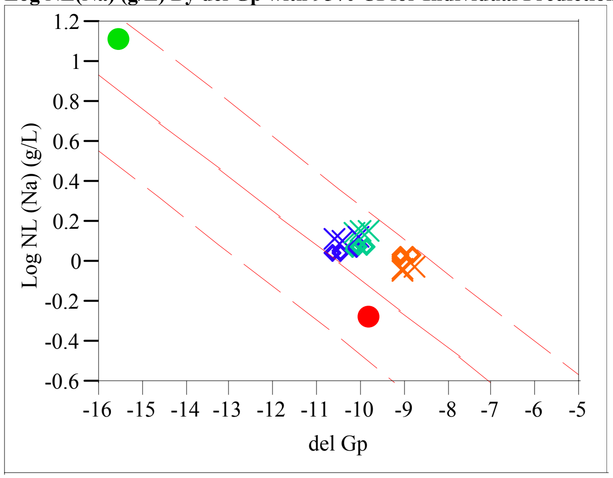
Exhibit D.10: del Gp (ΔG_p) Predictions versus Common Logarithm Normalized Leachate (log NL[.]) for B, Li, Na, and Si by Heat Treatment for Tank 40 Glasses for All Compositional Views

All Data

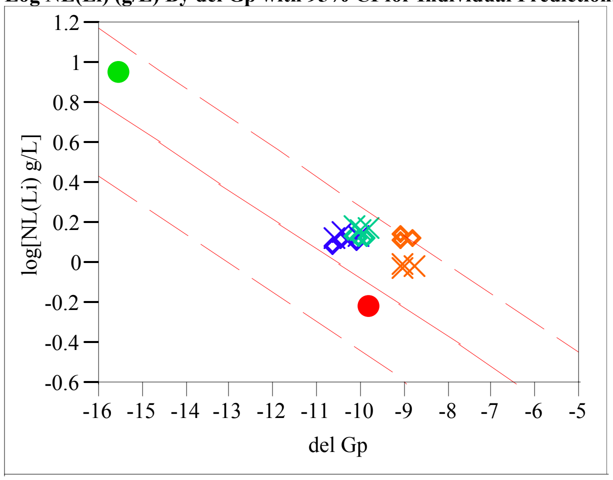
Log NL(B) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Na) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Li) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Si) (g/L) By del Gp with 95% CI for Individual Predictions

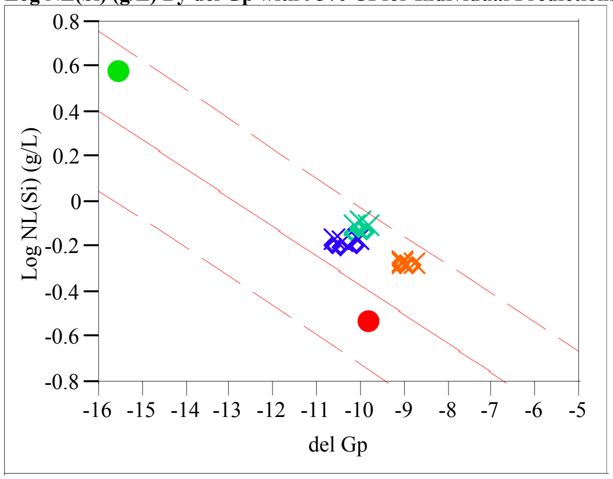
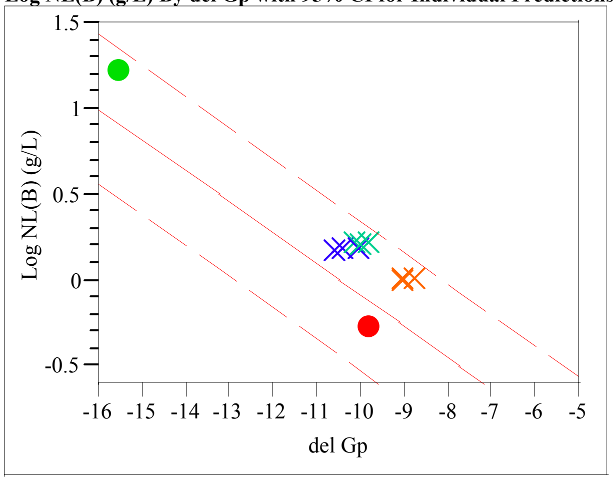


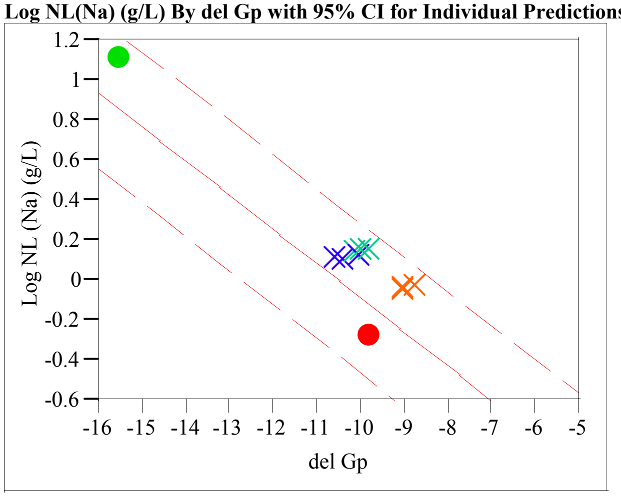
Exhibit D.10: del Gp (ΔG_p) Predictions versus Common Logarithm Normalized Leachate (log NL[.]) for B, Li, Na, and Si by Heat Treatment for Tank 40 Glasses for All Compositional Views

All quenched Data

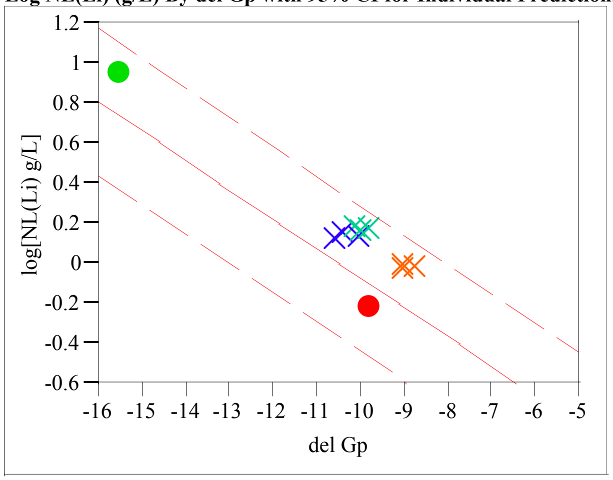
Log NL(B) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Na) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Li) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Si) (g/L) By del Gp with 95% CI for Individual Predictions

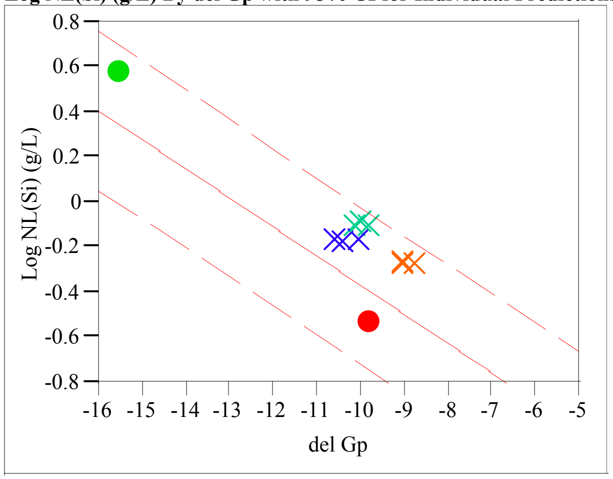
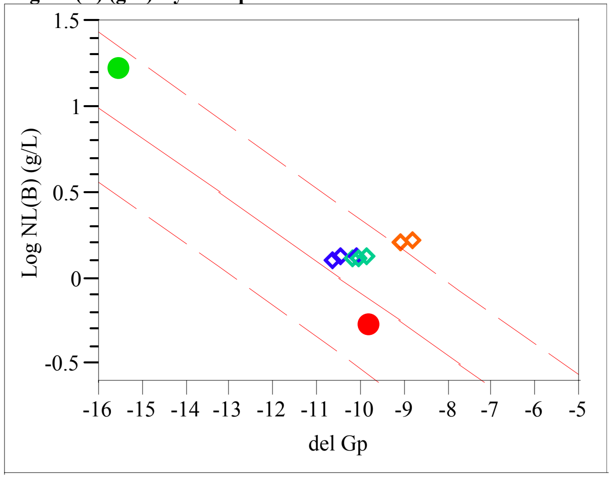


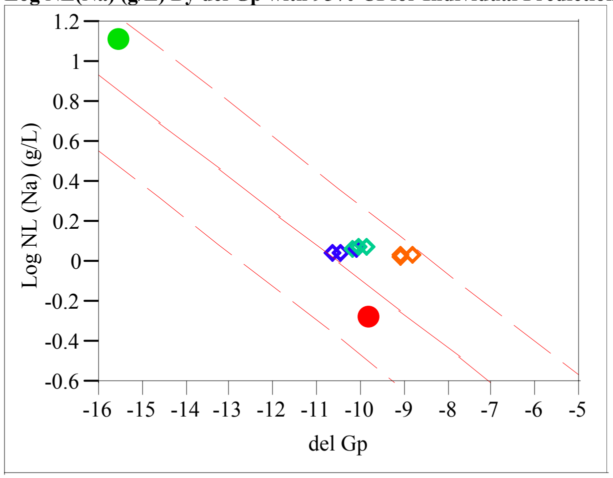
Exhibit D.10: del Gp (ΔG_p) Predictions versus Common Logarithm Normalized Leachate (log NL[.]) for B, Li, Na, and Si by Heat Treatment for Tank 40 Glasses for All Compositional Views

All ccc Data

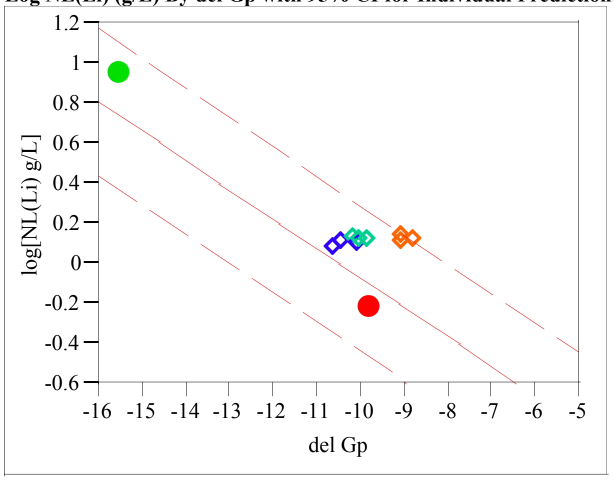
Log NL(B) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Na) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Li) (g/L) By del Gp with 95% CI for Individual Predictions



Log NL(Si) (g/L) By del Gp with 95% CI for Individual Predictions