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MELT RATE IMPROVEMENT FOR DWPF MB3:

Frit Development and Model Assessment (U)

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DISCLAIMER

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GLOSSARY

η	viscosity
ADS	Analytical Development Section
AES	atomic emission spectroscopy
ARM	Approved Reference Material
ASTM	American Society for Testing and Materials
bc	bias corrected
CELS	Corning Engineering Laboratory Services
clc	centerline canister cooled
CVS	composition variation study
DTA	differential thermal analysis
DWPF	Defense Waste Processing Facility
EA	Environmental Assessment
g/L	grams per liter
ICP	inductively coupled plasma
HLW	high-level waste
LM	lithium metaborate
MB2	macrobatch 2
MB3	macrobatch 3
NL	normalized leachate
PAR	Property Acceptability Region
PCCS	Product Composition Control System
PCT	product consistency test
PF	peroxide fusion
PHA	precipitate hydrolysis aqueous
PNNL	Pacific Northwest National Laboratory
ppm	parts per million
SME	slurry mix evaporator
SRAT	slurry receipt and adjustment tank
SRTC	Savannah River Technology Center
SRTC-ML	Savannah River Technology Center – Mobile Laboratory
TGA	thermogravimetric analysis

TFA	Tanks Focus Area
THERMO™	Thermodynamic Hydration Energy Reaction Model
T_L	liquidus temperature
TTR	Task Technical Request
U_{std}	uranium-containing glass
WAPS	Waste Acceptance Product Specifications
WCP	Wasteform Compliance Plan
WL	waste loading
WSRC	Westinghouse Savannah River Company

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EXECUTIVE SUMMARY

The objective of this research was to enhance the basic understanding of the role of glass batch chemistry (more specifically via control of frit composition) on the overall melting process for Macrobatch 3 (MB3). The overall strategy for the frit development activities was to explore frit compositional regions which challenged "acceptable" predicted property behavior. Once major frit components were identified, ranges were established to challenge current model predictions in an attempt to maximize melt rate. A series of frit compositions were developed not only to maintain the projected operational window (25-30% sludge oxide waste loading) relative to the Frit 200 baseline but to also increase melt rate. The intent of this effort was to explore compositional extremes in frit space to bound the effect on melt rate for MB3. While exploring these compositional limits, model assessments were made but not necessarily used to limit the final compositional envelope.

The decision or technical basis as to whether a candidate frit will improve melt rate relative to Frit 200 can not be made based on the model assessments or the limited data discussed in this report. However, the information presented in this report does provide input into the selection process for those glasses that have been shown to have an improved melt rate relative to the current Frit 200 baseline.

Glasses were fabricated using selected candidate frit compositions at a fixed target waste loading and various properties were measured. An important objective of this study was to investigate the potential impact on glass durability (as defined by the Product Consistency Test (PCT)) due to cooling rate. The data indicated no statistically significant difference between the quenched and centerline cooled PCTs for either the nominally washed or the underwashed MB3 sludge cases. The measured PCT data indicates that glasses produced from either the nominal or underwashed sludge (for both thermal heat treatments) are < 2 g/L (for all reportable elements); these are still well below that of the Environmental Assessment (EA) glass.

Based on an assessment of durability, the majority of the frits developed satisfy the current slurry mix evaporator (SME) acceptability criteria (i.e., ΔG_P limit) and lie within the 95% prediction confidence interval indicating that the PCTs are well predicted by the current model. Selection of a frit in this category (i.e., SME acceptance for durability is passed and the model predicts well) lowers the additional data needs prior to implementation in the Defense Waste Processing Facility (DWPF). However, this path may result in a frit that does not optimize melt rate for MB3.

Technical issues have been identified relative to SME acceptability issues for one candidate frit composition. Although the current durability model does not predict an acceptable release, the measured PCT data for glasses produced using this frit indicate that all elemental releases are less than 2 g/L.

For those glasses "failing" the current SME acceptability criteria for durability, alternative solutions have been proposed. Alternative pathways proposed include (but are not limited to): (i) developing non-parametric models over the composition regions, and/or (ii) refining the current DWPF durability model for this new composition region. Resolution of these alternative pathways is beyond the scope of this document and the supporting data.

It should be noted that the current task is focused specifically on improving melt rate for MB3. Although the "systems approach" will be utilized to the extent possible, this task does not attempt to optimize a frit for all "sludge-only" waste processing as projected by the current High Level Waste (HLW) System Plan. Therefore, the use of candidate frits to improve melt rate for MB3 may not be warranted for future sludge-only macrobatches.

The selection or recommendation of an alternative frit will ultimately be influenced by the relative increase in melt rate that one frit has over the current baseline, the acceptable risk level, and/or budget and schedule restrictions. The level of risk that is set must be balanced by the potential gains in terms of melter throughput.

1.0 INTRODUCTION

Glass melting is a complex process that involves a number of reactions and transformations. Consequently, it is necessary to identify the relevant processing properties for cold cap melting and possible laboratory test methods to evaluate these pertinent processing properties. Kim and Hrma (1994) suggested that developing appropriate laboratory test methods to assess melt rate should be preceded by understanding the basic processes involved in cold cap melting. The effects of various melter operating conditions and physical/chemical properties of the feed on the melting rate need to be clearly established. Because of the complexities involved, several analytical techniques should be used to characterize the local processes leading from batch to homogeneous glass and to link the bulk melt to the reaction at the interfaces.

The objective of this research was to enhance the basic understanding of the role of glass batch chemistry (more specifically via control of frit composition) on the overall melting process for Macrobatch 3 (MB3) (sludge-only processing). Through control of batch chemistry, cold cap reactions can be altered which may result in higher melter throughput. For melt rate limited systems, a small increase in melting efficiency translates into substantial savings by reducing operational costs without compromising product quality.

Although the primary focus was to improve melt rate for a specific macrobatch, a "systems approach" (Jantzen 1986) will be utilized to ensure other criteria important to glass production in DWPF will not be ignored. That is, any proposed frit composition change will be assessed using the current Thermodynamic Hydration Energy Reaction Model (THERMO™) predictions (Jantzen et al. 1995) in terms of the established Slurry Mix Evaporator (SME) acceptability criteria (Brown and Edwards 1995, Brown and Postles 1996). Potential chemical processing changes (see Lambert et al. 2001) must be tempered by a thorough assessment of related safety issues. If the systems approach or a thorough assessment of safety related issues are not utilized in an attempt to improve melt rate, one could make an off-specification glass faster or compromise melter processing and/or the safety basis.

Regardless of whether a potential frit composition change is acceptable or not in terms of model predictions, it is recommended that prior to implementation in the Defense Waste Processing Facility (DWPF) all properties be assessed to ensure that the proposed compositional changes do not invalidate current model predictions (e.g., the proposed glass composition is still within the compositional envelope over which the models were developed). It should be noted that frit development activities were directed solely toward MB3 and the use of a specific frit composition with another sludge batch may not be warranted.

This report does not address potential chemical processing changes (e.g., redox adjustments and/or acid addition strategies) and the downstream impacts they may have on process and product properties. Although the joint DWPF / Tanks Focus Area (TFA) program is evaluating both potential frit and/or redox/acid additions changes to enhance melt rate, this report focuses solely on compositional changes to the frit. Stone and Josephs (2001) provided a detailed discussion of the redox / acid addition strategy changes on enhancing melt rate.

Reliable recommendations for compositional and/or chemical processing changes will be possible if the mechanisms leading to foam are understood. Mechanisms of interest include the reaction pathway or kinetics of the batch-to-glass conversion process, off-gas behavior as a function of redox and/or decomposition reactions, and the temperature – viscosity (η) relationships for both the glass and frit (Peeler et al. 2001). A detailed knowledge of these fundamental parameters will be necessary to determine the optimum chemical-processing or fit-composition changes needed. This being the case, it would be desirable to focus on one of the parameters leaving the other “fixed” and hope to bound the effect. In the event that both frit compositional and chemical process changes are independently identified to improve melt rate, these effects may not be additive. Therefore, prior to recommending a coupled change, the effects must be jointly evaluated. This assumes that the test methodology or suite of tests being used to assess melt rate directly translates to a full scale system.

As previously mentioned, because of the complexities involved, several analytical techniques should be used in an effort to gain a fundamental understanding of the mechanisms leading to a high melt rate. It would be ideal to have a single, inexpensive short-term test that could provide a direct measure of melt rate for the full-scale system. Unfortunately, such a test does not exist. Previous studies have utilized a specific test or suite of tests to assess melt rate for various glass systems. These included (but were not limited to): isothermal tests to assess melting behavior as a function of time and temperature, batch-free time studies, gradient furnace studies to identify the major processes occurring during the batch-to-glass conversion, quartz crucible studies to assess the propensity for batch expansion and to characterize off-gas generated, DTA/TGA analysis of reaction pathways, evaluation of cold cap samples from melters, and melt rate furnace tests where unidirectional heat is applied to simulate heat transfer from the molten glass pool.

This program utilized the available analytical tools within the allocated funds to develop a sound technical basis (minimizing risk to the extent possible) for the recommended change to the current baseline DWPF operations. Test protocols and methodology established through the recent work by Stone and Lambert (2000) for MB2 form the foundation used to assess melt rate for MB3. The primary tools to be utilized include: laboratory-scale isothermal tests and melt rate furnace tests. Additional tests and/or analytical tools will be utilized as warranted. Lambert et al. (2001) discussed additional tests that should be performed prior to implementation of a frit or chemical processing change in DWPF (e.g., slurry-fed melt rate and mini-melter tests).

This report discusses the primary assessment of potential frit changes on various properties via model predictions. It should be noted that models to directly assess melt rate are not available (or do not exist). However, the "systems approach" concept (Jantzen 1986) will be applied to ensure that although a candidate frit may improve melt rate other properties (e.g., durability, liquidus temperature (T_L), and η) will not be compromised. Property – composition models will be used to assess the impact of a range of frit compositions on various properties. A limited number of tests will be performed on critical properties of interest in an effort to confirm model predictions and/or reduce technical risks.

This report is one in a series of reports that provide details on the MB3 melt rate improvement task. Lambert et al. (2001) provided the recommendations resulting from this integrated effort. The focus of the current report is on the joint Savannah River Technology Center (SRTC) / Pacific Northwest National Laboratory (PNNL) frit development and model assessment activities leading to candidate frit compositions to improve melt rate for MB3. Section 2 of this report provides a brief discussion of previous frit development activities for the Defense Waste Processing Facility (DWPF). Section 3 describes the objectives of the overall program to improve melt rate for MB3. The MB3 waste composition is discussed in Section 4. Section 5 presents the SRTC / PNNL frit development and model assessment activities. In Sections 6 and 7 we describe a limited number of tests that were performed on critical properties of interest (durability and η) in an effort to validate model predictions and reduce technical risks. Section 8 addresses technical issues regarding SME acceptability for candidate Frit compositions and provides input to the selection process for those glasses that have been shown to have an improved melt rate relative to the current Frit 200 baseline. Section 9 presents a summary and conclusions regarding the frit development and model assessment activities. This work is being performed in response to Technical Task Request (TTR) #HLW/DWPF/TTR-00-0044, DWPF Macrobatch 3 Melt Rate Study.

2.0 BACKGROUND: PREVIOUS WORK ON FRIT OPTIMIZATION FOR DWPF

Soper et al. (1983) defined an “optimum” sludge-only frit as “one which produced waste glass with leachability as low as possible, with a maximum viscosity at 1150°C as near 15 N-s/m^2 (or Pa-s) as possible, with a liquidus temperature as low as possible and with a coefficient of thermal expansion as low as possible.” Through a statistically designed study and after only 25 trials, a frit meeting this definition was found in spite of the fact that 8 chemical components were evaluated. Frit 165 was found to be superior to other potential frit candidates (including Frit 131) for sludge-only processing.

Jantzen (1988) mathematically developed a family of glasses for DWPF for both coupled-feed (waste sludge plus precipitate hydrolysis aqueous (PHA) product) based on Soper’s work. The glasses were formulated to meet specific durability and processing (T_L and η) criteria. One such criterion was that of melt temperature which was limited to 1150°C by volatilization of radionuclides (e.g., cesium and ruthenium) and the need to minimize corrosion / erosion of materials of construction. Therefore, frits were developed to dissolve the waste in the glass at this temperature while maintaining a high resistance to aqueous attack. Based on processing, fabrication, and durability considerations, Frit 202 (the coupled-feed frit formulation with the lowest alkali content) was recommended for initial DWPF coupled-operations.

It should be noted that the current task focuses specifically on MB3 and improving melt rate. Although the “systems approach” (Jantzen 1986) will be utilized to the extent possible, this task does not attempt to optimize a frit for all “sludge-only” waste processing as projected by the current HLW System Plan (HLW 2000). Therefore, the use of candidate frits to improve melt rate for MB3 may not be warranted for future sludge-only macrobatches.

Although this research is focused on increasing melt rate for MB3, the incentive stems from the following issues:

1. **Interim Frit:** A frit designed for coupled operation (e.g., the Frit 200 baseline) was being used as an “interim frit” for sludge-only operations until a decision was made on alternative salt processing.
2. **Poor Melt Rate:** Since the additional alkali and boron from salt processing is now questionable and will be delayed for several years, the DWPF melt rate was poor because of this flux deficiency.

3. **High Al_2O_3 Sludge:** MB3 is a high-alumina-containing sludge that, if used with the interim frit, would make the attainment of melt rate even worse, e.g., high-iron-containing sludges could be used with the interim frit, but high-alumina sludge cannot.

4. **Less Alkali Removal:** Removal of alkali from sludge in the tank farm was proving problematic, and there was a desire to process the sludge less, e.g., wash less alkali out of the sludge, than in previous sludge-only flowsheets developed in the 1980–1990 timeframe.

5. **Multiple Frits:** Due to limited space in the tank farm for blending sludge types, e.g., high Al with high Fe, the strategy of having one frit that can accommodate every waste type is being re-examined in favor of a strategy to optimize a frit for each type of sludge.

3.0 OBJECTIVE

The objective of this research was to enhance the basic understanding of the role of glass batch chemistry (more specifically via control of frit composition) and/or changes in acid addition strategies on the overall melting process for MB3 (sludge-only processing). Through control of batch chemistry, cold cap reactions can be altered resulting in higher melter throughput. For melt rate limited systems, a small increase in melting efficiency translates into substantial savings by reducing operational costs without compromising the quality of the final waste form or product.

4.0 MB3 WASTE COMPOSITION

According to the HLW System Plan (HLW 2000), the next sludge batch to be processed will be sludge batch 2 (referred to as MB3). Macrobatch 3 is assumed to be an equal blend of Tank 8 and Tank 40. Harbour et al. (2000) have completed the variability study, which is required prior to receiving this sludge in DWPF. The batch will also be qualified by process simulation with actual waste in the SRTC high level caves. Elder (2000) provided the target sludge compositions obtained from the HLW Database (Hester 1996). Elder indicated that the compositions derived compared favorably with samples taken from streams with similar histories.

Elder (2000) noted that the extent of sludge washing was somewhat uncertain which could result in variation of sodium and aluminum (to a lesser extent given aluminum dissolution issues) concentrations in the sludge feed to the melter. This potential unknown was accounted for in the fact that nominal, underwashed, and overwashed sludge scenarios were calculated.

Harbour et al. (2000) and Edwards (2000) also utilized Elder's sludge estimates as the basis for the MB3 variability study. The variability study evaluated two potential scenarios for processing MB3: (1) Tank 40 only and (2) a blended sludge consisting of equal parts (on an oxide wt% basis) of Tank 8 and Tank 40 (representing a transfer of the complete contents of Tank 8 into Tank 40).[1] For the current MB3 melt rate study, only the blended sludge option will be considered. The oxide concentrations for this option (i.e., sludge produced from an equal blend of Tank 8 / Tank 40) are given in Table 1.

[1] Since Elder's report was issued, Tank 8 has been transferred into Tank 40.

Table 1. Oxide Sludge Concentrations (wt%) of an Equal Blend of Tank 8 and Tank 40.

Oxide	Tank 8/40 Blend		
	Underwashed	**Nominal**	**Overwashed**
Al_2O_3	15.86	16.23	16.63
BaO	0.26	0.27	0.28
CaO	3.56	3.64	3.72
CeO_2	0.44	0.45	0.45
Cr_2O_3	0.37	0.37	0.39
CuO	0.20	0.22	0.22
Fe_2O_3	40.97	41.91	42.93
K_2O	0.40	0.42	0.42
La_2O_3	0.42	0.45	0.45
MgO	0.22	0.23	0.23
MnO	2.62	2.68	2.75
Na_2O	19.90	17.99	15.99
NiO	1.74	1.78	1.83
PbO	0.24	0.25	0.25
SiO_2	1.92	1.96	2.01
ThO_2	0.10	0.11	0.11
U_3O_8	9.71	9.94	10.20
ZnO	0.38	0.40	0.41
ZrO_2	0.73	0.75	0.77

For the 50/50-blend MB3 option, the major components are Fe_2O_3, Na_2O, Al_2O_3, and U_3O_8. As the extent of washing increases, the Na_2O concentration is reduced while the concentrations of the other oxides increases. Table 1 does not summarize the anions (or how they varied with sludge washing) associated with MB3. It is assumed that the anions will not have a negative impact or limit waste loadings in the model assessment activities. Experimental assessment of melt rate (Stone and Josephs 2001 and Lorier 2001) used a nonradioactive simulate MB3 sludge containing minor components (including the anions).

The potential for DWPF to receive an underwashed sludge is relatively high given current retrieval and/or tank farm space issues which may force a decision to minimize sludge washwater generation. This being the case, model assessments and frit development activities will be performed for both the nominal and underwashed sludge scenarios. As previously mentioned, one impact of sludge underwashing is a more Na_2O-rich sludge. The total alkali concentration will be dictated by the frit composition as well as the sludge washing scenario chosen. Glass formulation efforts will attempt to develop a frit that increases melt rate (relative to the use of Frit 200)[2] for MB3 regardless of the sludge washing scenario but does not compromise product performance. It should be noted that the model assessments and frit development activities will not account for compositional variation in the sludge due to sampling and/or analytical errors, washing efficiency, blending issues and/or waste loading (WL) differences. These latter issues would be addressed in a separate study (e.g., variability study) assuming an alternative is recommended for MB3.

Another major component for MB3 is U_3O_8. As this program utilizes a developed test methodology to assess melt rate, the majority of the research will be performed using non-radioactive simulants (to minimize cost and schedule impacts). With U_3O_8 comprising approximately 10 wt% of the sludge, fabrication of a non-radioactive simulant must account for this major component being absent. Stone and Lambert (2001) discussed the fabrication of the non-radioactive MB3 simulants used to support this testing program. Frit development and model assessment activities will utilize the projected U_3O_8-containing MB3 composition (shown in Table 1). Laboratory tests to assess various glass property – composition relationships will also be performed with uranium-bearing glasses to assess this issue and minimize risks.

[2] It is noted that Frit 200 was not formulated for sludge-only processing. The term "baseline" refers to the current use of Frit 200 with MB2 and its planned use for MB3 (consistent with Harbour et al. 2000).

The relatively high Al_2O_3 and Fe_2O_3 concentrations for MB3 may have an impact on both melt rate and T_L predictions. In an effort to implement the "systems approach" to the fullest extent possible, this task is integrated with current efforts by SRTC to improve the T_L correlation for DWPF (in an attempt to increase waste loadings). As the list of potential frits developed to increase melt rate is narrowed, the T_L should be assessed with the new model to ensure the processing window is not limited. It should be noted that initial model assessments will be performed using the current T_L model.

This task will utilize the compositional estimates provided by Elder (2000) for the blended MB3 option to assess compositional changes to the frit in an effort to increase melt rate. Based on programmatic direction, only the nominal and underwashed MB3 sludge scenarios will be evaluated.

5.0 FRIT DEVELOPMENT AND MODEL ASSESSMENTS ACTIVITIES

The approach for the joint SRTC / PNNL frit development activity was to define a frit compositional envelope that when blended with MB3 may yield improved melt rates relative to the "baseline" Frit 200 / MB3 flowsheet. This joint effort utilized knowledge from previous research focused on frit optimization for DWPF (Jantzen 1988; Soper et al. 1983) and model predictions to assess various property – composition relationships.

The overall strategy for the frit development activities was to explore frit compositional regions (both oxide components and ranges) that challenged "acceptable" predicted property behavior. Once major frit components were identified, ranges were established to push or challenge model predictions in an attempt to maximize melt rate. For example, an assessment on the extent that one could push total alkali content to increase melt rate but not have a negative effect on durability (either via model assessment and/or actual measurements) was addressed.

SRTC performed a series of calculations using models currently implemented in DWPF to assess the impacts of potential frit compositions on the projected operational window. The properties assessed included T_L, η, homogeneity, durability, and the constraints associated with the sum of alkali and/or Al_2O_3 concentrations (Edwards and Brown 1998; Peeler et al. 2000). These properties were assessed at the Property Acceptability Region (PAR) limits (Brown and Postles 1996).

PNNL conducted a similar series of calculations (utilizing existing Hanford property – composition models) to help define the frit compositional envelope that may yield improved melt rate for MB3. Both the SRTC and PNNL calculations were not limited to frit components that are currently used to fabricate DWPF frits, although a borosilicate glass system is required due to current Waste Acceptance Product Specifications (WAPS) criteria. In addition, the PNNL study did not take into account uncertainties associated with property and/or measurement errors. SRTC has the responsibility to ensure that a proposed alternative frit provides an adequate operational window and meets current DWPF acceptability criteria with the associated model error/uncertainties.

For consistency with the MB3 variability study (Harbour et al. 2000), initial SRTC and PNNL assessments used the nominal washed MB3 sludge composition with those oxides present in the sludge at concentrations that lead to amounts over 0.5 wt% in glass at sludge loadings up to 34 wt%. As noted by Edwards (2000), trace components (elements whose oxides are present in the glass at concentrations less than 0.5 wt%) are not expected to significantly impact durability and were omitted from the variability study.[3] It is noted that the current task focuses on melt rate for MB3 but the components expected to increase melt rate also have a significant impact on durability (in particular alkali). Table 2 shows the composition used in the SRTC / PNNL frit development and model assessment activities. It should also be noted that the composition used does not account for anions in glass (e.g., SO_3, Cl, F) for either the nominal or underwashed sludge scenarios. It is assumed that the concentrations of these components in glass will not negatively affect melter processing, product performance, or limit waste loading (WL) by other single component constraints currently implemented in DWPF.

The lack of Cr_2O_3, which is known to increase the T_L of many high-level waste (HLW) glasses, is probably the most questionable oxide. Based on Table 1, the maximum projected Cr_2O_3 content in the blended MB3 sludge (not considering the overwashed scenario) is 0.37 wt%. At waste loadings of 25 to 35 wt%, Cr_2O_3 levels in glass are projected to be 0.09 and 0.13 wt%, respectively. These levels may be important in the final assessment of T_L and the potential impacts on waste loading. Exclusion of these minor components from the paper studies will have minimal (if any) effect on model assessment or frit development activities regarding melt rate.[4]

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[3] Components not included: Ba, Ce, Cr, Cu, K, La, Pb, Th, Zn, and Zr. See Plodinec, M.J., et al., *"Technical Bases for the DWPF Glass Product Control Program (U),"* WSRC-IM-91-116-5, Rev. 1, December 1995, pp. 68 – 71. It should also be noted that there are slight discrepancies between the values used by Harbour et al (2000) and those reported by Elder (2000) when the minor components are removed and the remaining components are renormalized.

[4] Cr_2O_3 was added to the sludge simulant used in the laboratory tests and melt rate furnace tests.

Table 2. Composition (wt%) of Nominal MB3 Sludge Used for Initial Model Assessments and Frit Development Activities.

Oxide	Wt%
Al_2O_3	16.846
CaO	3.743
Cr_2O_3	0.000
Fe_2O_3	43.087
MgO	0.241
MnO	2.824
Na_2O	18.740
NiO	1.926
SiO_2	2.018
U_3O_8	10.575
Total	100.000

The outcome of the SRTC/PNNL assessment and development activities[5] was a series of frit compositions (both components and percentages) that should maintain the projected waste loadings for the nominal MB3 sludge (~25 – 28 wt% with Frit 200) based on model predictions while potentially increasing melt rate. The intent of this joint effort was to explore compositional extremes in frit space to bound the effect on melt rate for MB3. While exploring these compositional limits, model assessments were made but not necessarily used to limit the final compositional envelope. That is, given a specific frit composition, the frit was not excluded due to model predictions alone.

[5] Although discussed separately, the assessments and frit development activities at SRTC and PNNL were highly integrated to minimize overlap and to ensure complementary outputs to meet the overall task objective.

5.1 FRIT DEVELOPMENT

A series of frit compositions were generated which were expected to form acceptable glasses with 25.5 wt% MB3 while challenging "acceptable" predicted property behavior. Glass and melt properties including glass η at 1150°C (η_{1150}), electrical conductivity at 1150°C (ε_{1150}), normalized Na, B, and Li releases by the PCT (r_{Na}, r_B, and r_{Li}, respectively), and T_L (assuming a spinel primary crystalline phase) were predicted using coefficients from first-order expansion of glass properties in composition (listed in Table 3). The constraints placed on predicted properties (listed in Table 4) were generally more restrictive than those required for plant operation to account for model and waste composition uncertainties and in the case of η_{1150}, to allow for possible improvements in melt rate. A rough estimate of glasses propensity to form nepheline upon slow cooling, specifically, the normalized SiO_2 concentration in the SiO_2 – Na_2O – Al_2O_3 submixture (Li et al. 1997), was calculated but was not found to restrict glass composition.

Figure 1 shows the initial frit compositions in a pair-wise plot or scatter plot matrix. These compositions adequately cover (in two dimensions) the area created by the bounds for each component in the frits with the exceptions of: (1) high Al_2O_3 and high ZrO_2, (2) high SiO_2 and low Li_2O, (3) high SiO_2 and high B_2O_3, (4) high SiO_2 and high ZrO_2, (5) high SiO_2 and high Al_2O_3, and (6) high Na_2O and high Li_2O. Table 5 lists these initial frit compositions and the predicted properties that would result from melting each with 25.5 wt% of MB3. Each of the frits listed in Table 5 have acceptable properties (relative to those listed in Table 4) when blended with 25.5 wt% of the nominal washed MB3 (as shown in Table 2) based on the coefficients from the first-order expansion. This latter statement assumes that the minor components that were not used in this initial assessment have a minimal (or no) impact on these properties. As previously mentioned, of particular interest is the impact of Cr_2O_3 on T_L predictions since it is absent in the sludge composition used for model assessments.

Table 3. First-Order Coefficients for Selected Glass Properties.

	PCT Durability (g/m^2)						Liquidus (°C)	Viscosity (Pa-s)					Electrical Conductivity (S/m)		
Oxide[a]	**$\ln(r_B)$,[b] new**	**$\ln(r_{Li})$, new**	**$\ln(r_{Na})$, new**	**$Ln(r_B)$, CVS**	**$\ln(r_{Li})$, CVS**	**$\ln(r_{Na})$, CVS**	**T_L,[c,d] new**	**A_η,[e,f] new**	**B_η, new**	**A_η, CVS**	**B_η, CVS**	**$\ln(\eta_{1150})$, CVS**	**A_ε,[g] CVS**	**B_ε, CVS**	**$\ln(\varepsilon_{1150})$ CVS**
Al_2O_3	-32.132	-29.331	-32.858	-41.077	-36.078	-41.070	3222.386	-2.860	27599.0	-1.242	25113.0	17.088	6.260	-8646.92	0.170
B_2O_3	14.509	11.958	9.957	13.009	11.044	10.237	197.575	-13.594	8765.00	-13.096	9054.08	-6.842	12.960	-15483.0	2.153
CaO	-12.976	-9.121	-4.018	-7.473	-4.629	-1.770	1183.426	-25.804	27511.0	-20.768	20359.0	-6.279	13.820	-17621.0	1.600
Cr_2O_3							31677.695								
Fe_2O_3	-6.740	-9.463	-9.110	-9.027	-12.051	-10.975	3651.072	-3.490	-835.00	0.934	-5306.61	-2.525	10.870	-13527.0	1.778
K_2O	-10.312	-6.515	0.323				-929.671	-16.589	14436.0						
Li_2O	9.558	9.507	7.328	10.431	8.487	8.688	307.915	-7.100	-10377.0	-6.255	-12639.0	-15.030	7.770	6863.36	12.694
MgO	0.399	-0.484	2.575	7.044	4.592	7.483	2664.278	-19.102	25120.0	-17.677	23268.0	-1.198	9.970	-11589.0	2.974
MnO	-18.462	-14.389	-16.326				-124.103								
Na_2O	16.821	13.193	18.873	17.258	13.719	18.937	-440.469	-9.974	632.00	-8.780	-2002.31	-10.686	5.820	7157.78	10.844
NiO							13399.326								
SiO_2	-4.410	-3.605	-4.278	-3.917	-2.904	-3.994	1151.831	-10.136	26427.2	-11.711	28819.0	8.498	8.410	-10470.0	0.996
U_3O_8							3060.342								
ZrO_2	-14.976	-13.177	-18.384	-21.246	-20.152	-22.752	3975.649	-55.621	95153.0	-51.386	90415.0	12.811	7.310	-11830.0	-0.867
Others				-1.067	0.247	-2.825				-26.515	29680.0	-3.561	32.060	-39574.0	3.942
LN_2O_3[h]								43.460	-78677.0						

[a] For “new” fits, compositions should be normalized to mole fractions of those components for which coefficients exist; for Composition Variation Study (CVS) fits, compositions should be in mole fractions of components with all components without coefficients contained in “Others”.
[b] The units assumed for r_i are $g \cdot m^{-2}$.
[c] For the T_L fit, normalized mole fractions of cations are used rather than oxides.
[d] The units assumed for T_L are °C.
[e] A_α and B_α are Arrhenius parameters such that $Ln(\alpha)=A+B/T$, where, α is the property and T is absolute temperature.
[f] The units assumed for η are Pa·s.
[g] The units assumed for ε are $S \cdot m^{-1}$.
[h] LN_2O_3 represents total three valent lanthanide oxides and yttria ($Y_2O_3 + La_2O_3 + Ce_2O_3 + Pr_2O_3 + Nd_2O_3 + Sm_2O_3 + Gd_2O_3$).

Table 4. Constraints Used in This Study on Predicted Glass Properties.

Property	Lower Limit	Upper Limit	Units
r_B	-	4 (2)	g/L (g/m^2)
r_{Li}	-	4 (2)	g/L (g/m^2)
r_{Na}	-	4 (2)	g/L (g/m^2)
η_{1150}	30 (3.0)	45 (4.5)	Poise (Pa-s)
T_L	-	1000	°C

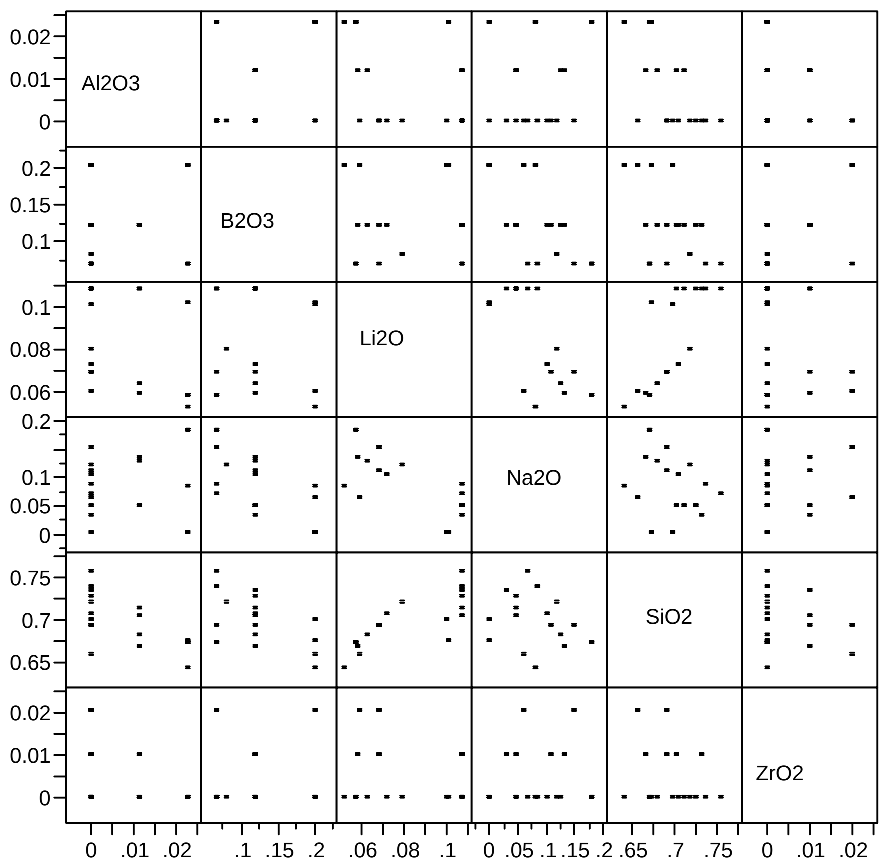

Figure 1. Pair-wise Plots (Scatter Plot Matrix) of Calculated Frit Compositions (in weight fractions).

Table 5. Frit Compositions (in wt%) and Resultant Glass Property Predictions.[6]

Frit ID	Frit 302	Frit 303	Frit 304	Frit 305	Frit 306	Frit 307	Frit 308	Frit 309	Frit 310	Frit 311[7]	Frit 312	Frit 313	Frit 314	Frit 315	Frit 316	Frit 317	Frit 318	Frit 319	Frit 320
Al_2O_3	2.29	2.29	2.29	0.00	0.00	0.00	2.29	0.00	1.14	1.14	0.00	0.00	0.00	0.00	0.00	0.00	1.14	1.14	0.00
B_2O_3	20.13	20.13	6.71	6.71	12.08	12.08	6.71	8.07	12.00	12.00	6.71	6.71	20.13	20.13	12.00	12.00	12.00	12.00	8.00
Li_2O	5.19	10.12	5.80	10.74	7.22	10.74	5.80	7.91	6.27	10.74	6.89	10.74	5.94	10.03	10.74	6.82	5.87	10.74	8.00
Na_2O	8.28	0.00	18.07	6.93	10.24	4.67	18.07	12.00	12.51	4.83	15.18	8.75	6.12	0.00	3.07	11.06	13.28	4.72	12.00
SiO_2	64.11	67.46	67.13	75.62	70.46	72.51	67.13	72.01	68.07	71.28	69.21	73.80	65.79	69.84	73.19	69.12	66.71	70.39	72.00
ZrO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.01	0.00	2.01	0.00	1.00	1.00	1.00	1.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
r_B (g/m^2), new	2.0	1.3	1.8	0.9	1.7	1.3	1.8	1.5	1.9	1.2	1.7	1.3	2.0	1.6	1.0	1.8	1.9	1.1	1.5
r_{Li} (g/m^2), new	1.5	1.2	1.3	1.0	1.4	1.3	1.3	1.3	1.4	1.1	1.3	1.2	1.5	1.5	1.0	1.4	1.4	1.1	1.3
r_{Na} (g/m^2), new	1.1	0.5	1.9	0.7	1.3	0.8	1.9	1.3	1.4	0.7	1.6	1.0	1.1	0.7	0.6	1.3	1.5	0.7	1.3
r_B (g/m^2), CVS	1.8	1.2	2.0	1.2	2.0	1.6	2.0	1.9	2.0	1.3	2.0	1.6	1.9	1.7	1.2	2.0	2.0	1.3	1.9
r_{Li} (g/m^2), CVS	1.4	1.1	1.5	1.1	1.6	1.4	1.5	1.5	1.6	1.2	1.5	1.3	1.5	1.5	1.0	1.6	1.5	1.1	1.5
r_{Na} (g/m^2), CVS	1.2	0.6	1.9	0.9	1.5	1.0	1.9	1.5	1.6	0.8	1.7	1.2	1.2	0.9	0.7	1.5	1.6	0.8	1.5
η_T @1150°C (Pa·s), new	4.5	3.1	4.5	4.5	4.5	3.3	4.5	4.5	4.5	3.3	4.5	3.5	4.5	3.1	4.1	4.5	4.5	3.3	4.4
η_{1150}(Pa·s), CVS	4.3	3.1	3.7	3.9	4.0	3.0	3.7	3.9	4.0	3.0	3.8	3.0	4.4	3.0	3.8	4.0	4.0	3.0	3.8
T_L(°C), new	912	971	856	930	884	922	856	879	879	935	868	901	918	941	955	885	879	944	878

[6] Predicted properties are based on a nominally washed MB3 sludge at 25.5 wt% waste loading.

[7] It should be noted that Frit 311 as defined in Table 5, does not correspond to the Frit 311 developed by Jantzen (1998).

To validate the predictions (using the coefficients from the first-order expansion from Table 3), a glass (Frit 320 with 25.5 wt% MB3 nominally washed sludge) was fabricated at the Savannah River Technology Center (SRTC) and various properties measured (durability and η).[8] SRTC measured the glass composition, r_B, r_{Li}, r_{Na}, and η_{1150}. Table 6 shows the target and measured compositions (wt%) of MB3N320q.

Table 6. Target and Measured Composition (wt%) of MB3N320q at 25.5 wt% Loading.

Oxide	Target	Measured
Al_2O_3	4.296	4.27
B_2O_3	5.96	5.73
CaO	0.954	0.21
Fe_2O_3	10.987	9.91
Li_2O	5.96	5.33
MgO	0.061	0.0
MnO	0.72	0.73
Na_2O	13.719	11.7
NiO	0.491	0.45
SiO_2	54.155	54.3
U_3O_8	2.697	2.51
Total	100.00	95.14

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[8] Glasses produced in this study will have the following nomenclature:

MB3 – to identify MB3 sludge

N or U – to identify nominal or underwashed sludge

301 – 326 – to identify the frit composition

q or clc – to identify the specific heat treatment (quenched or centerline cooled)

Therefore a glass identified is MB3N301q is a quenched glass with 25.5 wt% MB3 nominal washed sludge coupled with Frit 301. Glass MB3U320clc is a centerline cooled glass with 25.5 wt% MB3 underwashed sludge coupled with Frit 320. Appendix A summarizes the nomenclature for the frit and glass compositions used throughout this report.

Viscosity (as a function of temperature) and durability (as defined by the PCT) were measured on this particular uranium-bearing glass. Table 7 compares the measured and predicted (based on target composition using the coefficients from the first-order expansion) property values. Normalized elemental releases for B, Na, and Li are shown based on measured compositions. The calculations were found to over predict PCT releases (making the calculations conservative) and slightly underpredict η_{1150}. The T_L was not measured.

Table 7. Comparison of Predicted and Measured Property Values for MB3N320q at 25.5 wt% Loading.

Property	Predicted Value	Measured Values	Imposed Limit	Unit
r_B	3.0–3.8	1.12	< 4	g/L
r_{Li}	2.6–3.0	1.44	< 4	g/L
r_{Na}	2.6–3.0	1.52	< 4	g/L
$\eta_{1150\ (Poise)}$	38	44.8	30–45	Poise
$\eta_{1150\ (Pa\text{-}s)}$	3.8–4.4	4.48	3–4.5	Pa·s
T_L	878	not measured	<1000	ºC

A second series of candidate frit compositions were developed using compositional guidelines to supplement those listed in Table 5.[9] These guidelines included: an upper limit on total alkali in glass of approximately 20 wt%, an upper limit of B_2O_3 in glass of 11 wt%, and no Al_2O_3 in frit due to the presence of Al_2O_3 in sludge at relatively high concentrations. The resulting compositions, which explored compositional alternatives to the existing set are discussed below. Table 8 provides the compositions (in wt%) for the additional frits.

(i) Frit 322 – a "refractory frit" composition. As discussed by Peeler et al. (2001), one option to minimize foam production is to delay the onset of the initial liquid phase formation until off-gas generation is "complete". This may be accomplished by the use of a "refractory"

[9] Although guidelines were established, they did not restrict previous frits (as shown in Table 5) from being considered as candidate frits to improve melt rate. These guidelines were only applied to the development of the supplemental frit compositions.

frit. Frit 322 contains 77 wt% SiO_2 and its corresponding glass is predicted to have a relatively high η (75 Poise at 1150°C).

(ii) Frit 323 – which included adjustments to Frit 302 (shown in Table 5) that addressed concerns of the relatively high B_2O_3 content as well as the presence of Al_2O_3. One of the concerns was the potential to produce an amorphous phase separated glass if the B_2O_3 content exceeded 11 – 12 wt% in glass. Another concern was the presence of Al_2O_3 in Frit 302 given that 15 – 17 wt% Al_2O_3 is present in the MB3 sludge. Speculation was that the presence of additional Al_2O_3 in the frit would impede melt rate. The compositional adjustments for Frit 323 were simply to lower the B_2O_3 content to 15% in frit (projected to be ~11.5 wt% in glass at 25% waste loading), remove the Al_2O_3, and replace the difference (on a mass basis) by adding more SiO_2.

(iii) Frit 324 – which included adjustments to evaluate if the Li_2O or Na_2O content for a specific composition influenced melt rate. The difference between Frit 323 and Frit 324 is an exchange of the Li_2O and Na_2O contents.

(iv) Frit 325 – a composition developed to address a specific DWPF request regarding the potential to couple Frit 202 (currently in inventory) with another frit to improve melt rate while working off the current inventory.

(v) Frit 326 – a composition to address a concern that there were only a limited number of proposed frit compositions that include MgO. It was suggested that MgO should be included in the frit at the same level as in Frit 165 (i.e., 1 wt% in frit) as it may have a positive impact on durability. To address this issue as well as to evaluate whether the addition of 1% MgO to any of the frits would have an impact on the assessment of melt rate, 1 wt% Na_2O was replaced by 1% MgO in Frit 320 leading to Frit 326. This frit should provide for an assessment of whether the addition of 1% MgO or a 1% reduction of Na_2O impedes melt rate or lowers durability relative to Frit 320 (see Stone and Josephs 2001).

Table 8. Frit Compositions (wt%) of Existing Frits and Those Developed To Supplement the Existing Database.

Oxide	Frit 200	Frit 165	Frit 165 w/o ZrO_2	Frit 322	Frit 323	Frit 324	Frit 325	Frit 326
Al_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B_2O_3	12.00	10.00	10.10	8.00	15.00	15.00	9.10	8.00
Li_2O	5.00	7.00	7.07	5.00	5.19	8.28	8.10	8.00
Na_2O	11.00	13.00	13.13	10.00	8.28	5.19	12.20	11.00
SiO_2	70.00	68.00	68.69	77.00	71.53	71.53	68.60	72.00
ZrO_2	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	2.00	1.00	1.01	0.00	0.00	0.00	1.00	1.00

Table 8 includes Frit 200 (considered to be the baseline frit) and Frit 165 (a sludge-only frit developed by Soper et al. [1983]). It should be noted that Frit 165 with and without ZrO_2 is also shown in Table 8 and will be evaluated by PCCS model assessments as well as via the suite of melt rate tests. The Frit 165 without ZrO_2 option surfaced as it may prove beneficial to DWPF. It should be noted that the PCCS model assessments for Frit 200 and Frit 165 (as discussed in Section 5.2) are based on target compositions as defined by Fowler et al. (1991) and do not include allowable compositional tolerances of minor components.

5.2 PCCS Model Assessment of Candidate Frits

Lorier (2001) discussed the initial down selection process[10] used to narrow the 27 potential frit compositions (shown in Table 5 and 8) down to a more manageable size (i.e., 15). Again, it should also be noted that the PCCS assessments were based on the MB3 sludge composition shown in Table 2 (which includes uranium, but excludes the minor components for consistency with the variability study [Harbour et al. 2000]). Exclusion of these components from the paper studies should have minimal (if any) effect on model assessment or frit development activities regarding melt rate. Although the objective of this task is to improve melt rate for MB3, one must continually assess other properties which are critical to DWPF operations.

[10] The initial down selection process was primarily based on the compositional guidelines established by SRTC, laboratory scale crucible scale tests and initial melt rate furnace testing. Refer to Section 5.1 for a discussion of the compositional guidelines.

Table 9 summarizes the 15 candidate frits compositions and the estimated properties (using existing PCCS model predictions) for both the nominal and underwashed MB3 sludge scenarios. The estimated property values provided are those at the maximum allowable waste loading as defined by the current PCCS model predictions at the PAR. Table 10 provides the predicted properties at a fixed waste loading (25.5 wt%[11]) so that various properties (e.g., η or durability) can be directly compared. Definition of acceptable properties for this assessment are based on PAR limit values (see Table 11, Brown and Postles [1996]) for the respective properties.

[11] For the non-radioactive laboratory and melt rate furnace test, the required amount of slurry receipt and adjustment tank (SRAT) product was combined with the required amount of frit based on a waste loading of 23.2 wt%. This is equivalent to a waste laoding of ~25.5 wt% in glass for the uranium-containing glasses.

Table 9. Candidate Frit Compositions (wt%) and Estimated Properties[12] at the Maximum Allowable Waste Loading For Nominal and Underwashed MB3 Sludge.

Oxide	Frit 165	Frit 165 w/o ZrO_2	Frit 200	Frit 303	Frit 304	Frit 307	Frit 313	Frit 314	Frit 315	Frit 320	Frit 322	Frit 323	Frit 324	Frit 325	Frit 326
Al_2O_3	0.00	0.00	0.00	2.29	2.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B_2O_3	10.00	10.10	12.00	20.13	6.71	12.08	6.71	20.13	20.13	8.00	8.00	15.00	15.00	8.55	8.00
Li_2O	7.00	7.07	5.00	10.12	5.80	10.74	10.74	5.94	10.03	8.00	5.00	5.19	8.28	7.55	8.00
Na_2O	13.00	13.13	11.00	0.00	18.07	4.67	8.75	6.12	0.00	12.00	10.00	8.28	5.19	9.10	11.00
SiO_2	68.00	68.69	70.00	67.46	67.13	72.51	73.80	65.79	69.84	72.00	77.00	71.53	71.53	72.80	72.00
ZrO_2	1.00	0.00	0.00	0.00	0.00	0.00	0.00	2.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	1.00	1.01	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	1.00
Nominal Wash Case															
WL Range	23.0–29.0	22.5–29.0	23.0–29.5	21.0–28.0	0	22.0–30.5	22.0–30.5	23.0–28.5	22.0–29.5	22.0–30.0	26.5–31.5	22.0–30.0	22.0–30.0	23.0–30.5	22.5–30.0
MAX WL	29	29	29.5	28	Restricted	30.5	30.5	28.5	29.5	30	31.5	30	30	30.5	30
Viscosity (Poise)	28.3	28.6	51.8	40.4		33.1	30.4	40.4	38.2	33.5	83.7	59.9	43.8	47.7	36.8
T_L (°C)	1022.3	1019.8	1021.1	1023.9		1024.2	1019.8	1024.4	1021.6	1020	1020.8	1021.7	1021.7	1023.2	1020
ΔG_P	-12.04	-12.24	-10.01	-6.39		-9.08	-10.89	-8.22	-6.85	-11.54	-8.4	-8.48	-8.37	-9.68	-11.05
Homo	225.5	226.6	226.7	232.1		231.3	231.3	224.3	229	230.1	233.6	230.1	230.1	229.1	229
Alkali (wt%)	19.6	19.8	16.8	12.5	>22%	16.4	19.3	14.0	12.6	19.6	16.2	15.1	15.1	17.3	18.9
B_2O_3 in glass (wt%)	7.1	7.17	8.46	14.5	~ 5.0	8.4	4.66	14.39	14.19	5.6	5.48	10.5	10.5	5.94	5.6
Al_2O_3 in glass (wt%)	4.9	4.9	5.0	6.4	> 5.0%	5.1	5.1	4.8	5.0	5.1	5.3	5.1	5.1	5.1	5.1
Underwashed Case															
WL Range	25.0–29.5	0	23.5–30.0	21.0–28.0	0	22.5–30.5	22.5–31.0	23.5–28.5	22.5–30.0	22.5–30.5	25.0–32.0	22.5–30.5	22.5–30.5	23.5–30.5	23.0–30.5
MAX WL	29.5	Restricted	30	28	Restricted	30.5	31	28.5	30	30.5	32	30.5	30.5	30.5	30.5
Viscosity (Poise)	25.5		46.7	37.5		30.6	27.5	37.3	34.5	30.2	75.6	54.1	39.5	44.2	33.2
T_L (°C)	1024.3		1023	1019.8		1020.1	1021.6	1020.3	1023.6	1021.9	1022.5	1023.5	1023.5	1019.1	1021.9
ΔG_P	-12.54		-10.52	-6.88		-9.62	-11.42	-8.72	-7.39	-12.05	-8.96	-9.01	-8.9	-10.21	-11.57
Homo	225.7		226.9	231.2		230.3	231.4	223.4	229.2	230.3	233.7	230.3	230.3	228.1	229.2
Alkali (wt%)	20.2	> 20.0%	17.4	13.1	> 22%	17	19.8	14.5	13.2	20.2	16.8	15.7	15.7	17.9	19.5
B_2O_3 in glass (wt%)	7.05	~7.5	8.4	14.49	~5.0	8.40	4.63	14.39	14.09	5.56	5.44	10.43	10.43	5.94	5.56
Al_2O_3 in glass (wt%)	4.8	~4.5	4.9	6.3	> 5.0%	5.0	5.1	4.7	4.9	5.0	5.3	5.0	5.0	5.0	5.0

12 See Brown and Postles (1996) for a more detailed description of the property predictions.

Table 10. Candidate Frit Compositions (wt%) and Estimated Properties at a Fixed Waste Loading (25.5 wt%) For Nominal and Underwashed MB3 Sludge.

Oxide	Frit 165	Frit 165 w/o ZrO_2	Frit 200	Frit 303	Frit 304	Frit 307	Frit 313	Frit 314	Frit 315	Frit 320	Frit 322	Frit 323	Frit 324	Frit 325	Frit 326
Al_2O_3	0.00	0.00	0.00	2.29	2.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B_2O_3	10.00	10.10	12.00	20.13	6.71	12.08	6.71	20.13	20.13	8.00	8.00	15.00	15.00	8.55	8.00
Li_2O	7.00	7.07	5.00	10.12	5.80	10.74	10.74	5.94	10.03	8.00	5.00	5.19	8.28	7.55	8.00
Na_2O	13.00	13.13	11.00	0.00	18.07	4.67	8.75	6.12	0.00	12.00	10.00	8.28	5.19	9.10	11.00
SiO_2	68.00	68.69	70.00	67.46	67.13	72.51	73.80	65.79	69.84	72.00	77.00	71.53	71.53	72.80	72.00
ZrO_2	1.00	0.00	0.00	0.00	0.00	0.00	0.00	2.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	1.00	1.01	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	1.00
Nominal Wash Case															
WL Range	23.0–29.0	22.5–29.0	23.0–29.5	21.0–28.0	0	22.0–30.5	22.0–30.5	23.0–28.5	22.0–29.5	22.0–30.0	26.5–31.5	22.0–30.0	22.0–30.0	23.0–30.5	22.5–30.0
WL = 25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5
Viscosity (Poise)	33.1	33.4	61.9	45.2	32.4	41.1	37.6	46.4	45.6	40.7	107.6	73.1	53.3	59.3	44.7
T_L (°C)	982.7	980.7	977.0	994.2	995.3	970.4	967.2	989.4	977.5	971.7	959.7	972.9	972.9	969.6	971.7
ΔG_P	-12.25	-12.45	-10.12	-6.33	-13.79	-9.16	-11.1	-8.23	-6.79	-11.77	-8.44	-8.51	-8.39	-9.80	-11.25
Homo	217.3	218.4	217.3	226.6	226.6	219.7	219.7	217.3	219.7	219.7	219.7	219.7	219.7	217.3	218.5
Alkali (wt%)	19.7	19.8	16.7	12.3	22.6	16.3	19.3	13.8	12.3	19.7	16.0	14.8	14.8	17.2	18.9
B_2O_3 in glass (wt%)	7.45	7.525	8.94	14.997	4.999	9	4.999	14.997	14.997	5.96	5.96	11.175	11.175	6.37	5.96
Al_2O_3 in glass (wt%)	4.3	4.3	4.3	6.0	6.0	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Underwashed Case															
WL Range	25.0–29.5	0	23.5–30.0	21.0–28.0	0	22.5–30.5	22.5–31.0	23.5–28.5	22.5–30.0	22.5–30.5	25.0–32.0	22.5–30.5	22.5–30.5	25.5–29.5	23.0–30.5
WL = 25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5
Viscosity (Poise)	31.1	31.4	58.1	42.4	30.3	38.7	35.5	43.4	42.8	38.3	101.6	68.7	50.1	55.8	42.1
T_L (°C)	979.6	977.6	974	990.8	991.8	967.5	964.3	986.1	974.4	968.7	957	969.9	969.9	966.7	968.7
ΔG_P	-12.69	-12.90	-10.57	-6.78	-14.24	-9.61	-11.55	-8.68	-7.24	-12.22	-8.89	-8.96	-8.84	-10.25	-11.7
Homo	216.4	217.6	216.4	225.7	225.7	218.8	218.8	216.4	218.8	218.8	218.8	218.8	218.8	216.4	217.6
Alkali (wt%)	20.2	20.3	17.2	12.8	23	16.7	19.8	14.2	12.7	20.2	16.4	15.3	15.3	17.7	19.4
B_2O_3 in glass (wt%)	7.45	7.525	8.94	14.997	4.999	9	4.999	14.997	14.997	5.96	5.96	11.175	11.175	6.37	5.96
Al_2O_3 in glass (wt%)	4.2	4.2	4.2	5.9	5.9	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.3	4.2

Table 11. PAR Limits for Various Properties.

Property	PAR Limit
T_L	< 1024.95°C
Homogeneity	> 210.92
ΔG_P (durability)	> -12.7178
$\eta_{1150°C}$	21.5 – 105.4 Poise

5.2.1 Nominal and Underwashed Scenarios at Maximum Waste Loadings

From Table 9, all proposed frit compositions, with the exception of Frit 304, yield relatively wide operating windows based on PCCS model predictions. Maximum waste loadings for each of the frits (again excluding Frit 304) range from 28.0 wt% (Frit 303) to 31.5 wt% (Frit 322). Current PCCS model predictions will not allow Frit 304 to be processed. This is a result of the predicted ΔG_P (durability) values being less than the PAR limit (-12.7178 kcal/100 g glass) and is an issue that will be discussed in detail in Sections 7.2 and 8.0.

Numerous comparisons could be made given the property predictions listed in Table 9. In this report, a brief description of those that the authors feel are critical to meeting the objectives of this overall task will be discussed. For example, MB3N320q (MB3, nominal wash, Frit 320, quenched) at 30.0 wt% loading has a predicted $\eta_{1150°C}$, T_L, and ΔG_P of 33.5 Poise, 1020°C, and –11.54, respectively. This particular glass appears to be T_L limited (PAR limit = 1024.95°C) in terms of waste loading. MB3U320q (MB3, underwashed, Frit 320, quenched) is predicted to have a slightly higher waste loading compared to its nominal washed counterpart (30.5 wt% versus 30.0 wt%). At 30.5% loading, the underwashed Frit 320 glass still appears T_L limited. As expected, the predicted impact of the underwashed sludge (increased Na_2O content) is on durability. The ΔG_P for MB3U320q is –12.05 which is approaching the –12.7178 PAR limit listed in Table 11. If the hypothesis holds true that increasing the total alkali content in the glass should improve melt rate, glass formulation efforts will strive to maximize the sum of alkali while maintaining acceptable property predictions or actual measurements.

The “baseline” frit (Frit 200) does yield a processing window with both the nominal and underwashed MB3 sludge. Projected maximum waste loadings range up to 29.5 and 30.0 wt% for the nominal and underwashed scenarios, respectively. For Frit 200, η seems to be the property that stands out relative to the majority of other candidate frits. For comparison, if lowering η enhances melt rate, the $\eta_{1150°C}$ for MB3N200 and MB3U200 are 51.8 and 46.7 Poise respectively. Although not as high as that predicted for glasses produced from Frit 322, Frit 323, Frit 324, or Frit 325, the relatively high viscosities of MB3N200 and MB3U200 may slow down melt rate relative to other candidate frits (e.g., Frit 165, Frit 304 or Frit 320). It should be noted that the η values shown in Tables 9 and 10 are predicted glass viscosities at 1150°C, not the η of the liquid phase critical to foam formation. The η of the liquid phase critical to foam formation will likely be the result of an interaction between a molten salt (e.g., $NaNO_3$ or $NaNO_2$) and the frit. The η of the glass does provide insight into the potential for convection currents in the molten glass pool to sweep the foamy layer (if it exists) from the batch-melt interface, which would accelerate melt rates. A low-η glass should increase convection rates resulting in a heat transfer rate increase to the bottom of the cold cap. Therefore, a lower η (but still within the PAR limits) is being considered a positive influence on melt rate as candidate frits are assessed.

The use of Frit 165 without ZrO_2 is a very interesting case. With the nominally washed sludge, PCCS predictions (at the PAR) provide an operational window from 22.5 – 29.0 wt%. At the maximum waste loading, the system appears to be either T_L or durability limited with predicted values of T_L = 1019.8°C and a ΔG_P = -12.24. If Frit 165 without ZrO_2 was selected as the primary candidate for MB3, based on the PCCS calculations (again these initial model assessment calculations excluded some minor components), there would be no operating window for the underwashed MB3 scenario. The system is durability limited with ΔG_P’s on the order of –12.90 at 25.5% WL (not meeting the PAR limit). Given that uncertainties in washing efficiencies, analysis and loadings have not been considered, it would appear that the use of Frit 165 without ZrO_2 for MB3 would be questionable or on the “borderline of unacceptability”.[13]

The use of Frit 165 (with ZrO_2) does provide operational windows for both the nominal and underwashed MB3 scenarios. Based on ΔG_P and T_L predictions, this system again appears to be either durability or T_L limited in terms of waste loadings.

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13 It should be noted that this discussion is based on the removal of 1 wt% ZrO_2 and renormalizing the remaining frit components. Other options exists for reformulating a non-ZrO_2 based Frit 165 that may lead to a predictable operational window.

Although the initial screening process considered compositional limits (e.g., B_2O_3 contents < 11 – 12 wt% in glass), the impact of these higher B_2O_3 glasses on predicted properties does not appear to be a concern. This may be the result of the data from which the models were developed did not contain high B_2O_3 glasses. Consider MB3N303q which has 14.9% B_2O_3 in glass (WL = 28 wt%) but still yields a predicted ΔG_P of -6.39 and a homogeneity calculation of 232.1. Both predicted values are well within the PAR limits listed in Table 11.

Again, it should be noted that the objective of this study was to improve melt rate and the predictions are only intended to help guide our thought process. General trends indicate that over the frit compositional range evaluated the impact of an underwashed MB3 sludge (for a given frit composition and WL) is that both durability and T_L are slightly reduced. If total alkali content does enhance melt rate, one would hope to be in a position of making the glass "durability limited" instead of T_L limited.

5.2.2 Nominal and Underwashed Scenarios at Fixed Waste Loading

Numerous comparisons could also be made given the property predictions listed in Table 10. In this report, a brief description of those that the authors feel are critical to meeting the objectives of this overall task will be discussed. By fixing the WL one can make direct comparisons between frit compositions and their effect on predicted properties. The operational window or WL range for Frit 322 is 26.5 – 31.5 wt%. Therefore, the properties shown at 25.5 wt% are "invalid" for Frit 322 in terms of acceptability per current PCCS model predictions (fails PAR η criteria as shown in Table 11). Even though properties are shown for Frit 304, this system is predicted to be durability limited over the entire range of waste loadings evaluated (21.0 – 36.0 wt%) for both nominal and underwashed scenarios.

6.0 EXPERIMENTAL

In this section, we describe a limited number of tests that were performed on critical properties of interest in an effort to validate model predictions and/or reduce technical risks. The experimental procedures, test equipment, and application of standards used to generate the required data in support of the test objective(s) are discussed. It should be noted that models to directly assess melt rate do not exist and that the models being utilized to assess specific properties may not have been developed over the projected compositional range of interest for all possible compositional combinations of candidate frit(s) and MB3 mixtures.

6.1 GLASS FABRICATION

Table 12 identifies twenty-six uranium-based MB3 glasses prepared (at a fixed waste loading of 25.5%) and tested in this study. Thirteen glasses were fabricated based on the nominal MB3 sludge composition. The other thirteen glasses were based on the underwashed MB3 composition. The primary objective was to measure the effect of frit composition on durability (as defined by the PCT) for both nominal and underwashed sludge cases. In an effort to address the potential impacts of thermal history on durability, both quenched and centerline canister cooled (clc) glasses were tested.

Each batch was prepared to produce 100 grams of glass[14] from the proper proportions of reagent grade chemicals using SRTC technical procedure "Glass Batch Preparation Procedure – GTOP-3-003" (SRTC 1996a). Weigh sheets were filled out as the materials were weighed. Once batched, these glasses were melted in accordance with the technical procedure "Glass Melting Procedure – GTOP-3-004" (SRTC 1996b). 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 ~10°C/minute to 1150°C. After an isothermal hold at 1150°C for 4 h, the crucible was removed and the glass was poured onto a clean stainless steel plate and allowed to air cool. It should be noted that these glasses were not fabricated using the dried melter feed prepared by Stone and Lambert (2001). The objective of this study was to assess property – composition relationships; not to assess melt rate behavior.

Approximately 90 grams of glass were removed (poured) from the crucible while ~10 grams remained in the crucible along the walls.[15] The pour patty was used as a sampling stock for the various heat treatments and property measurements (i.e., chemical composition, durability, and η). Glasses were stored in marked containers (using unique nomenclatures (see Appendix A)).

To bound the effects of thermal history on the product performance, approximately 25 grams of each MB3 glass was 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 cooling (clc) curve. This terminology will be utilized in this report to differentiate samples from different cooling regimes (quenched versus clc).

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14 This would produce enough glass from which all processing and product performance properties could be measured.

15 Visual observations of homogeneity were documented in WSRC-NB-99-00237 for both the pour patty and the residual crucible glass. No visual signs of undissolved solids or compositional inhomogeneities were observed.

Table 12. Targeted Oxide Compositions (in weight percents, wt%'s) of the MR Glasses.

Glass Identifiers	Glass ID's (shortened)	Oxide											
		Al_2O_3	B_2O_3	CaO	Fe_2O_3	Li_2O	MgO	MnO	Na_2O	NiO	SiO_2	U_3O_8	ZrO_2
MB3N165	N165	4.296	7.450	0.954	10.987	5.215	0.806	0.720	14.464	0.491	51.175	2.697	0.745
MB3N200	N200	4.296	8.940	0.954	10.987	3.725	1.551	0.720	12.974	0.491	52.665	2.697	0.000
MB3N303	N303	6.002	14.997	0.954	10.987	7.539	0.061	0.720	4.779	0.491	50.772	2.697	0.000
MB3N304	N304	6.002	4.999	0.954	10.987	4.321	0.061	0.720	18.241	0.491	50.526	2.697	0.000
MB3N307	N307	4.296	9.000	0.954	10.987	8.001	0.061	0.720	8.258	0.491	54.535	2.697	0.000
MB3N313	N313	4.296	4.999	0.954	10.987	8.001	0.061	0.720	11.298	0.491	55.496	2.697	0.000
MB3N314	N314	4.296	14.997	0.954	10.987	4.425	0.061	0.720	9.338	0.491	49.536	2.697	1.497
MB3N315	N315	4.296	14.997	0.954	10.987	7.472	0.061	0.720	4.779	0.491	52.545	2.697	0.000
MB3N320	N320	4.296	5.960	0.954	10.987	5.960	0.061	0.720	13.719	0.491	54.155	2.697	0.000
MB3N322	N322	4.296	5.960	0.954	10.987	3.725	0.061	0.720	12.229	0.491	57.880	2.697	0.000
MB3N323	N323	4.296	11.175	0.954	10.987	3.867	0.061	0.720	10.947	0.491	53.804	2.697	0.000
MB3N324	N324	4.296	11.175	0.954	10.987	6.169	0.061	0.720	8.645	0.491	53.804	2.697	0.000
MB3N326	N326	4.296	5.960	0.954	10.987	5.960	0.806	0.720	12.974	0.491	54.155	2.697	0.000
MB3U165	U165	4.192	7.450	0.941	10.824	5.215	0.806	0.691	14.944	0.460	51.168	2.563	0.745
MB3U200	U200	4.192	8.940	0.941	10.824	3.725	1.551	0.691	13.454	0.460	52.658	2.563	0.000
MB3U303	U303	5.898	14.997	0.941	10.824	7.539	0.061	0.691	5.259	0.460	50.766	2.563	0.000
MB3U304	U304	5.898	4.999	0.941	10.824	4.321	0.061	0.691	18.721	0.460	50.520	2.563	0.000
MB3U307	U307	4.192	9.000	0.941	10.824	8.001	0.061	0.691	8.738	0.460	54.528	2.563	0.000
MB3U313	U313	4.192	4.999	0.941	10.824	8.001	0.061	0.691	11.778	0.460	55.489	2.563	0.000
MB3U314	U314	4.192	14.997	0.941	10.824	4.425	0.061	0.691	9.819	0.460	49.529	2.563	1.497
MB3U315	U315	4.192	14.997	0.941	10.824	7.472	0.061	0.691	5.259	0.460	52.539	2.563	0.000
MB3U320	U320	4.192	5.960	0.941	10.824	5.960	0.061	0.691	14.199	0.460	54.148	2.563	0.000
MB3U322	U322	4.192	5.960	0.941	10.824	3.725	0.061	0.691	12.709	0.460	57.873	2.563	0.000
MB3U323	U323	4.192	11.175	0.941	10.824	3.867	0.061	0.691	11.428	0.460	53.798	2.563	0.000
MB3U324	U324	4.192	11.175	0.941	10.824	6.169	0.061	0.691	9.126	0.460	53.798	2.563	0.000
MB3U326	U326	4.192	5.960	0.941	10.824	5.960	0.806	0.691	13.454	0.460	54.148	2.563	0.000

6.2 PROPERTY MEASUREMENTS

6.2.1 CHEMICAL COMPOSITION ANALYSIS

To confirm that the as-fabricated glasses corresponded to the target compositions (as shown in Table 12), a representative sample from each as-fabricated MB3 glass was submitted to the SRTC Mobile Laboratory (SRTC-ML) for chemical analysis. Edwards provided an analytical plan (see Appendix B) that accompanied these samples. This plan identified the elements to be analyzed and the dissolution techniques (i.e., sodium peroxide fusion [PF] or lithium-metaborate [LM] flux) to be used. Each glass was prepared in duplicate by each of the dissolution techniques. Concentrations (as weight %) for the following elements were measured by Inductively Coupled Plasma – Atomic Emission Spectroscopy (ICP – AES): aluminum, boron, calcium, chromium, iron, lithium, magnesium, manganese, nickel, sodium, silicon, uranium, and zirconium. The analytical plan was developed in such a way as to provide the opportunity to evaluate potential sources of error. The results were evaluated to confirm that the target glass compositions were adequately met. Standard glasses (including the Wasteform Compliance Plan (WCP) Batch 1 standard and a Corning Engineering Laboratory Services [CELS] uranium-containing glass [U_{std}]) were intermittently run to assess the performance of the ICP over the course of these analyses and to determine potential bias-correction (bc) needs.

6.2.2 DURABILITY

The Product Consistency Test (PCT) was performed on each glass to assess chemical durability using technical procedure "Nuclear Waste Glass Product Consistency Test (PCT) Method – GTOP-3-025" (SRTC 1998) which is compliant with the ASTM C1285-97 (ASTM 1997). The PCT was conducted in triplicate for each MB3 glass (both quenched and clc 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. Samples were ground, washed, and prepared according to procedure. Fifteen (15) ml of Type I ASTM water were added to 1.5 grams of glass in stainless steel vessels. The vessels were closed, sealed, and placed in an oven at 90 ± 2°C. Samples were left at 90°C ± 2°C for 7 days. The resulting solutions (once cooled) were sampled (filtered and acidified), labeled (according to the analytical plan), and analyzed. Edwards provided analytical plans for the solution analysis (see Appendices C and D – due to the large number of vessels, two sets of tests were initiated).[16] The overall philosophy of these plans 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 MB3 glasses. Normalized releases were calculated based on target, measured and bias-corrected compositions using the average of the logs.

6.2.3 VISCOSITY

High temperature η was measured as a function of temperature (T) using a spindle viscometer for selected MB3 glasses. The measurements were obtained using Glass Technology Operating Procedure (GTOP) 3-111 "Determination of Glass Viscosity" (SRTC 1999 and Schumacher and Peeler 1998). High temperature η data were measured over the maximum temperature range allowable for each glass. The low temperature limit was based on the effects of crystallization on the melt pool. The high temperature limit was based on limiting the effects of volatilization. To validate the glass-η data, the η of the Batch 1

[16] Due to the number of glasses to be tested (52 glasses as a result of 26 glasses with two heat treatments – not including blanks and standards), PCT's were performed in two sets. Set #1 contained all the nominal washed MB3 glasses (both quenched and clc. Set #2 contained all the underwashed MB3 glasses (both quenched and clc). It should be noted that blanks and standards were run in both sets. See Appendix C and Appendix D for more details.

standard glass (Schumacher and Peeler 1998) was measured at the beginning and end of this study. Viscosity at 1150°C ($\eta_{1150°C}$) for each glass was predicted from a Fulcher fit of the measured data.

7.0 RESULTS AND DISCUSSION

This section provides a detailed discussion and analysis of the measured MB3 glass compositions, homogeneity evaluation via visual observations, PCT results and η results.

7.1 CHEMICAL COMPOSITION ANALYSIS

The measured chemical compositions of the MB3 glasses are presented and reviewed in this section. Comparisons are made between measured and targeted compositions. Measurements of standards that were analyzed along with the study glasses are also presented. The results from the standards were used to bias correct the measurements for the study glasses (when possible). This approach provides an additional view of the chemical compositions of the study glasses for consideration and interpretation. The statistical review was conducted using JMP® Version 4.0, a commercially available software package from SAS Institute, Inc. (SAS 2000).

Table 12 provides the targeted oxide compositions and the glass identifiers for each of the MB3 study glasses. In some instances, shortened versions (also in Table 12) of the identifiers are used in the discussion that follows.

In addition to the study glasses, a standard glass (WCP Batch 1) and an uranium-bearing glass (U_{std}) were included in the planning of the analyses (for possible bc). An analytical plan (in the form of a memorandum) was provided to assist the SRTC-Mobile Laboratory (SRTC-ML) in conducting these analyses (see Appendix B).

Tables E1 and E2 in Appendix E provide the composition measurements obtained by the SRTC-ML for the analytical plan given in Appendix B. Table E1 provides the measurements generated from lithium metaborate preparations. Table E2 presents the measurements generated from the peroxide fusion preparations. The measurements of Tables E1 and E2 are provided in elemental weight percents (wt%'s). Values below the detection limit of the procedures are indicated by a "<" symbol followed by the detection limit. These elemental concentrations were replaced by ½ of the detection limits in this report. The elemental concentrations were converted to oxide concentrations by multiplying by the appropriate gravimetric factors, and in the discussion that follows the chemical compositions of the glasses are presented as oxides. The measurements were completed by the use of ICP-AES.

Exhibit E1 in Appendix E provides plots of the oxide concentration measurements (as wt%'s) in ICP analytical sequence for the samples prepared via LM, and Exhibit E2 in Appendix E provides similar plots for the samples prepared using PF.

A review of the results from the standards provides insight into the possibility that the ICP calibration contributes (in a systematic way) to the oxide measurements for the study glasses. Exhibit E3 in Appendix E provides plots of the Batch 1 and U_{std} oxide measurements per analytical block by oxide for the LM results, and Exhibit E4 in Appendix E provides the same type of plots for the PF results. For many of these oxides, the Batch 1 results indicate statistically significant differences among the block averages. The behavior of the U_{std} values for an oxide follows that of the Batch 1 measurements as well. These results suggest that bias correcting for ICP calibration effects may be advantageous.

Table 13 provides the average measured composition by analytical block for the two glass standards included in the analytical plan. It also provides the reference values for the standards.

The analytical results from the Batch 1 samples are to be used to bias correct for a possible ICP calibration effect (a block effect) in the other measurements. This is accomplished for each oxide in turn by taking the original oxide measurement, noting its block, and then multiplying the measurement by the ratio of the corresponding reference value for Batch 1 divided by the average oxide measurement for Batch 1 in that block. This approach was used to bias correct the composition measurements of the MB3 and both standard glasses for all oxides except U_3O_8. The U_{std} results were used to bias correct only the uranium numbers for the study glasses and for Batch 1.

Table 13. Average Measurements by Analytical Block for Glass Standards.

Batch 1 Oxide	**1-1 3 obs**	**1-2 3 obs**	**2-1 3 obs**	**2-2 3 obs**	**3-1 3 obs**	**3-2 3 obs**	**4-1 3 obs**	**4-2 3 obs**	**Reference Value**
Al_2O_3	4.831	4.875	4.837	4.919	4.881	4.888	4.799	4.799	4.877
B_2O_3	8.179	8.093	7.824	7.964	7.910	8.039	7.910	7.803	7.777
CaO	1.278	1.292	1.299	1.251	1.294	1.285	1.290	1.289	1.220
Cr_2O_3	0.103	0.111	0.100	0.128	0.118	0.104	0.108	0.110	0.107
Fe_2O_3	13.339	12.939	12.834	13.072	13.067	12.434	13.449	13.501	12.839
Li_2O	4.385	4.421	4.421	4.485	4.449	4.500	4.406	4.392	4.429
MgO	1.418	1.448	1.429	1.521	1.437	1.452	1.451	1.448	1.419
MnO	1.679	1.691	1.683	1.782	1.687	1.709	1.683	1.679	1.726
Na_2O	8.901	9.216	9.288	9.202	8.996	9.202	9.310	9.175	9.003
NiO	0.709	0.720	0.715	0.753	0.717	0.720	0.718	0.716	0.751
SiO_2	51.272	50.131	49.774	50.202	50.202	48.419	50.773	51.058	50.220
U_3O_8	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.000
ZrO_2	0.123	0.127	0.127	0.152	0.121	0.125	0.124	0.123	0.098
Sum of Oxides	96.38	95.23	94.50	95.60	95.05	93.04	96.19	96.26	94.37
U_{std} Oxide	**1-1 2 obs**	**1-2 2 obs**	**2-1 2 obs**	**2-2 2 obs**	**3-1 2 obs**	**3-2 2 obs**	**4-1 2 obs**	**4-2 2 obs**	**Reference Value**
Al_2O_3	4.025	4.119	4.015	4.138	4.053	4.100	4.072	4.053	4.100
B_2O_3	9.241	9.354	8.984	9.273	8.984	9.064	9.257	8.839	9.209
CaO	1.281	1.294	1.291	1.243	1.307	1.296	1.291	1.292	1.301
Cr_2O_3	0.243	0.253	0.245	0.277	0.254	0.246	0.251	0.247	0.000
Fe_2O_3	13.311	13.218	12.967	13.232	13.246	12.117	13.704	13.589	13.196
Li_2O	2.960	3.014	2.993	3.036	2.993	3.046	2.982	2.949	3.057
MgO	1.181	1.212	1.210	1.277	1.191	1.207	1.221	1.201	1.210
MnO	2.641	2.666	2.686	2.795	2.621	2.673	2.666	2.628	2.892
Na_2O	11.505	11.829	11.721	11.680	11.404	12.220	11.822	11.579	11.795
NiO	0.991	1.007	1.010	1.046	0.989	1.008	1.005	0.993	1.120
SiO_2	47.279	46.851	46.209	46.530	46.637	44.497	47.279	47.279	45.353
U_3O_8	2.288	2.364	2.258	2.400	2.376	2.335	2.382	2.347	2.406
ZrO_2	0.006	0.007	0.001	0.030	0.005	0.005	0.009	0.004	0.000
Sum of Oxides	96.95	97.19	95.59	96.96	96.06	93.81	97.94	97.00	95.64

More specifically, for each dissolution method, let $\bar{a}_{ij}$ be the average measurement for the ith oxide at analytical block j for Batch 1 (or U_{std} for uranium), and let t_i be the reference value for the ith oxide. Table 13 provides the averages and reference values for each oxide of interest. Let $\bar{c}_{ijk}$ be the average measurement for the ith oxide at analytical block j for the kth glass prepared by the given dissolution method. The bias adjustment was conducted as follows for each of the two dissolution methods

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

Bias corrected measurements are indicated by a "bc" suffix, and such adjustments were performed for all of the oxides and both of the dissolution methods of this study. This approach was used to bias correct the composition measurements of the MB3 study glasses and standard glasses. Both measured and measured "bc" values are included in the discussion that follows.

Exhibits E5 and E6 in Appendix E provide plots of the concentration measurements for each oxide for each of the glasses (including the standards) for the LM and PF preparations, respectively. Both measured and bias-corrected values are plotted. These plots are useful in assessing the repeatability of the measurements for each glass. The most significant observation for these glasses is that several glasses show one exceptionally low Fe_2O_3 value in Exhibit E5. Most of these low values appear to have occurred in analytical block 3-2. A look back at Exhibit E3 shows that the measurements for the standards were low for this block as well. Bias correction does not appear to remedy this problem as seen in Exhibit E5.

Table 14 provides summary information for the measurements of the study glasses as well as their targeted values. The sums of oxides for the targeted, measured, and measured bias-corrected (bc) compositions are also provided. A review of these sums shows that they are all within the interval of 95 to 105 weight percent with the smallest value being 98.6 wt% for the measured, bias-corrected composition of N314 and the largest value being 104.4 wt% for the measured composition of N323. The measurements and bias-corrected measurements that differ from the targeted values by more than 5% have been shaded in Table 14.

Table 14. Measured, Measured Bias-Corrected (bc), and Targeted Compositions for the MB3 Study Glasses.

Glass ID	Glass ID (shortened)	Compositional View	Al_2O_3	B_2O_3	CaO	Cr_2O_3	Fe_2O_3	Li_2O	MgO	MnO	Na_2O	NiO	SiO_2	U_3O_8	ZrO_2	Sum of Oxides
MB3N165	N165	Measured	4.469	7.285	0.964	0.019	11.277	5.135	0.845	0.748	14.828	0.485	52.466	2.388	0.692	101.600
MB3N165	N165	Measured bc	4.468	7.177	0.912	0.018	11.359	5.107	0.830	0.760	14.673	0.506	53.444	2.467	0.551	102.272
MB3N165	N165	Targeted	4.296	7.450	0.954	0.000	10.987	5.215	0.806	0.720	14.464	0.491	51.175	2.697	0.745	100.000
MB3N200	N200	Measured	4.483	8.959	0.946	0.014	11.195	3.725	1.584	0.764	13.224	0.505	53.322	2.683	0.007	101.410
MB3N200	N200	Measured bc	4.482	8.826	0.905	0.012	11.095	3.704	1.525	0.761	12.878	0.516	53.569	2.771	0.005	101.049
MB3N200	N200	Targeted	4.296	8.940	0.954	0.000	10.987	3.725	1.551	0.720	12.974	0.491	52.665	2.697	0.000	100.000
MB3N303	N303	Measured	6.174	14.916	0.961	0.011	11.963	7.562	0.042	0.753	5.004	0.490	51.932	2.821	0.001	102.630
MB3N303	N303	Measured bc	6.165	14.548	0.909	0.011	11.399	7.486	0.041	0.773	4.874	0.513	51.223	2.881	0.001	100.824
MB3N303	N303	Targeted	6.002	14.997	0.954	0.000	10.987	7.539	0.061	0.720	4.779	0.491	50.772	2.697	0.000	99.999
MB3N304	N304	Measured	6.155	5.071	0.968	0.014	11.102	4.376	0.032	0.748	18.265	0.493	51.236	2.700	0.001	101.161
MB3N304	N304	Measured bc	6.255	5.019	0.916	0.013	11.173	4.405	0.031	0.760	18.074	0.515	52.196	2.748	0.001	102.106
MB3N304	N304	Targeted	6.002	4.999	0.954	0.000	10.987	4.321	0.061	0.720	18.241	0.491	50.526	2.697	0.000	99.999
MB3N307	N307	Measured	4.540	9.169	0.972	0.011	11.488	8.122	0.031	0.748	8.509	0.500	56.478	2.718	0.004	103.288
MB3N307	N307	Measured bc	4.613	9.073	0.923	0.011	11.228	8.177	0.030	0.766	8.458	0.525	55.948	2.765	0.003	102.522
MB3N307	N307	Targeted	4.296	9.000	0.954	0.000	10.987	8.001	0.061	0.720	8.258	0.491	54.535	2.697	0.000	100.000
MB3N313	N313	Measured	4.374	4.822	0.942	0.024	11.270	7.950	0.044	0.777	11.566	0.511	55.889	2.518	0.007	100.693
MB3N313	N313	Measured bc	4.373	4.750	0.901	0.022	11.170	7.906	0.042	0.774	11.264	0.523	56.148	2.599	0.005	100.477
MB3N313	N313	Targeted	4.296	4.999	0.954	0.000	10.987	8.001	0.061	0.720	11.298	0.491	55.496	2.697	0.000	100.000
MB3N314	N314	Measured	4.431	14.852	0.956	0.107	11.813	4.327	0.033	0.735	9.372	0.498	49.311	2.409	1.335	100.179
MB3N314	N314	Measured bc	4.453	14.198	0.908	0.108	11.543	4.353	0.033	0.753	9.314	0.523	48.841	2.491	1.049	98.566
MB3N314	N314	Targeted	4.296	14.997	0.954	0.000	10.987	4.425	0.061	0.720	9.338	0.491	49.536	2.697	1.497	99.999
MB3N315	N315	Measured	4.473	14.997	0.958	0.012	11.909	7.428	0.042	0.752	4.900	0.488	54.231	2.774	0.001	102.967
MB3N315	N315	Measured bc	4.496	14.336	0.907	0.011	11.348	7.472	0.041	0.772	4.773	0.512	53.490	2.870	0.001	101.028
MB3N315	N315	Targeted	4.296	14.997	0.954	0.000	10.987	7.472	0.061	0.720	4.779	0.491	52.545	2.697	0.000	99.999
MB3N320	N320	Measured	4.426	5.917	0.954	0.014	11.416	5.845	0.044	0.778	14.221	0.507	55.568	2.668	0.007	102.366
MB3N320	N320	Measured bc	4.448	5.656	0.912	0.012	11.315	5.880	0.042	0.775	13.849	0.519	55.825	2.760	0.005	101.999
MB3N320	N320	Targeted	4.296	5.960	0.954	0.000	10.987	5.960	0.061	0.720	13.719	0.491	54.155	2.697	0.000	100.000
MB3N322	N322	Measured	4.355	5.884	0.961	0.015	11.677	3.703	0.032	0.765	12.452	0.506	59.152	2.559	0.092	102.152
MB3N322	N322	Measured bc	4.377	5.624	0.912	0.015	11.408	3.725	0.032	0.783	12.375	0.531	58.594	2.647	0.072	101.096
MB3N322	N322	Targeted	4.296	5.960	0.954	0.000	10.987	3.725	0.061	0.720	12.229	0.491	57.880	2.697	0.000	100.000
MB3N323	N323	Measured	4.440	11.020	0.959	0.011	11.838	3.859	0.039	0.749	11.263	0.486	56.959	2.686	0.056	104.365

Glass ID	Glass ID (shortened)	Compositional View	Al_2O_3	B_2O_3	CaO	Cr_2O_3	Fe_2O_3	Li_2O	MgO	MnO	Na_2O	NiO	SiO_2	U_3O_8	ZrO_2	Sum of Oxides
MB3N323	N323	Measured bc	4.439	10.855	0.908	0.011	11.280	3.838	0.038	0.769	10.971	0.509	56.183	2.774	0.045	102.620
MB3N323	N323	Targeted	4.296	11.175	0.954	0.000	10.987	3.867	0.061	0.720	10.947	0.491	53.804	2.697	0.000	99.999
MB3N324	N324	Measured	4.398	11.358	0.972	0.018	11.023	6.125	0.028	0.741	8.792	0.470	54.873	2.694	0.001	101.495
MB3N324	N324	Measured bc	4.420	10.858	0.920	0.017	11.097	6.162	0.028	0.753	8.700	0.491	55.897	2.788	0.001	102.131
MB3N324	N324	Targeted	4.296	11.175	0.954	0.000	10.987	6.169	0.061	0.720	8.645	0.491	53.804	2.697	0.000	99.999
MB3N326	N326	Measured	4.521	5.989	0.978	0.022	11.055	6.082	0.816	0.750	13.369	0.487	54.820	2.756	0.001	101.646
MB3N326	N326	Measured bc	4.514	5.843	0.925	0.021	11.126	6.022	0.802	0.763	13.225	0.509	55.842	2.815	0.001	102.406
MB3N326	N326	Targeted	4.296	5.960	0.954	0.000	10.987	5.960	0.806	0.720	12.974	0.491	54.155	2.697	0.000	100.000
MB3U165	U165	Measured	4.204	7.285	0.972	0.019	10.769	5.210	0.851	0.718	15.232	0.461	51.985	2.273	0.686	100.665
MB3U165	U165	Measured bc	4.203	7.177	0.920	0.018	10.841	5.182	0.836	0.729	15.071	0.482	52.961	2.348	0.546	101.313
MB3U165	U165	Targeted	4.192	7.450	0.941	0.000	10.824	5.215	0.806	0.691	14.944	0.460	51.168	2.563	0.745	99.999
MB3U200	U200	Measured	4.384	8.927	0.945	0.016	11.459	3.741	1.572	0.724	13.692	0.497	53.215	2.671	0.001	101.845
MB3U200	U200	Measured bc	4.455	8.837	0.897	0.016	11.199	3.766	1.557	0.742	13.609	0.523	52.717	2.718	0.001	101.037
MB3U200	U200	Targeted	4.192	8.940	0.941	0.000	10.824	3.725	1.551	0.691	13.454	0.460	52.658	2.563	0.000	99.999
MB3U303	U303	Measured	6.231	14.836	0.982	0.020	11.466	7.718	0.044	0.738	5.416	0.494	52.199	2.683	0.008	102.833
MB3U303	U303	Measured bc	6.221	14.470	0.932	0.020	11.205	7.640	0.043	0.756	5.382	0.520	51.703	2.740	0.006	101.639
MB3U303	U303	Targeted	5.898	14.997	0.941	0.000	10.824	7.539	0.061	0.691	5.259	0.460	50.766	2.563	0.000	99.999
MB3U304	U304	Measured	5.961	4.910	0.956	0.072	11.327	4.284	0.036	0.724	19.310	0.497	51.611	2.529	0.004	102.223
MB3U304	U304	Measured bc	6.058	4.859	0.908	0.072	11.066	4.313	0.036	0.742	19.192	0.523	51.122	2.573	0.003	101.467
MB3U304	U304	Targeted	5.898	4.999	0.941	0.000	10.824	4.321	0.061	0.691	18.721	0.460	50.520	2.563	0.000	99.999
MB3U307	U307	Measured	4.450	8.823	0.921	0.014	11.252	7.993	0.046	0.747	9.028	0.461	55.461	2.597	0.058	101.851
MB3U307	U307	Measured bc	4.449	8.692	0.881	0.012	11.153	7.950	0.043	0.744	8.792	0.472	55.719	2.682	0.041	101.630
MB3U307	U307	Targeted	4.192	9.000	0.941	0.000	10.824	8.001	0.061	0.691	8.738	0.460	54.528	2.563	0.000	99.999
MB3U313	U313	Measured	4.318	4.999	0.948	0.012	11.152	7.890	0.035	0.704	11.761	0.489	56.050	2.509	0.001	100.868
MB3U313	U313	Measured bc	4.311	4.875	0.897	0.011	11.235	7.810	0.035	0.716	11.638	0.511	57.100	2.562	0.001	101.703
MB3U313	U313	Targeted	4.192	4.999	0.941	0.000	10.824	8.001	0.061	0.691	11.778	0.460	55.489	2.563	0.000	99.999
MB3U314	U314	Measured	4.110	13.000	0.905	0.021	10.480	3.983	0.073	0.705	9.554	0.440	53.269	2.488	1.375	100.402
MB3U314	U314	Measured bc	4.176	12.870	0.866	0.019	10.387	4.010	0.070	0.702	9.304	0.450	53.516	2.532	0.972	99.874
MB3U314	U314	Targeted	4.192	14.997	0.941	0.000	10.824	4.425	0.061	0.691	9.819	0.460	49.529	2.563	1.497	99.999
MB3U315	U315	Measured	4.445	14.506	0.932	0.012	10.694	7.546	0.036	0.698	6.379	0.458	52.092	2.624	0.001	100.423
MB3U315	U315	Measured bc	4.517	14.355	0.881	0.011	10.762	7.597	0.035	0.709	6.312	0.479	53.040	2.669	0.001	101.370
MB3U315	U315	Targeted	4.192	14.997	0.941	0.000	10.824	7.472	0.061	0.691	5.259	0.460	52.539	2.563	0.000	99.999
MB3U320	U320	Measured	4.379	5.949	0.949	0.012	11.259	6.017	0.032	0.718	14.424	0.451	55.622	2.553	0.001	102.364

Glass ID	Glass ID (shortened)	Compositional View	Al_2O_3	B_2O_3	CaO	Cr_2O_3	Fe_2O_3	Li_2O	MgO	MnO	Na_2O	NiO	SiO_2	U_3O_8	ZrO_2	Sum of Oxides
MB3U320	U320	Measured bc	4.372	5.802	0.901	0.012	11.001	5.957	0.031	0.735	14.335	0.474	55.097	2.607	0.001	101.325
MB3U320	U320	Targeted	4.192	5.960	0.941	0.000	10.824	5.960	0.061	0.691	14.199	0.460	54.148	2.563	0.000	99.999
MB3U322	U322	Measured	4.237	5.892	0.927	0.029	11.434	3.644	0.050	0.725	12.739	0.450	60.489	2.450	0.005	103.071
MB3U322	U322	Measured bc	4.258	5.633	0.877	0.028	10.895	3.666	0.049	0.745	12.408	0.471	59.663	2.534	0.004	101.232
MB3U322	U322	Targeted	4.192	5.960	0.941	0.000	10.824	3.725	0.061	0.691	12.709	0.460	57.873	2.563	0.000	99.999
MB3U323	U323	Measured	4.454	11.068	0.918	0.015	10.952	3.864	0.046	0.734	11.606	0.503	54.927	2.565	0.136	101.788
MB3U323	U323	Measured bc	4.448	10.797	0.878	0.013	10.854	3.826	0.043	0.732	11.303	0.515	55.181	2.619	0.096	101.303
MB3U323	U323	Targeted	4.192	11.175	0.941	0.000	10.824	3.867	0.061	0.691	11.428	0.460	53.798	2.563	0.000	100.000
MB3U324	U324	Measured	4.398	10.859	0.961	0.027	11.763	6.141	0.051	0.730	9.460	0.469	55.247	2.597	0.001	102.704
MB3U324	U324	Measured bc	4.391	10.590	0.910	0.026	11.208	6.079	0.050	0.750	9.214	0.491	54.492	2.653	0.001	100.854
MB3U324	U324	Targeted	4.192	11.175	0.941	0.000	10.824	6.169	0.061	0.691	9.126	0.460	53.798	2.563	0.000	100.000
MB3U326	U326	Measured	4.322	6.070	0.942	0.015	11.727	5.867	0.829	0.731	13.918	0.494	54.927	2.547	0.001	102.390
MB3U326	U326	Measured bc	4.344	5.802	0.892	0.015	11.174	5.902	0.811	0.751	13.557	0.517	54.177	2.635	0.001	100.577
MB3U326	U326	Targeted	4.192	5.960	0.941	0.000	10.824	5.960	0.806	0.691	13.454	0.460	54.148	2.563	0.000	99.999

Exhibit E7 in Appendix E provides plots that compare measured and measure bias-corrected values to targeted values by oxide for the study glasses. A plot of the sum of oxides is also provided in this exhibit. As seen in Table 14 and Exhibit E7, no major problems are seen in the agreement among the measured, measured bias-corrected, and targeted compositional views of the MB3 glasses. All three of these compositional views will be utilized to represent the MB3 glasses in the discussions that follow to ensure that there are no differences in the conclusions.

7.2 DURABILITY

Samples of the MB3 study glasses, after being batched and fabricated (via quenching), were subjected to a second heat treatment – they were cooled to simulate a centerline canister cooling profile. Differences in glass durability for these two cooling regimes (quenched versus centerline cooled) are of interest to this study. The investigation into this question required durability to be measured for the quenched and centerline cooled versions of each of the study glasses.

The 7-day Product Consistency Test (PCT) was used as the assessment of glass durability. More specifically, Method A of the PCT (ASTM C1285-97) was used for these measurements. The PCTs were conducted in triplicate for the study glasses in two sets: set #1 included the glasses representing nominally washed sludge, and set #2 included glasses representing the underwashed sludge. In addition, PCTs were also conducted in triplicate for samples of the EA glass, the ARM glass, and a blank (ASTM Type I water) for each set. Analytical plans supporting these tests were provided in the form of memoranda (see Appendices C and D). The plans assisted the SRTC-ML in measuring the compositions of the solutions resulting from the two groups of PCTs. Of primary interest were the concentrations (in parts per million, ppm) of boron (B), lithium (Li), sodium (Na), and silicon (Si). Samples of a multi-element solution standard were also included in each analytical plan (as a check on the accuracy of the ICP – AES used for these measurements).

The results from these tests are given in Table E3 (for set #1) and Table E4 (for set #2) of Appendix E. The PCT results for the centerline-cooled version of each study glass are indicated by the "clc" suffix on the glass ID. One of the quality control checkpoints for the PCT procedure is solution weight loss over the course of the 7-day test. The shaded entries of Tables E3 and E4 indicate those solutions that fell outside the weight-loss guidelines (weight loss must be less than 5 wt%). At least two successful solutions out of the 3 conducted for a glass are required to generate a representative PCT for that glass. Although this criterion has not been met for all of the MB3 study glasses, the results are believed to provide meaningful and representative comparisons for assessing the impact of the cooling regimes since the impact must be larger than the measurement variability to be of consequence.

Any measurement in the "as reported" columns of Tables E3 and E4 proceeded by a "<" was below the detection limit for the ICP, and the measurement was replaced by ½ of the detection limit in the determination of the parts per million (ppm) columns of the tables. The values in the ppm columns were also adjusted for the dilution factors by multiplying the "as-reported" values by 1.6667 for the MB3 and ARM glasses and by 16.6667 for the EA glass. Thus, the concentrations in the ppm columns reflect detection and dilution adjustments.

7.2.1 PCT Results for the Glasses Representing the Nominally Washed Sludge

Exhibit E8 in Appendix E provides plots of the leachate concentrations and standards in the analytical sequence reported by the SRTC-ML for the PCTs from the nominally washed case. These plots include the values from the EA PCTs and the blanks. These values expand the scales of these plots, making it difficult to distinguish among the results of the other analyses. Exhibit E9 in Appendix E provides these same plots excluding the EA and blank, yielding a clearer picture of the behavior of the PCTs for the other glasses and standards.

Exhibit E10 in Appendix E provides plots of the leachate concentrations for each type of submitted solution: the standards, the blanks, EA, ARM, and the study glasses representing the nominally washed case. Once again, excluding the results for EA and the blanks improves the opportunity for investigating the behavior of the PCTs for the other glasses and standards. Such results are shown in Exhibit E11 in Appendix E.

PCT leachate concentrations are typically normalized using the corresponding cation concentration (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 concentrations will also be used to conduct this normalization.

As is the usual convention, the common logarithm of the normalized PCT (normalized leachate, NL) for each element of interest will be determined and used for 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 (Table E3 of Appendix E provides these values),

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.

As a preliminary step to completing these normalizations of the PCTs, statistical analyses were conducted of the results from the three analyses of the multi-element standard solution per analytical block. Exhibit E12 in Appendix E provides these analyses. Although there appears to be statistical differences among the block averages for most of the elements of interest, 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 results for each set of triplicates helps to minimize the impact of the ICP effects.

Table 15 presents the block averages of the solution standards, and they indicate consistent and reasonably accurate results (e.g., most differences of overall average versus reference value < 5%) from these analyses.

Table 15: Average Measurements of Standard Solution by Analytical Block - PCTs for Glasses from Nominally Washed Sludge.

Analytical Block	Avg B (ppm)	Avg Li (ppm)	Avg Na (ppm)	Avg Si (ppm)
1	20.8	10.7	74.0	51.7
2	18.6	10.5	77.4	46.9
3	19.2	10.7	77.5	46.4
4	18.8	10.7	78.5	48.2
5	18.9	10.7	78.3	47.4
6	18.9	11.0	80.4	49.3
Grand Average	19.2	10.7	77.7	48.3
Reference Value	20	10	81	50
% difference	-4.0%	7.0%	-4.1%	-3.3%

Table 16 provides the results from the normalization process using the information in Table 15 and all of the data of Table E3 (i.e., before screening the PCT results for solution-weight problems). Exhibit E13 in Appendix E provides scatter plots for these results (both quenched and centerline cooled) offering an opportunity to investigate the consistency in the leaching across the elements for the glasses of this study. The consistency is typically demonstrated by a high degree of linear correlation among the values. PCT values normalized using targeted, measured, and bias-corrected compositions were investigated. A high degree of correlation is seen for these data for some pairs of elements. However, small correlations (as small as 58%) can be seen between the data for some pairs of elements (e.g., particularly between B and Na). While poor correlation coefficients are expected with Si in the PCT (due to Si saturation in solution), Na, B, and Li should be correlated to a relatively high degree. Low correlations found in this study may indicate that some of the glasses are phase separated (e.g., amorphous phase separation). Similar trends were observed by Jantzen et al. (1999).

Table 16. Normalized PCTs before Screening for Solution-Weight Problems – Nominally Washed Sludge.

		Quenched								Centerline Cooled							
Glass ID	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)	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 [8]	-0.2861	-0.1716	-0.2812	-0.5482	0.52	0.67	0.52	0.28								
EA	see [8]	1.1976	0.9791	1.0689	0.5506	15.76	9.53	11.72	3.55								
N165	Measured	-0.0046	0.0439	0.0493	-0.2108	0.99	1.11	1.12	0.62	-0.0348	0.0309	-0.0044	-0.2222	0.92	1.07	0.99	0.60
N165	Measured bc	0.0019	0.0463	0.0539	-0.2188	1.00	1.11	1.13	0.60	-0.0283	0.0333	0.0002	-0.2302	0.94	1.08	1.00	0.59
N165	Targeted	-0.0143	0.0372	0.0601	-0.2000	0.97	1.09	1.15	0.63	-0.0445	0.0242	0.0064	-0.2114	0.90	1.06	1.01	0.61
N200	Measured	-0.1145	-0.0451	-0.1169	-0.3155	0.77	0.90	0.76	0.48	-0.1352	-0.0665	-0.1453	-0.3215	0.73	0.86	0.72	0.48
N200	Measured bc	-0.1079	-0.0427	-0.1054	-0.3175	0.78	0.91	0.78	0.48	-0.1287	-0.0641	-0.1338	-0.3235	0.74	0.86	0.73	0.47
N200	Targeted	-0.1135	-0.0451	-0.1086	-0.3101	0.77	0.90	0.78	0.49	-0.1343	-0.0665	-0.1370	-0.3161	0.73	0.86	0.73	0.48
N303	Measured	-0.1023	-0.0443	-0.4328	-0.3010	0.79	0.90	0.37	0.50	-0.1348	-0.0808	-0.3797	-0.3161	0.73	0.83	0.42	0.48
N303	Measured bc	-0.0914	-0.0399	-0.4214	-0.2950	0.81	0.91	0.38	0.51	-0.1239	-0.0764	-0.3683	-0.3101	0.75	0.84	0.43	0.49
N303	Targeted	-0.1046	-0.0429	-0.4128	-0.2912	0.79	0.91	0.39	0.51	-0.1371	-0.0794	-0.3597	-0.3063	0.73	0.83	0.44	0.49
N304	Measured	0.0292	0.0956	0.2955	-0.0638	1.07	1.25	1.97	0.86	0.0191	0.1030	0.2700	-0.0557	1.05	1.27	1.86	0.88
N304	Measured bc	0.0337	0.0926	0.2991	-0.0719	1.08	1.24	1.99	0.85	0.0236	0.1001	0.2736	-0.0637	1.06	1.26	1.88	0.86
N304	Targeted	0.0354	0.1010	0.2186	-0.0577	1.09	1.26	1.65	0.88	0.0253	0.1085	0.1931	-0.0496	1.06	1.28	1.56	0.89
N307	Measured	-0.0518	0.0385	-0.1338	-0.1956	0.89	1.09	0.73	0.64	-0.0277	0.1534	-0.0751	-0.0960	0.94	1.42	0.84	0.80
N307	Measured bc	-0.0473	0.0355	-0.1312	-0.1915	0.90	1.09	0.74	0.64	-0.0231	0.1505	-0.0725	-0.0919	0.95	1.41	0.85	0.81
N307	Targeted	-0.0437	0.0450	-0.1208	-0.1804	0.90	1.11	0.76	0.66	-0.0196	0.1600	-0.0621	-0.0808	0.96	1.45	0.87	0.83
N313	Measured	0.1154	0.1773	0.1070	-0.0028	1.30	1.50	1.28	0.99	0.2499	0.4336	0.2001	0.2005	1.78	2.71	1.59	1.59
N313	Measured bc	0.1219	0.1797	0.1185	-0.0048	1.32	1.51	1.31	0.99	0.2564	0.4360	0.2116	0.1985	1.80	2.73	1.63	1.58
N313	Targeted	0.0997	0.1745	0.1172	0.0003	1.26	1.49	1.31	1.00	0.2342	0.4308	0.2103	0.2036	1.71	2.70	1.62	1.60
N314	Measured	0.0071	0.0928	-0.1825	-0.3997	1.02	1.24	0.66	0.40	-0.0512	0.0447	-0.2050	-0.3969	0.89	1.11	0.62	0.40
N314	Measured bc	0.0267	0.0902	-0.1798	-0.3955	1.06	1.23	0.66	0.40	-0.0316	0.0421	-0.2023	-0.3928	0.93	1.10	0.63	0.40
N314	Targeted	0.0029	0.0831	-0.1810	-0.4017	1.01	1.21	0.66	0.40	-0.0554	0.0349	-0.2034	-0.3989	0.88	1.08	0.63	0.40
N315	Measured	0.0902	0.1353	-0.1579	-0.2389	1.23	1.37	0.70	0.58	0.0898	0.1296	-0.1186	-0.2423	1.23	1.35	0.76	0.57
N315	Measured bc	0.1098	0.1327	-0.1464	-0.2329	1.29	1.36	0.71	0.58	0.1094	0.1270	-0.1072	-0.2364	1.29	1.34	0.78	0.58
N315	Targeted	0.0902	0.1327	-0.1470	-0.2252	1.23	1.36	0.71	0.60	0.0898	0.1270	-0.1078	-0.2286	1.23	1.34	0.78	0.59
N320	Measured	0.0001	0.1177	0.0979	-0.1089	1.00	1.31	1.25	0.78	-0.0104	0.1454	0.0769	-0.0947	0.98	1.40	1.19	0.80
N320	Measured bc	0.0196	0.1151	0.1094	-0.1109	1.05	1.30	1.29	0.77	0.0092	0.1428	0.0884	-0.0967	1.02	1.39	1.23	0.80
N320	Targeted	-0.0031	0.1092	0.1135	-0.0977	0.99	1.29	1.30	0.80	-0.0135	0.1369	0.0925	-0.0835	0.97	1.37	1.24	0.83
N322	Measured	-0.2463	-0.1005	-0.2249	-0.3362	0.57	0.79	0.60	0.46	-0.2314	-0.0984	-0.2368	-0.3206	0.59	0.80	0.58	0.48
N322	Measured bc	-0.2267	-0.1031	-0.2222	-0.3321	0.59	0.79	0.60	0.47	-0.2118	-0.1010	-0.2342	-0.3165	0.61	0.79	0.58	0.48
N322	Targeted	-0.2519	-0.1031	-0.2171	-0.3268	0.56	0.79	0.61	0.47	-0.2370	-0.1010	-0.2290	-0.3112	0.58	0.79	0.59	0.49
N323	Measured	-0.1517	-0.0548	-0.2709	-0.3734	0.71	0.88	0.54	0.42	-0.2115	-0.0979	-0.2977	-0.3969	0.61	0.80	0.50	0.40
N323	Measured bc	-0.1451	-0.0525	-0.2595	-0.3674	0.72	0.89	0.55	0.43	-0.2049	-0.0955	-0.2863	-0.3909	0.62	0.80	0.52	0.41
N323	Targeted	-0.1578	-0.0557	-0.2586	-0.3486	0.70	0.88	0.55	0.45	-0.2175	-0.0988	-0.2854	-0.3721	0.61	0.80	0.52	0.42
N324	Measured	-0.0577	0.0155	-0.2124	-0.2642	0.88	1.04	0.61	0.54	-0.0657	0.0189	-0.1942	-0.2665	0.86	1.04	0.64	0.54
N324	Measured bc	-0.0382	0.0129	-0.2078	-0.2722	0.92	1.03	0.62	0.53	-0.0461	0.0163	-0.1897	-0.2746	0.90	1.04	0.65	0.53
N324	Targeted	-0.0507	0.0124	-0.2051	-0.2556	0.89	1.03	0.62	0.56	-0.0586	0.0158	-0.1869	-0.2580	0.87	1.04	0.65	0.55
N326	Measured	0.0194	0.0644	0.0393	-0.1359	1.05	1.16	1.09	0.73	0.0281	0.1032	0.0320	-0.1208	1.07	1.27	1.08	0.76
N326	Measured bc	0.0302	0.0687	0.0441	-0.1439	1.07	1.17	1.11	0.72	0.0388	0.1075	0.0367	-0.1289	1.09	1.28	1.09	0.74
N326	Targeted	0.0215	0.0732	0.0524	-0.1306	1.05	1.18	1.13	0.74	0.0302	0.1120	0.0450	-0.1155	1.07	1.29	1.11	0.77

7.2.2 PCT Results for the Glasses Representing the Underwashed Sludge

Exhibit E14 in Appendix E provides plots of the leachate concentrations and standards in the analytical sequence reported by the SRTC-ML for the PCTs from the underwashed case. These plots include the values from the EA PCTs and the blanks. These values expand the scales of these plots, making it difficult to distinguish among the results of the other analyses. Exhibit E15 in Appendix E provides these same plots excluding the EA and blank, yielding a clearer picture of the behavior of the PCTs for the other glasses and standards.

Exhibit E16 in Appendix E provides plots of the leachate concentrations for each type of submitted solution: the standards, the blanks, EA, ARM, and the study glasses representing the underwashed case. Once again, excluding the results for EA and the blanks improves the opportunity for investigating the behavior of the PCTs for the other glasses and standards. Exhibit E17 in Appendix E shows such results.

As a preliminary step to normalizing the PCTs from the underwashed case, statistical analyses were conducted on the results from the three analyses of the multi-element standard solution per analytical block. Exhibit E18 in Appendix E provides these analyses. Although there appears to be statistical differences among the block averages for most of the elements of interest, 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 17 presents the block averages of the solution standards, and they indicate consistent and reasonably accurate results (differences of overall averages versus reference values ~ 5%) from these analyses.

Table 17. Average Measurements of Standard Solution By Analytical Block - PCTs for Glasses from Underwashed Sludge.

Analytical Block	Average			
	B (ppm)	Li (ppm)	Na (ppm)	Si (ppm)
1	18.9	9.5	79.3	47.9
2	18.5	9.2	76.9	47.4
3	18.7	9.3	78.3	47.5
4	18.7	9.3	79.5	46.9
5	19.2	9.4	77.9	48.4
6	19.0	9.4	79.2	45.5
Grand Average	18.8	9.3	78.5	47.3
Reference Value	20	10	81	50
% difference	-5.9%	-6.7%	-3.1%	-5.5%

The PCTs for the underwashed case were normalized (in a manner similar to the nominally-washed case discussed above) using the measured, measured bias-corrected, and the targeted compositions for the glasses from the underwashed case. Table 18 provides the results from the normalization process using the information in Table 15 and all of the data of Table E4 (i.e., before screening the PCT results for solution-weight problems). Exhibit E19 in Appendix E provides scatter plots for these results (both quenched and centerline cooled) offering an opportunity to investigate the consistency in the leaching across the elements for the glasses of this study. The consistency is typically demonstrated by a high degree of linear correlation among the values. PCT values normalized using targeted, measured, and bias-corrected compositions were investigated. A high degree of correlation is seen for these data for some pairs of elements. However, small correlations (as small as 49%) can be seen between the data for some pairs of elements (e.g., in particular between B and Na as well as Na and Li).

Table 18. Normalized PCTs before Screening for Solution-Weight Problems – Underwashed Sludge.

		Quenched								Centerline Cooled							
Glass ID	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)	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 [8]	-0.2991	-0.2178	-0.2713	-0.5380	0.50	0.61	0.54	0.29								
EA	See [8]	1.2254	0.9668	1.1221	0.5890	16.80	9.26	13.25	3.88								
U165	Measured	0.0164	0.0150	0.0842	-0.1800	1.04	1.04	1.21	0.66	-0.0057	0.0150	0.0422	-0.1919	0.99	1.04	1.10	0.64
U165	Measured bc	0.0229	0.0173	0.0889	-0.1881	1.05	1.04	1.23	0.65	0.0008	0.0173	0.0469	-0.2000	1.00	1.04	1.11	0.63
U165	Targeted	0.0067	0.0146	0.0925	-0.1731	1.02	1.03	1.24	0.67	-0.0155	0.0146	0.0505	-0.1850	0.97	1.03	1.12	0.65
U200	Measured	-0.0749	-0.0743	-0.0607	-0.2942	0.84	0.84	0.87	0.51	-0.1150	-0.1047	-0.1052	-0.3124	0.77	0.79	0.78	0.49
U200	Measured bc	-0.0705	-0.0773	-0.0581	-0.2901	0.85	0.84	0.87	0.51	-0.1106	-0.1076	-0.1026	-0.3083	0.78	0.78	0.79	0.49
U200	Targeted	-0.0756	-0.0725	-0.0531	-0.2896	0.84	0.85	0.88	0.51	-0.1156	-0.1028	-0.0976	-0.3078	0.77	0.79	0.80	0.49
U303	Measured	-0.0933	-0.0479	-0.3265	-0.3201	0.81	0.90	0.47	0.48	-0.1392	-0.0947	-0.3042	-0.3295	0.73	0.80	0.50	0.47
U303	Measured bc	-0.0825	-0.0435	-0.3238	-0.3159	0.83	0.90	0.47	0.48	-0.1284	-0.0902	-0.3015	-0.3253	0.74	0.81	0.50	0.47
U303	Targeted	-0.0980	-0.0377	-0.3138	-0.3080	0.80	0.92	0.49	0.49	-0.1439	-0.0845	-0.2914	-0.3174	0.72	0.82	0.51	0.48
U304	Measured	0.0225	0.0919	0.2566	-0.0615	1.05	1.24	1.81	0.87	-0.0134	0.0841	0.1991	-0.1053	0.97	1.21	1.58	0.78
U304	Measured bc	0.0270	0.0890	0.2593	-0.0574	1.06	1.23	1.82	0.88	-0.0088	0.0812	0.2017	-0.1012	0.98	1.21	1.59	0.79
U304	Targeted	0.0147	0.0882	0.2701	-0.0523	1.03	1.23	1.86	0.89	-0.0212	0.0804	0.2125	-0.0961	0.95	1.20	1.63	0.80
U307	Measured	0.0213	0.1729	-0.0262	-0.0695	1.05	1.49	0.94	0.85	0.0725	0.1024	-0.0274	-0.1415	1.18	1.27	0.94	0.72
U307	Measured bc	0.0277	0.1752	-0.0147	-0.0715	1.07	1.50	0.97	0.85	0.0790	0.1047	-0.0159	-0.1435	1.20	1.27	0.96	0.72
U307	Targeted	0.0126	0.1724	-0.0120	-0.0621	1.03	1.49	0.97	0.87	0.0638	0.1020	-0.0132	-0.1342	1.16	1.26	0.97	0.73
U313	Measured	0.0668	0.1840	0.1735	-0.0129	1.17	1.53	1.49	0.97	0.2000	0.4480	0.2391	0.1989	1.59	2.81	1.73	1.58
U313	Measured bc	0.0777	0.1884	0.1780	-0.0210	1.20	1.54	1.51	0.95	0.2109	0.4524	0.2437	0.1909	1.63	2.83	1.75	1.55
U313	Targeted	0.0668	0.1780	0.1729	-0.0085	1.17	1.51	1.49	0.98	0.2000	0.4419	0.2385	0.2033	1.59	2.77	1.73	1.60
U314	Measured	0.1061	0.1267	-0.0994	-0.4168	1.28	1.34	0.80	0.38	0.0691	0.0818	-0.1119	-0.4155	1.17	1.21	0.77	0.38
U314	Measured bc	0.1105	0.1238	-0.0879	-0.4188	1.29	1.33	0.82	0.38	0.0734	0.0788	-0.1004	-0.4175	1.18	1.20	0.79	0.38
U314	Targeted	0.0440	0.0810	-0.1113	-0.3852	1.11	1.21	0.77	0.41	0.0070	0.0361	-0.1238	-0.3838	1.02	1.09	0.75	0.41
U315	Measured	0.1220	0.1195	-0.1887	-0.2483	1.32	1.32	0.65	0.56	0.1720	0.1638	-0.0963	-0.1952	1.49	1.46	0.80	0.64
U315	Measured bc	0.1265	0.1165	-0.1842	-0.2562	1.34	1.31	0.65	0.55	0.1766	0.1608	-0.0918	-0.2030	1.50	1.45	0.81	0.63
U315	Targeted	0.1075	0.1237	-0.1174	-0.2521	1.28	1.33	0.76	0.56	0.1576	0.1680	-0.0250	-0.1989	1.44	1.47	0.94	0.63
U320	Measured	-0.0020	0.0615	0.1060	-0.1300	1.00	1.15	1.28	0.74	-0.0264	0.0837	0.0692	-0.1116	0.94	1.21	1.17	0.77
U320	Measured bc	0.0088	0.0659	0.1087	-0.1259	1.02	1.16	1.28	0.75	-0.0155	0.0880	0.0719	-0.1074	0.96	1.22	1.18	0.78
U320	Targeted	-0.0029	0.0657	0.1129	-0.1184	0.99	1.16	1.30	0.76	-0.0272	0.0878	0.0760	-0.0999	0.94	1.22	1.19	0.79
U322	Measured	-0.2768	-0.1553	-0.1796	-0.3666	0.53	0.70	0.66	0.43	-0.2780	-0.1550	-0.1929	-0.3623	0.53	0.70	0.64	0.43
U322	Measured bc	-0.2572	-0.1579	-0.1682	-0.3607	0.55	0.70	0.68	0.44	-0.2585	-0.1577	-0.1815	-0.3564	0.55	0.70	0.66	0.44
U322	Targeted	-0.2817	-0.1649	-0.1786	-0.3474	0.52	0.68	0.66	0.45	-0.2830	-0.1646	-0.1919	-0.3431	0.52	0.68	0.64	0.45
U323	Measured	-0.0823	-0.0439	-0.1651	-0.3410	0.83	0.90	0.68	0.46	-0.1263	-0.0911	-0.1982	-0.3547	0.75	0.81	0.63	0.44
U323	Measured bc	-0.0715	-0.0395	-0.1536	-0.3430	0.85	0.91	0.70	0.45	-0.1155	-0.0868	-0.1867	-0.3567	0.77	0.82	0.65	0.44
U323	Targeted	-0.0864	-0.0442	-0.1584	-0.3319	0.82	0.90	0.69	0.47	-0.1305	-0.0914	-0.1915	-0.3457	0.74	0.81	0.64	0.45
U324	Measured	0.0181	0.0484	-0.1234	-0.2379	1.04	1.12	0.75	0.58	-0.0376	-0.0081	-0.1458	-0.2640	0.92	0.98	0.71	0.54
U324	Measured bc	0.0290	0.0528	-0.1120	-0.2320	1.07	1.13	0.77	0.59	-0.0267	-0.0037	-0.1344	-0.2580	0.94	0.99	0.73	0.55
U324	Targeted	0.0056	0.0464	-0.1078	-0.2264	1.01	1.11	0.78	0.59	-0.0501	-0.0100	-0.1302	-0.2525	0.89	0.98	0.74	0.56
U326	Measured	0.0376	0.0917	0.1201	-0.1121	1.09	1.24	1.32	0.77	0.0433	0.1169	0.0878	-0.1027	1.10	1.31	1.22	0.79
U326	Measured bc	0.0572	0.0891	0.1315	-0.1062	1.14	1.23	1.35	0.78	0.0629	0.1143	0.0992	-0.0967	1.16	1.30	1.26	0.80
U326	Targeted	0.0455	0.0848	0.1348	-0.1059	1.11	1.22	1.36	0.78	0.0512	0.1100	0.1025	-0.0965	1.13	1.29	1.27	0.80

Table 19 compares the common logarithms of the leachate concentrations (in ppm) for the unscreened and screened PCTs where the screening was for the water-loss problem as discussed earlier; it also provides sludge representations. These results demonstrate that for these PCTs there were no significant differences in the screened and unscreened results. In this discussion that follows, all of the PCT results have been used to calculate the values of interest (i.e., the unscreened values were used).

Table 19. Average Leachate Concentrations from Screened and Unscreened PCTs.

Glass ID (shortened)	# Used in Calculations	Mean			
		log[B ppm]	log[Li ppm]	log[Na ppm]	log[Si ppm]
N165q	3	1.350	1.421	2.091	2.179
N165q	2	1.347	1.419	2.088	2.178
N200q	3	1.330	1.193	1.875	2.081
N200q	2	1.320	1.183	1.863	2.071
N307clc	3	1.403	1.615	1.666	2.226
N307clc	2	1.408	1.619	1.670	2.226
N314clc	3	1.613	1.348	1.637	1.966
N314clc	2	1.611	1.344	1.642	1.962
U165q	2	1.376	1.405	2.144	2.210
U165q	3	1.371	1.399	2.137	2.206
U303clc	1	1.512	1.450	1.294	2.051
U303clc	3	1.524	1.460	1.300	2.058
U313clc	2	1.388	2.008	2.175	2.596
U313clc	3	1.391	2.012	2.180	2.617

7.2.3 PCT RESULTS VERSUS MODEL PREDICTIONS

The PCT response is a measure of the critical product quality metric for vitrified HLW — the durability of the glass. A review of Tables 16 and 18 reveals that the durabilities (as reflected by the PCTs) of the MB3 glasses compare very favorably to the durability of the EA glass. DWPF utilizes models to predict PCT responses based upon glass compositions. These models relate

PCT response to glass compositions via an approach based on free energy of hydration (Jantzen et al. 1995).

The predictability of the PCT's of the MB3 glasses by these models is of concern. Exhibits E20 through E25 in Appendix E address this concern. Each of these exhibits presents a set of plots covering the four PCT elements of interest: boron (B), lithium (Li), sodium (Na), and silicon (Si). Each plot relates log NL [x (g/L)] (where x represents B, Li, Na, or Si) to a linear function of ΔG_p (also represented as del G_P, a measured of the free energy of hydration in units of kcal/100 grams of glass) (Jantzen et al. 1995). Also, each plot shows the linear model surrounded by two lines that form a 95% prediction interval for an individual PCT response corresponding to a ΔG_p value. Thus, one would expect a large portion of the PCT responses to fall within these prediction limits. The exhibits are organized around two features: the nominal versus underwashed cases and the composition view (measured, measured bc, and targeted).

Two final comments regarding these exhibits are warranted. The quenched and clc glasses were plotted using a closed, small square and an open circle, respectively. The EA and ARM results are shown (and labeled) on each plot.

Overall, the PCT's appear to be reasonably well predicted. The model underpredicted some of the PCT's at the more positive ΔG_p values. This behavior has been seen and documented in prior studies (Harbour et al. 2000). One or two glasses (e.g., N313 and N307) reveal predictable PCT responses for their quenched versions while their clc versions are just above the prediction limits. The next section provides a closer look at the quenched versus clc results.

7.2.4 Quenched Versus Centerline Cooled PCTs

An important objective of this study was to investigate the potential impact of cooling rate on glass durability. Exhibits E26 (nominal-washed case) and E27 (underwashed case) provide a statistical comparison between the PCTs for the quenched and centerline cooled glasses. These exhibits show no statistically significant difference between the quenched and clc PCTs for either the nominally-washed or the underwashed cases.

Figure 2 provides a series of scatter plots for the quenched versus clc PCTs for the nominally washed case. A plot is provided for each of the four elements along with a diagonal line as well as a fitted line for the average difference in the PCTs and 95% confidence limits for this average. Figure 3 provides a similar series of scatter plots for the quenched versus clc PCTs for the underwashed case. In both figures, the nominal and underwashed MB3 glasses produced with Frit 313 appear to be outliers. The quenched versions of these glasses have a lower release than their counterpart clc versions. To identify potential sources for this difference, the nominal and underwashed Frit 313 glasses (both quenched and clc) were submitted to the SRTC-Analytical Development Section (ADS) for XRD analysis. Figures 4 and 5 represent the XRD results for the quenched and clc glasses using the nominally washed MB3 sludge and Frit 313. Figures 6 and 7 represent the XRD results for the quenched and clc glasses using the underwashed MB3 sludge and Frit 313.

XRD patterns of MB3N313q and MB3U313q (quenched) show the characteristic high background devoid of crystalline spectral lines indicative of an amorphous (non-crystalline) product. The absence of distinct spectral lines does not eliminate the possibility of amorphous phase separation in these glasses. For the clc versions of these glasses (see Figures 4 and 6), Li_2SiO_3 was detected in the glass (as noted by the well-defined or distinct spectral lines).

Although no formal analysis has been completed, the presence of amorphous phase separation in the quenched glasses and the formation of Li_2SiO_3 (during clc) may have led to the higher releases shown in Figures 2 and 3. It is known that amorphous phase separation can be a precursor to devitrification (Tomozawa 1972; Peeler and Hrma 1996)

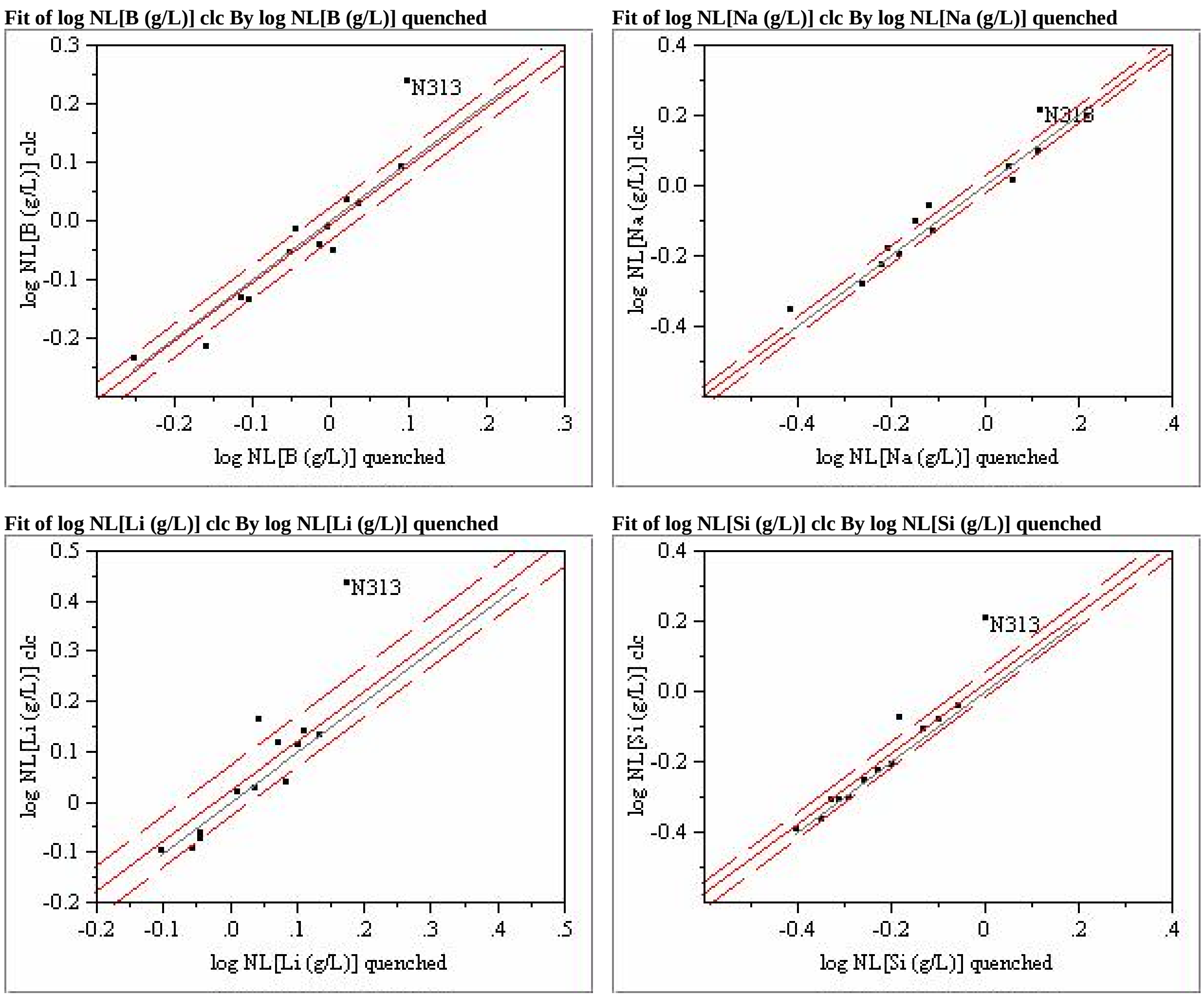

Figure 2. Quenched versus CLC PCTs for Nominally Washed Case.

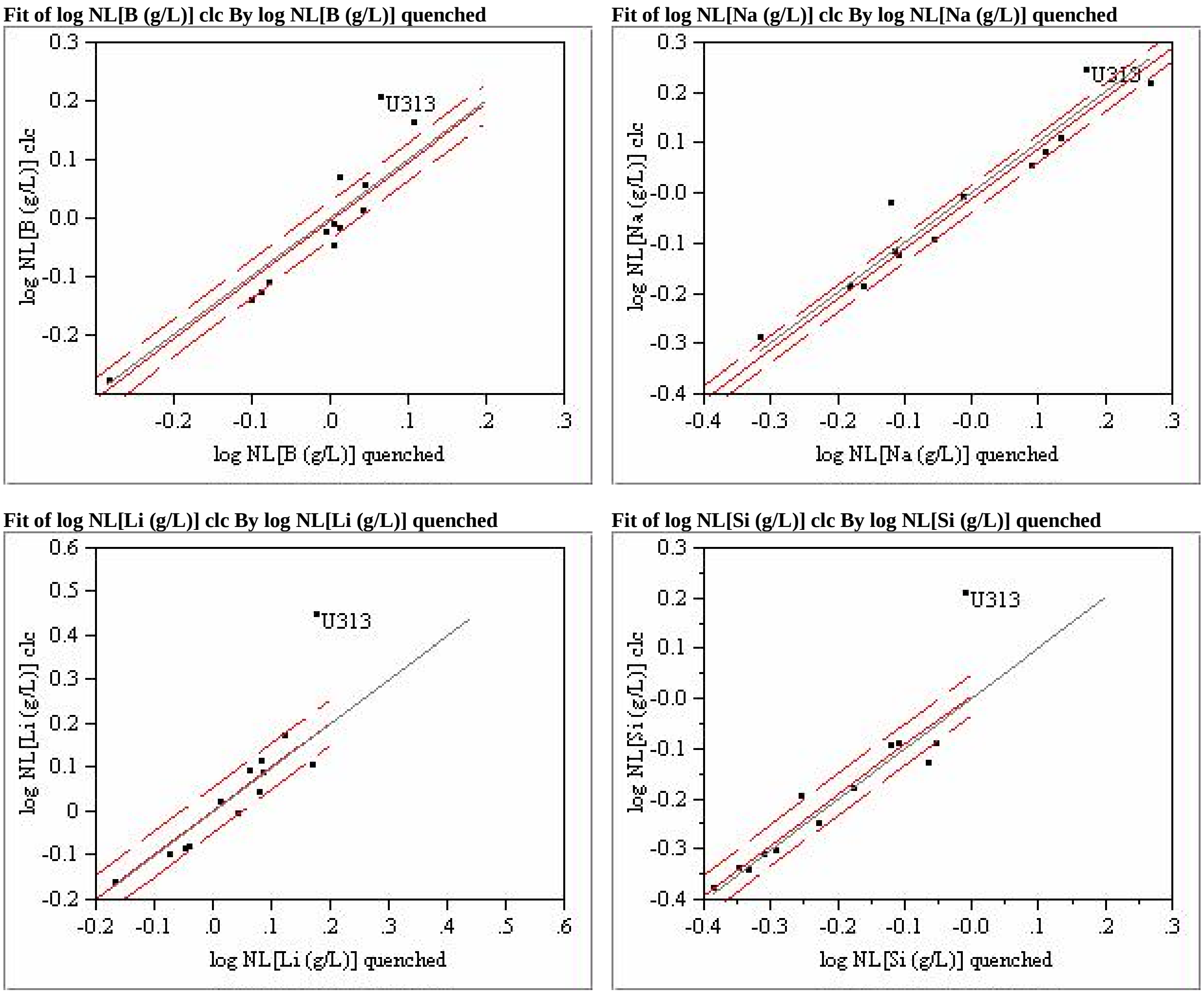

Figure 3. Quenched versus CLC PCTs for Underwashed Case.

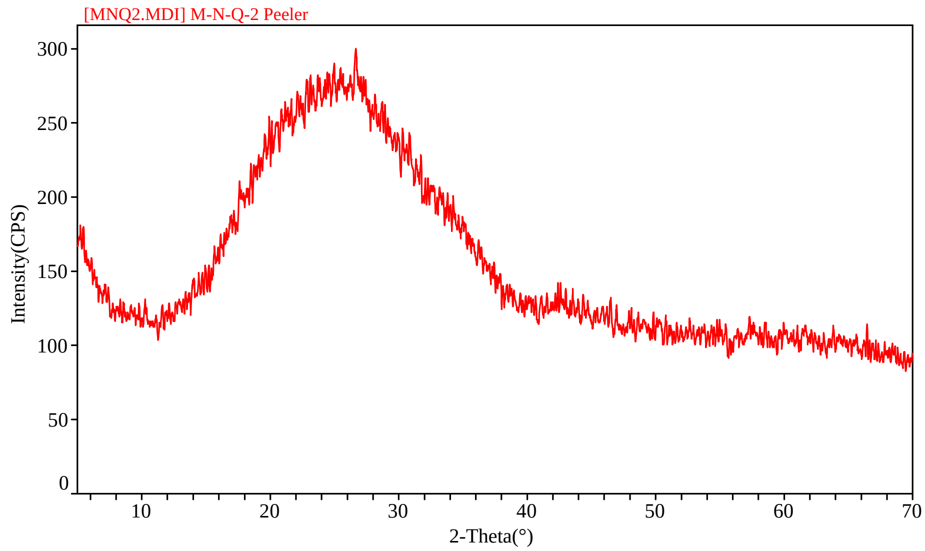

Figure 4. XRD Results of the MB3N313q.

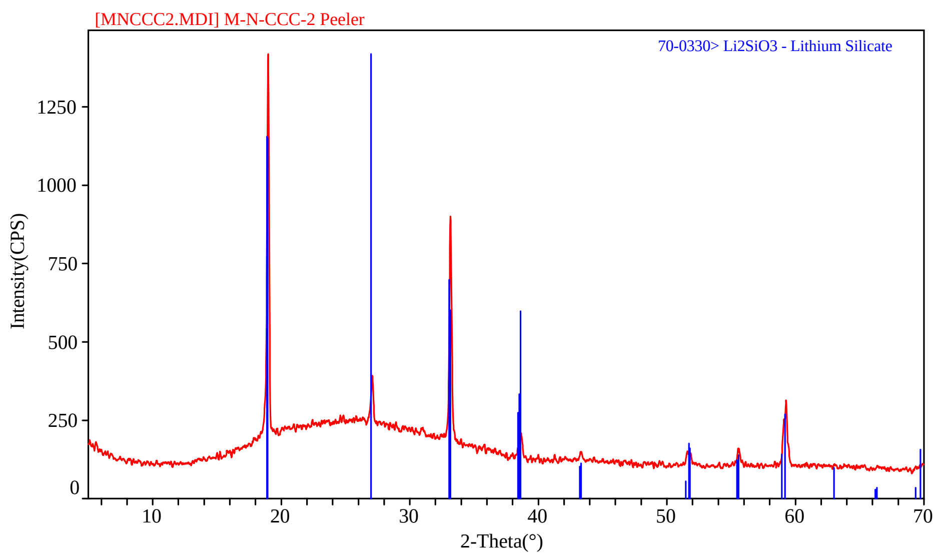

Figure 5. XRD Results of MB3N313clc.

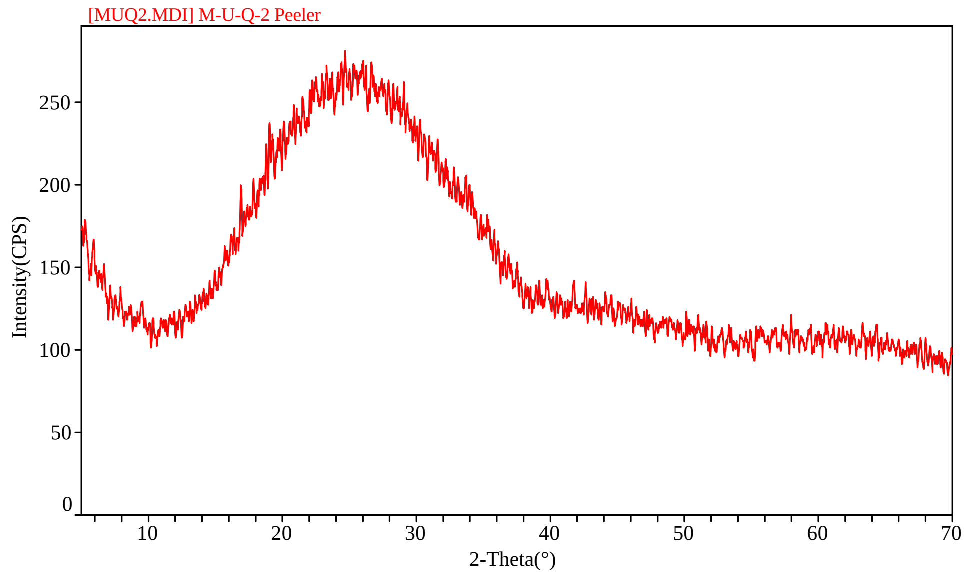

Figure 6. XRD Results of the MB3U313q.

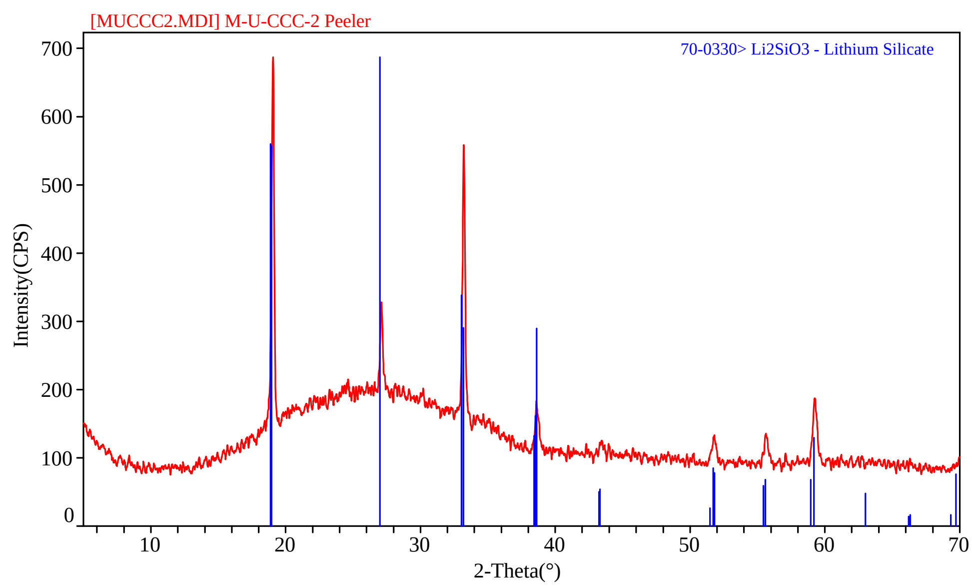

Figure 7. XRD Results of MB3U313clc.

7.3 VISCOSITY

Table 19 summarizes the measured and predicted (via PCCS η model) high temperature η data for 12 MB3 glasses. Six unique frit compositions were used coupled with both the nominal and underwashed sludge at 25.5 wt% loading. Section 7.1 discusses target and measured chemical compositions of these glasses. The Batch 1 standard was measured to be 48.3 Poise at 1150°C which is consistent with that reported by Schumacher and Peeler (1998). General trends in the data indicate that for a given frit composition the η of the underwashed sludge is slightly lower relative to its nominal sludge counterpart. This is primarily a result of the additional Na_2O in the underwashed sludge (refer to Table 1, Section 4.0). All glasses meet the current 20 – 100 Poise processing criteria for acceptability. However, the viscosities of these glasses are lower relative to those previously processed through DWPF. This may be advantageous with respect to melt rate given convection currents control the batch – melt interface by minimizing foam formation and/or stability.

Table 19. Measured and Predicted $\eta_{1150°C}$ (in Poise) of Select MB3 Glasses.

Glass	$\eta_{1150°C}$ Poise (measured)	$\eta_{1150°C}$ Poise (predicted)
MB3N304	43.05	32.4
MB3U304	41.07	30.3
MB3N307	32.88	41.1
MB3U307	29.24	38.7
MB3N313	35.31	37.6
MB3U313	34.08	35.5
MB3N320	38.55	40.7
MB3U320	38.02	38.3
MB3N324	44.64	53.3
MB3U324	42.07	50.1
MB3N165	34.86	33.1
MB3U165	34.51	31.1

8.0 SME ACCEPTABILITY: OPTIONS FOR IMPROVING MELT RATE

The determination as to whether a candidate frit will improve melt rate relative to Frit 200 (assumed to be the baseline case in this study) cannot be made based solely on the model assessments or the limited data discussed in this report. It must be reiterated that models that allow a direct assessment of melt rate do not exist. Lorier (2001) and Stone and Josephs (2001) compared melt rates (based on experimental data using a suite of tests) for the glasses developed in this study. The information presented in this report could, however, provide input to the selection process for those glasses that have been shown to have an improved melt rate relative to the current Frit 200 baseline. The decision as whether or not to select a candidate frit (with respect to durability) may be based on the answers to the following series of questions:

(1) Does the glass "pass" the current SME acceptability durability criteria (Brown and Postles 1996)? That is, does the glass, based on a measured composition, have a predicted $\Delta G_P > -12.72$ (i.e., the most conservative of the element release limits at the PAR)?
(2) Does the model predict the PCT well? That is, does the measured PCT result lie within the 95% confidence intervals for individual PCT results?
(3) How does the release for the candidate frit compare to EA?

To demonstrate how the model assessments could impact the decision process, consider the following scenario. Figure 8 is a plot of the DWPF durability model that relates the logarithm of the normalized PCT (in this case for boron) to a linear function of a free energy of hydration term (ΔG_P, kcal/100 g glass) derived from the glass composition. Prediction limits (represented by the dashed lines) at 95% confidence for individual PCT results are also shown around this linear fit. The position of each glass (based on a 25.5 wt% MB3 loading (with uranium) using a nominal wash scenario) in Figure 8 is based on measured data (both composition and PCT release).

First consider glasses produced from Frit 200 and Frit 165 using MB3 at 25.5 wt% loading. Both glasses would "pass" the initial questions regarding the SME acceptability durability criterion. The ΔG_P values for MB3N200 and MB3N165 (at 25.5 wt% loading) are approximately -10.45 and -12.25, respectively. Both glasses fall within the 95% confidence intervals indicating that the PCTs are well predicted by the current durability model (addressing the second question). Their respective B release values are also well below the EA release values making them "acceptable".

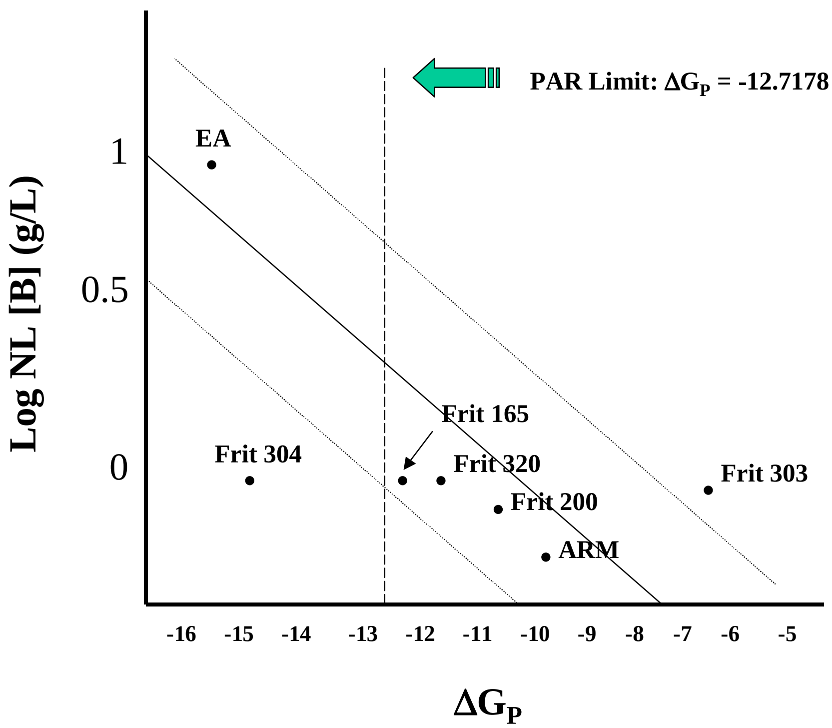

Figure 8. Schematic of ΔG_P Versus Log NL [B] (g/L) for Various MB3 Glasses.

(although nomenclatures for frits are used the PCT results are based on MB3 glasses produced from these frits)

Assuming that the use of Frit 200 does impede melt rate for MB3, Frit 165 appears to be a viable candidate to use with nominally washed MB3 sludge. However, if an underwashed sludge is received in DWPF, the use of Frit 165 could push the durability acceptability criterion to the edge. Based on the PCCS model predictions shown in Table 10 (again recognizing that the minor components have been normalized out), the projected ΔG_P (based on the target composition) is -12.69 with the SME acceptability limit being -12.72 at the PAR (see Table 11 for PAR limits.) Selecting Frit 165 may be a high risk because the ΔG_P prediction is based on a target glass composition, and the uncertainties associated with actual MB3 sludge composition, washing efficiencies, and/or waste loadings have not been accounted for. The latter statement is based on the assumption that, if melt rate improvements are such that Frit 165 is a viable candidate, the required variability study may indicate compositional areas in which the initial SME acceptability criteria would limit processing. It does appear that Frit 165 defines the bounds in terms of challenging the current ΔG_P limit while remaining within the prediction intervals. If Frit 165 is demonstrated to have a significant improvement in melt rate, any negative ramification encountered in the variability study (e.g., creating a “no go” situation in terms of SME acceptability over some portion of the composition region) could be addressed using an alternative acceptability method (as described in the discussion below for Frit 304).

Next consider the glass (e.g., MB3N320) produced from Frit 320. Assuming this glass demonstrated an improved melt rate relative to Frit 200, there appears to be no negative impacts of selecting of this glass in terms of the SME acceptability durability criterion. That is, this glass “passes” the ΔG_P criteria with a predicted ΔG_P of -11.77 (based on measured composition and a nominally washed sludge). The glass lies within the 95% confidence intervals indicating the PCT is well predicted, and its measured PCT values are well below that of EA. If an underwashed sludge is delivered to DWPF, Frit 320 would still be an “acceptable candidate” from the SME durability criterion perspective (ΔG_P = -12.22 for the underwashed sludge case).

A glass (e.g., MB3N303) made from Frit 303 is another option to consider. Based on ΔG_P predictions, this glass would be well above the -12.72 PAR acceptability limit with a ΔG_P of -6.33 (based on a nominal washed MB3 sludge target composition). However, its prediction lies outside the 95% confidence intervals indicating that the model does not predict its PCT release value well. Historically, these glasses have been “acceptable”, however, given the fact that their release values are well below that of EA. Assuming Frit 303 shows a marked improvement in melt rate over that of Frit 200 (for MB3), its selection would not pose a high risk in terms of the SME acceptability criteria that would be subsequently assessed in a variability study. It should be noted that Frit 303 contains 20.13 wt% B_2O_3 and may be phase separated (amorphous).

The last case to consider (Frit 304) poses a more difficult challenge in terms of SME acceptability for durability. Glass produced from Frit 304 and MB3 “fails” the first two major hurdles for SME acceptability. That is, its predicted ΔG_P is more negative than the -12.72 PAR limit (ΔG_P = -13.79 and -14.24 for the nominal and underwashed MB3 sludge cases, respectively) and it lies outside the 95% confidence intervals indicating that the model does not predict its PCT release well. However, prior to eliminating this frit from further consideration to improve melt rate for MB3, a review of the technical issues relative to measured PCT data (see Section 7.0) should be made. This is especially the case since the composition for this glass lies outside the region from which the model represented in Figure 8 was generated. This review or assessment could provide a basis for making the decision on whether Frit 304 poses an unacceptable technical risk to pursue as a candidate frit. The risk level one sets must be balanced by the potential gains in terms of melter throughput.

Table 20 summarizes the B, Na, Li, and Si normalized release (NR) values based on measured compositions for MB3N304 and MB3U304 (both quenched and clc). Although ΔG_P predictions would currently restrict DWPF from processing MB3N304 or MB3U304, the measured PCT data indicate that glasses produced from either the nominal or underwashed sludge (for both thermal heat treatments) are < 2 g/L (for all reportable elementals) which are still well below that of EA (approximately 16.7 g/L for B). The data also indicated no significant difference between the quenched and clc PCTs for either the nominally washed or the underwashed MB3 sludge cases.

Table 20. Normalized Release for Glasses Produced with MB3 and Frit 304 (Nominal and Underwashed Sludge).

Glass		NR [B]	NR [Li]	NR [Na]	NR [Si]
MB3N304q	g/L	1.07	1.25	1.97	0.87
	Log g/L	0.029	0.096	0.296	-0.064
MB3N304clc	g/L	1.05	1.27	1.86	0.88
	Log g/L	0.019	0.103	0.270	-0.056
MB3U304q	g/L	1.05	1.24	1.81	0.87
	Log g/L	0.023	0.092	0.257	-0.062
MB3U304clc	g/L	0.97	1.21	1.58	0.78
	Log g/L	-0.013	0.084	0.199	-0.105

Assume that Frit 304 increases melt rate and its relative increase compared to Frit 200 (or other frits assessed) is such that one would consider Frit 304 as the primary candidate for MB3. It must be reiterated that the assessment of melt rate given the suite of tests or test methodology used is assumed to translate directly to DWPF (see Lorier (2001) and Stone and Josephs (2001) for a discussion of the results of these tests). Although the current durability model does not predict an acceptable release, the data presented in Table 20 indicate that all elemental releases are less than 2 g/L.

If Frit 304 were selected as the primary candidate, one must develop an alternative technique that could be used by DWPF to address the SME acceptability issue. Alternative methods exist to derive constraints that would allow DWPF to utilize Frit 304. Alternatives include but are not limited to: (i) developing a non-parametric model over the composition region and/or (ii) revising the current DWPF durability model. Regardless of the pathway selected, the development of a technical foundation to support replacing the current durability acceptance criteria may be a non-trivial task. Although the options to address the technical issues with SME durability acceptance for Frit 304 are not trivial, the technical team does feel that they can and should be adequately addressed since this has promise to open up the operating window.

These options would have to be integrated with other studies such as the current effort on reducing constraints for sludge-only processing and/or the new T_L modeling effort. In fact, the results of the reduction of constraints task aimed at relaxing constraints on durability could benefit this particular frit selection option.

The pathforward chosen will ultimately be influenced by the relative increase in melt rate that one frit has over the current baseline, the acceptable risk level one is willing to take, and/or budget/schedule restrictions. Based on this assessment, budget/schedule impacts would be minimized by the selection of a frit that “passes” the current SME acceptability criteria for durability. However, this path may result in a frit that does not maximize melt rate for MB3. If selection of Frit 304 is deemed unacceptable for MB3 (either due to an associated risk level or budget/schedule influences), one should continue to address the technical issues identified (e.g., model prediction of durability for Frit 304) at some level given that future sludge-only (or coupled) flowsheets may yield these same issues. If so, then frits can be rapidly developed and implemented while reducing technical risks.

9.0 SUMMARY

The objective of this research was to enhance the basic understanding of the role of glass batch chemistry (more specifically via control of frit composition) on the overall melting process for Macrobatch 3 (MB3). Through control of the frit composition, cold cap reactions can be altered which may result in higher melter throughput. For melt rate limited systems, a small increase in melting efficiency translates into substantial savings by reducing operational costs without compromising the quality of the final waste form or product.

The overall strategy for the frit development activities was to explore frit compositional regions (both oxide components and ranges) which challenged "acceptable" predicted property behavior. Once major frit components were identified, ranges were established to push or challenge model predictions in an attempt to maximize melt rate. Twenty-seven frits were developed using various model predictions as a guide. All frits are projected to maintain an equivalent operational window in terms of waste loading range relative to the "baseline case" (~25 – 28 wt% MB3 with Frit 200) based on model predictions while hopefully increasing melt rate. Candidate frit compositions were screened to ensure that although melt rate may be improved other properties (e.g., durability, liquid, and η) are not compromised (i.e., the systems approach was applied).

To obtain a manageable set of candidate frits for which melt rate could be experimentally assessed within budget and schedule constraints, an initial selection process was used to narrow the 27 potential frit compositions down to 15. Compositional guidelines established by SRTC researchers along with preliminary isothermal crucible tests were used in the down selection process. Glasses were fabricated at a target waste loading of 25.5 wt% and selected properties were measured. An important objective of this study was to investigate for a potential impact on glass durability (as defined by the PCT) due to cooling rate. The data indicated no statistically significant difference between the quenched and clc PCTs for either the nominally washed or the underwashed MB3 sludge cases.

The ultimate determination as to whether a candidate frit will improve melt rate relative to Frit 200 (assumed to be the baseline case in this study) can not be made based solely on the model assessments or limited data discussed in this report. Comparisons of melt rates (based on experimental data using a suite of tests) for the glasses developed in this study have been made by

Lorier (2001) and Stone and Josephs (2001). Information is presented which provides input in the selection process for those glasses that are shown to have an improved melt rate relative to the current Frit 200 baseline.

The decision as to whether or not to select a candidate frit is influenced by the answers to the following series of questions:

(1) Does the glass "pass" the SME acceptability durability criteria? That is, does the glass, based on a measured composition, have a predicted $\Delta G_P > -12.72$ (the most conservative of the element release limits at the PAR)?
(2) Does the model predict the PCT well? That is, does the PCT lie within the 95% confidence intervals for individual PCT results?
(3) How does the release for the candidate frit compare to EA?

The majority of the frits developed "pass" the SME acceptability criteria (i.e., ΔG_P limit) and lie within the 95% prediction confidence interval indicating that the current model accurately predicts the PCTs. Selection of a glass in this category poses a minimum risk in terms of passing other predicted SME acceptability criteria (i.e., process and product performance properties). However, prior to DWPF implementation of a glass within this category, a variability study is required and other properties beyond durability should be assessed. One property of particular interest would be T_L to ensure that the current (or future) model predictions do not limit the operational window and are applicable (i.e., within the same primary phase field).

A few of the MB3 glasses fall in the category of "passing" the SME acceptability criteria for durability (i.e., ΔG_P) but lying outside the 95% interval at more positive ΔG_Ps (e.g., a MB3 glass produced from Frit 303). Historically, glasses in this category have been "acceptable" given the fact that their release values are well below that of EA. Selection of a glass in this category again poses a minimum risk in terms of passing other predicted SME acceptability criteria. However, prior to implementing a glass in this category, a variability study is required to evaluate durability over the projected compositional range.

A MB3 glass produced using Frit 304 falls into a third category: it "fails" the primary acceptance criterion based on current model predictions and it lies outside the 95% confidence interval.

Although ΔG_P predictions would currently restrict DWPF from processing MB3N304 or MB3U304, the measured PCT data indicates that glasses produced from either the nominal or underwashed sludge (for both thermal heat treatments) have elemental releases < 2 g/L which are still well below that of EA.

Assuming that Frit 304 increases melt rate and its relative increase compared to Frit 200 (or other frits assessed) is such that one would consider Frit 304 as the primary candidate for MB3, alternative technique(s) must be developed to address the SME acceptability criteria. Alternative pathways proposed include (but are not limited to): (i) developing non-parametric models over the composition regions, and/or (ii) enhancing the current DWPF durability model predictions.

10.0 REFERENCES

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Appendix A

Frit and Glass Nomenclature

Frit		**Glass**	
Previous Reference Name	**New Reference Name**	**(nominal wash)**	**(underwashed)**
A	Frit 301	MB3N301-(q or clc)	MB3U301-(q or clc)
B	Frit 302	MB3N302	MB3U302
C	Frit 303	MB3N303	MB3U303
D	Frit 304	MB3N304	MB3U304
E	Frit 305	MB3N305	MB3U305
F	Frit 306	MB3N306	MB3U306
G	Frit 307	MB3N307	MB3U307
H	Frit 308	MB3N308	MB3U308
I	Frit 309	MB3N309	MB3U309
J	Frit 310	MB3N310	MB3U310
K	Frit 311	MB3N311	MB3U311
L	Frit 312	MB3N312	MB3U312
M	Frit 313	MB3N313	MB3U313
N	Frit 314	MB3N314	MB3U314
O	Frit 315	MB3N315	MB3U315
P	Frit 316	MB3N316	MB3U316
Q	Frit 317	MB3N317	MB3U317
R	Frit 318	MB3N318	MB3U318
S	Frit 319	MB3N319	MB3U319
T	Frit 320	MB3N320	MB3U320
U	Frit 321	MB3N321	MB3U321
Mimi	Frit 322	MB3N322	MB3U322
KMA-2	Frit 323	MB3N323	MB3U323
KMA-2a	Frit 324	MB3N324	MB3U324
Bick	Frit 325	MB3N325	MB3U325
Bone2 (t adjusted)	Frit 326	MB3N326	MB3U326

Appendix B

Analytical Plan for Measuring Chemical Compositions
(SRT-SCS-2001-00008)

SRS savannah river site

WESTINGHOUSE SAVANNAH RIVER COMPANY
INTEROFFICE MEMORANDUM

SRT-SCS-2001-00008

January 19, 2001

To: D. K. Peeler, 773-43A (wi)

cc: D. F. Bickford, 773-43A (wi)
D. R. Best, 773-41A (wo)
K. G. Brown, 773-43A (wi)
E. M. Frickey, 786-1A (wo)
D. P. Lambert, 704-1T (wi)
T. H. Lorier, 773-23A (wi)
S. L. Marra, 704-T (wi)
I. R. Reamer, 773-A (wi)
E. P. Shine, 773-4A (wi)
M. E. Stone, 704-1T (wi)
R. C. Tuckfield, 773-42A (wi)
D. C. Witt, 704-1T (wi)
R. J. Workman, 773-A (wi)

wi - with sample identifiers
wo - without sample identifiers
es - executive summary only

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

E. P. Shine, Technical Reviewer — Date: 1/24/01

R. C. Tuckfield, Manager, Statistical Consulting Section — Date: 1/24/01

An Analytical Plan for the SRTC Mobile Laboratory to Follow in Measuring the Chemical Compositions of Glasses Supporting the Melt-Rate Study (U)

EXECUTIVE SUMMARY

A task technical and quality assurance plan has been prepared to direct activities associated with SRTC glass studies investigating melt-rate. One aspect of the melt-rate study is the selection of a frit composition to improve melt-rate. Thirteen frit formulations have been selected for study, and glasses were fabricated using each of these frits and a waste simulant representing normal and underwashed, Tank 8 and 40 sludge. This resulted in 26 glasses, and the chemical compositions of the 26 glasses are to be determined by the SRTC Mobile Laboratory (SRTC-ML). This memorandum provides an analytical plan for the SRTC-ML to follow in measuring the chemical compositions of the 26 study glasses.

INTRODUCTION

A task technical and quality assurance (TT&QA) plan [1] has been prepared to direct activities associated with increasing the melting rate at the Defense Waste Processing Facility (DWPF). One aspect of the melt-rate study is the selection of a frit composition to improve melt-rate. Thirteen frit formulations have been selected for study, and glasses were fabricated using each of these frits and a waste simulant representing normal and underwashed, Tank 8 and 40 sludge, as defined by Elder [2]. This resulted in 26 glasses, and the chemical compositions of the 26 glasses are to be determined by the SRTC Mobile Laboratory (SRTC-ML). This memorandum provides an analytical plan for the SRTC-ML to follow in measuring the chemical compositions of the 26 study glasses.

DISCUSSION

Table 1 provides the naming conventions for the 26 glass samples that are to be used by the SRTC-ML in conducting the compositional analyses and in reporting the measurements.[17]

Table 1: Unique Sample ID's for the 17 Glasses

Original ID	Lab ID	Original ID	Lab ID
Frit 165 - N	mr11	Frit 165 - U	mr16
Frit 200 - N	mr21	Frit 200 - U	mr18
Frit "C" - N	mr10	Frit "C" - U	mr05
Frit "D" - N	mr19	Frit "D" - U	mr20
Frit "G" - N	mr24	Frit "G" - U	mr14
Frit "M" - N	mr07	Frit "M" - U	mr02
Frit "N" - N	mr15	Frit "N" - U	mr01
Frit "O" - N	mr06	Frit "O" - U	mr08
Frit "T" - N	mr25	Frit "T" - U	mr17
Frit "Mimi" - N	mr09	Frit "Mimi" - U	mr22
Frit KMA-2-N	mr26	Frit KMA-2-U	mr23
Frit KMA-2A-N	mr03	Frit KMA-2A-U	mr13
Frit "Bone2"-N	mr04	Frit "Bone2"-U	mr12

PREPARATION OF THE SAMPLES

The analytical procedures used by the SRTC-ML to determine cation concentrations for a glass sample include steps for sample preparation and for calibration of the Inductively Coupled Plasma (ICP) – Emission Spectrometer. These procedural steps are of primary concern in the development of this analytical plan.

The primary dissolution methods that are to be used by the SRTC-ML to complete this compositional study are lithium metaborate (LM) and peroxide fusion (pf). A third dissolution method (microwave fusion, mf) is to be used if necessary to assure complete sample dissolution. All three dissolution methods are considered in this analytical plan.

The cation concentrations are to be measured (as weight percents) for the submitted samples prepared using one or more of the dissolution methods for the following elements: aluminum (Al), boron (B), calcium (Ca), chromium (Cr), iron (Fe), lithium (Li), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), silicon (Si), uranium (U), and zirconium (Zr).

[17] Renaming these samples ensures that they will be processed as blind samples. This table is complete only for those on the distribution list with a "wi" following their names.

Each of the 26 samples submitted to the SRTC-ML is to be prepared twice by each of the dissolution methods utilized, and the prepared samples are to be read twice by Inductively Coupled Plasma – Emission Spectroscopy, with the instrument being calibrated before each of these two readings (for each of the prepared samples). This will lead to 4 measurements for each cation of interest for each of the 26 samples submitted to the lab. Table 2 provides unique identifiers for the 52 preparations for each dissolution method and a random sequencing scheme for conducting the dissolutions.

In Table 2, the sample identifier has been modified with a suffix consisting of a two-letter indicator for the preparation method (LM for lithium metaborate, pf for peroxide fusion, and mw for microwave) and a 1-digit indicator for preparation number.

Table 2: Preparation Blocks

Lithium Metaborate Block 1	**Lithium Metaborate** Block 2	**Peroxide Fusion** Block 1	**Peroxide Fusion** Block 2	**Microwave Fusion (if necessary)** Block 1	**Microwave Fusion (if necessary)** Block 2
mr02LM1	mr07LM1	mr02pf1	mr01pf1	mr17mw1	mr10mw1
mr26LM1	mr05LM1	mr21pf1	mr04pf1	mr25mw1	mr05mw1
mr25LM1	mr07LM2	mr03pf1	mr01pf2	mr17mw2	mr19mw1
mr10LM1	mr16LM1	mr17pf1	mr08pf1	mr25mw2	mr24mw1
mr08LM1	mr05LM2	mr17pf2	mr08pf2	mr11mw1	mr14mw1
mr10LM2	mr09LM1	mr02pf2	mr04pf2	mr07mw1	mr24mw2
mr02LM2	mr16LM2	mr03pf2	mr11pf1	mr12mw1	mr05mw2
mr24LM1	mr23LM1	mr21pf2	mr07pf1	mr21mw1	mr19mw2
mr04LM1	mr01LM1	mr15pf1	mr20pf1	mr07mw2	mr16mw1
mr25LM2	mr09LM2	mr15pf2	mr22pf1	mr02mw1	mr10mw2
mr08LM2	mr17LM1	mr18pf1	mr20pf2	mr12mw2	mr26mw1
mr15LM1	mr01LM2	mr26pf1	mr07pf2	mr21mw2	mr03mw1
mr13LM1	mr03LM1	mr05pf1	mr12pf1	mr02mw2	mr14mw2
mr24LM2	mr14LM1	mr18pf2	mr09pf1	mr22mw1	mr18mw1
mr13LM2	mr14LM2	mr23pf1	mr13pf1	mr15mw1	mr09mw1
mr18LM1	mr12LM1	mr25pf1	mr11pf2	mr20mw1	mr26mw2
mr26LM2	mr19LM1	mr25pf2	mr10pf1	mr15mw2	mr04mw1
mr11LM1	mr17LM2	mr16pf1	mr13pf2	mr22mw2	mr18mw2
mr20LM1	mr03LM2	mr24pf1	mr19pf1	mr11mw2	mr13mw1
mr04LM2	mr21LM1	mr06pf1	mr14pf1	mr20mw2	mr16mw2
mr18LM2	mr19LM2	mr23pf2	mr22pf2	mr08mw1	mr23mw1
mr22LM1	mr12LM2	mr26pf2	mr12pf2	mr01mw1	mr09mw2
mr15LM2	mr06LM1	mr05pf2	mr09pf2	mr06mw1	mr04mw2
mr20LM2	mr21LM2	mr16pf2	mr10pf2	mr06mw2	mr03mw2
mr22LM2	mr06LM2	mr24pf2	mr19pf2	mr08mw2	mr13mw2
mr11LM2	mr23LM2	mr06pf2	mr14pf2	mr01mw2	mr23mw2

MEASUREMENT OF THE SAMPLES WITH THE ICP

The samples prepared by each of the dissolution methods employed are to be analyzed using ICP instrumentation calibrated for the particular preparation method. After the initial set of cation concentration measurements have been completed for a set of samples, the ICP instrumentation is to be recalibrated and a second set of concentration measurements for the appropriate cations determined.

Two additional glasses are included in this analytical plan to provide an opportunity for checking the performance of the ICP instrumentation over the course of these analyses and for possible bias-correction of the measurements of the other glasses. One of these glasses is the standard, Batch 1, whose composition is provided in Table 3.

Table 3: Composition of Batch 1 in Weight Percent (wt%)

Oxide	Wt%	Oxide	Wt%
Al_2O_3	4.877	MgO	1.419
B_2O_3	7.777	MnO	1.726
BaO	0.151	Na_2O	9.003
CaO	1.220	Nd_2O_3	0.147
Cr_2O_3	0.107	NiO	0.751
Cs_2O	0.060	RuO_2	0.0214
CuO	0.399	SiO_2	50.22
Fe_2O_3	12.839	TiO_2	0.677
K_2O	3.327	ZrO_2	0.098
Li_2O	4.429		

The second glass that will be used as a standard for these measurements is a uranium glass that is to be provided to the SRTC-ML along with other glass samples.

A randomized plan for measuring cation concentrations in the prepared samples by each dissolution method is provided in Tables 4-6. In these tables, the sample identifiers have been modified by the addition of a one-digit suffix to indicate whether the measurement is to be made during the first or second ICP calibration block for that sample.

Samples of the standards, Batch 1 and the uranium-bearing glasses, which are to be prepared using the appropriate dissolution method, have been added to Tables 4-6. The identifiers for the Batch 1 standard samples begin with the 3-letter designation “std” followed by the 2-letter dissolution indicator, then the 2-digit ICP block number, and finally, a number 1 through 3 for the three replicates of this glass per block. The identifiers for the uranium standard samples begin with the 4-letter designation “ustd” followed by the 2-letter dissolution indicator, then the 2-digit ICP block number, and finally, a number 1 through 2 for the duplicate measurements per block of this glass.

Table 4: ICP Blocks for Samples Prepared Using Lithium Metaborate (LM)

1-1	1-2	2-1	2-2	3-1	3-2	4-1	4-2
stdLM111	stdLM121	stdLM211	stdLM221	stdLM311	stdLM321	stdLM411	stdLM421
mr24LM21	mr09LM22	mr23LM21	mr21LM22	mr11LM21	mr03LM22	mr13LM11	mr10LM12
mr24LM11	mr17LM22	mr25LM11	mr01LM12	mr19LM21	mr04LM12	mr12LM21	mr26LM12
ustdLM111	ustdLM121	ustdLM211	ustdLM221	ustdLM311	ustdLM321	ustdLM411	ustdLM421
mr17LM11	mr17LM12	mr14LM11	mr14LM12	mr03LM11	mr11LM22	mr06LM21	mr22LM12
mr05LM11	mr24LM12	mr01LM11	mr25LM22	mr03LM21	mr19LM22	mr22LM21	mr06LM22
mr18LM11	mr09LM12	mr01LM21	mr01LM22	mr11LM11	mr11LM12	mr13LM21	mr12LM12
stdLM112	stdLM122	stdLM212	stdLM222	stdLM312	stdLM322	stdLM412	stdLM422
mr20LM11	mr20LM12	mr21LM11	mr23LM22	mr16LM11	mr02LM12	mr26LM11	mr22LM22
mr15LM11	mr20LM22	mr07LM21	mr21LM12	mr02LM11	mr16LM12	mr10LM11	mr26LM22
mr20LM21	mr24LM22	mr25LM21	mr07LM22	mr04LM11	mr02LM22	mr22LM11	mr06LM12
mr09LM11	mr05LM22	mr14LM21	mr25LM12	mr16LM21	mr08LM12	mr10LM21	mr13LM12
ustdLM112	ustdLM122	ustdLM212	ustdLM222	ustdLM312	ustdLM322	ustdLM412	ustdLM422
mr18LM21	mr15LM12	mr21LM21	mr07LM12	mr02LM21	mr04LM22	mr12LM11	mr13LM22
mr17LM21	mr15LM22	mr07LM11	mr23LM12	mr08LM11	mr08LM22	mr06LM11	mr10LM22
mr15LM21	mr05LM12	mr23LM11	mr14LM22	mr08LM21	mr19LM12	mr26LM21	mr12LM22
mr05LM21	mr18LM12	stdLM213	stdLM223	mr19LM11	mr16LM22	stdLM413	stdLM423
mr09LM21	mr18LM22			mr04LM21	mr03LM12		
stdLM113	stdLM123			stdLM313	stdLM323		

Table 5: ICP Blocks for Samples Prepared Using Peroxide Fusion (pf)

1-1	1-2	2-1	2-2	3-1	3-2	4-1	4-2
stdpf111	stdpf121	stdpf211	stdpf221	stdpf311	stdpf321	stdpf411	stdpf421
mr12pf21	mr09pf22	mr16pf11	mr11pf22	mr04pf11	mr02pf12	mr20pf21	mr01pf22
mr15pf11	mr12pf22	mr21pf21	mr11pf12	mr10pf11	mr02pf22	mr08pf21	mr18pf12
ustdpf111	ustdpf121	ustdpf211	ustdpf221	ustdpf311	ustdpf321	ustdpf411	ustdpf421
mr15pf21	mr12pf12	mr16pf21	mr26pf22	mr10pf21	mr13pf22	mr18pf21	mr19pf12
mr09pf21	mr03pf12	mr26pf11	mr26pf12	mr23pf11	mr04pf22	mr19pf11	mr20pf22
mr25pf11	mr03pf22	mr11pf21	mr16pf22	mr13pf21	mr10pf12	mr01pf11	mr24pf22
stdpf112	stdpf122	stdpf212	stdpf222	stdpf312	stdpf322	stdpf412	stdpf422
mr25pf21	mr15pf12	mr26pf21	mr14pf12	mr17pf11	mr10pf22	mr24pf11	mr08pf12
mr03pf11	mr22pf22	mr14pf21	mr16pf12	mr13pf11	mr17pf22	mr24pf21	mr20pf12
mr12pf11	mr25pf12	mr07pf11	mr14pf22	mr05pf11	mr23pf12	mr20pf11	mr18pf22
mr22pf21	mr06pf12	mr07pf21	mr07pf22	mr05pf21	mr05pf22	mr01pf21	mr19pf22
ustdpf112	ustdpf122	ustdpf211	ustdpf222	ustdpf312	ustdpf322	ustdpf412	ustdpf422
mr06pf21	mr06pf22	mr21pf11	mr21pf22	mr02pf11	mr05pf12	mr18pf11	mr24pf12
mr22pf11	mr25pf22	mr14pf11	mr21pf12	mr23pf21	mr17pf12	mr08pf11	mr01pf12
mr06pf11	mr09pf12	mr11pf11	mr07pf12	mr02pf21	mr04pf12	mr19pf21	mr08pf22
mr09pf11	mr15pf22	stdpf213	stdpf223	mr17pf21	mr13pf12	stdpf413	stdpf423
mr03pf21	mr22pf12			mr04pf21	mr23pf22		
stdpf113	stdpf123			stdpf313	stdpf323		

Table 6: ICP Blocks for Samples Prepared Using Microwave Fusion (mf)

1-1	1-2	2-1	2-2	3-1	3-2	4-1	4-2
stdmf111	stdmf121	stdmf211	stdmf221	stdmf311	stdmf321	stdmf411	stdmf421
mr03mf21	mr03mf22	mr14mf21	mr22mf22	mr04mf21	mr04mf22	mr06mf21	mr06mf12
mr19mf11	mr21mf12	mr18mf21	mr11mf12	mr10mf11	mr25mf12	mr23mf21	mr20mf12
ustdmf111	ustdmf121	ustdmf211	ustdmf221	ustdmf311	ustdmf321	ustdmf411	ustdmf421
mr21mf11	mr08mf12	mr05mf11	mr14mf22	mr24mf21	mr24mf22	mr07mf11	mr23mf12
mr21mf21	mr02mf12	mr22mf21	mr11mf22	mr16mf11	mr01mf22	mr06mf11	mr13mf12
mr08mf21	mr09mf12	mr22mf11	mr14mf12	mr17mf21	mr04mf12	mr20mf21	mr07mf12
stdmf112	stdmf122	stdmf212	stdmf222	stdmf312	stdmf322	stdmf412	stdmf422
mr03mf11	mr08mf22	mr18mf11	mr22mf12	mr24mf11	mr10mf12	mr07mf21	mr26mf12
mr15mf21	mr15mf22	mr05mf21	mr12mf22	mr25mf21	mr10mf22	mr13mf21	mr06mf22
mr19mf21	mr19mf22	mr11mf21	mr05mf12	mr01mf21	mr16mf12	mr23mf11	mr20mf22
mr08mf11	mr02mf22	mr12mf21	mr05mf22	mr04mf11	mr01mf12	mr13mf11	mr23mf22
ustdmf112	ustdmf122	ustdmf212	ustdmf222	ustdmf312	ustdmf322	ustdmf412	ustdmf422
mr15mf11	mr19mf12	mr14mf11	mr18mf22	mr25mf11	mr17mf22	mr26mf11	mr13mf22
mr09mf11	mr15mf12	mr12mf11	mr18mf12	mr16mf21	mr25mf22	mr26mf21	mr07mf22
mr09mf21	mr03mf12	mr11mf11	mr12mf12	mr10mf21	mr16mf22	mr20mf11	mr26mf22
mr02mf11	mr09mf22	stdmf213	Stdmf223	mr17mf11	mr17mf12	stdmf413	stdmf423
mr02mf21	mr21mf22			mr01mf11	mr24mf12		
stdmf113	stdmf123			stdmf313	stdmf323		

CONCLUDING COMMENTS

This memorandum provides an analytical plan for the SRTC-ML to follow in measuring the chemical compositions of 26 glasses that support the melt-rate study. The analytical plan identifies several ICP calibration blocks in Tables 4-6 as well as preparation blocks in Table 2. 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 is such that it should be completed in a single work shift.

If for some reason the measurements are not conducted in the sequences presented in this memorandum, the actual order used should be recorded along with any explanative comments.

The analytical plan provided 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.

REFERENCES

[1] Lambert, D. P., D. K. Peeler, M. E. Stone, and T. H. Lorier, "Task Technical and QA Plan: Alternative Process Options to Improve Melt Rate," WSRC-RP-2001-00183, January 2001.

[2] Elder, H. H., "Sludge Batch 2 Qualification Strategy and Simulant Composition," HLW-SDT-2000-00128, Rev. 0, May 2000.

Appendix C

Analytical Plan for Measuring PCT Solutions: Nominal MB3 Sludge
(SRT-SCS-2001-00009)

WESTINGHOUSE SAVANNAH RIVER COMPANY
INTEROFFICE MEMORANDUM

SRT-SCS-2001-00009

January 24, 2001

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R. J. Workman, 773-A (wi)

wi - with sample identifiers
wo - without sample identifiers
es - executive summary only

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

E. P. Shine, Technical Reviewer 1/31/01 — Date 1/31/01

R. C. Tuckfield, Manager, Statistical Consulting Section — Date 1/31/01

An Analytical Plan for Measuring PCT Solutions of Glasses Representing Nominally Washed Tank 8/40 Sludge (U)

Executive Summary

The Immobilization Technology Section currently is exploring improvements in melt-rate for the Defense Waste Processing Facility (DWPF) via changes to the frit composition. Twenty-six glasses were recently batched in support of the study with thirteen of the glasses representing nominally washed Tank 8/40 sludge, while the other 13 represented underwashed sludge. During fabrication, these glasses were cooled by quenching and centerline cooling. The durabilities of both versions of the 26 glasses are to be determined. The Product Consistency Test, or PCT, is used as a measure of glass durability, and its requirements are described in ASTM C1285-97 (Method A). Each PCT results in a leachate solution whose elemental concentrations must be measured to complete the determination of glass durability.

The PCTs are to be conducted in two sets: the glasses representing the nominally washed sludge and the glasses representing the underwashed sludge. This memorandum addresses the PCTs that are being conducted for the thirteen glasses representing nominally washed sludge. (A separate analytical plan is to be issued to cover the PCTs for the thirteen glasses representing underwashed sludge.). Since the glasses were cooled by both quenching and centerline cooling, a total of twenty-six glass samples are to be subjected to the PCT to cover the nominally washed case.

The Savannah River Technology Center-Mobile Laboratory (SRTC-ML) is to measure elemental concentrations of the resulting leachate solutions. 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 these glasses.

INTRODUCTION

The Immobilization Technology Section currently is exploring improvements in melt-rate for the Defense Waste Processing Facility (DWPF) via changes to the frit composition [1]. Twenty-six glasses were recently batched in support of the study with thirteen of the glasses representing nominally washed Tank 8/40 sludge, while the other 13 represented underwashed sludge. During fabrication, all glasses were cooled both by quenching and by centerline cooling. The durabilities of both versions of the 26 glasses are to be determined. The Product Consistency Test, or PCT, is used as a measure of glass durability, and its requirements are described in ASTM C1285-97 (Method A) [2]. Each PCT results in a leachate solution whose elemental concentrations must be measured to complete the determination of glass durability.

This memorandum addresses the PCTs that are being conducted for the thirteen glasses representing nominally washed sludge. (A separate analytical plan is to be issued to cover the PCTs for the thirteen glasses representing underwashed sludge.). Since the glasses were cooled by both quenching and centerline cooling, there are twenty-six glass samples representing the nominally washed case that are to be subjected to the PCT.

The Savannah River Technology Center Mobile Laboratory (SRTC-ML) is to measure the compositions of the leachate solutions resulting from the PCTs for these glasses, and this memorandum provides an analytical plan for the SRTC-ML to follow in conducting the measurements.

DISCUSSION

Twenty-six, melt-rate-study, glass samples (those representing the nominally washed Tank 8/40 case) are to be subjected to the PCT. Each of the tests is to be conducted in triplicate. In addition to the test 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. Thus, a total of 86 samples are required to complete these PCTs.

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

Table 1 enumerates the study glasses and the standards (EA, ARM, and blanks) and presents identifying codes, ga01 through ga86, for the PCTs. The glass identifiers in Table 1 indicate glasses that were centerline cooled via a "clc" suffix. The naming convention of Table 1 is to be used by the SRTC-ML in analyzing these solutions and reporting the relevant concentration measurements.[18]

18 Renaming these samples ensures that they will be processed as blind samples by the SRTC-ML. This table is complete only for those on the distribution list with a "wi" following their names.

Table 1: Solution Identifiers

Original Sample	Cooling Profile	Solution Identifier	Original Sample	Cooling Profile	Solution Identifier
Frit “Bone2”-N	quenched	ga75	Frit “O” - N	quenched	ga48
Frit “Bone2”-N	quenched	ga10	Frit “O” - N	quenched	ga19
Frit “Bone2”-N	quenched	ga27	Frit “O” - N	clc	ga72
Frit “Bone2”-N	clc	ga06	Frit “O” - N	clc	ga04
Frit “Bone2”-N	clc	ga50	Frit “O” - N	clc	ga51
Frit “Bone2”-N	clc	ga76	Frit “T” - N	quenched	ga34
Frit “C” - N	quenched	ga58	Frit “T” - N	quenched	ga61
Frit “C” - N	quenched	ga23	Frit “T” - N	quenched	ga52
Frit “C” - N	quenched	ga69	Frit “T” - N	clc	ga08
Frit “C” - N	clc	ga83	Frit “T” - N	clc	ga40
Frit “C” - N	clc	ga22	Frit “T” - N	clc	ga73
Frit “C” - N	clc	ga29	Frit 165 - N	quenched	ga11
Frit “D” - N	quenched	ga63	Frit 165 - N	quenched	ga70
Frit “D” - N	quenched	ga17	Frit 165 - N	quenched	ga85
Frit “D” - N	quenched	ga36	Frit 165 - N	clc	ga57
Frit “D” - N	clc	ga18	Frit 165 - N	clc	ga81
Frit “D” - N	clc	ga59	Frit 165 - N	clc	ga30
Frit “D” - N	clc	ga14	Frit 200 - N	quenched	ga54
Frit “G” - N	quenched	ga42	Frit 200 - N	quenched	ga35
Frit “G” - N	quenched	ga82	Frit 200 - N	quenched	ga68
Frit “G” - N	quenched	ga03	Frit 200 - N	clc	ga66
Frit “G” - N	clc	ga49	Frit 200 - N	clc	ga43
Frit “G” - N	clc	ga05	Frit 200 - N	clc	ga44
Frit “G” - N	clc	ga07	Frit KMA-2A-N	quenched	ga28
Frit “M” - N	quenched	ga25	Frit KMA-2A-N	quenched	ga84
Frit “M” - N	quenched	ga15	Frit KMA-2A-N	quenched	ga12
Frit “M” - N	quenched	ga74	Frit KMA-2A-N	clc	ga78
Frit “M” - N	clc	ga21	Frit KMA-2A-N	clc	ga67
Frit “M” - N	clc	ga47	Frit KMA-2A-N	clc	ga60
Frit “M” - N	clc	ga26	Frit KMA-2-N	quenched	ga64
Frit “Mimi” - N	quenched	ga55	Frit KMA-2-N	quenched	ga65
Frit “Mimi” - N	quenched	ga39	Frit KMA-2-N	quenched	ga24
Frit “Mimi” - N	quenched	ga71	Frit KMA-2-N	clc	ga37
Frit “Mimi” - N	clc	ga16	Frit KMA-2-N	clc	ga62
Frit “Mimi” - N	clc	ga20	Frit KMA-2-N	clc	ga45
Frit “Mimi” - N	clc	ga79	EA		ga80
Frit “N” - N	quenched	ga13	EA		ga53
Frit “N” - N	quenched	ga38	EA		ga86
Frit “N” - N	quenched	ga46	ARM		ga56
Frit “N” - N	clc	ga33	ARM		ga31
Frit “N” - N	clc	ga77	ARM		ga02
Frit “N” - N	clc	ga01	blank		ga41
Frit “O” - N	quenched	ga32	blank		ga09

ANALYTICAL PLAN

The analytical plan for the Mobile Lab 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: boron (B), lithium (Li), sodium (Na), and silicon (Si). These measurements are to be made in parts per million (ppm). The analytical procedure used by the SRTC-ML to determine the relevant concentrations involves an Inductively Coupled Plasma (ICP) – Emission Spectrometer. The PCT solutions (as identified in Table 1) are grouped in six ICP blocks for processing by the Mobile Lab in Table 2. Each block will probably require a different calibration of the ICP.

Table 2: 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
ga58	ga50	ga76	ga66	ga61	ga52
ga18	ga59	ga86	ga54	ga48	ga03
ga78	ga62	ga79	ga57	ga38	ga02
ga63	ga67	ga69	ga49	ga81	ga44
ga41	ga10	ga12	ga11	ga77	ga01
ga55	ga39	ga27	ga56	ga40	ga30
ga75	ga17	ga29	ga08	ga05	ga73
ga64	ga53	ga45	std-b4-2	std-b5-2	std-b6-2
std-b1-2	std-b2-2	std-b3-2	ga33	ga70	ga51
ga21	ga22	ga26	ga42	ga31	ga68
ga83	ga65	ga71	ga72	ga35	ga09
ga80	ga15	ga60	ga13	ga82	ga19
ga37	ga20	ga36	ga32	ga04	ga46
ga06	ga47	ga74	ga34	ga43	ga07
ga16	ga84	ga14	std-b4-3	std-b5-3	ga85
ga25	ga23	ga24			std-b6-3
ga28	std-b2-3	std-b3-3			
std-b1-3					

A multi-element solution standard (denoted by "std-bi-j" where i=1, 2, 3, 4, 5, and 6 represents the block number and j=1, 2, 3 represents the position in the block) was added at the beginning, middle, and end of each of the six blocks. This standard may be useful in checking and correcting for bias in the concentration measurements resulting from the ICP calibrations.

CONCLUDING COMMENTS

In summary, this analytical plan identifies six ICP calibration blocks in Table 2 that are to be used by the SRTC-ML in conducting the boron (B), lithium (Li), sodium (Na), and silicon (Si) concentration measurements for the PCTs that are being conducted for the thirteen melt-rate glasses representing nominally washed Tank 8/40 sludge. The sequencing of the activities associated with each of these steps in the analytical procedures has been randomized. The size of the blocks was selected so that each 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 used should be recorded 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 the standard operating procedures.

REFERENCES

[1] Lambert, D. P., D. K. Peeler, M. E. Stone, and T. H. Lorier, "Task Technical and QA Plan: Alternative Process Options to Improve Melt Rate," WSRC-RP-2001-00183, January 2001.

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

Appendix D

Analytical Plan for Measuring PCT Solutions: Underwashed MB3 Sludge
(SRT-SCS-2001-00011)

SRS savannah river site

WESTINGHOUSE SAVANNAH RIVER COMPANY
INTEROFFICE MEMORANDUM

SRT-SCS-2001-00011

February 6, 2001

To: D. K. Peeler, 773-43A (wi)

cc: D. F. Bickford, 773-43A (wi)
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S. L. Marra, 704-T (wi)
I. R. Reamer, 773-A (wi)
E. P. Shine, 773-4A (wi)
M. E. Stone, 704-1T (wi)
R. C. Tuckfield, 773-42A (wi)
D. C. Witt, 704-1T (wi)
R. J. Workman, 773-A (wi)

wi - with sample identifiers
wo - without sample identifiers
es - executive summary only

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

E. P. Shine, Technical Reviewer — Date: 2/6/01

R. C. Tuckfield, Manager
Statistical Consulting Section — Date: 2/6/01

An Analytical Plan for Measuring PCT Solutions of Glasses Representing Under-Washed Tank 8/40 Sludge (U)

EXECUTIVE SUMMARY

The Immobilization Technology Section currently is exploring improvements in melt-rate for the Defense Waste Processing Facility (DWPF) via changes to the frit composition. Twenty-six glasses were recently batched in support of the study with thirteen of the glasses representing nominally washed Tank 8/40 sludge, while the other 13 represented underwashed sludge. During fabrication, these glasses were cooled by quenching and centerline cooling. The durabilities of both versions of the 26 glasses are to be determined. The Product Consistency Test, or PCT, is used as a measure of glass durability, and its requirements are described in ASTM C1285-97 (Method A). Each PCT results in a leachate solution whose elemental concentrations must be measured to complete the determination of glass durability.

The PCTs are to be conducted in two sets: the glasses representing the nominally washed sludge and the glasses representing the underwashed sludge. This memorandum addresses the PCTs that are being conducted for the thirteen glasses representing underwashed sludge. (A separate analytical plan was previously issued to cover the PCTs for the thirteen glasses representing nominally washed sludge.) Since the glasses were cooled both by quenching and by centerline cooling, a total of twenty-six glass samples are to be subjected to the PCT to cover the underwashed case.

The Savannah River Technology Center-Mobile Laboratory (SRTC-ML) is to measure elemental concentrations of the resulting leachate solutions. 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 these glasses.

INTRODUCTION

The Immobilization Technology Section currently is exploring improvements in melt-rate for the Defense Waste Processing Facility (DWPF) via changes to the frit composition [1]. Twenty-six glasses were recently batched in support of the study with thirteen of the glasses representing nominally washed Tank 8/40 sludge, while the other 13 represented underwashed sludge. During fabrication, all glasses were cooled both by quenching and by centerline cooling. The durabilities of both versions of the 26 glasses are to be determined. The Product Consistency Test, or PCT, is used as a measure of glass durability, and its requirements are described in ASTM C1285-97 (Method A) [2]. Each PCT results in a leachate solution whose elemental concentrations must be measured to complete the determination of glass durability.

This memorandum addresses the PCTs that are being conducted for the thirteen glasses representing underwashed sludge. (A separate analytical plan was issued to cover the PCTs for the thirteen glasses representing nominally washed sludge.) Since the glasses were cooled both by quenching and by centerline cooling, there are twenty-six glass samples representing the underwashed case that are to be subjected to the PCT.

The Savannah River Technology Center Mobile Laboratory (SRTC-ML) is to measure the compositions of the leachate solutions resulting from the PCTs for these glasses, and this memorandum provides an analytical plan for the SRTC-ML to follow in conducting the measurements.

DISCUSSION

Twenty-six, melt-rate-study, glass samples (those representing the underwashed Tank 8/40 case) are to be subjected to the PCT. Each of the tests is to be conducted in triplicate. In addition to the test 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. Thus, a total of 86 samples are required to complete these PCTs.

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

Table 1 enumerates the study glasses and the standards (EA, ARM, and blanks) and presents identifying codes, jp01 through jp86, for the PCTs. The glass identifiers in Table 1 indicate glasses that were centerline cooled via a “clc” suffix. The naming convention of Table 1 is to be used by the SRTC-ML in analyzing these solutions and reporting the relevant concentration measurements.[19]

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19 Renaming these samples ensures that they will be processed as blind samples by the SRTC-ML. This table is complete only for those on the distribution list with a “wi” following their names.

Table 1: Solution Identifiers

Original Sample	Cooling Profile	Solution Identifier	Original Sample	Cooling Profile	Solution Identifier
Frit “Bone2”-U	quenched	jp47	Frit “O” - U	quenched	jp86
Frit “Bone2”-U	quenched	jp02	Frit “O” - U	quenched	jp05
Frit “Bone2”-U	quenched	jp09	Frit “O” - U	clc	jp44
Frit “Bone2”-U	clc	jp45	Frit “O” - U	clc	jp12
Frit “Bone2”-U	clc	jp26	Frit “O” - U	clc	jp58
Frit “Bone2”-U	clc	jp34	Frit “T” - U	quenched	jp70
Frit “C” - U	quenched	jp50	Frit “T” - U	quenched	jp32
Frit “C” - U	quenched	jp19	Frit “T” - U	quenched	jp04
Frit “C” - U	quenched	jp59	Frit “T” - U	clc	jp21
Frit “C” - U	clc	jp78	Frit “T” - U	clc	jp76
Frit “C” - U	clc	jp13	Frit “T” - U	clc	jp53
Frit “C” - U	clc	jp10	Frit 165 - U	quenched	jp73
Frit “D” - U	quenched	jp24	Frit 165 - U	quenched	jp55
Frit “D” - U	quenched	jp56	Frit 165 - U	quenched	jp65
Frit “D” - U	quenched	jp07	Frit 165 - U	clc	jp79
Frit “D” - U	clc	jp42	Frit 165 - U	clc	jp17
Frit “D” - U	clc	jp62	Frit 165 - U	clc	jp48
Frit “D” - U	clc	jp16	Frit 200 - U	quenched	jp33
Frit “G” - U	quenched	jp60	Frit 200 - U	quenched	jp75
Frit “G” - U	quenched	jp61	Frit 200 - U	quenched	jp46
Frit “G” - U	quenched	jp82	Frit 200 - U	clc	jp68
Frit “G” - U	clc	jp38	Frit 200 - U	clc	jp41
Frit “G” - U	clc	jp51	Frit 200 - U	clc	jp15
Frit “G” - U	clc	jp35	Frit KMA-2A-U	quenched	jp03
Frit “M” - U	quenched	jp14	Frit KMA-2A-U	quenched	jp77
Frit “M” - U	quenched	jp06	Frit KMA-2A-U	quenched	jp40
Frit “M” - U	quenched	jp31	Frit KMA-2A-U	clc	jp80
Frit “M” - U	clc	jp74	Frit KMA-2A-U	clc	jp57
Frit “M” - U	clc	jp84	Frit KMA-2A-U	clc	jp20
Frit “M” - U	clc	jp28	Frit KMA-2-U	quenched	jp37
Frit “Mimi” - U	quenched	jp39	Frit KMA-2-U	quenched	jp49
Frit “Mimi” - U	quenched	jp30	Frit KMA-2-U	quenched	jp72
Frit “Mimi” - U	quenched	jp81	Frit KMA-2-U	clc	jp66
Frit “Mimi” - U	clc	jp63	Frit KMA-2-U	clc	jp29
Frit “Mimi” - U	clc	jp18	Frit KMA-2-U	clc	jp85
Frit “Mimi” - U	clc	jp25	EA		jp83
Frit “N” - U	quenched	jp43	EA		jp27
Frit “N” - U	quenched	jp71	EA		jp64
Frit “N” - U	quenched	jp08	ARM		jp01
Frit “N” - U	clc	jp69	ARM		jp11
Frit “N” - U	clc	jp54	ARM		jp67
Frit “N” - U	clc	jp22	blank		jp52
Frit “O” - U	quenched	jp23	blank		jp36

ANALYTICAL PLAN

The analytical plan for the Mobile Lab 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: boron (B), lithium (Li), sodium (Na), and silicon (Si). These measurements are to be made in parts per million (ppm). The analytical procedure used by the SRTC-ML to determine the relevant concentrations involves an Inductively Coupled Plasma (ICP) – Emission Spectrometer. The PCT solutions (as identified in Table 1) are grouped in six ICP blocks for processing by the Mobile Lab in Table 2. Each block will probably require a different calibration of the ICP.

Table 2: 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
jp33	jp36	jp46	jp21	jp29	jp05
jp83	jp56	jp67	jp63	jp02	jp58
jp79	jp11	jp22	jp03	jp18	jp20
jp73	jp19	jp31	jp38	jp30	jp09
jp78	jp75	jp10	jp47	jp77	jp34
jp14	jp71	jp08	jp45	jp32	jp82
jp68	jp06	jp59	jp70	jp49	jp85
jp43	jp62	jp07	jp37	jp86	jp35
std-b1-2	std-b2-2	std-b3-2	std-b4-2	std-b5-2	std-b6-2
jp74	jp55	jp15	jp60	jp12	jp04
jp01	jp84	jp48	jp80	jp57	jp25
jp42	jp41	jp65	jp39	jp61	jp72
jp24	jp17	jp16	jp66	jp76	jp53
jp50	jp54	jp64	jp23	jp51	jp81
jp52	jp27	jp28	jp44	jp26	jp40
jp69	jp13	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, 2, 3, 4, 5, and 6 represents the block number and j=1, 2, 3 represents the position in the block) was added at the beginning, middle, and end of each of the six blocks. This standard may be useful in checking and correcting for bias in the concentration measurements resulting from the ICP calibrations.

CONCLUDING COMMENTS

In summary, this analytical plan identifies six ICP calibration blocks in Table 2 that are to be used by the SRTC-ML in conducting the boron (B), lithium (Li), sodium (Na), and silicon (Si) concentration measurements for the PCTs that are being conducted for the thirteen melt-rate glasses representing underwashed Tank 8/40 sludge. The sequencing of the activities associated with each of these steps in the analytical procedures has been randomized. The size of the blocks was selected so that each 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 used should be recorded 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 the standard operating procedures.

REFERENCES

[1] Lambert, D. P., D. K. Peeler, M. E. Stone, and T. H. Lorier, "Task Technical and QA Plan: Alternative Process Options to Improve Melt Rate," WSRC-RP-2001-00183, January 2001.

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

Appendix E

Tables of Chemical Composition Measurements, Tables of PCT Measurements, and Exhibits of Statistical Analyses

TABLE E1: SRTC-ML MEASUREMENTS FOR SAMPLES PREPARED USING LITHIUM METABORATE (LM) METHOD

(Values are in elemental weight percents, wt%'s.)

Block	Sub-Block	Sequence	SRTC-ML ID (LM)	Glass/Frit ID	Glass ID	Shortened Glass ID	Ca(v)	Cr(v)	Fe(v)	Mg(v)	Mn(v)	Na(v)	Ni(v)	Si(v)	Zr(v)
1	1	1	stdlm111	Batch 1	Batch 1	Batch 1	0.910	0.071	9.02	0.863	1.31	6.62	0.561	23.2	0.091
1	1	2	mr24lm21	Frit "G" - N	MB3N307	N307	0.688	0.007	8.07	0.015	0.579	6.26	0.392	26.4	0.006
1	1	3	mr24lm11	Frit "G" - N	MB3N307	N307	0.688	0.004	8.00	0.013	0.576	6.26	0.389	26.4	<0.002
1	1	4	ustdlm111	Ustd	Ustd	Ustd	0.919	0.164	9.07	0.705	2.03	8.61	0.771	21.6	0.004
1	1	5	mr17lm11	Frit "T" - U	MB3U320	U320	0.681	0.007	7.83	0.014	0.546	10.6	0.345	25.9	<0.002
1	1	6	mr05lm11	Frit "C" - U	MB3U303	U303	0.678	0.014	7.95	0.019	0.556	3.96	0.380	24.3	<0.002
1	1	7	mr18lm11	Frit 200 - U	MB3U200	U200	0.665	0.010	7.83	0.913	0.542	9.83	0.376	24.2	<0.002
1	1	8	stdlm112	Batch 1	Batch 1	Batch 1	0.922	0.070	9.33	0.846	1.29	6.68	0.552	24.1	0.090
1	1	9	mr20lm11	Frit "D" - U	MB3U304	U304	0.695	0.040	8.36	0.015	0.563	14.0	0.396	24.6	<0.002
1	1	10	mr15lm11	Frit "N" - N	MB3N314	N314	0.684	0.006	8.46	0.015	0.573	6.90	0.392	24.2	1.03
1	1	11	mr20lm21	Frit "D" - U	MB3U304	U304	0.657	0.055	7.91	0.020	0.567	14.2	0.389	24.1	0.008
1	1	12	mr09lm11	Frit "Mimi" - N	MB3N322	N322	0.674	0.008	8.29	0.015	0.587	9.04	0.398	28.3	<0.002
1	1	13	ustdlm112	Ustd	Ustd	Ustd	0.912	0.168	9.55	0.719	2.06	8.46	0.786	22.6	0.005
1	1	14	mr18lm21	Frit 200 - U	MB3U200	U200	0.671	0.007	8.31	0.951	0.567	10.2	0.393	25.5	<0.002
1	1	15	mr17lm21	Frit "T" - U	MB3U320	U320	0.663	0.004	8.27	0.014	0.551	10.4	0.351	26.4	<0.002
1	1	16	mr15lm21	Frit "N" - N	MB3N314	N314	0.671	0.136	8.35	0.016	0.560	6.72	0.384	22.6	0.928
1	1	17	mr05lm21	Frit "C" - U	MB3U303	U303	0.713	0.009	8.28	0.025	0.577	3.93	0.389	25.1	0.010
1	1	18	mr09lm21	Frit "Mimi" - N	MB3N322	N322	0.680	0.008	8.49	0.015	0.592	9.03	0.391	27.3	0.132
1	1	19	stdlm113	Batch 1	Batch 1	Batch 1	0.908	0.070	9.64	0.856	1.30	6.51	0.558	24.6	0.092
1	2	1	stdlm121	Batch 1	Batch 1	Batch 1	0.919	0.077	8.89	0.883	1.32	6.72	0.572	23.1	0.096
1	2	2	mr09lm22	Frit "Mimi" - N	MB3N322	N322	0.704	0.013	7.89	0.025	0.603	9.42	0.401	27.3	0.137
1	2	3	mr17lm22	Frit "T" - U	MB3U320	U320	0.677	0.009	7.65	0.024	0.568	10.9	0.365	25.8	<0.002
1	2	4	ustdlm121	Ustd	Ustd	Ustd	0.925	0.174	9.19	0.736	2.08	8.76	0.796	21.7	0.006
1	2	5	mr17lm12	Frit "T" - U	MB3U320	U320	0.691	0.012	7.75	0.024	0.559	10.9	0.356	25.9	<0.002
1	2	6	mr24lm12	Frit "G" - N	MB3N307	N307	0.698	0.008	8.09	0.023	0.584	6.31	0.397	26.5	<0.002
1	2	7	mr09lm12	Frit "Mimi" - N	MB3N322	N322	0.688	0.013	8.00	0.023	0.587	9.46	0.399	27.7	<0.002
1	2	8	stdlm122	Batch 1	Batch 1	Batch 1	0.929	0.075	8.90	0.866	1.30	7.00	0.562	23.3	0.092
1	2	9	mr20lm12	Frit "D" - U	MB3U304	U304	0.711	0.044	7.87	0.025	0.568	14.6	0.400	24.6	<0.002
1	2	10	mr20lm22	Frit "D" - U	MB3U304	U304	0.670	0.058	7.55	0.028	0.546	14.5	0.378	23.2	<0.002
1	2	11	mr24lm22	Frit "G" - N	MB3N307	N307	0.704	0.011	7.98	0.023	0.577	6.42	0.393	26.3	0.005
1	2	12	mr05lm22	Frit "C" - U	MB3U303	U303	0.730	0.013	7.91	0.032	0.575	4.10	0.390	24.0	<0.002
1	2	13	ustdlm122	Ustd	Ustd	Ustd	0.925	0.172	9.30	0.726	2.05	8.79	0.786	22.1	0.005
1	2	14	mr15lm12	Frit "N" - N	MB3N314	N314	0.692	0.010	8.31	0.023	0.572	7.16	0.394	23.7	1.03
1	2	15	mr15lm22	Frit "N" - N	MB3N314	N314	0.687	0.142	7.93	0.026	0.572	7.03	0.395	21.7	0.964
1	2	16	mr05lm12	Frit "C" - U	MB3U303	U303	0.686	0.018	7.94	0.030	0.578	4.08	0.395	24.2	0.011
1	2	17	mr18lm12	Frit 200 - U	MB3U200	U200	0.677	0.014	7.79	0.956	0.560	10.1	0.391	24.0	<0.002
1	2	18	mr18lm22	Frit 200 - U	MB3U200	U200	0.689	0.012	8.13	0.973	0.575	10.5	0.403	25.8	<0.002
1	2	19	stdlm123	Batch 1	Batch 1	Batch 1	0.922	0.076	9.36	0.871	1.31	6.79	0.563	23.9	0.093
2	1	1	stdlm211	Batch 1	Batch 1	Batch 1	0.928	0.069	9.04	0.862	1.30	6.86	0.564	23.4	0.091
2	1	2	mr23lm21	Frit KMA-2-U	MB3U323	U323	0.675	<0.003	7.55	0.018	0.541	8.57	0.379	25.7	<0.002
2	1	3	mr25lm11	Frit "T" - N	MB3N320	N320	0.700	<0.003	7.87	0.017	0.571	10.6	0.380	26.0	<0.002
2	1	4	ustdlm211	Ustd	Ustd	Ustd	0.928	0.163	9.29	0.709	2.02	8.69	0.775	21.9	<0.002
2	1	5	mr14lm11	Frit "G" - U	MB3U307	U307	0.686	<0.003	7.80	0.018	0.544	6.61	0.346	26.0	0.070
2	1	6	mr01lm11	Frit "N" - U	MB3U314	U314	0.657	0.008	7.30	0.034	0.522	7.13	0.333	24.8	0.963
2	1	7	mr01lm21	Frit "N" - U	MB3U314	U314	0.652	0.005	7.22	0.035	0.524	7.12	0.333	24.9	1.01
2	1	8	stdlm212	Batch 1	Batch 1	Batch 1	0.924	0.068	9.04	0.853	1.29	6.89	0.558	23.4	0.099
2	1	9	mr21lm11	Frit 200 - N	MB3N200	N200	0.692	<0.003	7.85	0.914	0.561	9.88	0.377	25.0	<0.002
2	1	10	mr07lm21	Frit "M" - N	MB3N313	N313	0.691	0.006	7.85	0.019	0.584	8.53	0.393	26.1	<0.002

Table E1: SRTC-ML Measurements for Samples Prepared Using Lithium Metaborate Method *(continued)*

(Values are in elemental weight percents, wt%'s.)

Block	Sub-Block	Sequence	SRTC-ML ID (LM)	Glass/Frit ID	Glass ID	Shortened Glass ID	Ca(v)	Cr(v)	Fe(v)	Mg(v)	Mn(v)	Na(v)	Ni(v)	Si(v)	Zr(v)
2	1	11	mr25lm21	Frit "T" - N	MB3N320	N320	0.689	<0.003	7.93	0.020	0.594	10.6	0.396	25.6	<0.002
2	1	12	mr14lm21	Frit "G" - U	MB3U307	U307	0.657	<0.003	7.77	0.019	0.573	6.70	0.359	25.7	<0.002
2	1	13	ustdlm212	Ustd	Ustd	Ustd	0.917	0.172	8.85	0.750	2.14	8.70	0.813	21.3	<0.002
2	1	14	mr21lm21	Frit 200 - N	MB3N200	N200	0.670	<0.003	7.59	0.961	0.590	9.86	0.398	24.6	<0.002
2	1	15	mr07lm11	Frit "M" - N	MB3N313	N313	0.686	0.012	7.72	0.018	0.586	8.55	0.391	25.9	<0.002
2	1	16	mr23lm11	Frit KMA-2-U	MB3U323	U323	0.671	0.003	7.52	0.020	0.556	8.70	0.387	25.3	0.183
2	1	17	stdlm213	Batch 1	Batch 1	Batch 1	0.933	0.069	8.85	0.871	1.32	6.92	0.563	23.0	0.092
2	2	1	stdlm221	Batch 1	Batch 1	Batch 1	0.925	0.087	9.04	0.908	1.36	6.90	0.586	23.3	0.109
2	2	2	mr21lm22	Frit 200 - N	MB3N200	N200	0.678	0.018	7.87	0.976	0.609	9.76	0.410	25.0	0.010
2	2	3	mr01lm12	Frit "N" - U	MB3U314	U314	0.646	0.024	7.39	0.053	0.566	7.07	0.356	24.8	1.03
2	2	4	ustdlm221	Ustd	Ustd	Ustd	0.904	0.188	9.24	0.765	2.15	8.64	0.818	21.6	0.027
2	2	5	mr14lm12	Frit "G" - U	MB3U307	U307	0.663	0.017	7.84	0.037	0.598	6.60	0.372	25.9	0.091
2	2	6	mr25lm22	Frit "T" - N	MB3N320	N320	0.679	0.018	8.15	0.036	0.622	10.4	0.410	25.7	0.011
2	2	7	mr01lm22	Frit "N" - U	MB3U314	U314	0.631	0.021	7.41	0.054	0.572	7.03	0.361	25.1	1.07
2	2	8	stdlm222	Batch 1	Batch 1	Batch 1	0.886	0.087	9.09	0.919	1.39	6.69	0.592	23.3	0.119
2	2	9	mr23lm22	Frit KMA-2-U	MB3U323	U323	0.645	0.017	7.68	0.035	0.583	8.57	0.402	25.8	0.015
2	2	10	mr21lm12	Frit 200 - N	MB3N200	N200	0.664	0.018	8.01	0.971	0.606	9.74	0.401	25.1	0.010
2	2	11	mr07lm22	Frit "M" - N	MB3N313	N313	0.665	0.021	7.95	0.035	0.616	8.70	0.409	26.2	0.009
2	2	12	mr25lm12	Frit "T" - N	MB3N320	N320	0.658	0.016	7.99	0.034	0.622	10.6	0.409	26.6	0.009
2	2	13	ustdlm222	Ustd	Ustd	Ustd	0.873	0.191	9.27	0.775	2.18	8.69	0.826	21.9	0.018
2	2	14	mr07lm12	Frit "M" - N	MB3N313	N313	0.650	0.028	8.01	0.035	0.622	8.54	0.412	26.3	0.010
2	2	15	mr23lm12	Frit KMA-2-U	MB3U323	U323	0.633	0.019	7.89	0.037	0.595	8.60	0.413	25.9	0.205
2	2	16	mr14lm22	Frit "G" - U	MB3U307	U307	0.626	0.019	8.07	0.036	0.600	6.88	0.373	26.1	0.011
2	2	17	stdlm223	Batch 1	Batch 1	Batch 1	0.872	0.088	9.30	0.925	1.39	6.89	0.597	23.8	0.109
3	1	1	stdlm311	Batch 1	Batch 1	Batch 1	0.913	0.083	9.07	0.890	1.33	6.76	0.574	23.4	0.090
3	1	2	mr11lm21	Frit 165 - N	MB3N165	N165	0.686	0.023	7.81	0.518	0.586	10.9	0.387	24.4	0.515
3	1	3	mr19lm21	Frit "D" - N	MB3N304	N304	0.698	0.014	8.08	0.025	0.582	13.7	0.387	23.9	<0.002
3	1	4	ustdlm311	Ustd	Ustd	Ustd	0.934	0.176	9.24	0.727	2.05	8.50	0.782	21.8	<0.002
3	1	5	mr03lm11	Frit KMA-2A-N	MB3N324	N324	0.702	0.018	7.94	0.022	0.572	6.45	0.367	25.8	<0.002
3	1	6	mr03lm21	Frit KMA-2A-N	MB3N324	N324	0.694	0.017	7.99	0.022	0.576	6.46	0.372	25.8	<0.002
3	1	7	mr11lm11	Frit 165 - N	MB3N165	N165	0.699	0.014	8.14	0.500	0.572	11.0	0.376	25.0	0.505
3	1	8	stdlm312	Batch 1	Batch 1	Batch 1	0.930	0.080	9.16	0.856	1.30	6.70	0.558	23.5	0.093
3	1	9	mr16lm11	Frit 165 - U	MB3U165	U165	0.702	0.018	7.76	0.509	0.553	11.2	0.362	24.3	0.508
3	1	10	mr02lm11	Frit "M" - U	MB3U313	U313	0.688	0.013	7.96	0.026	0.546	8.80	0.386	26.5	<0.002
3	1	11	mr04lm11	Frit "Bone2"-N	MB3N326	N326	0.710	0.021	8.04	0.483	0.574	9.73	0.378	25.6	<0.002
3	1	12	mr16lm21	Frit 165 - U	MB3U165	U165	0.703	0.018	7.86	0.506	0.548	11.0	0.358	24.3	0.498
3	1	13	ustdlm322	Ustd	Ustd	Ustd	0.934	0.172	9.29	0.709	2.01	8.42	0.773	21.8	0.007
3	1	14	mr02lm21	Frit "M" - U	MB3U313	U313	0.673	0.014	7.71	0.026	0.532	8.59	0.375	26.0	<0.002
3	1	15	mr08lm11	Frit "O" - U	MB3U315	U315	0.686	0.014	8.12	0.029	0.559	4.92	0.355	25.3	<0.002
3	1	16	mr08lm21	Frit "O" - U	MB3U315	U315	0.655	0.014	7.55	0.023	0.509	4.45	0.360	24.9	<0.002
3	1	17	mr19lm11	Frit "D" - N	MB3N304	N304	0.695	0.015	8.13	0.023	0.570	13.3	0.384	24.1	<0.002
3	1	18	mr04lm21	Frit "Bone2"-N	MB3N326	N326	0.698	0.019	8.14	0.493	0.579	9.48	0.384	26.0	<0.002
3	1	19	stdlm313	Batch 1	Batch 1	Batch 1	0.931	0.079	9.19	0.854	1.29	6.56	0.558	23.5	0.086
3	2	1	stdlm321	Batch 1	Batch 1	Batch 1	0.917	0.071	9.03	0.868	1.31	6.85	0.562	23.2	0.090
3	2	2	mr03lm22	Frit KMA-2A-N	MB3N324	N324	0.688	0.006	7.88	0.013	0.574	6.49	0.371	25.6	<0.002
3	2	3	mr04lm12	Frit "Bone2"-N	MB3N326	N326	0.697	0.011	7.96	0.493	0.582	9.86	0.382	25.4	<0.002
3	2	4	ustdlm321	Ustd	Ustd	Ustd	0.920	0.168	9.06	0.728	2.06	8.58	0.792	21.5	0.003
3	2	5	mr11lm22	Frit 165 - N	MB3N165	N165	0.675	0.012	7.72	0.509	0.578	10.9	0.380	24.2	0.512

Table E1: SRTC-ML Measurements for Samples Prepared Using Lithium Metaborate Method *(continued)*
(Values are in elemental weight percents, wt%'s.)

Block	Sub-Block	Sequence	SRTC-ML ID (LM)	Glass/Frit ID	Glass ID	Shortened Glass ID	Ca(v)	Cr(v)	Fe(v)	Mg(v)	Mn(v)	Na(v)	Ni(v)	Si(v)	Zr(v)
3	2	6	mr19lm22	Frit "D" - N	MB3N304	N304	0.690	0.003	7.89	0.014	0.576	13.6	0.384	23.5	<0.002
3	2	7	mr11lm12	Frit 165 - N	MB3N165	N165	0.696	0.003	7.88	0.511	0.581	11.2	0.380	24.5	0.517
3	2	8	stdlm322	Batch 1	Batch 1	Batch 1	0.916	0.071	8.90	0.882	1.33	6.70	0.569	23.0	0.097
3	2	9	mr02lm12	Frit "M" - U	MB3U313	U313	0.668	<0.003	7.87	0.017	0.561	8.82	0.396	26.3	<0.002
3	2	10	mr16lm12	Frit 165 - U	MB3U165	U165	0.686	0.008	7.68	0.516	0.558	11.2	0.363	24.0	0.512
3	2	11	mr02lm22	Frit "M" - U	MB3U313	U313	0.682	0.004	7.66	0.016	0.542	8.69	0.381	26.0	<0.002
3	2	12	mr08lm12	Frit "O" - U	MB3U315	U315	0.681	<0.003	7.88	0.020	0.570	5.02	0.360	24.9	<0.002
3	2	13	ustdlm322	Ustd	Ustd	Ustd	0.932	0.168	7.89	0.728	2.08	9.55	0.793	20.1	0.004
3	2	14	mr04lm22	Frit "Bone2"-N	MB3N326	N326	0.691	0.009	6.79	0.500	0.589	10.6	0.387	25.5	<0.002
3	2	15	mr08lm22	Frit "O" - U	MB3U315	U315	0.641	0.003	6.37	0.014	0.524	4.54	0.366	22.3	<0.002
3	2	16	mr19lm12	Frit "D" - N	MB3N304	N304	0.685	0.005	6.96	0.014	0.588	13.6	0.394	24.3	<0.002
3	2	17	mr16lm22	Frit 165 - U	MB3U165	U165	0.688	0.007	6.83	0.522	0.564	11.8	0.367	24.6	0.512
3	2	18	mr03lm12	Frit KMA-2A-N	MB3N324	N324	0.696	0.007	7.03	0.011	0.574	6.69	0.368	25.4	<0.002
3	2	19	stdlm323	Batch 1	Batch 1	Batch 1	0.923	0.071	8.16	0.877	1.33	6.93	0.567	21.7	0.091
4	1	1	stdlm411	Batch 1	Batch 1	Batch 1	0.923	0.074	8.90	0.877	1.31	6.98	0.566	22.8	0.093
4	1	2	mr13lm11	Frit KMA-2A-U	MB3U324	U324	0.677	0.030	7.78	0.028	0.561	6.99	0.367	24.8	<0.002
4	1	3	mr12lm21	Frit "Bone2"-U	MB3U326	U326	0.670	0.008	8.01	0.499	0.566	10.4	0.387	25.6	<0.002
4	1	4	ustdlm411	Ustd	Ustd	Ustd	0.929	0.172	9.41	0.735	2.06	8.76	0.788	21.8	0.006
4	1	5	mr06lm21	Frit "O" - N	MB3N315	N315	0.687	0.008	8.16	0.023	0.582	3.66	0.383	25.3	<0.002
4	1	6	mr22lm21	Frit "Mimi" - U	MB3U322	U322	0.657	0.010	7.90	0.027	0.559	9.49	0.352	28.3	0.005
4	1	7	mr13lm21	Frit KMA-2A-U	MB3U324	U324	0.694	0.007	8.51	0.029	0.573	7.08	0.373	26.3	<0.002
4	1	8	stdlm412	Batch 1	Batch 1	Batch 1	0.924	0.074	9.67	0.872	1.30	6.82	0.562	24.2	0.090
4	1	9	mr26lm11	Frit KMA-2-N	MB3N323	N323	0.689	0.007	8.38	0.023	0.580	8.37	0.381	26.7	<0.002
4	1	10	mr10lm11	Frit "C" - N	MB3N303	N303	0.690	0.007	8.37	0.025	0.584	3.77	0.386	24.2	<0.002
4	1	11	mr22lm11	Frit "Mimi" - U	MB3U322	U322	0.669	0.029	8.15	0.029	0.569	9.57	0.357	28.2	0.003
4	1	12	mr10lm21	Frit "C" - N	MB3N303	N303	0.680	0.007	8.49	0.022	0.589	3.74	0.390	24.3	<0.002
4	1	13	ustdlm412	Ustd	Ustd	Ustd	0.917	0.171	9.76	0.738	2.07	8.78	0.792	22.4	0.007
4	1	14	mr12lm11	Frit "Bone2"-U	MB3U326	U326	0.679	0.012	8.41	0.506	0.572	10.4	0.394	25.7	<0.002
4	1	15	mr06lm11	Frit "O" - N	MB3N315	N315	0.681	0.007	8.67	0.023	0.592	3.68	0.389	24.9	<0.002
4	1	16	mr26lm21	Frit KMA-2-N	MB3N323	N323	0.678	0.008	8.47	0.020	0.590	8.39	0.389	27.0	0.081
4	1	17	stdlm413	Batch 1	Batch 1	Batch 1	0.918	0.074	9.65	0.877	1.30	6.92	0.564	24.2	0.092
4	2	1	stdlm421	Batch 1	Batch 1	Batch 1	0.920	0.077	9.25	0.872	1.30	6.80	0.561	23.5	0.093
4	2	2	mr10lm12	Frit "C" - N	MB3N303	N303	0.692	0.008	8.10	0.028	0.573	3.70	0.378	24.2	<0.002
4	2	3	mr26lm12	Frit KMA-2-N	MB3N323	N323	0.683	0.008	8.08	0.027	0.576	8.26	0.380	26.2	0.006
4	2	4	ustdlm421	Ustd	Ustd	Ustd	0.924	0.168	9.43	0.719	2.03	8.55	0.774	22.0	0.003
4	2	5	mr22lm12	Frit "Mimi" - U	MB3U322	U322	0.670	0.029	7.99	0.033	0.563	9.39	0.353	28.1	<0.002
4	2	6	mr06lm22	Frit "O" - N	MB3N315	N315	0.680	0.009	8.21	0.028	0.578	3.55	0.382	25.4	<0.002
4	2	7	mr12lm12	Frit "Bone2"-U	MB3U326	U326	0.679	0.013	8.14	0.497	0.561	10.2	0.386	25.7	<0.002
4	2	8	stdlm422	Batch 1	Batch 1	Batch 1	0.927	0.074	9.49	0.866	1.29	6.80	0.560	24.0	0.090
4	2	9	mr22lm22	Frit "Mimi" - U	MB3U322	U322	0.655	0.011	7.95	0.032	0.556	9.35	0.351	28.5	0.007
4	2	10	mr26lm22	Frit KMA-2-N	MB3N323	N323	0.692	0.008	8.19	0.024	0.574	8.40	0.378	26.6	0.079
4	2	11	mr06lm12	Frit "O" - N	MB3N315	N315	0.692	0.008	8.28	0.028	0.578	3.65	0.381	25.8	<0.002
4	2	12	mr13lm12	Frit KMA-2A-U	MB3U324	U324	0.681	0.029	8.26	0.032	0.554	6.84	0.362	25.9	<0.002
4	2	13	ustdlm422	Ustd	Ustd	Ustd	0.923	0.170	9.58	0.730	2.04	8.63	0.787	22.2	0.003
4	2	14	mr13lm22	Frit KMA-2A-U	MB3U324	U324	0.696	0.007	8.36	0.034	0.573	7.16	0.372	26.3	<0.002
4	2	15	mr10lm22	Frit "C" - N	MB3N303	N303	0.685	0.008	8.51	0.027	0.586	3.64	0.385	24.4	<0.002
4	2	16	mr12lm22	Frit "Bone2"-U	MB3U326	U326	0.666	0.008	8.25	0.498	0.565	10.3	0.385	25.7	<0.002
4	2	17	stdlm423	Batch 1	Batch 1	Batch 1	0.917	0.075	9.59	0.882	1.31	6.82	0.566	24.1	0.091

Table E2: SRTC-ML Measurements for Samples Prepared Using the Peroxide Fusion Method
(Values are in elemental weight percents, wt%'s.)

Block	Sub-Block	Sequence (pf)	SRTC-ML ID (pf)	Glass/Frit ID	Glass ID	Shortened Glass ID	Al(v)	B(v)	Li(v)	U(v)
1	1	1	stdpf111	Batch 1	Batch 1	Batch 1	2.55	2.49	2.03	<0.281
1	1	2	mr12pf21	Frit "Bone2"-U	MB3U326	U326	2.28	1.90	2.71	2.13
1	1	3	mr15pf11	Frit "N" - N	MB3N314	N314	2.33	4.55	1.99	1.99
1	1	4	ustdpf111	Ustd	Ustd	Ustd	2.12	2.84	1.37	1.92
1	1	5	mr15pf21	Frit "N" - N	MB3N314	N314	2.34	4.63	2.01	2.03
1	1	6	mr09pf21	Frit "Mimi" - N	MB3N322	N322	2.31	1.85	1.72	2.13
1	1	7	mr25pf11	Frit "T" - N	MB3N320	N320	2.31	1.85	2.69	2.21
1	1	8	stdpf112	Batch 1	Batch 1	Batch 1	2.55	2.51	2.03	<0.281
1	1	9	mr25pf21	Frit "T" - N	MB3N320	N320	2.34	1.84	2.70	2.24
1	1	10	mr03pf11	Frit KMA-2A-N	MB3N324	N324	2.32	3.45	2.81	2.26
1	1	11	mr12pf11	Frit "Bone2"-U	MB3U326	U326	2.29	1.89	2.72	2.13
1	1	12	mr22pf21	Frit "Mimi" - U	MB3U322	U322	2.23	1.81	1.67	2.06
1	1	13	ustdpf112	Ustd	Ustd	Ustd	2.14	2.90	1.38	1.96
1	1	14	mr06pf21	Frit "O" - N	MB3N315	N315	2.38	4.71	3.47	2.36
1	1	15	mr22pf11	Frit "Mimi" - U	MB3U322	U322	2.24	1.85	1.71	2.06
1	1	16	mr06pf11	Frit "O" - N	MB3N315	N315	2.34	4.67	3.41	2.32
1	1	17	mr09pf11	Frit "Mimi" - N	MB3N322	N322	2.29	1.90	1.72	2.13
1	1	18	mr03pf21	Frit KMA-2A-N	MB3N324	N324	2.33	3.62	2.86	2.28
1	1	19	stdpf113	Batch 1	Batch 1	Batch 1	2.57	2.62	2.05	<0.281
1	2	1	stdpf121	Batch 1	Batch 1	Batch 1	2.57	2.50	2.05	<0.281
1	2	2	mr09pf22	Frit "Mimi" - N	MB3N322	N322	2.34	1.81	1.74	2.21
1	2	3	mr12pf22	Frit "Bone2"-U	MB3U326	U326	2.29	1.86	2.73	2.20
1	2	4	ustdpf121	Ustd	Ustd	Ustd	2.16	2.86	1.39	1.99
1	2	5	mr12pf12	Frit "Bone2"-U	MB3U326	U326	2.29	1.89	2.74	2.18
1	2	6	mr03pf12	Frit KMA-2A-N	MB3N324	N324	2.33	3.54	2.85	2.29
1	2	7	mr03pf22	Frit KMA-2A-N	MB3N324	N324	2.33	3.50	2.86	2.31
1	2	8	stdpf122	Batch 1	Batch 1	Batch 1	2.57	2.51	2.05	<0.281
1	2	9	mr15pf12	Frit "N" - N	MB3N314	N314	2.36	4.67	2.03	2.07
1	2	10	mr22pf22	Frit "Mimi" - U	MB3U322	U322	2.26	1.81	1.69	2.09
1	2	11	mr25pf12	Frit "T" - N	MB3N320	N320	2.38	1.87	2.77	2.25
1	2	12	mr06pf12	Frit "O" - N	MB3N315	N315	2.36	4.63	3.45	2.31
1	2	13	ustdpf122	Ustd	Ustd	Ustd	2.2	2.95	1.41	2.02
1	2	14	mr06pf22	Frit "O" - N	MB3N315	N315	2.39	4.62	3.47	2.42
1	2	15	mr25pf22	Frit "T" - N	MB3N320	N320	2.34	1.79	2.70	2.35
1	2	16	mr09pf12	Frit "Mimi" - N	MB3N322	N322	2.28	1.75	1.70	2.21
1	2	17	mr15pf22	Frit "N" - N	MB3N314	N314	2.35	4.60	2.01	2.08
1	2	18	mr22p12	Frit "Mimi" - U	MB3U322	U322	2.24	1.85	1.70	2.10
1	2	19	stdpf123	Batch 1	Batch 1	Batch 1	2.6	2.53	2.06	<0.281
2	1	1	stdpf211	Batch 1	Batch 1	Batch 1	2.56	2.49	2.06	<0.281
2	1	2	mr16pf11	Frit 165 - U	MB3U165	U165	2.21	2.25	2.41	1.86
2	1	3	mr21pf21	Frit 200 - N	MB3N200	N200	2.33	2.71	1.71	2.20
2	1	4	ustdpf211	Ustd	Ustd	Ustd	2.14	2.79	1.39	1.94
2	1	5	mr16pf21	Frit 165 - U	MB3U165	U165	2.19	2.26	2.39	1.87
2	1	6	mr26pf11	Frit KMA-2-N	MB3N323	N323	2.32	3.37	1.78	2.21
2	1	7	mr11pf21	Frit 165 - N	MB3N165	N165	2.32	2.26	2.36	1.95
2	1	8	stdpf212	Batch 1	Batch 1	Batch 1	2.52	2.39	2.04	<0.281
2	1	9	mr26pf21	Frit KMA-2-N	MB3N323	N323	2.31	3.31	1.77	2.20
2	1	10	mr14pf21	Frit "G" - U	MB3U307	U307	2.31	2.71	3.68	2.08
2	1	11	mr07pf11	Frit "M" - N	MB3N313	N313	2.25	1.46	3.61	2.00
2	1	12	mr07pf21	Frit "M" - N	MB3N313	N313	2.28	1.49	3.67	2.02
2	1	13	ustdpf212	Ustd	Ustd	Ustd	2.11	2.79	1.39	1.89
2	1	14	mr21pf11	Frit 200 - N	MB3N200	N200	2.35	2.75	1.72	2.17
2	1	15	mr14pf11	Frit "G" - U	MB3U307	U307	2.33	2.76	3.70	2.13
2	1	16	mr11pf11	Frit 165 - N	MB3N165	N165	2.36	2.23	2.39	1.99
2	1	17	stdpf213	Batch 1	Batch 1	Batch 1	2.6	2.41	2.06	<0.281
2	2	1	stdpf221	Batch 1	Batch 1	Batch 1	2.58	2.46	2.07	<0.281
2	2	2	mr11pf22	Frit 165 - N	MB3N165	N165	2.37	2.28	2.39	2.05
2	2	3	mr11pf12	Frit 165 - N	MB3N165	N165	2.41	2.28	2.40	2.11
2	2	4	ustdpf221	Ustd	Ustd	Ustd	2.19	2.89	1.41	2.02
2	2	5	mr26pf22	Frit KMA-2-N	MB3N323	N323	2.38	3.51	1.81	2.33
2	2	6	mr26pf12	Frit KMA-2-N	MB3N323	N323	2.39	3.50	1.81	2.37
2	2	7	mr16pf22	Frit 165 - U	MB3U165	U165	2.25	2.29	2.44	1.98
2	2	8	stdpf222	Batch 1	Batch 1	Batch 1	2.61	2.49	2.09	<0.281
2	2	9	mr14pf12	Frit "G" - U	MB3U307	U307	2.4	2.76	3.74	2.31
2	2	10	mr16pf12	Frit 165 - U	MB3U165	U165	2.25	2.25	2.44	2.00
2	2	11	mr14pf22	Frit "G" - U	MB3U307	U307	2.38	2.73	3.73	2.29
2	2	12	mr07pf22	Frit "M" - N	MB3N313	N313	2.38	1.52	3.77	2.25
2	2	13	ustdpf222	Ustd	Ustd	Ustd	2.19	2.87	1.41	2.05
2	2	14	mr21pf22	Frit 200 - N	MB3N200	N200	2.39	2.84	1.75	2.38
2	2	15	mr21pf12	Frit 200 - N	MB3N200	N200	2.42	2.83	1.74	2.35
2	2	16	mr07pf12	Frit "M" - N	MB3N313	N313	2.35	1.52	3.72	2.27
2	2	17	stdp223	Batch 1	Batch 1	Batch 1	2.62	2.47	2.09	<0.281

Table E2: SRTC-ML Measurements for Samples Prepared Using the Peroxide Fusion Method *(continued)*

(Values are in elemental weight percents, wt%'s.)

Block	Sub-Block	Sequence (pf)	SRTC-ML ID (pf)	Glass/Frit ID	Glass ID	Shortened Glass ID	Al(v)	B(v)	Li(v)	U(v)
3	1	1	stdpf311	Batch 1	Batch 1	Batch 1	2.59	2.45	2.08	<0.281
3	1	2	mr04pf11	Frit "Bone2"-N	MB3N326	N326	2.51	1.92	2.94	2.47
3	1	3	mr10pf11	Frit "C" - N	MB3N303	N303	3.27	4.57	3.5	2.41
3	1	4	ustdpf311	Ustd	Ustd	Ustd	2.15	2.79	1.39	2.02
3	1	5	mr10pf21	Frit "C" - N	MB3N303	N303	3.34	4.74	3.58	2.49
3	1	6	mr23pf11	Frit KMA-2-U	MB3U323	U323	2.41	3.53	1.83	2.25
3	1	7	mr13pf21	Frit KMA-2A-U	MB3U324	U324	2.27	3.29	2.77	2.18
3	1	8	stdpf312	Batch 1	Batch 1	Batch 1	2.57	2.43	2.04	<0.281
3	1	9	mr17pf11	Frit "T" - U	MB3U320	U320	2.46	1.92	2.95	2.32
3	1	10	mr13pf11	Frit KMA-2A-U	MB3U324	U324	2.39	3.41	2.92	2.29
3	1	11	mr05pf11	Frit "C" - U	MB3U303	U303	3.44	4.78	3.73	2.40
3	1	12	mr05pf21	Frit "C" - U	MB3U303	U303	3.24	4.54	3.52	2.26
3	1	13	ustdpf312	Ustd	Ustd	Ustd	2.14	2.79	1.39	2.01
3	1	14	mr02pf11	Frit "M" - U	MB3U313	U313	2.28	1.56	3.63	2.17
3	1	15	mr23pf21	Frit KMA-2-U	MB3U323	U323	2.38	3.48	1.80	2.21
3	1	16	mr02pf21	Frit "M" - U	MB3U313	U313	2.3	1.55	3.68	2.20
3	1	17	mr17pf21	Frit "T" - U	MB3U320	U320	2.28	1.82	2.74	2.15
3	1	18	mr04pf21	Frit "Bone2"-N	MB3N326	N326	2.48	1.93	2.91	2.42
3	1	19	stdpf313	Batch 1	Batch 1	Batch 1	2.59	2.49	2.08	<0.281
3	2	1	stdpf321	Batch 1	Batch 1	Batch 1	2.56	2.49	2.07	<0.281
3	2	2	mr02pf12	Frit "M" - U	MB3U313	U313	2.27	1.56	3.65	2.06
3	2	3	mr02pf22	Frit "M" - U	MB3U313	U313	2.29	1.54	3.70	2.08
3	2	4	ustdpf321	Ustd	Ustd	Ustd	2.16	2.81	1.42	1.96
3	2	5	mr13pf22	Frit KMA-2A-U	MB3U324	U324	2.3	3.36	2.84	2.13
3	2	6	mr04pf22	Frit "Bone2"-N	MB3N326	N326	2.31	1.82	2.76	2.24
3	2	7	mr10pf12	Frit "C" - N	MB3N303	N303	3.22	4.57	3.48	2.32
3	2	8	stdpf322	Batch 1	Batch 1	Batch 1	2.59	2.48	2.09	<0.281
3	2	9	mr10pf22	Frit "C" - N	MB3N303	N303	3.24	4.65	3.49	2.35
3	2	10	mr17pf22	Frit "T" - U	MB3U320	U320	2.29	1.85	2.77	2.11
3	2	11	mr23pf12	Frit KMA-2-U	MB3U323	U323	2.29	3.33	1.76	2.11
3	2	12	mr05pf12	Frit "C" - U	MB3U303	U303	3.26	4.51	3.55	2.22
3	2	13	ustdpf322	Ustd	Ustd	Ustd	2.18	2.82	1.41	2.00
3	2	14	mr05pf12	Frit "C" - U	MB3U303	U303	3.25	4.60	3.54	2.22
3	2	15	mr17pf12	Frit "T" - U	MB3U320	U320	2.24	1.80	2.72	2.08
3	2	16	mr04pf12	Frit "Bone2"-N	MB3N326	N326	2.27	1.77	2.69	2.22
3	2	17	mr13pf12	Frit KMA-2A-U	MB3U324	U324	2.35	3.43	2.88	2.21
3	2	18	mr23pf22	Frit KMA-2-U	MB3U323	U323	2.35	3.41	1.79	2.13
3	2	19	stdpf323	Batch 1	Batch 1	Batch 1	2.61	2.52	2.11	<0.281
4	1	1	stdp411	Batch 1	Batch 1	Batch 1	2.47	2.32	1.99	<0.281
4	1	2	mr20pf21	Frit "D" - U	MB3U304	U304	3.21	1.53	2.04	2.20
4	1	3	mr08pf21	Frit "O" - U	MB3U315	U315	2.48	4.71	3.72	2.38
4	1	4	ustdpf411	Ustd	Ustd	Ustd	2.13	2.82	1.38	1.99
4	1	5	mr18pf21	Frit 200 - U	MB3U200	U200	2.29	2.72	1.68	2.28
4	1	6	mr19pf11	Frit "D" - N	MB3N304	N304	3.42	1.66	2.14	2.39
4	1	7	mr01pf11	Frit "N" - U	MB3U314	U314	2.13	3.98	1.83	2.06
4	1	8	stdpf412	Batch 1	Batch 1	Batch 1	2.57	2.52	2.07	<0.281
4	1	9	mr24pf11	Frit "G" - N	MB3N307	N307	2.47	2.99	3.90	2.39
4	1	10	mr24pf21	Frit "G" - N	MB3N307	N307	2.45	2.98	3.86	2.37
4	1	11	mr20pf11	Frit "D" - U	MB3U304	U304	3.31	1.65	2.09	2.27
4	1	12	mr01pf21	Frit "N" - U	MB3U314	U314	2.17	4.05	1.84	2.09
4	1	13	ustdpf412	Ustd	Ustd	Ustd	2.18	2.93	1.39	2.05
4	1	14	mr18pf11	Frit 200 - U	MB3U200	U200	2.31	2.82	1.78	2.30
4	1	15	mr08pf11	Frit "O" - U	MB3U315	U315	2.38	4.67	3.55	2.26
4	1	16	mr19pf21	Frit "D" - N	MB3N304	N304	3.24	1.59	2.03	2.31
4	1	17	stdpf413	Batch 1	Batch 1	Batch 1	2.58	2.53	2.08	<0.281
4	2	1	stdpf421	Batch 1	Batch 1	Batch 1	2.52	2.45	2.03	<0.281
4	2	2	mr01pf22	Frit "N" - U	MB3U314	U314	2.22	4.08	1.87	2.17
4	2	3	mr18pf12	Frit 200 - U	MB3U200	U200	2.34	2.84	1.79	2.14
4	2	4	ustdpf421	Ustd	Ustd	Ustd	2.15	2.73	1.37	1.98
4	2	5	mr19pf12	Frit "D" - N	MB3N304	N304	3.16	1.51	1.95	2.22
4	2	6	mr20pf22	Frit "D" - U	MB3U304	U304	3.04	1.45	1.90	2.05
4	2	7	mr24pf22	Frit "G" - N	MB3N307	N307	2.34	2.68	3.66	2.23
4	2	8	stdpf422	Batch 1	Batch 1	Batch 1	2.51	2.37	2.02	<0.281
4	2	9	mr08pf12	Frit "O" - U	MB3U315	U315	2.28	4.32	3.39	2.13
4	2	10	mr20pf12	Frit "D" - U	MB3U304	U304	3.06	1.47	1.93	2.06
4	2	11	mr18pf22	Frit 200 - U	MB3U200	U200	2.34	2.71	1.70	2.34
4	2	12	mr19pf22	Frit "D" - N	MB3N304	N304	3.21	1.54	2.01	2.24
4	2	13	ustdpf422	Ustd	Ustd	Ustd	2.14	2.76	1.37	2.00
4	2	14	mr24pf12	Frit "G" - N	MB3N307	N307	2.35	2.74	3.67	2.23
4	2	15	mr01pf12	Frit "N" - U	MB3U314	U314	2.18	4.04	1.86	2.12
4	2	16	mr08pf22	Frit "O" - U	MB3U315	U315	2.27	4.32	3.36	2.13
4	2	17	stdpf423	Batch 1	Batch 1	Batch 1	2.59	2.45	2.07	<0.281

Table E3: Composition of PCT Leachate Solutions for Glasses from Nominally Washed Sludge.

Glass ID	Lab ID	Blk	Seq	Concentrations in ppm (as reported) B	Li	Na	Si	Concentrations in ppm (after correcting for dilution) B	Li	Na	Si	Common Logarithm of ppm Concentrations log[B]	log[Li]	log[Na]	log[Si]
std	std-b1-1	1	1	20.40	10.80	75.60	50.30	20.40	10.80	75.60	50.30	1.3096	1.0334	1.8785	1.7016
MB3N303q	ga58	1	2	22.30	19.00	8.61	74.10	37.17	31.67	14.35	123.50	1.5702	1.5006	1.1569	2.0917
MB3N304clc	ga18	1	3	10.70	16.10	126.00	138.00	17.83	26.83	210.00	230.00	1.2512	1.4287	2.3222	2.3617
MB3N324clc	ga78	1	4	18.80	17.70	24.30	87.70	31.33	29.50	40.50	146.17	1.4960	1.4698	1.6075	2.1649
MB3N304q	ga63	1	5	11.00	15.60	132.00	135.00	18.33	26.00	220.00	225.00	1.2633	1.4150	2.3424	2.3522
blank	ga41	1	6	0.53	<0.040	0.95	<0.790	0.88	0.03	1.59	0.66	-0.0563	-1.4771	0.2010	-0.1816
MB3N322q	ga55	1	7	6.85	8.22	32.50	81.20	11.42	13.70	54.17	135.34	1.0575	1.1367	1.7337	2.1314
MB3N326q	ga75	1	8	12.90	20.00	62.80	122.00	21.50	33.33	104.67	203.34	1.3324	1.5229	2.0198	2.3082
MB3N323q	ga64	1	9	15.50	9.51	26.40	72.50	25.83	15.85	44.00	120.84	1.4122	1.2000	1.6435	2.0822
std	std-b1-2	1	10	20.80	10.50	72.80	52.00	20.80	10.50	72.80	52.00	1.3181	1.0212	1.8621	1.7160
MB3N313clc	ga21	1	11	17.20	61.20	80.10	286.00	28.67	102.00	133.50	476.68	1.4574	2.0086	2.1255	2.6782
MB3N303clc	ga83	1	12	21.70	17.50	9.17	75.40	36.17	29.17	15.28	125.67	1.5583	1.4649	1.1842	2.0992
EA	ga80	1	13	38.30	12.20	92.50	55.20	638.33	203.33	1541.67	920.00	2.8050	2.3082	3.1880	2.9638
MB3N323clc	ga37	1	14	13.50	8.62	24.70	67.40	22.50	14.37	41.17	112.34	1.3522	1.1574	1.6146	2.0505
MB3N326clc	ga06	1	15	13.10	21.90	62.70	127.00	21.83	36.50	104.50	211.67	1.3391	1.5623	2.0191	2.3257
MB3N322clc	ga16	1	16	6.78	7.91	29.90	80.10	11.30	13.18	49.83	133.50	1.0531	1.1200	1.6975	2.1255
MB3N313q	ga25	1	17	12.50	34.10	65.30	168.00	20.83	56.83	108.84	280.01	1.3188	1.7546	2.0368	2.4472
MB3N324q	ga28	1	18	20.20	18.50	24.40	90.50	33.67	30.83	40.67	150.84	1.5272	1.4890	1.6092	2.1785
std	std-b1-3	1	19	21.10	10.70	73.70	52.90	21.10	10.70	73.70	52.90	1.3243	1.0294	1.8675	1.7235
std	std-b2-1	2	1	18.10	10.20	75.80	45.60	18.10	10.20	75.80	45.60	1.2577	1.0086	1.8797	1.6590
MB3N326clc	ga50	2	2	11.50	21.50	66.20	115.00	19.17	35.83	110.34	191.67	1.2826	1.5543	2.0427	2.2826
MB3N304clc	ga59	2	3	9.22	15.30	130.00	123.00	15.37	25.50	216.67	205.00	1.1866	1.4065	2.3358	2.3118
MB3N323clc	ga62	2	4	12.10	8.82	26.20	62.60	20.17	14.70	43.67	104.34	1.3046	1.1673	1.6402	2.0184
MB3N324clc	ga67	2	5	17.70	18.30	26.10	80.80	29.50	30.50	43.50	134.67	1.4698	1.4843	1.6385	2.1293
MB3N326q	ga10	2	6	11.20	20.10	68.90	111.00	18.67	33.50	114.84	185.00	1.2711	1.5251	2.0601	2.2672
MB3N322q	ga39	2	7	5.85	8.38	34.30	75.00	9.75	13.97	57.17	125.00	0.9890	1.1451	1.7572	2.0969
MB3N304q	ga17	2	8	9.50	15.20	139.00	123.00	15.83	25.33	231.67	205.00	1.1996	1.4037	2.3649	2.3118
EA	ga53	2	9	35.10	12.10	97.80	51.60	585.00	201.67	1630.00	860.00	2.7672	2.3046	3.2122	2.9345
std	std-b2-2	2	10	19.10	10.70	79.00	47.90	19.10	10.70	79.00	47.90	1.2810	1.0294	1.8976	1.6803
MB3N303clc	ga22	2	11	19.70	17.80	9.95	68.30	32.83	29.67	16.58	113.84	1.5163	1.4723	1.2197	2.0563
MB3N323q	ga65	2	12	13.70	9.46	26.90	65.40	22.83	15.77	44.83	109.00	1.3586	1.1977	1.6516	2.0374
MB3N313q	ga15	2	13	11.10	32.50	65.80	153.00	18.50	54.17	109.67	255.01	1.2672	1.7337	2.0401	2.4065
MB3N322clc	ga20	2	14	6.26	8.40	33.40	79.70	10.43	14.00	55.67	132.84	1.0184	1.1461	1.7456	2.1233
MB3N313clc	ga47	2	15	15.80	59.90	83.90	269.00	26.33	99.84	139.84	448.34	1.4205	1.9993	2.1456	2.6516
MB3N324q	ga84	2	16	17.50	17.40	23.60	82.10	29.17	29.00	39.33	136.84	1.4649	1.4624	1.5948	2.1362
MB3N303q	ga23	2	17	21.40	18.80	8.00	72.50	35.67	31.33	13.33	120.84	1.5523	1.4960	1.1249	2.0822
std	std-b2-3	2	18	18.70	10.50	77.50	47.20	18.70	10.50	77.50	47.20	1.2718	1.0212	1.8893	1.6739
std	std-b3-1	3	1	18.30	10.40	75.80	43.90	18.30	10.40	75.80	43.90	1.2625	1.0170	1.8797	1.6425
MB3N326clc	ga76	3	2	11.20	21.10	63.30	108.00	18.67	35.17	105.50	180.00	1.2711	1.5461	2.0233	2.2553
EA	ga86	3	3	27.20	9.81	74.40	40.20	453.33	163.50	1240.00	670.00	2.6564	2.2135	3.0934	2.8261
MB3N322clc	ga79	3	4	6.28	8.38	33.20	78.10	10.47	13.97	55.33	130.17	1.0198	1.1451	1.7430	2.1145
MB3N303q	ga69	3	5	22.20	19.30	8.07	71.90	37.00	32.17	13.45	119.84	1.5682	1.5074	1.1287	2.0786
MB3N324q	ga12	3	6	18.00	17.20	24.00	79.10	30.00	28.67	40.00	131.84	1.4771	1.4574	1.6021	2.1200
MB3N326q	ga27	3	7	11.00	18.90	63.90	105.00	18.33	31.50	106.50	175.00	1.2633	1.4983	2.0274	2.2430
MB3N303clc	ga29	3	8	19.80	17.20	8.79	67.60	33.00	28.67	14.65	112.67	1.5185	1.4574	1.1658	2.0518
MB3N323clc	ga45	3	9	12.30	8.32	24.90	62.30	20.50	13.87	41.50	103.84	1.3118	1.1420	1.6181	2.0163
std	std-b3-2	3	10	19.40	10.70	77.80	46.90	19.40	10.70	77.80	46.90	1.2878	1.0294	1.8910	1.6712
MB3N313clc	ga26	3	11	15.00	59.30	80.90	200.00	25.00	98.84	134.84	333.34	1.3979	1.9949	2.1298	2.5229
MB3N322q	ga71	3	12	6.00	7.97	32.30	73.50	10.00	13.28	53.83	122.50	1.0000	1.1233	1.7311	2.0881
MB3N324clc	ga60	3	13	18.10	17.50	24.70	81.60	30.17	29.17	41.17	136.00	1.4795	1.4649	1.6146	2.1335
MB3N304q	ga36	3	14	9.88	14.80	132.00	115.00	16.47	24.67	220.00	191.67	1.2166	1.3921	2.3424	2.2826
MB3N313q	ga74	3	15	11.60	33.40	66.50	147.00	19.33	55.67	110.84	245.00	1.2863	1.7456	2.0447	2.3892
MB3N304clc	ga14	3	16	9.76	15.00	124.00	119.00	16.27	25.00	206.67	198.34	1.2113	1.3979	2.3153	2.2974
MB3N323q	ga24	3	17	14.30	9.47	27.30	65.20	23.83	15.78	45.50	108.67	1.3772	1.1982	1.6580	2.0361
std	std-b3-3	3	18	19.90	10.90	78.80	48.50	19.90	10.90	78.80	48.50	1.2989	1.0374	1.8965	1.6857
std	std-b4-1	4	1	18.80	10.50	77.00	47.80	18.80	10.50	77.00	47.80	1.2742	1.0212	1.8865	1.6794
MB3N200clc	ga66	4	2	12.10	8.78	41.80	71.30	20.17	14.63	69.67	118.84	1.3046	1.1654	1.8430	2.0749
MB3N200q	ga54	4	3	12.70	9.35	44.10	71.30	21.17	15.58	73.50	118.84	1.3257	1.1927	1.8663	2.0749
MB3N165clc	ga57	4	4	12.70	15.40	65.30	89.90	21.17	25.67	108.84	149.84	1.3257	1.4094	2.0368	2.1756
MB3N307q	ga49	4	5	16.10	31.80	31.30	129.00	26.83	53.00	52.17	215.00	1.4287	1.7243	1.7174	2.3324
MB3N165q	ga11	4	6	13.60	16.00	74.80	91.10	22.67	26.67	124.67	151.84	1.3554	1.4260	2.0958	2.1814
ARM	ga56	4	7	10.60	9.40	22.20	35.80	17.67	15.67	37.00	59.67	1.2472	1.1950	1.5682	1.7757
MB3N320clc	ga08	4	8	10.90	22.70	75.20	127.00	18.17	37.83	125.34	211.67	1.2593	1.5779	2.0981	2.3257
std	std-b4-2	4	9	18.80	10.80	79.30	48.40	18.80	10.80	79.30	48.40	1.2742	1.0334	1.8993	1.6848

Notes:

(1). Values that were below detection (indicated by a "<") were converted to ½ the detection limit.

(2) The shaded entries indicate that the solution-weight fell outside of the guidelines for a successful PCT result.

Table E3: Composition of PCT Leachate Solutions for Glasses from Nominally Washed Sludge *(continued)*

				Concentrations in ppm				Concentrations in ppm							
Glass	**Lab**			**(as reported)**				**(after correcting for dilution)**				**Common Logarithm of ppm Concentrations**			
ID	**ID**	**Blk**	**Seq**	**B**	**Li**	**Na**	**Si**	**B**	**Li**	**Na**	**Si**	**log[B]**	**log[Li]**	**log[Na]**	**log[Si]**
MB3N314clc	ga33	4	10	24.80	13.60	25.40	56.30	41.33	22.67	42.33	93.84	1.6163	1.3554	1.6267	1.9724
MB3N307clc	ga42	4	11	15.20	24.80	27.90	99.90	25.33	41.33	46.50	166.50	1.4037	1.6163	1.6675	2.2214
MB3N315clc	ga72	4	12	34.40	27.80	16.40	86.20	57.33	46.33	27.33	143.67	1.7584	1.6659	1.4367	2.1574
MB3N314q	ga13	4	13	28.20	15.00	27.50	54.80	47.00	25.00	45.83	91.34	1.6721	1.3979	1.6612	1.9606
MB3N315q	ga32	4	14	35.40	28.80	15.60	90.20	59.00	48.00	26.00	150.34	1.7709	1.6813	1.4150	2.1771
MB3N320q	ga34	4	15	11.60	22.10	82.20	126.00	19.33	36.83	137.00	210.00	1.2863	1.5663	2.1367	2.3222
std	std-b4-3	4	16	18.90	10.80	79.30	48.40	18.90	10.80	79.30	48.40	1.2765	1.0334	1.8993	1.6848
std	std-b5-1	5	1	18.90	10.50	77.10	47.30	18.90	10.50	77.10	47.30	1.2765	1.0212	1.8871	1.6749
MB3N320q	ga61	5	2	10.70	21.00	78.20	119.00	17.83	35.00	130.34	198.34	1.2512	1.5441	2.1151	2.2974
MB3N315q	ga48	5	3	33.90	27.80	14.80	86.10	56.50	46.33	24.67	143.50	1.7521	1.6659	1.3921	2.1569
MB3N314q	ga38	5	4	28.20	14.80	27.30	54.70	47.00	24.67	45.50	91.17	1.6721	1.3921	1.6580	1.9598
MB3N165clc	ga81	5	5	12.80	15.40	65.90	88.60	21.33	25.67	109.84	147.67	1.3291	1.4094	2.0407	2.1693
MB3N314clc	ga77	5	6	24.50	13.10	25.50	53.60	40.83	21.83	42.50	89.34	1.6110	1.3391	1.6284	1.9510
MB3N320clc	ga40	5	7	10.90	22.90	76.40	127.00	18.17	38.17	127.34	211.67	1.2593	1.5817	2.1050	2.3257
MB3N307q	ga05	5	8	15.60	31.80	31.30	127.00	26.00	53.00	52.17	211.67	1.4150	1.7243	1.7174	2.3257
std	std-b5-2	5	9	18.80	10.70	78.70	47.30	18.80	10.70	78.70	47.30	1.2742	1.0294	1.8960	1.6749
MB3N165q	ga70	5	10	13.50	15.70	72.80	90.80	22.50	26.17	121.34	151.34	1.3522	1.4178	2.0840	2.1799
ARM	ga31	5	11	10.80	9.31	22.20	36.00	18.00	15.52	37.00	60.00	1.2553	1.1908	1.5682	1.7782
MB3N200q	ga35	5	12	12.40	8.94	43.50	69.90	20.67	14.90	72.50	116.50	1.3153	1.1732	1.8603	2.0663
MB3N307clc	ga82	5	13	14.80	24.30	27.40	101.00	24.67	40.50	45.67	168.34	1.3921	1.6075	1.6596	2.2262
MB3N315clc	ga04	5	14	34.40	27.40	16.30	85.90	57.33	45.67	27.17	143.17	1.7584	1.6596	1.4340	2.1559
MB3N200clc	ga43	5	15	11.90	8.69	41.30	68.60	19.83	14.48	68.83	114.34	1.2974	1.1609	1.8378	2.0582
std	std-b5-3	5	16	19.00	10.80	79.10	47.70	19.00	10.80	79.10	47.70	1.2788	1.0334	1.8982	1.6785
std	std-b6-1	6	1	19.10	11.20	81.30	49.70	19.10	11.20	81.30	49.70	1.2810	1.0492	1.9101	1.6964
MB3N320q	ga52	6	2	10.80	21.00	77.60	119.00	18.00	35.00	129.34	198.34	1.2553	1.5441	2.1117	2.2974
MB3N307clc	ga03	6	3	15.50	25.10	28.20	102.00	25.83	41.83	47.00	170.00	1.4122	1.6215	1.6721	2.2305
ARM	ga02	6	4	11.30	9.91	23.20	39.00	18.83	16.52	38.67	65.00	1.2749	1.2179	1.5873	1.8129
MB3N200clc	ga44	6	5	12.70	9.26	43.30	74.20	21.17	15.43	72.17	123.67	1.3257	1.1885	1.8583	2.0923
MB3N314clc	ga01	6	6	24.50	13.40	27.20	56.50	40.83	22.33	45.33	94.17	1.6110	1.3490	1.6564	1.9739
MB3N165clc	ga30	6	7	12.10	15.30	64.80	86.20	20.17	25.50	108.00	143.67	1.3046	1.4065	2.0334	2.1574
MB3N320clc	ga73	6	8	10.50	22.70	75.10	122.00	17.50	37.83	125.17	203.34	1.2430	1.5779	2.0975	2.3082
std	std-b6-2	6	9	18.70	10.90	79.70	48.70	18.70	10.90	79.70	48.70	1.2718	1.0374	1.9015	1.6875
MB3N315clc	ga51	6	10	34.30	28.50	17.10	89.10	57.17	47.50	28.50	148.50	1.7572	1.6767	1.4549	2.1717
MB3N200q	ga68	6	11	13.40	9.80	47.40	75.90	22.33	16.33	79.00	126.50	1.3490	1.2131	1.8976	2.1021
blank	ga09	6	12	<0.150	<0.040	0.46	<0.790	0.13	0.03	0.77	0.66	-0.9031	-1.4771	-0.1116	-0.1816
MB3N315q	ga19	6	13	33.90	28.20	15.10	87.00	56.50	47.00	25.17	145.00	1.7521	1.6721	1.4008	2.1614
MB3N314q	ga46	6	14	28.00	15.00	27.40	55.80	46.67	25.00	45.67	93.00	1.6690	1.3979	1.6596	1.9685
MB3N307q	ga07	6	15	16.40	33.10	33.00	125.00	27.33	55.17	55.00	208.34	1.4367	1.7417	1.7404	2.3188
MB3N165q	ga85	6	16	13.20	15.80	74.20	89.80	22.00	26.33	123.67	149.67	1.3424	1.4205	2.0923	2.1751
std	std-b6-3	6	17	18.90	11.00	80.10	49.50	18.90	11.00	80.10	49.50	1.2765	1.0414	1.9036	1.6946

Notes:

(1). Values that were below detection (indicated by a "<") were converted to ½ the detection limit.

(3) The shaded entries indicate that the solution-weight fell outside of the guidelines for a successful PCT result.

Table E4: Composition of PCT Leachate Solutions for Glasses from Underwashed Sludge

Glass ID	Lab ID	Blk	Seq	Concentrations in ppm (as reported) B	Li	Na	Si	Concentrations in ppm (after correcting for dilution) B	Li	Na	Si	Common Logarithm of ppm Concentrations log[B]	log[Li]	log[Na]	log[Si]
std	std-b1-1	1	1	18.90	9.45	78.60	47.50	18.90	9.45	78.60	47.50	1.2765	0.9754	1.8954	1.6767
MB3U200q	jp33	1	2	14.10	8.93	53.90	76.90	23.50	14.88	89.84	128.17	1.3711	1.1727	1.9534	2.1078
EA	jp83	1	3	34.40	10.80	97.40	51.80	573.33	180.00	1623.34	863.34	2.7584	2.2553	3.2104	2.9362
MB3U165clc	jp79	1	4	13.80	15.50	76.50	95.50	23.00	25.83	127.50	159.17	1.3617	1.4122	2.1055	2.2019
MB3U165q	jp73	1	5	14.40	15.40	84.60	97.70	24.00	25.67	141.00	162.84	1.3802	1.4094	2.1492	2.2118
MB3U303clc	jp78	1	6	20.40	17.70	12.20	68.60	34.00	29.50	20.33	114.34	1.5315	1.4698	1.3082	2.0582
MB3U313q	jp14	1	7	11.20	34.60	80.20	147.00	18.67	57.67	133.67	245.00	1.2711	1.7609	2.1260	2.3892
MB3U200clc	jp68	1	8	12.80	8.19	48.20	73.70	21.33	13.65	80.33	122.84	1.3291	1.1351	1.9049	2.0893
MB3U314q	jp43	1	9	31.30	15.20	34.90	57.80	52.17	25.33	58.17	96.34	1.7174	1.4037	1.7647	1.9838
std	std-b1-2	1	10	18.90	9.49	79.40	48.30	18.90	9.49	79.40	48.30	1.2765	0.9773	1.8998	1.6839
MB3U313clc	jp74	1	11	14.90	62.40	91.40	218.00	24.83	104.00	152.34	363.34	1.3950	2.0170	2.1828	2.5603
ARM	jp01	1	12	11.30	9.09	24.30	39.10	18.83	15.15	40.50	65.17	1.2749	1.1804	1.6075	1.8140
MB3U304clc	jp42	1	13	9.13	14.90	140.00	109.00	15.22	24.83	233.34	181.67	1.1823	1.3950	2.3680	2.2593
MB3U304q	jp24	1	14	9.83	15.00	160.00	121.00	16.38	25.00	266.67	201.67	1.2144	1.3979	2.4260	2.3046
MB3U303q	jp50	1	15	22.60	19.80	11.60	71.30	37.67	33.00	19.33	118.84	1.5760	1.5185	1.2863	2.0749
blank	jp52	1	16	<0.150	0.37	0.61	<0.790	0.13	0.62	1.02	0.66	-0.9031	-0.2111	0.0065	-0.1816
MB3U314clc	jp69	1	17	28.30	13.50	32.80	57.20	47.17	22.50	54.67	95.34	1.6736	1.3522	1.7377	1.9793
std	std-b1-3	1	18	18.90	9.50	79.90	47.90	18.90	9.50	79.90	47.90	1.2765	0.9777	1.9025	1.6803
std	std-b2-1	2	1	18.80	9.20	77.60	47.80	18.80	9.20	77.60	47.80	1.2742	0.9638	1.8899	1.6794
blank	jp36	2	2	<0.150	0.35	0.59	<0.790	0.13	0.59	0.99	0.66	-0.9031	-0.2316	-0.0044	-0.1816
MB3U304q	jp56	2	3	9.10	13.90	146.00	128.00	15.17	23.17	243.34	213.34	1.1809	1.3649	2.3862	2.3291
ARM	jp11	2	4	9.97	8.15	21.90	36.30	16.62	13.58	36.50	60.50	1.2206	1.1330	1.5623	1.7818
MB3U303q	jp19	2	5	22.30	19.00	11.30	69.80	37.17	31.67	18.83	116.34	1.5702	1.5006	1.2749	2.0657
MB3U200q	jp75	2	6	13.70	8.53	51.70	73.50	22.83	14.22	86.17	122.50	1.3586	1.1528	1.9353	2.0881
MB3U314q	jp71	2	7	30.10	14.30	32.80	55.80	50.17	23.83	54.67	93.00	1.7004	1.3772	1.7377	1.9685
MB3U313q	jp06	2	8	10.70	32.70	76.40	158.00	17.83	54.50	127.34	263.34	1.2512	1.7364	2.1050	2.4205
MB3U304clc	jp62	2	9	8.46	13.80	130.00	120.00	14.10	23.00	216.67	200.00	1.1492	1.3617	2.3358	2.3010
std	std-b2-2	2	10	18.10	9.14	76.80	46.70	18.10	9.14	76.80	46.70	1.2577	0.9609	1.8854	1.6693
MB3U165q	jp55	2	11	13.80	14.60	80.00	94.30	23.00	24.33	133.34	157.17	1.3617	1.3862	2.1249	2.1964
MB3U313clc	jp84	2	12	14.40	59.80	88.30	257.00	24.00	99.67	147.17	428.34	1.3802	1.9986	2.1678	2.6318
MB3U200clc	jp41	2	13	12.60	8.10	47.00	71.90	21.00	13.50	78.33	119.84	1.3222	1.1303	1.8940	2.0786
MB3U165clc	jp17	2	14	13.30	14.80	73.90	93.00	22.17	24.67	123.17	155.00	1.3457	1.3921	2.0905	2.1903
MB3U314clc	jp54	2	15	28.50	13.30	32.80	58.00	47.50	22.17	54.67	96.67	1.6767	1.3457	1.7377	1.9853
EA	jp27	2	16	37.10	11.20	102.00	55.00	618.33	186.67	1700.00	916.67	2.7912	2.2711	3.2305	2.9622
MB3U303clc	jp13	2	17	20.30	17.30	11.90	69.60	33.83	28.83	19.83	116.00	1.5294	1.4599	1.2974	2.0645
std	std-b2-3	2	18	18.50	9.18	76.20	47.60	18.50	9.18	76.20	47.60	1.2672	0.9628	1.8820	1.6776
std	std-b3-1	3	1	18.80	9.28	78.30	47.80	18.80	9.28	78.30	47.80	1.2742	0.9675	1.8938	1.6794
MB3U200q	jp46	3	2	14.20	8.90	53.40	77.10	23.67	14.83	89.00	128.50	1.3741	1.1712	1.9494	2.1089
ARM	jp67	3	3	10.50	8.51	23.00	38.00	17.50	14.18	38.33	63.33	1.2430	1.1518	1.5836	1.8016
MB3U314clc	jp22	3	4	28.40	13.40	33.00	57.00	47.33	22.33	55.00	95.00	1.6752	1.3490	1.7404	1.9777
MB3U313q	jp31	3	5	10.70	33.50	77.60	153.00	17.83	55.83	129.34	255.01	1.2512	1.7469	2.1117	2.4065
MB3U303clc	jp10	3	6	19.50	16.90	11.80	67.50	32.50	28.17	19.67	112.50	1.5119	1.4497	1.2937	2.0512
MB3U314q	jp08	3	7	31.40	15.10	33.80	58.10	52.33	25.17	56.33	96.84	1.7188	1.4008	1.7508	1.9860
MB3U303q	jp59	3	8	22.00	19.00	11.20	69.10	36.67	31.67	18.67	115.17	1.5643	1.5006	1.2711	2.0613
MB3U304q	jp07	3	9	10.00	15.40	160.00	128.00	16.67	25.67	266.67	213.34	1.2219	1.4094	2.4260	2.3291
std	std-b3-2	3	10	18.70	9.31	78.20	47.70	18.70	9.31	78.20	47.70	1.2718	0.9690	1.8932	1.6785
MB3U200clc	jp15	3	11	12.90	8.29	48.30	72.50	21.50	13.82	80.50	120.84	1.3324	1.1404	1.9058	2.0822
MB3U165clc	jp48	3	12	13.10	14.80	73.80	92.70	21.83	24.67	123.00	154.50	1.3391	1.3921	2.0899	2.1889
MB3U165q	jp65	3	13	14.10	15.10	82.40	97.00	23.50	25.17	137.34	161.67	1.3711	1.4008	2.1378	2.2086
MB3U304clc	jp16	3	14	9.04	14.80	138.00	112.00	15.07	24.67	230.00	186.67	1.1780	1.3921	2.3617	2.2711
EA	jp64	3	15	34.70	11.00	97.80	52.40	578.33	183.33	1630.00	873.34	2.7622	2.2632	3.2122	2.9412
MB3U313clc	jp28	3	16	15.00	62.90	92.70	274.00	25.00	104.84	154.50	456.68	1.3979	2.0205	2.1889	2.6596
std	std-b3-3	3	17	18.50	9.25	78.30	46.90	18.50	9.25	78.30	46.90	1.2672	0.9661	1.8938	1.6712
std	std-b4-1	4	1	18.60	9.29	79.80	46.70	18.60	9.29	79.80	46.70	1.2695	0.9680	1.9020	1.6693
MB3U320clc	jp21	4	2	10.30	20.60	76.90	121.00	17.17	34.33	128.17	201.67	1.2347	1.5357	2.1078	2.3046
MB3U322clc	jp63	4	3	5.63	7.10	37.20	73.10	9.38	11.83	62.00	121.84	0.9724	1.0731	1.7924	2.0858
MB3U324q	jp03	4	4	20.40	19.40	32.40	89.60	34.00	32.33	54.00	149.34	1.5315	1.5097	1.7324	2.1742
MB3U307q	jp38	4	5	16.90	33.60	38.60	118.00	28.17	56.00	64.33	196.67	1.4497	1.7482	1.8084	2.2937
MB3U326q	jp47	4	6	12.30	20.70	83.90	120.00	20.50	34.50	139.84	200.00	1.3118	1.5378	2.1456	2.3010
MB3U326clc	jp45	4	7	12.10	21.60	77.10	118.00	20.17	36.00	128.50	196.67	1.3046	1.5563	2.1089	2.2937
MB3U320q	jp70	4	8	11.10	20.10	86.70	112.00	18.50	33.50	144.50	186.67	1.2672	1.5251	2.1599	2.2711
MB3U323q	jp37	4	9	17.00	10.00	36.40	70.50	28.33	16.67	60.67	117.50	1.4523	1.2219	1.7830	2.0700
std	std-b4-2	4	10	18.50	9.26	79.30	46.50	18.50	9.26	79.30	46.50	1.2672	0.9666	1.8993	1.6675
MB3U307clc	jp60	4	11	18.70	28.40	38.40	108.00	31.17	47.33	64.00	180.00	1.4937	1.6752	1.8062	2.2553

Notes:

(1). Values that were below detection (indicated by a "<") were converted to ½ the detection limit.

(4) The shaded entries indicate that the solution-weight fell outside of the guidelines for a successful PCT result.

Table E4: Composition of PCT Leachate Solutions for Glasses from Underwashed Sludge

Glass	Lab			Concentrations in ppm (as reported)				Concentrations in ppm (after correcting for dilution)				Common Logarithm of ppm Concentrations			
ID	ID	Blk	Seq	B	Li	Na	Si	B	Li	Na	Si	log[B]	log[Li]	log[Na]	log[Si]
MB3U324clc	jp80	4	12	17.70	16.70	30.30	83.50	29.50	27.83	50.50	139.17	1.4698	1.4446	1.7033	2.1435
MB3U322q	jp39	4	13	5.70	7.12	38.90	73.30	9.50	11.87	64.83	122.17	0.9777	1.0743	1.8118	2.0870
MB3U323clc	jp66	4	14	14.60	8.61	32.40	67.50	24.33	14.35	54.00	112.50	1.3862	1.1569	1.7324	2.0512
MB3U315q	jp23	4	15	40.10	32.50	20.60	96.30	66.83	54.17	34.33	160.50	1.8250	1.7337	1.5357	2.2055
MB3U315clc	jp44	4	16	40.20	31.40	22.20	95.70	67.00	52.33	37.00	159.50	1.8261	1.7188	1.5682	2.2028
std	std-b4-3	4	17	19.00	9.35	79.30	47.60	19.00	9.35	79.30	47.60	1.2788	0.9708	1.8993	1.6776
std	std-b5-1	5	1	19.50	9.52	79.60	48.80	19.50	9.52	79.60	48.80	1.2900	0.9786	1.9009	1.6884
MB3U323clc	jp29	5	2	15.50	8.59	32.30	68.50	25.83	14.32	53.83	114.17	1.4122	1.1559	1.7311	2.0575
MB3U326q	jp02	5	3	12.20	19.50	79.20	119.00	20.33	32.50	132.00	198.34	1.3082	1.5119	2.1206	2.2974
MB3U322clc	jp18	5	4	5.88	7.08	36.00	75.20	9.80	11.80	60.00	125.34	0.9912	1.0719	1.7782	2.0981
MB3U322q	jp30	5	5	5.74	6.91	35.20	73.10	9.57	11.52	58.67	121.84	0.9808	1.0613	1.7684	2.0858
MB3U324q	jp77	5	6	21.50	18.90	30.80	91.30	35.83	31.50	51.33	152.17	1.5543	1.4983	1.7104	2.1823
MB3U320q	jp32	5	7	10.90	18.50	77.90	116.00	18.17	30.83	129.84	193.34	1.2593	1.4890	2.1134	2.2863
MB3U323q	jp49	5	8	16.90	9.47	34.30	71.50	28.17	15.78	57.17	119.17	1.4497	1.1982	1.7572	2.0762
MB3U315q	jp86	5	9	28.10	20.80	13.70	63.80	46.83	34.67	22.83	106.34	1.6706	1.5399	1.3586	2.0267
std	std-b5-2	5	10	19.20	9.34	76.90	48.70	19.20	9.34	76.90	48.70	1.2833	0.9703	1.8859	1.6875
MB3U315clc	jp12	5	11	39.90	30.60	22.40	92.70	66.50	51.00	37.33	154.50	1.8228	1.7076	1.5721	2.1889
MB3U324clc	jp57	5	12	19.30	17.00	30.40	87.70	32.17	28.33	50.67	146.17	1.5074	1.4523	1.7047	2.1649
MB3U307clc	jp61	5	13	19.70	27.80	37.10	115.00	32.83	46.33	61.83	191.67	1.5163	1.6659	1.7912	2.2826
MB3U320clc	jp76	5	14	10.60	20.20	73.90	122.00	17.67	33.67	123.17	203.34	1.2472	1.5272	2.0905	2.3082
MB3U307q	jp51	5	15	17.60	33.00	37.30	143.00	29.33	55.00	62.17	238.34	1.4674	1.7404	1.7936	2.3772
MB3U326clc	jp26	5	16	12.80	21.40	75.40	127.00	21.33	35.67	125.67	211.67	1.3291	1.5523	2.0992	2.3257
std	std-b5-3	5	17	19.00	9.32	77.20	47.80	19.00	9.32	77.20	47.80	1.2788	0.9694	1.8876	1.6794
std	std-b6-1	6	1	18.80	9.33	80.10	45.20	18.80	9.33	80.10	45.20	1.2742	0.9699	1.9036	1.6551
MB3U315q	jp05	6	2	40.70	31.40	20.20	91.30	67.83	52.33	33.67	152.17	1.8315	1.7188	1.5272	2.1823
MB3U315clc	jp58	6	3	40.40	30.00	21.70	91.30	67.33	50.00	36.17	152.17	1.8282	1.6990	1.5583	2.1823
MB3U324clc	jp20	6	4	18.70	16.70	29.60	82.00	31.17	27.83	49.33	136.67	1.4937	1.4446	1.6931	2.1357
MB3U326q	jp09	6	5	12.50	20.40	82.00	118.00	20.83	34.00	136.67	196.67	1.3188	1.5315	2.1357	2.2937
MB3U326clc	jp34	6	6	12.60	21.20	75.00	120.00	21.00	35.33	125.00	200.00	1.3222	1.5482	2.0969	2.3010
MB3U307clc	jp82	6	7	19.90	28.40	37.70	114.00	33.17	47.33	62.83	190.00	1.5207	1.6752	1.7982	2.2788
MB3U323clc	jp85	6	8	16.20	9.00	33.50	68.20	27.00	15.00	55.83	113.67	1.4314	1.1761	1.7469	2.0556
MB3U307q	jp35	6	9	17.30	32.90	37.60	138.00	28.83	54.83	62.67	230.00	1.4599	1.7391	1.7970	2.3617
std	std-b6-2	6	10	19.30	9.49	79.20	46.30	19.30	9.49	79.20	46.30	1.2856	0.9773	1.8987	1.6656
MB3U320q	jp04	6	11	11.10	19.40	81.50	119.00	18.50	32.33	135.84	198.34	1.2672	1.5097	2.1330	2.2974
MB3U322clc	jp25	6	12	5.86	7.14	35.90	72.70	9.77	11.90	59.83	121.17	0.9898	1.0756	1.7770	2.0834
MB3U323q	jp72	6	13	17.30	9.74	35.30	68.80	28.83	16.23	58.83	114.67	1.4599	1.2104	1.7696	2.0594
MB3U320clc	jp53	6	14	10.40	20.20	75.10	119.00	17.33	33.67	125.17	198.34	1.2389	1.5272	2.0975	2.2974
MB3U322q	jp81	6	15	5.98	7.28	38.50	72.40	9.97	12.13	64.17	120.67	0.9986	1.0840	1.8073	2.0816
MB3U324q	jp40	6	16	21.40	19.10	31.90	87.90	35.67	31.83	53.17	146.50	1.5523	1.5029	1.7256	2.1658
std	std-b6-3	6	17	18.90	9.32	78.30	45.10	18.90	9.32	78.30	45.10	1.2765	0.9694	1.8938	1.6542

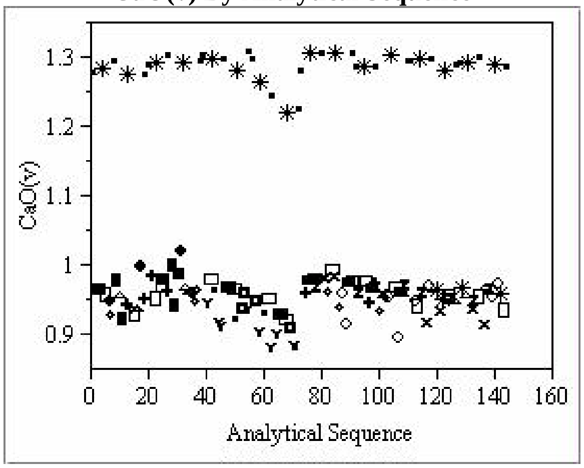
Notes:

(1). Values that were below detection (indicated by a "<") were converted to ½ the detection limit.

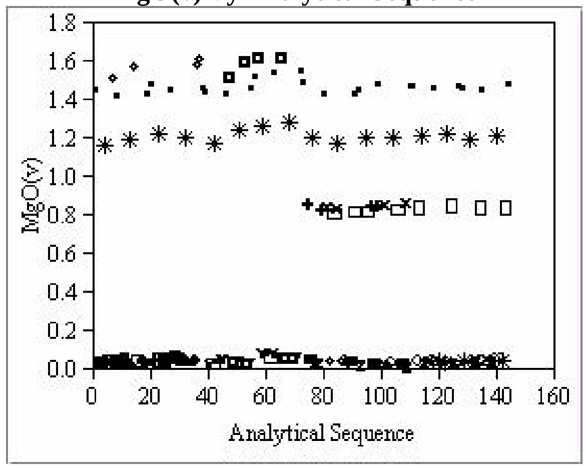
(5) The shaded entries indicate that the solution-weight fell outside of the guidelines for a successful PCT result.

Exhibit E1. Plot of Oxide Concentrations (as wt%'s) in Analytical Sequence for LM Prep

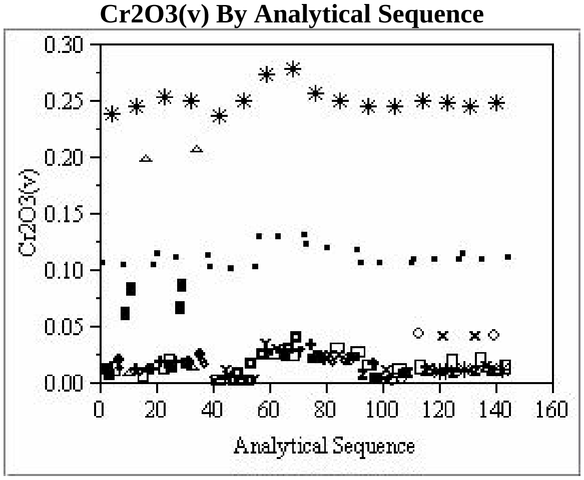
CaO(v) By Analytical Sequence



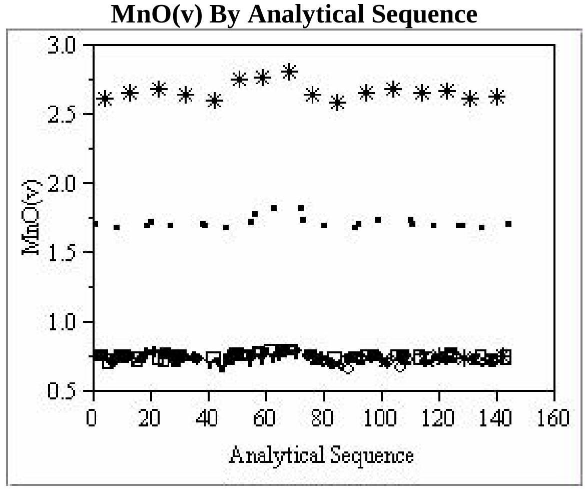
MgO(v) By Analytical Sequence



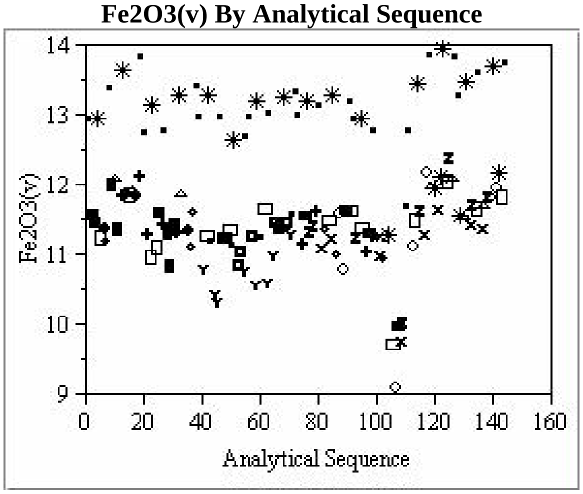
Cr2O3(v) By Analytical Sequence



MnO(v) By Analytical Sequence



Fe2O3(v) By Analytical Sequence



Na2O(v) By Analytical Sequence

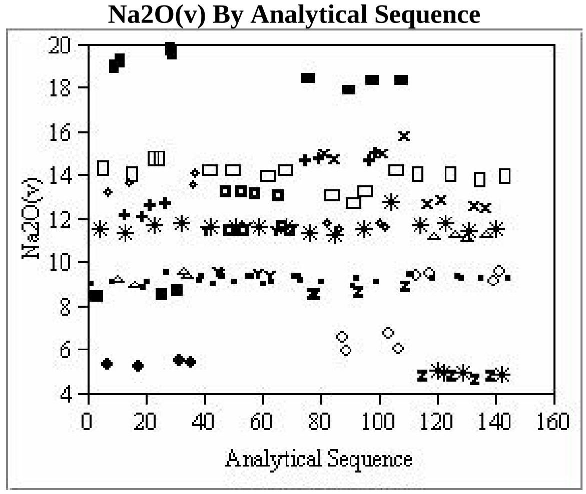
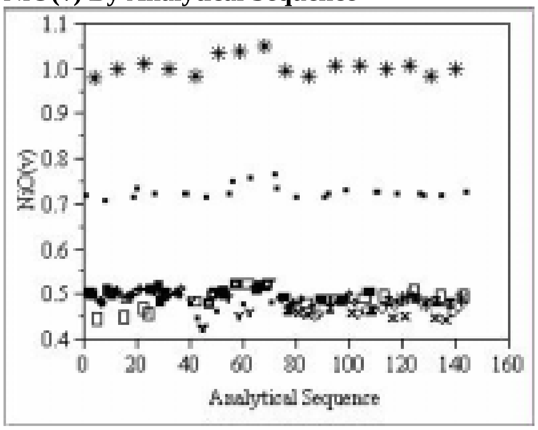
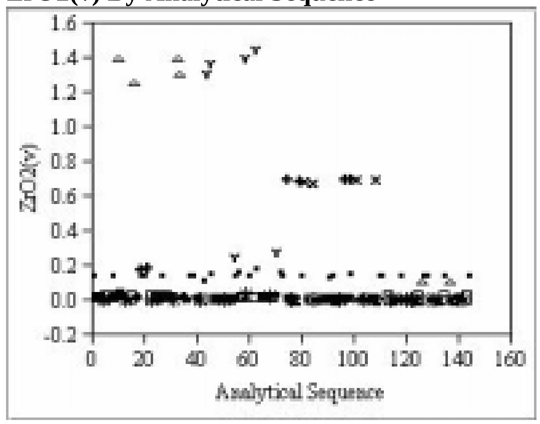


Exhibit E1. Plot of Oxide Concentrations (as wt%'s) in Analytical Sequence for LM Prep *(continued)*

NiO(v) By Analytical Sequence



ZrO2(v) By Analytical Sequence



SiO2(v) By Analytical Sequence

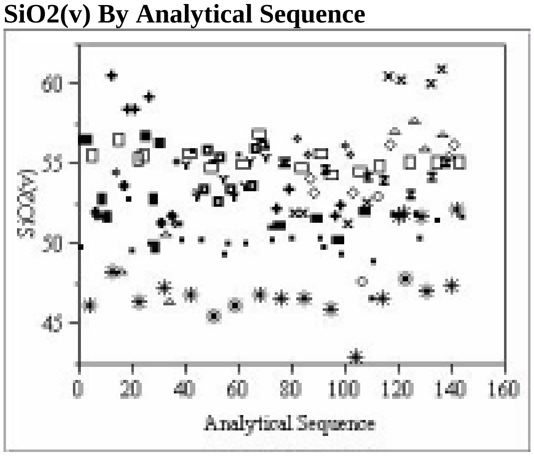
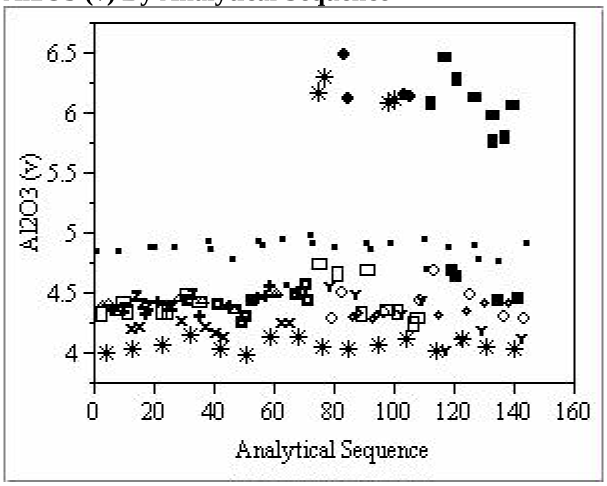
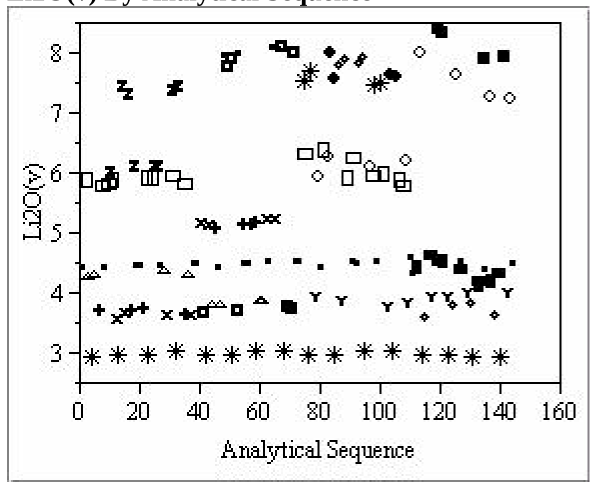


Exhibit E2. Plot of Oxide Concentrations (as wt%'s) in Analytical Sequence for PF Prep

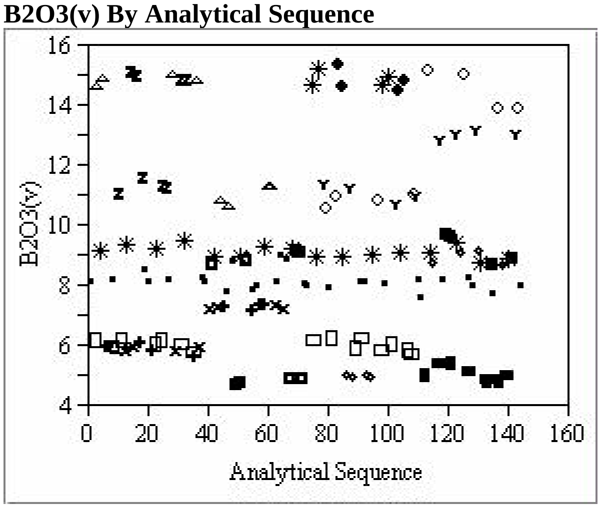
Al2O3 (v) By Analytical Sequence



Li2O(v) By Analytical Sequence



B2O3(v) By Analytical Sequence



U3O8(v) By Analytical Sequence

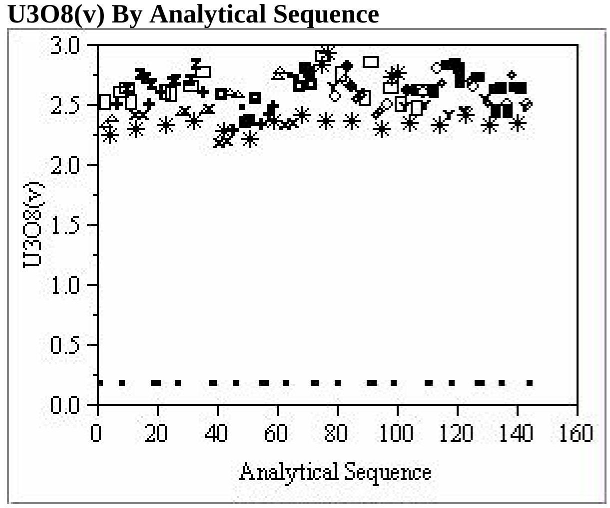
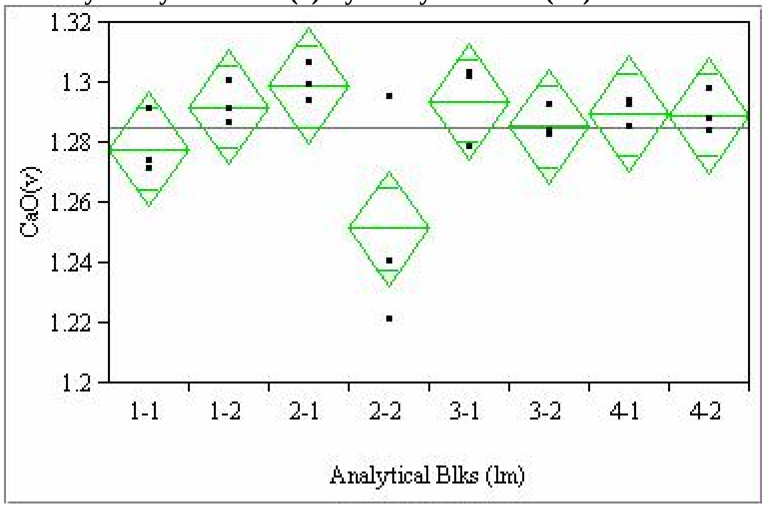


Exhibit E3. Measurements of Standards Prepared Using the Lithium Metaborate (LM) Method by Oxide by Analytical Block

(Small Square – Batch 1 and Asterisk – Ustd)

Oneway Analysis of CaO(v) By Analytical Blks (lm)



Oneway Anova

Summary of Fit

Rsquare	0.538258
Adj Rsquare	0.336246
Root Mean Square Error	0.015735
Mean of Response	1.284757
Observations (or Sum Wgts)	24

Analysis of Variance

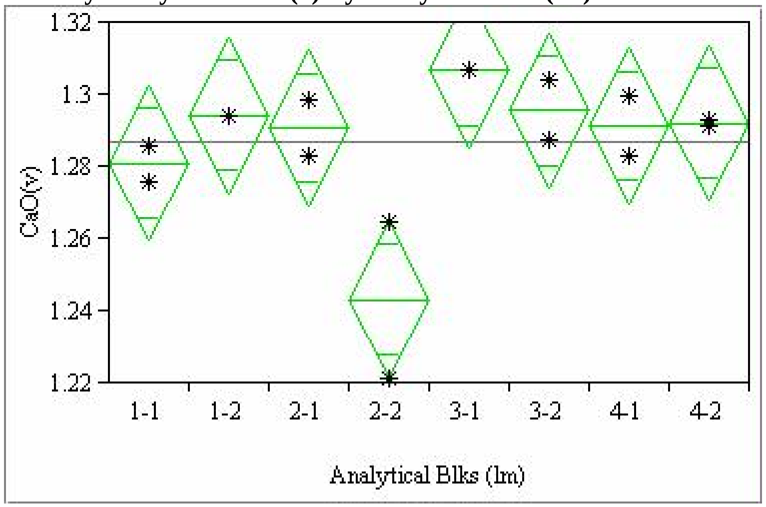
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.00461762	0.000660	2.6645	0.0495
Error	16	0.00396120	0.000248		
C. Total	23	0.00857883			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	1.27794	0.00908	1.2587	1.2972
1-2	3	1.29193	0.00908	1.2727	1.3112
2-1	3	1.29892	0.00908	1.2797	1.3182
2-2	3	1.25135	0.00908	1.2321	1.2706
3-1	3	1.29379	0.00908	1.2745	1.3131
3-2	3	1.28540	0.00908	1.2661	1.3047
4-1	3	1.28960	0.00908	1.2703	1.3089
4-2	3	1.28913	0.00908	1.2699	1.3084

Std Error uses a pooled estimate of error variance

Oneway Analysis of CaO(v) By Analytical Blks (lm)



Oneway Anova

Summary of Fit

Rsquare	0.785044
Adj Rsquare	0.596957
Root Mean Square Error	0.013181
Mean of Response	1.286914
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.00507647	0.000725	4.1738	0.0314
Error	8	0.00139001	0.000174		
C. Total	15	0.00646648			

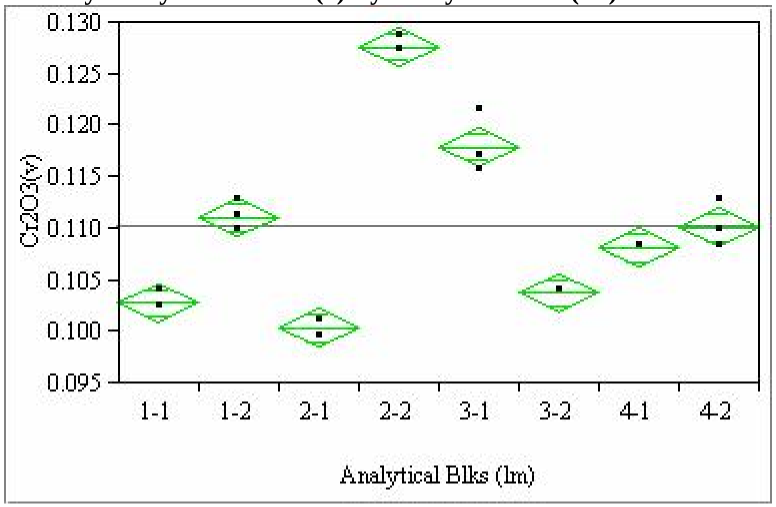
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	1.28097	0.00932	1.2595	1.3025
1-2	2	1.29426	0.00932	1.2728	1.3158
2-1	2	1.29076	0.00932	1.2693	1.3123
2-2	2	1.24319	0.00932	1.2217	1.2647
3-1	2	1.30685	0.00932	1.2854	1.3283
3-2	2	1.29566	0.00932	1.2742	1.3172
4-1	2	1.29146	0.00932	1.2700	1.3130
4-2	2	1.29216	0.00932	1.2707	1.3137

Std Error uses a pooled estimate of error variance

Exhibit E3. Measurements of Standards Prepared Using the Lithium Metaborate (LM) Method by Oxide by Analytical Block
(Small Square – Batch 1 and Asterisk – Ustd) *(Continued)*

Oneway Analysis of Cr2O3(v) By Analytical Blks (lm)



Oneway Anova
Summary of Fit

Rsquare	0.97849
Adj Rsquare	0.96908
Root Mean Square Error	0.001521
Mean of Response	0.110229
Observations (or Sum Wgts)	24

Analysis of Variance

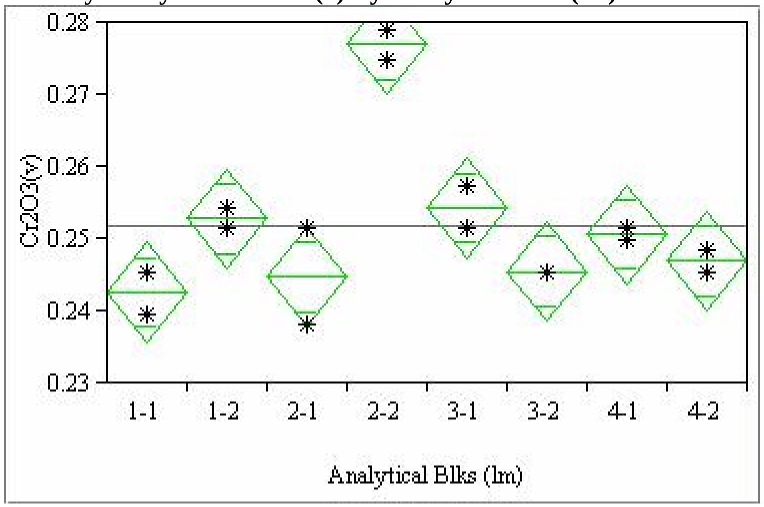
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.00168445	0.000241	103.9780	<.0001
Error	16	0.00003703	0.000002		
C. Total	23	0.00172148			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	0.102799	0.00088	0.10094	0.10466
1-2	3	0.111082	0.00088	0.10922	0.11294
2-1	3	0.100363	0.00088	0.09850	0.10223
2-2	3	0.127646	0.00088	0.12578	0.12951
3-1	3	0.117902	0.00088	0.11604	0.11976
3-2	3	0.103774	0.00088	0.10191	0.10564
4-1	3	0.108158	0.00088	0.10630	0.11002
4-2	3	0.110107	0.00088	0.10825	0.11197

Std Error uses a pooled estimate of error variance

Oneway Analysis of Cr2O3(v) By Analytical Blks (lm)



Oneway Anova
Summary of Fit

Rsquare	0.92289
Adj Rsquare	0.855419
Root Mean Square Error	0.004182
Mean of Response	0.251852
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.00167471	0.000239	13.6783	0.0007
Error	8	0.00013993	0.000017		
C. Total	15	0.00181463			

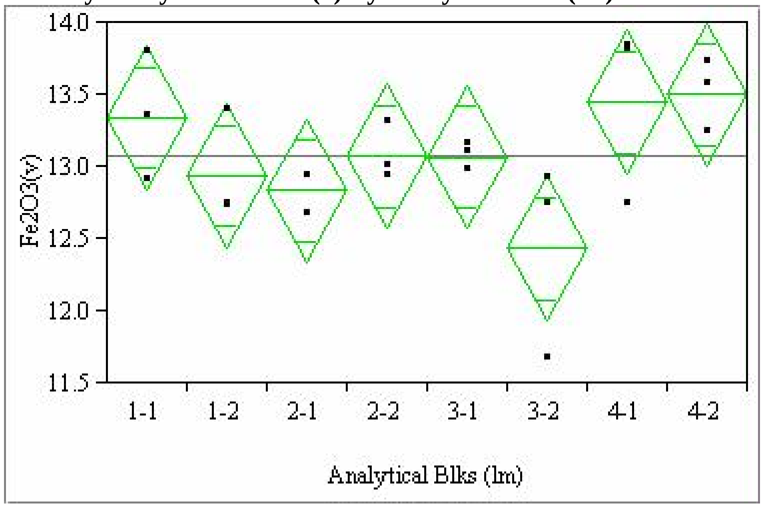
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	0.242626	0.00296	0.23581	0.24945
1-2	2	0.252857	0.00296	0.24604	0.25968
2-1	2	0.244818	0.00296	0.23800	0.25164
2-2	2	0.276973	0.00296	0.27015	0.28379
3-1	2	0.254318	0.00296	0.24750	0.26114
3-2	2	0.245549	0.00296	0.23873	0.25237
4-1	2	0.250664	0.00296	0.24384	0.25748
4-2	2	0.247010	0.00296	0.24019	0.25383

Std Error uses a pooled estimate of error variance

Exhibit E3. Measurements of Standards Prepared Using the Lithium Metaborate (LM) Method by Oxide by Analytical Block
(Small Square – Batch 1 and Asterisk – Ustd) *(Continued)*

Oneway Analysis of Fe2O3(v) By Analytical Blks (lm)



Oneway Anova
Summary of Fit

Rsquare	0.499394
Adj Rsquare	0.280378
Root Mean Square Error	0.406449
Mean of Response	13.07937
Observations (or Sum Wgts)	24

Analysis of Variance

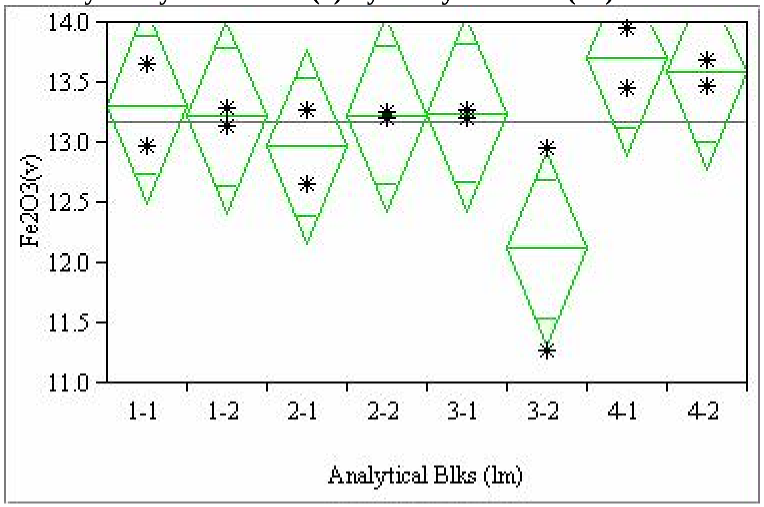
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	2.6368143	0.376688	2.2802	0.0816
Error	16	2.6432190	0.165201		
C. Total	23	5.2800333			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	13.3391	0.23466	12.842	13.837
1-2	3	12.9388	0.23466	12.441	13.436
2-1	3	12.8339	0.23466	12.336	13.331
2-2	3	13.0722	0.23466	12.575	13.570
3-1	3	13.0675	0.23466	12.570	13.565
3-2	3	12.4336	0.23466	11.936	12.931
4-1	3	13.4487	0.23466	12.951	13.946
4-2	3	13.5011	0.23466	13.004	13.999

Std Error uses a pooled estimate of error variance

Oneway Analysis of Fe2O3(v) By Analytical Blks (lm)



Oneway Anova
Summary of Fit

Rsquare	0.622016
Adj Rsquare	0.291281
Root Mean Square Error	0.499552
Mean of Response	13.1729
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	3.2853378	0.469334	1.8807	0.1976
Error	8	1.9964159	0.249552		
C. Total	15	5.2817537			

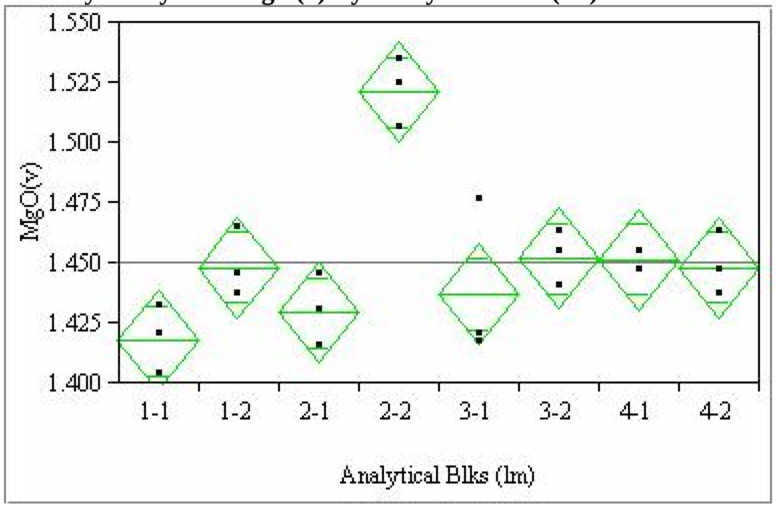
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	13.3105	0.35324	12.496	14.125
1-2	2	13.2176	0.35324	12.403	14.032
2-1	2	12.9674	0.35324	12.153	13.782
2-2	2	13.2319	0.35324	12.417	14.046
3-1	2	13.2462	0.35324	12.432	14.061
3-2	2	12.1167	0.35324	11.302	12.931
4-1	2	13.7037	0.35324	12.889	14.518
4-2	2	13.5893	0.35324	12.775	14.404

Std Error uses a pooled estimate of error variance

Exhibit E3. Measurements of Standards Prepared Using the Lithium Metaborate (LM) Method by Oxide by Analytical Block
(Small Square – Batch 1 and Asterisk – Ustd) *(Continued)*

Oneway Analysis of MgO(v) By Analytical Blks (lm)



Oneway Anova
Summary of Fit

Rsquare	0.813474
Adj Rsquare	0.731869
Root Mean Square Error	0.01697
Mean of Response	1.450561
Observations (or Sum Wgts)	24

Analysis of Variance

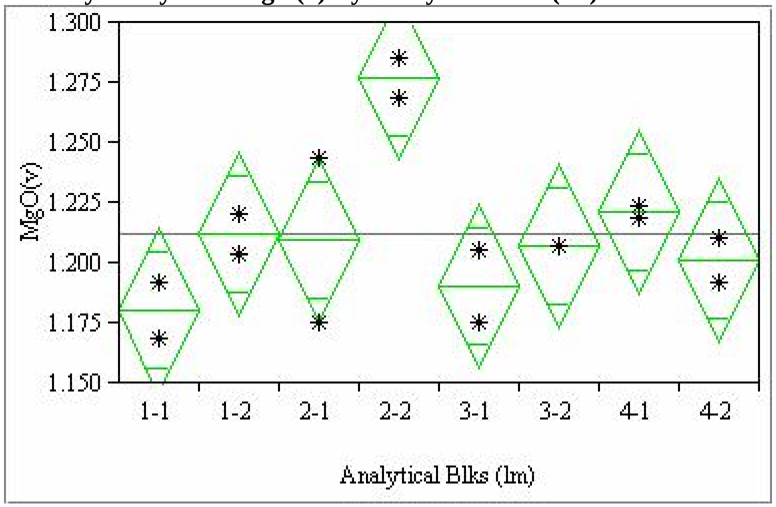
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.02009552	0.002871	9.9684	<.0001
Error	16	0.00460782	0.000288		
C. Total	23	0.02470334			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	1.41768	0.00980	1.3969	1.4384
1-2	3	1.44807	0.00980	1.4273	1.4688
2-1	3	1.42928	0.00980	1.4085	1.4501
2-2	3	1.52103	0.00980	1.5003	1.5418
3-1	3	1.43702	0.00980	1.4162	1.4578
3-2	3	1.45194	0.00980	1.4312	1.4727
4-1	3	1.45139	0.00980	1.4306	1.4722
4-2	3	1.44807	0.00980	1.4273	1.4688

Std Error uses a pooled estimate of error variance

Oneway Analysis of MgO(v) By Analytical Blks (lm)



Oneway Anova
Summary of Fit

Rsquare	0.771341
Adj Rsquare	0.571264
Root Mean Square Error	0.020854
Mean of Response	1.212382
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.01173657	0.001677	3.8552	0.0389
Error	8	0.00347923	0.000435		
C. Total	15	0.01521580			

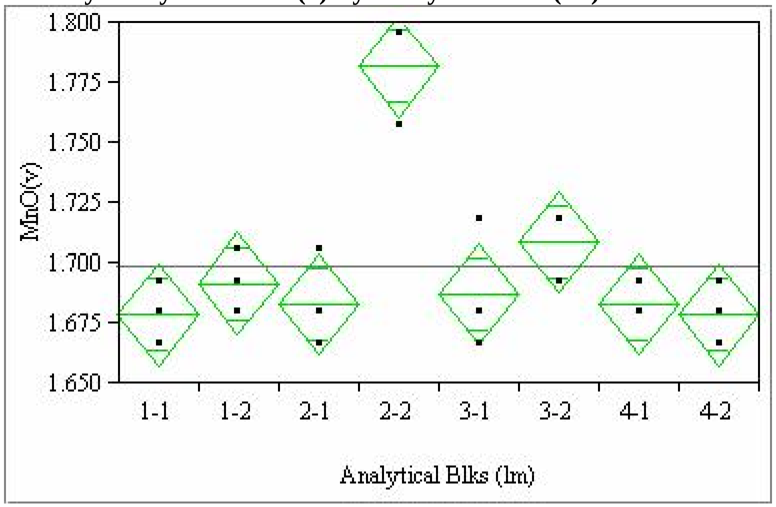
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	1.18057	0.01475	1.1466	1.2146
1-2	2	1.21207	0.01475	1.1781	1.2461
2-1	2	1.20958	0.01475	1.1756	1.2436
2-2	2	1.27674	0.01475	1.2427	1.3107
3-1	2	1.19052	0.01475	1.1565	1.2245
3-2	2	1.20710	0.01475	1.1731	1.2411
4-1	2	1.22119	0.01475	1.1872	1.2552
4-2	2	1.20129	0.01475	1.1673	1.2353

Std Error uses a pooled estimate of error variance

Exhibit E3. Measurements of Standards Prepared Using the Lithium Metaborate (LM) Method by Oxide by Analytical Block
(Small Square – Batch 1 and Asterisk – Ustd) *(Continued)*

Oneway Analysis of MnO(v) By Analytical Blks (lm)



Oneway Anova

Summary of Fit

Rsquare	0.842346
Adj Rsquare	0.773373
Root Mean Square Error	0.017283
Mean of Response	1.699004
Observations (or Sum Wgts)	24

Analysis of Variance

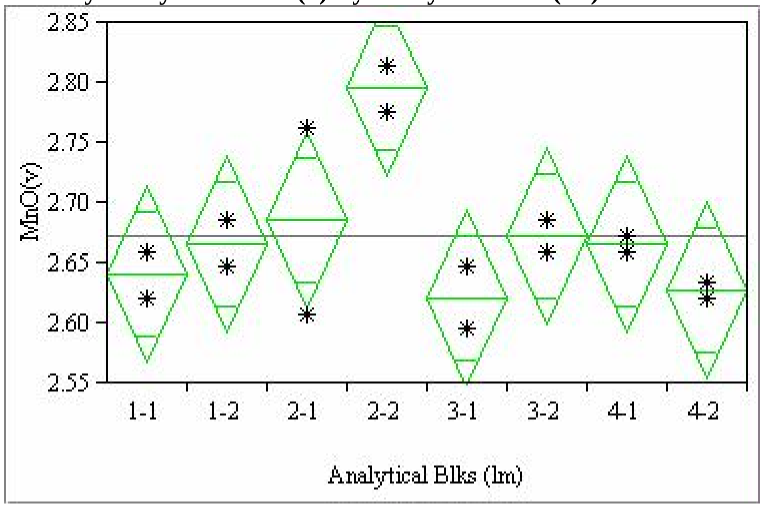
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.02553591	0.003648	12.2126	<.0001
Error	16	0.00477930	0.000299		
C. Total	23	0.03031521			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	1.67856	0.00998	1.6574	1.6997
1-2	3	1.69147	0.00998	1.6703	1.7126
2-1	3	1.68286	0.00998	1.6617	1.7040
2-2	3	1.78186	0.00998	1.7607	1.8030
3-1	3	1.68717	0.00998	1.6660	1.7083
3-2	3	1.70869	0.00998	1.6875	1.7298
4-1	3	1.68286	0.00998	1.6617	1.7040
4-2	3	1.67856	0.00998	1.6574	1.6997

Std Error uses a pooled estimate of error variance

Oneway Analysis of MnO(v) By Analytical Blks (lm)



Oneway Anova

Summary of Fit

Rsquare	0.723446
Adj Rsquare	0.481462
Root Mean Square Error	0.044845
Mean of Response	2.671977
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.04208632	0.006012	2.9896	0.0739
Error	8	0.01608846	0.002011		
C. Total	15	0.05817477			

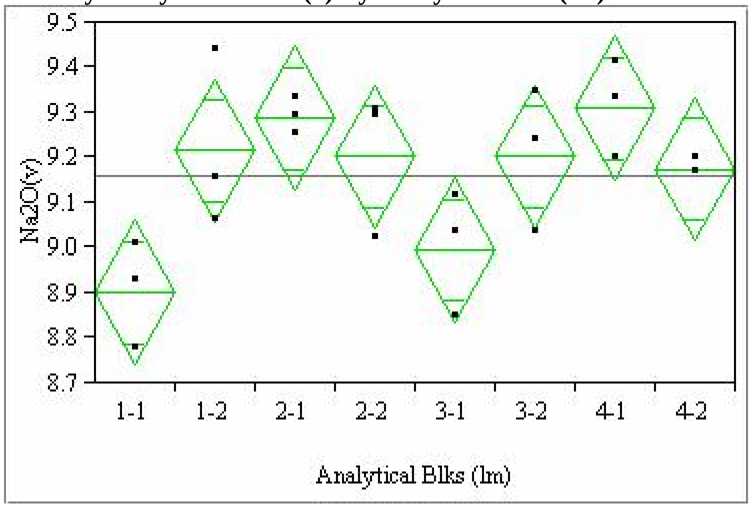
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	2.64050	0.03171	2.5674	2.7136
1-2	2	2.66633	0.03171	2.5932	2.7395
2-1	2	2.68570	0.03171	2.6126	2.7588
2-2	2	2.79545	0.03171	2.7223	2.8686
3-1	2	2.62114	0.03171	2.5480	2.6943
3-2	2	2.67278	0.03171	2.5997	2.7459
4-1	2	2.66633	0.03171	2.5932	2.7395
4-2	2	2.62759	0.03171	2.5545	2.7007

Std Error uses a pooled estimate of error variance

Exhibit E3. Measurements of Standards Prepared Using the Lithium Metaborate (LM) Method by Oxide by Analytical Block
(Small Square – Batch 1 and Asterisk – Ustd) *(Continued)*

Oneway Analysis of Na2O(v) By Analytical Blks (lm)



Oneway Anova
Summary of Fit

Rsquare	0.607794
Adj Rsquare	0.436204
Root Mean Square Error	0.130026
Mean of Response	9.161345
Observations (or Sum Wgts)	24

Analysis of Variance

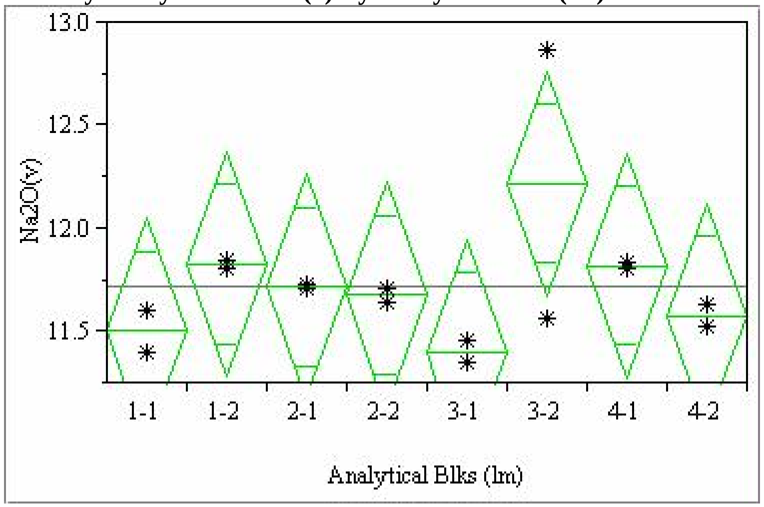
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.41919832	0.059885	3.5421	0.0171
Error	16	0.27050622	0.016907		
C. Total	23	0.68970454			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	8.90129	0.07507	8.7422	9.0604
1-2	3	9.21583	0.07507	9.0567	9.3750
2-1	3	9.28772	0.07507	9.1286	9.4469
2-2	3	9.20235	0.07507	9.0432	9.3615
3-1	3	8.99565	0.07507	8.8365	9.1548
3-2	3	9.20235	0.07507	9.0432	9.3615
4-1	3	9.31019	0.07507	9.1510	9.4693
4-2	3	9.17539	0.07507	9.0162	9.3345

Std Error uses a pooled estimate of error variance

Oneway Analysis of Na2O(v) By Analytical Blks (lm)



Oneway Anova
Summary of Fit

Rsquare	0.496555
Adj Rsquare	0.056041
Root Mean Square Error	0.33363
Mean of Response	11.72002
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.8782859	0.125469	1.1272	0.4306
Error	8	0.8904718	0.111309		
C. Total	15	1.7687577			

Means for Oneway Anova

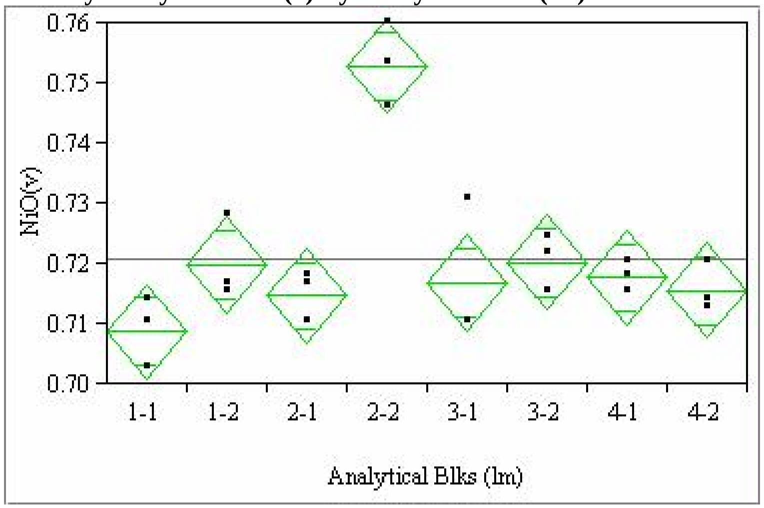
Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	11.5052	0.23591	10.961	12.049
1-2	2	11.8287	0.23591	11.285	12.373
2-1	2	11.7209	0.23591	11.177	12.265
2-2	2	11.6804	0.23591	11.136	12.224
3-1	2	11.4041	0.23591	10.860	11.948
3-2	2	12.2196	0.23591	11.676	12.764
4-1	2	11.8220	0.23591	11.278	12.366
4-2	2	11.5793	0.23591	11.035	12.123

Std Error uses a pooled estimate of error variance

Exhibit E3. Measurements of Standards Prepared Using the Lithium Metaborate (LM) Method by Oxide by Analytical Block

(Small Square – Batch 1 and Asterisk – Ustd) *(Continued)*

Oneway Analysis of NiO(v) By Analytical Blks (lm)



Oneway Anova

Summary of Fit

Rsquare	0.851365
Adj Rsquare	0.786338
Root Mean Square Error	0.006436
Mean of Response	0.720818
Observations (or Sum Wgts)	24

Analysis of Variance

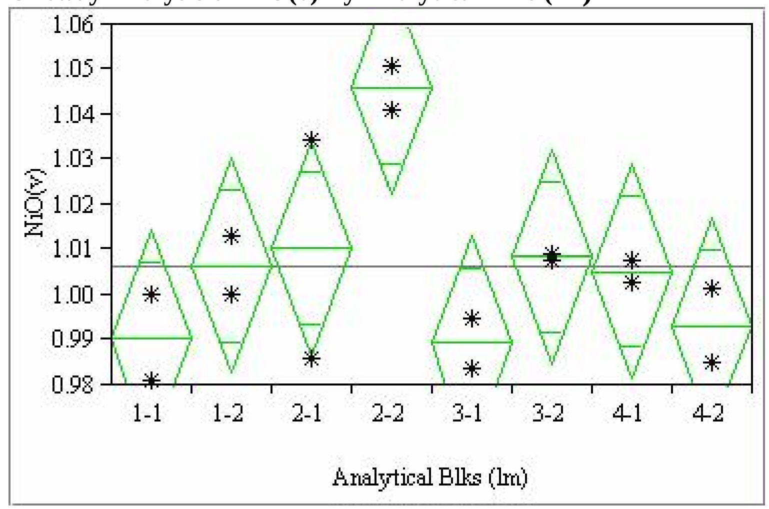
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.00379655	0.000542	13.0924	<.0001
Error	16	0.00066282	0.000041		
C. Total	23	0.00445936			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	0.708782	0.00372	0.70090	0.71666
1-2	3	0.719811	0.00372	0.71193	0.72769
2-1	3	0.714721	0.00372	0.70684	0.72260
2-2	3	0.752896	0.00372	0.74502	0.76077
3-1	3	0.716842	0.00372	0.70896	0.72472
3-2	3	0.720235	0.00372	0.71236	0.72811
4-1	3	0.717690	0.00372	0.70981	0.72557
4-2	3	0.715569	0.00372	0.70769	0.72345

Std Error uses a pooled estimate of error variance

Oneway Analysis of NiO(v) By Analytical Blks (lm)



Oneway Anova

Summary of Fit

Rsquare	0.730285
Adj Rsquare	0.494285
Root Mean Square Error	0.014578
Mean of Response	1.006229
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.00460355	0.000658	3.0944	0.0680
Error	8	0.00170022	0.000213		
C. Total	15	0.00630376			

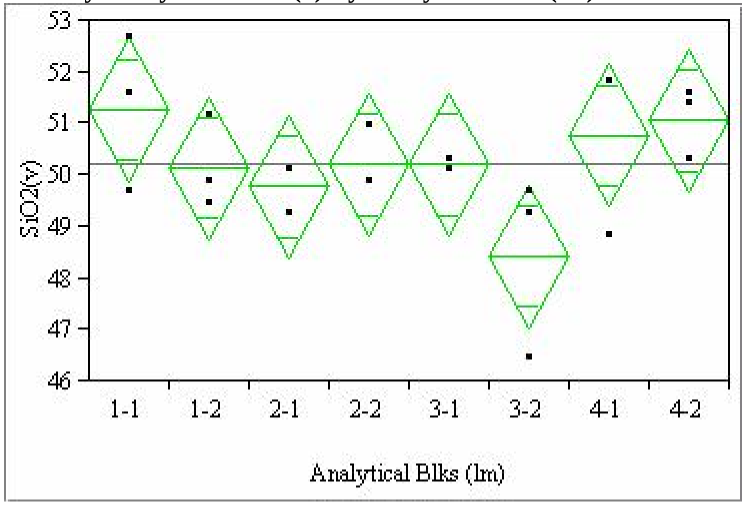
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	0.99064	0.01031	0.9669	1.0144
1-2	2	1.00655	0.01031	0.9828	1.0303
2-1	2	1.01037	0.01031	0.9866	1.0341
2-2	2	1.04600	0.01031	1.0222	1.0698
3-1	2	0.98937	0.01031	0.9656	1.0131
3-2	2	1.00846	0.01031	0.9847	1.0322
4-1	2	1.00528	0.01031	0.9815	1.0290
4-2	2	0.99319	0.01031	0.9694	1.0170

Std Error uses a pooled estimate of error variance

Exhibit E3. Measurements of Standards Prepared Using the Lithium Metaborate (LM) Method by Oxide by Analytical Block
(Small Square – Batch 1 and Asterisk – Ustd) *(Continued)*

Oneway Analysis of SiO2(v) By Analytical Blks (lm)



Oneway Anova
Summary of Fit

Rsquare	0.449069
Adj Rsquare	0.208036
Root Mean Square Error	1.131169
Mean of Response	50.22898
Observations (or Sum Wgts)	24

Analysis of Variance

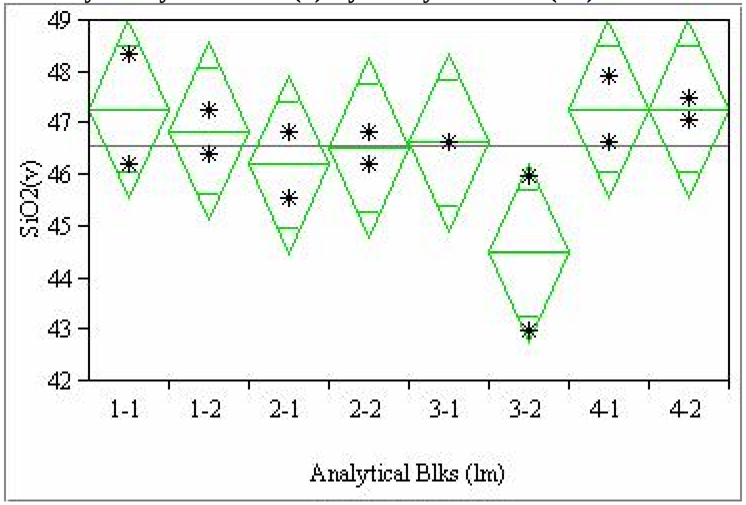
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	16.687444	2.38392	1.8631	0.1433
Error	16	20.472677	1.27954		
C. Total	23	37.160122			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	51.2719	0.65308	49.887	52.656
1-2	3	50.1309	0.65308	48.746	51.515
2-1	3	49.7744	0.65308	48.390	51.159
2-2	3	50.2022	0.65308	48.818	51.587
3-1	3	50.2022	0.65308	48.818	51.587
3-2	3	48.4195	0.65308	47.035	49.804
4-1	3	50.7727	0.65308	49.388	52.157
4-2	3	51.0580	0.65308	49.673	52.442

Std Error uses a pooled estimate of error variance

Oneway Analysis of SiO2(v) By Analytical Blks (lm)



Oneway Anova
Summary of Fit

Rsquare	0.569823
Adj Rsquare	0.193417
Root Mean Square Error	1.065631
Mean of Response	46.56989
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	12.033609	1.71909	1.5139	0.2860
Error	8	9.084560	1.13557		
C. Total	15	21.118169			

Means for Oneway Anova

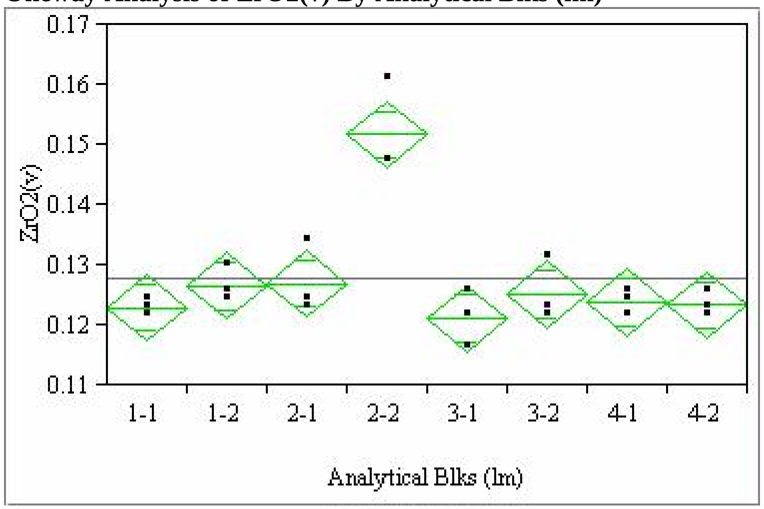
Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	47.2785	0.75352	45.541	49.016
1-2	2	46.8507	0.75352	45.113	48.588
2-1	2	46.2089	0.75352	44.471	47.946
2-2	2	46.5298	0.75352	44.792	48.267
3-1	2	46.6367	0.75352	44.899	48.374
3-2	2	44.4974	0.75352	42.760	46.235
4-1	2	47.2785	0.75352	45.541	49.016
4-2	2	47.2785	0.75352	45.541	49.016

Std Error uses a pooled estimate of error variance

Exhibit E3. Measurements of Standards Prepared Using the Lithium Metaborate (LM) Method by Oxide by Analytical Block

(Small Square – Batch 1 and Asterisk – Ustd) *(Continued*

Oneway Analysis of ZrO2(v) By Analytical Blks (lm)



Oneway Anova

Summary of Fit

Rsquare	0.863702
Adj Rsquare	0.804071
Root Mean Square Error	0.004505
Mean of Response	0.127707
Observations (or Sum Wgts)	24

Analysis of Variance

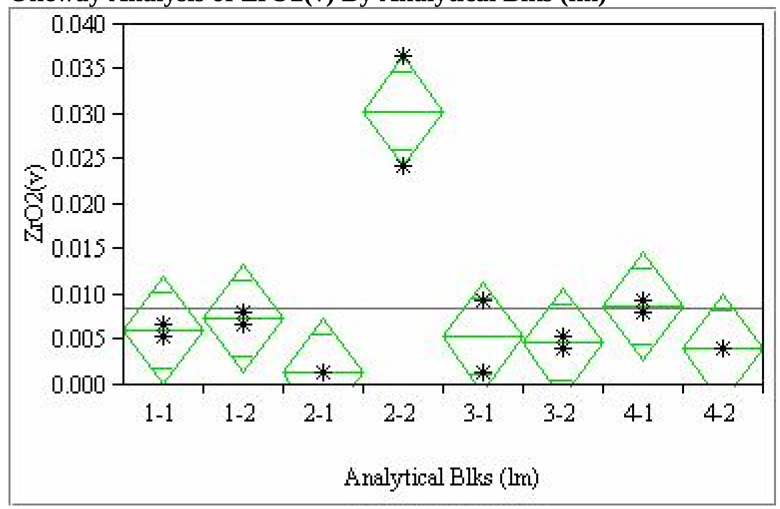
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.00205814	0.000294	14.4842	<.0001
Error	16	0.00032479	0.000020		
C. Total	23	0.00238293			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	0.122923	0.00260	0.11741	0.12844
1-2	3	0.126525	0.00260	0.12101	0.13204
2-1	3	0.126975	0.00260	0.12146	0.13249
2-2	3	0.151740	0.00260	0.14623	0.15725
3-1	3	0.121122	0.00260	0.11561	0.12664
3-2	3	0.125174	0.00260	0.11966	0.13069
4-1	3	0.123823	0.00260	0.11831	0.12934
4-2	3	0.123373	0.00260	0.11786	0.12889

Std Error uses a pooled estimate of error variance

Oneway Analysis of ZrO2(v) By Analytical Blks (lm)



Oneway Anova

Summary of Fit

Rsquare	0.913254
Adj Rsquare	0.837351
Root Mean Square Error	0.003715
Mean of Response	0.008527
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Blks (lm)	7	0.00116219	0.000166	12.0319	0.0011
Error	8	0.00011039	0.000014		
C. Total	15	0.00127259			

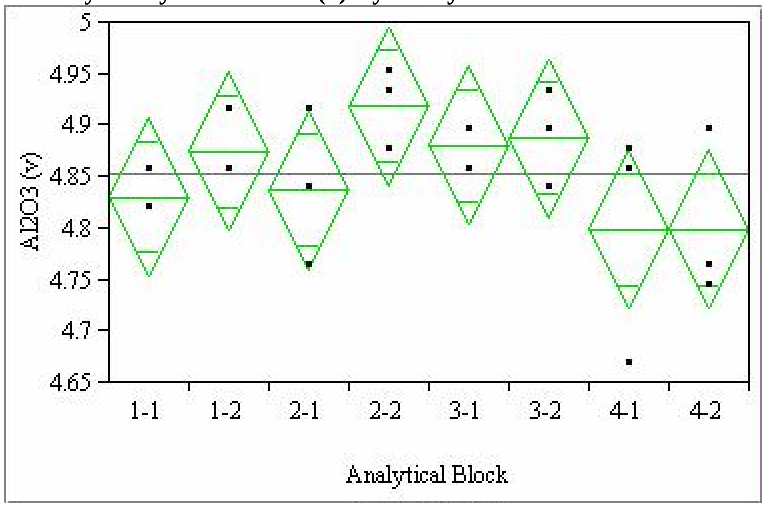
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	0.006079	0.00263	0.00002	0.01214
1-2	2	0.007429	0.00263	0.00137	0.01349
2-1	2	0.001351	0.00263	-0.0047	0.00741
2-2	2	0.030393	0.00263	0.02434	0.03645
3-1	2	0.005403	0.00263	-0.0007	0.01146
3-2	2	0.004728	0.00263	-0.0013	0.01078
4-1	2	0.008780	0.00263	0.00272	0.01484
4-2	2	0.004052	0.00263	-0.002	0.01011

Std Error uses a pooled estimate of error variance

Exhibit E4. Measurements of Standards Prepared Using the Peroxide Fusion (PF) Method by Oxide by Analytical Block
(Small Square – Batch 1 and Asterisk – Ustd)

Oneway Analysis of Al2O3 (v) By Analytical Block



Oneway Anova

Summary of Fit

Rsquare	0.387902
Adj Rsquare	0.12011
Root Mean Square Error	0.062786
Mean of Response	4.853653
Observations (or Sum Wgts)	24

Analysis of Variance

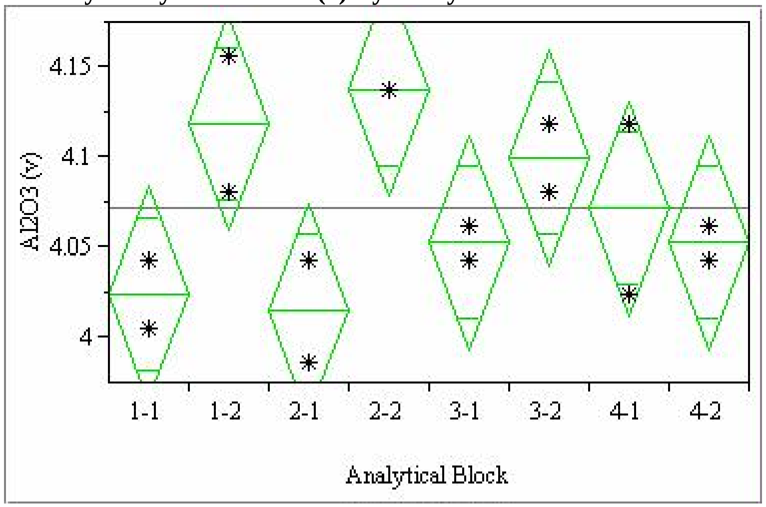
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Block	7	0.03997148	0.005710	1.4485	0.2540
Error	16	0.06307371	0.003942		
C. Total	23	0.10304519			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	4.83082	0.03625	4.7540	4.9077
1-2	3	4.87491	0.03625	4.7981	4.9518
2-1	3	4.83712	0.03625	4.7603	4.9140
2-2	3	4.91900	0.03625	4.8422	4.9958
3-1	3	4.88121	0.03625	4.8044	4.9581
3-2	3	4.88751	0.03625	4.8107	4.9644
4-1	3	4.79933	0.03625	4.7225	4.8762
4-2	3	4.79933	0.03625	4.7225	4.8762

Std Error uses a pooled estimate of error variance

Oneway Analysis of Al2O3 (v) By Analytical Block



Oneway Anova

Summary of Fit

Rsquare	0.716981
Adj Rsquare	0.46934
Root Mean Square Error	0.03659
Mean of Response	4.071872
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Block	7	0.02713360	0.003876	2.8952	0.0798
Error	8	0.01071063	0.001339		
C. Total	15	0.03784423			

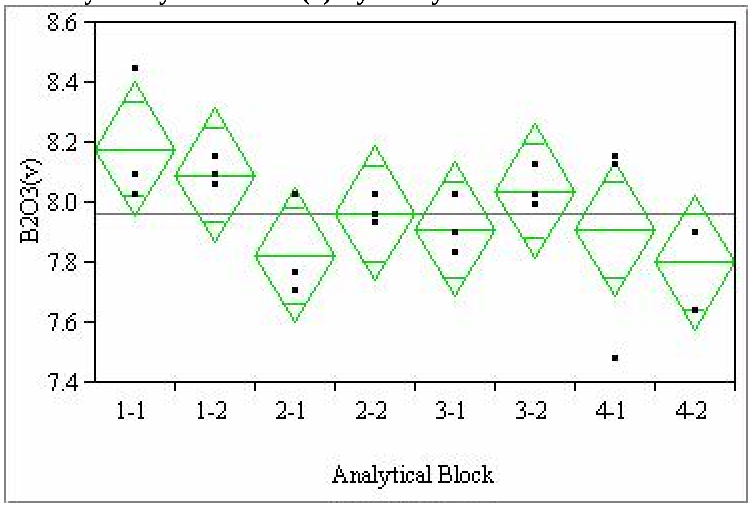
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	4.02464	0.02587	3.9650	4.0843
1-2	2	4.11911	0.02587	4.0594	4.1788
2-1	2	4.01519	0.02587	3.9555	4.0749
2-2	2	4.13800	0.02587	4.0783	4.1977
3-1	2	4.05298	0.02587	3.9933	4.1126
3-2	2	4.10022	0.02587	4.0406	4.1599
4-1	2	4.07187	0.02587	4.0122	4.1315
4-2	2	4.05298	0.02587	3.9933	4.1126

Std Error uses a pooled estimate of error variance

Exhibit E4. Measurements of Standards Prepared Using the Peroxide Fusion (PF) Method by Oxide by Analytical Block
(Small Square – Batch 1 and Asterisk – Ustd) *(Continued*

Oneway Analysis of B2O3(v) By Analytical Block



Oneway Anova

Summary of Fit

Rsquare	0.402065
Adj Rsquare	0.140468
Root Mean Square Error	0.1825
Mean of Response	7.965228
Observations (or Sum Wgts)	24

Analysis of Variance

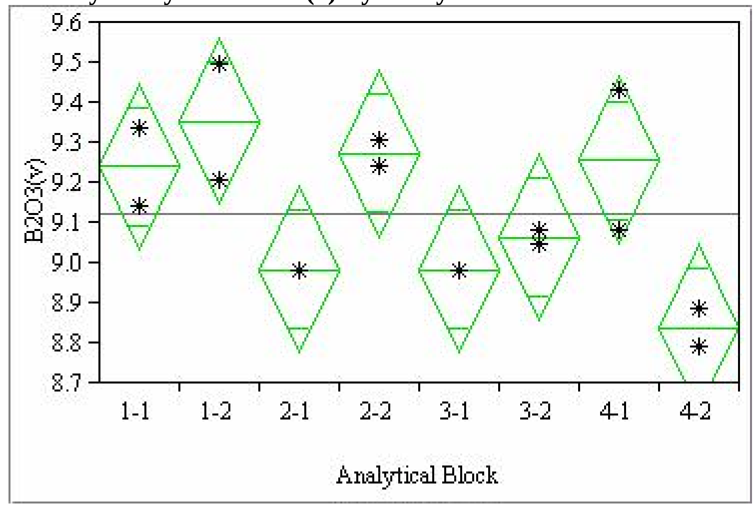
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Block	7	0.35833557	0.051191	1.5370	0.2248
Error	16	0.53290266	0.033306		
C. Total	23	0.89123823			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	8.17855	0.10537	7.9552	8.4019
1-2	3	8.09268	0.10537	7.8693	8.3160
2-1	3	7.82436	0.10537	7.6010	8.0477
2-2	3	7.96389	0.10537	7.7405	8.1873
3-1	3	7.91022	0.10537	7.6869	8.1336
3-2	3	8.03902	0.10537	7.8156	8.2624
4-1	3	7.91022	0.10537	7.6869	8.1336
4-2	3	7.80289	0.10537	7.5795	8.0263

Std Error uses a pooled estimate of error variance

Oneway Analysis of B2O3(v) By Analytical Block



Oneway Anova

Summary of Fit

Rsquare	0.779624
Adj Rsquare	0.586795
Root Mean Square Error	0.127786
Mean of Response	9.124392
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Block	7	0.46214272	0.066020	4.0431	0.0342
Error	8	0.13063373	0.016329		
C. Total	15	0.59277645			

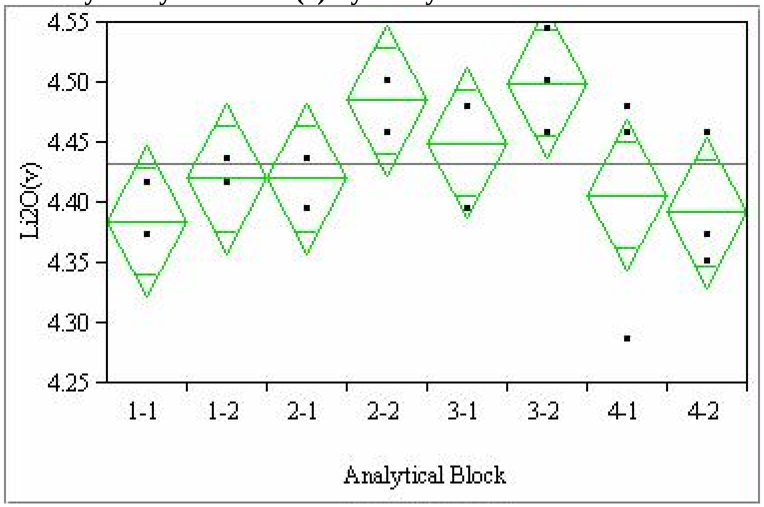
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	9.24111	0.09036	9.0327	9.4495
1-2	2	9.35381	0.09036	9.1454	9.5622
2-1	2	8.98352	0.09036	8.7752	9.1919
2-2	2	9.27331	0.09036	9.0649	9.4817
3-1	2	8.98352	0.09036	8.7752	9.1919
3-2	2	9.06402	0.09036	8.8557	9.2724
4-1	2	9.25721	0.09036	9.0488	9.4656
4-2	2	8.83863	0.09036	8.6303	9.0470

Std Error uses a pooled estimate of error variance

Exhibit E4. Measurements of Standards Prepared Using the Peroxide Fusion (PF) Method by Oxide by Analytical Block
(Small Square – Batch 1 and Asterisk – Ustd) *(Continued*

Oneway Analysis of Li2O(v) By Analytical Block



Oneway Anova
Summary of Fit

Rsquare	0.472527
Adj Rsquare	0.241758
Root Mean Square Error	0.051061
Mean of Response	4.432283
Observations (or Sum Wgts)	24

Analysis of Variance

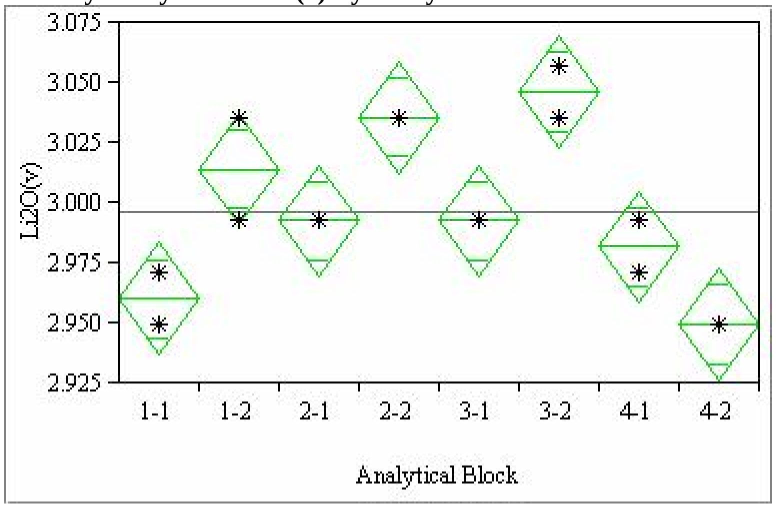
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Block	7	0.03736951	0.005339	2.0476	0.1114
Error	16	0.04171481	0.002607		
C. Total	23	0.07908432			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	4.38474	0.02948	4.3222	4.4472
1-2	3	4.42062	0.02948	4.3581	4.4831
2-1	3	4.42062	0.02948	4.3581	4.4831
2-2	3	4.48521	0.02948	4.4227	4.5477
3-1	3	4.44933	0.02948	4.3868	4.5118
3-2	3	4.49956	0.02948	4.4371	4.5621
4-1	3	4.40627	0.02948	4.3438	4.4688
4-2	3	4.39192	0.02948	4.3294	4.4544

Std Error uses a pooled estimate of error variance

Oneway Analysis of Li2O(v) By Analytical Block



Oneway Anova
Summary of Fit

Rsquare	0.908943
Adj Rsquare	0.829268
Root Mean Square Error	0.01424
Mean of Response	2.996568
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Block	7	0.01619346	0.002313	11.4082	0.0013
Error	8	0.00162224	0.000203		
C. Total	15	0.01781570			

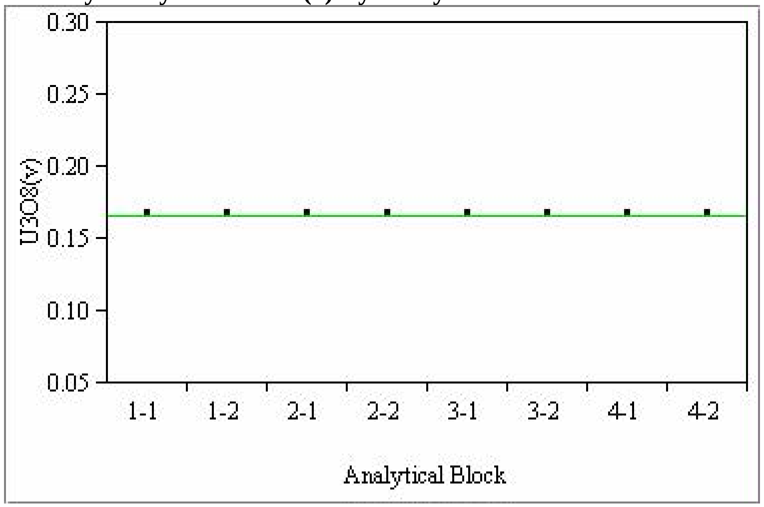
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	2.96024	0.01007	2.9370	2.9835
1-2	2	3.01406	0.01007	2.9908	3.0373
2-1	2	2.99253	0.01007	2.9693	3.0158
2-2	2	3.03559	0.01007	3.0124	3.0588
3-1	2	2.99253	0.01007	2.9693	3.0158
3-2	2	3.04635	0.01007	3.0231	3.0696
4-1	2	2.98177	0.01007	2.9585	3.0050
4-2	2	2.94947	0.01007	2.9263	2.9727

Std Error uses a pooled estimate of error variance

Exhibit E4. Measurements of Standards Prepared Using the Peroxide Fusion (PF) Method by Oxide by Analytical Block
(Small Square – Batch 1 and Asterisk – Ustd) *(Continued*

Oneway Analysis of U3O8(v) By Analytical Block



Oneway Anova
Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.165678
Observations (or Sum Wgts)	24

Analysis of Variance

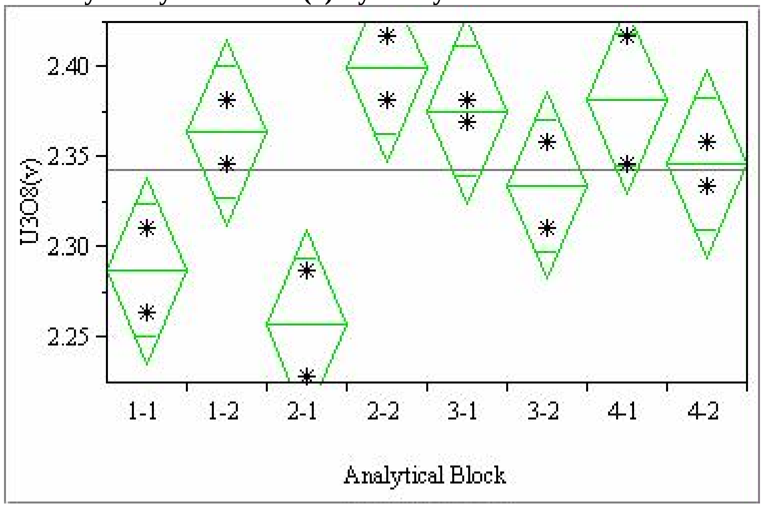
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Block	7	0	0	.	-1.0000
Error	16	0	0		
C. Total	23	0			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	3	0.165678	0	0.16568	0.16568
1-2	3	0.165678	0	0.16568	0.16568
2-1	3	0.165678	0	0.16568	0.16568
2-2	3	0.165678	0	0.16568	0.16568
3-1	3	0.165678	0	0.16568	0.16568
3-2	3	0.165678	0	0.16568	0.16568
4-1	3	0.165678	0	0.16568	0.16568
4-2	3	0.165678	0	0.16568	0.16568

Std Error uses a pooled estimate of error variance

Oneway Analysis of U3O8(v) By Analytical Block



Oneway Anova
Summary of Fit

Rsquare	0.804714
Adj Rsquare	0.633838
Root Mean Square Error	0.031751
Mean of Response	2.34366
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Analytical Block	7	0.03323325	0.004748	4.7094	0.0224
Error	8	0.00806497	0.001008		
C. Total	15	0.04129823			

Means for Oneway Anova

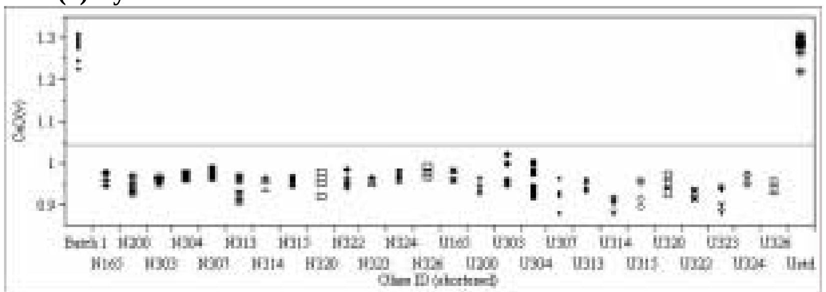
Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1-1	2	2.28765	0.02245	2.2359	2.3394
1-2	2	2.36430	0.02245	2.3125	2.4161
2-1	2	2.25817	0.02245	2.2064	2.3099
2-2	2	2.39967	0.02245	2.3479	2.4514
3-1	2	2.37609	0.02245	2.3243	2.4279
3-2	2	2.33482	0.02245	2.2830	2.3866
4-1	2	2.38198	0.02245	2.3302	2.4338
4-2	2	2.34661	0.02245	2.2948	2.3984

Std Error uses a pooled estimate of error variance

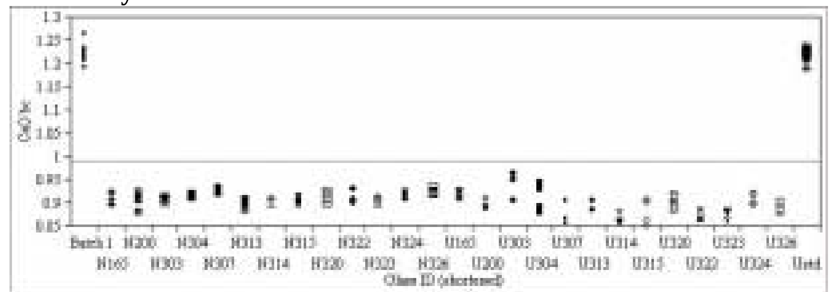
Exhibit E5. Plots of Oxide Concentrations by Shortened Glass ID for LM Method

(Concentrations in wt%'s, Plots for both Measured and Measured Bias-Corrected (bc) are shown)

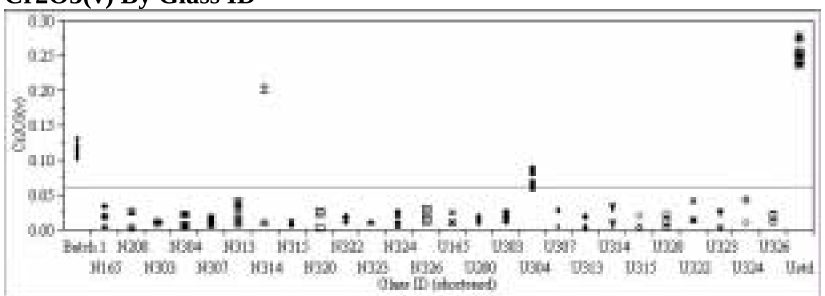
CaO(v) By Glass ID



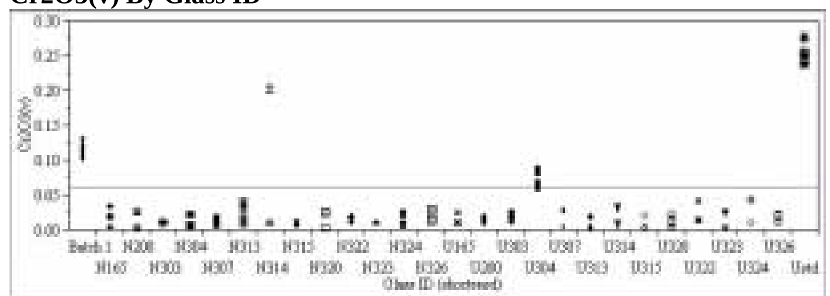
CaO bc By Glass ID



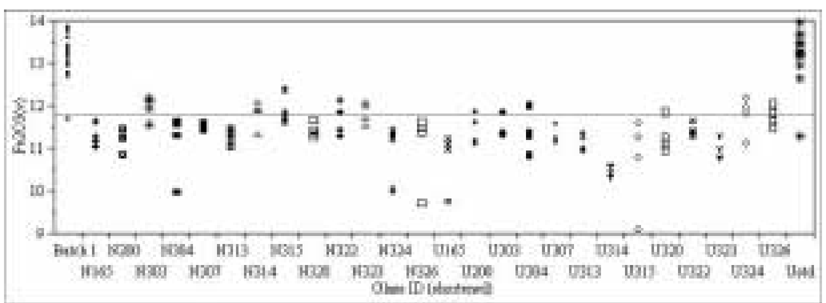
Cr2O3(v) By Glass ID



Cr2O3(v) By Glass ID



Fe2O3(v) By Glass ID



Fe2O3 bc By Glass ID

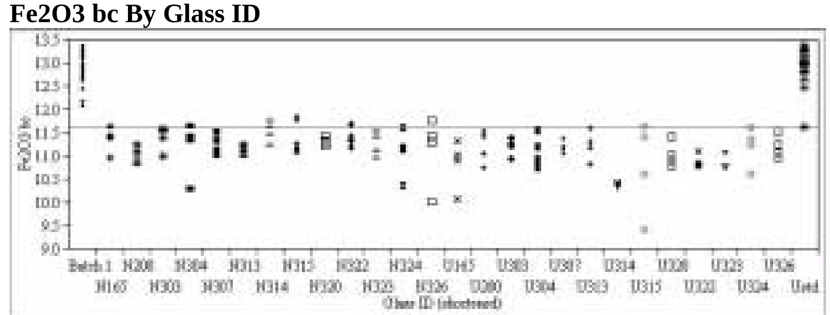
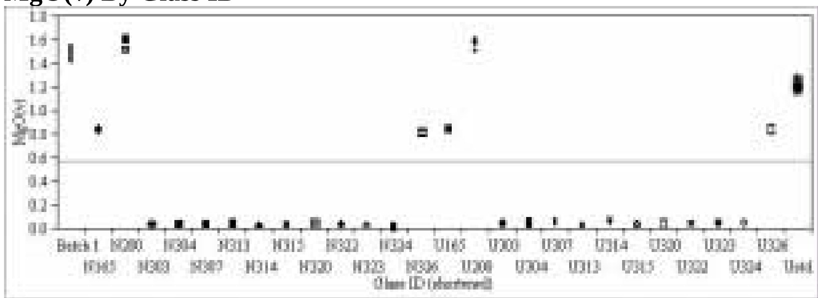
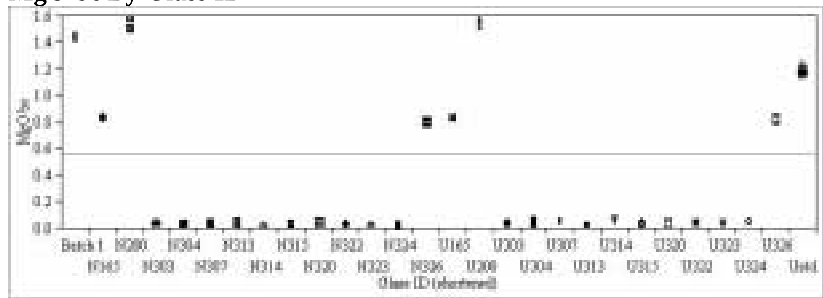


Exhibit E5. Plots of Oxide Concentrations by Shortened Glass ID for LM Method *(continued)*
(Concentrations in wt%'s, Plots for both Measured and Measured Bias-Corrected (bc) are shown)

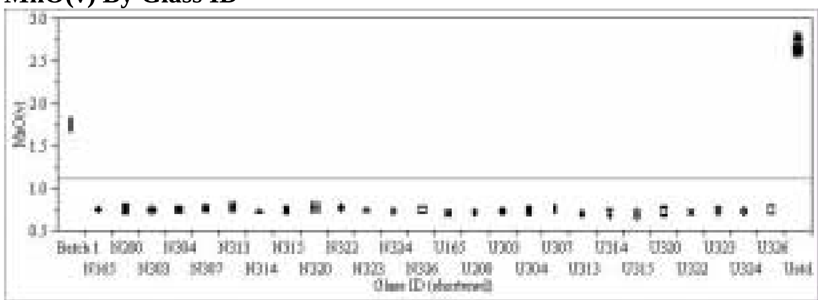
MgO(v) By Glass ID



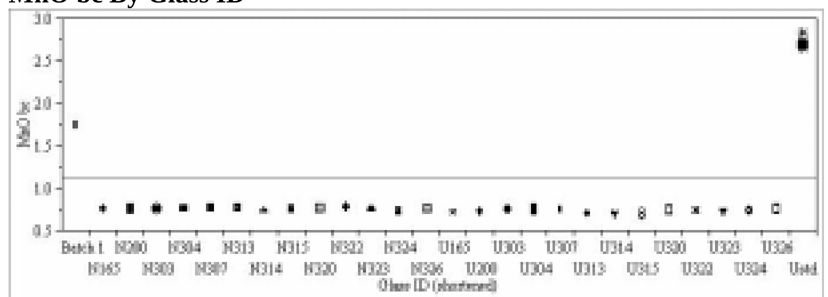
MgO bc By Glass ID



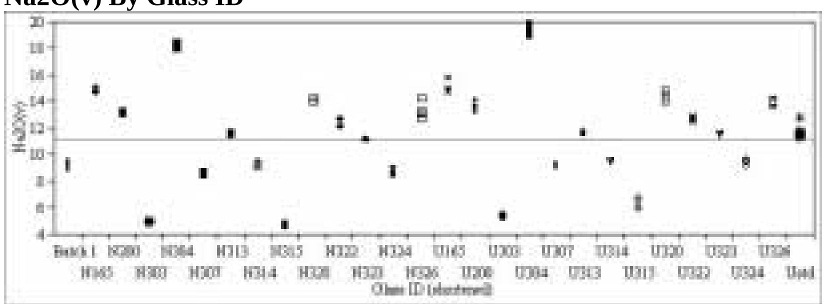
MnO(v) By Glass ID



MnO bc By Glass ID



Na2O(v) By Glass ID



Na2O bc By Glass ID

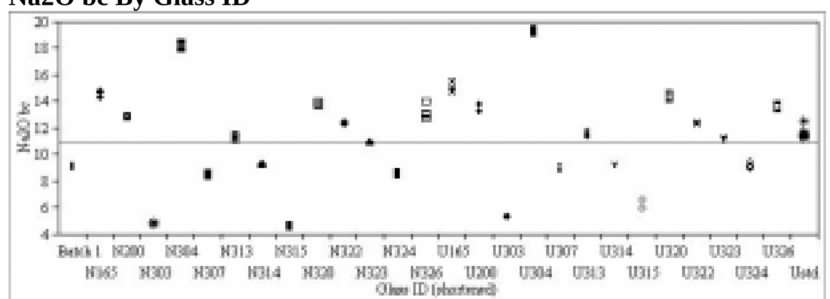
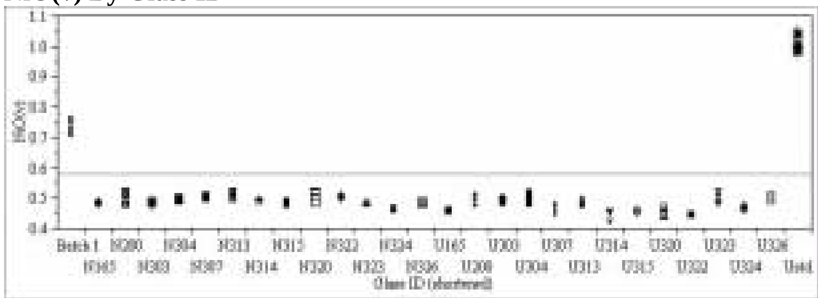
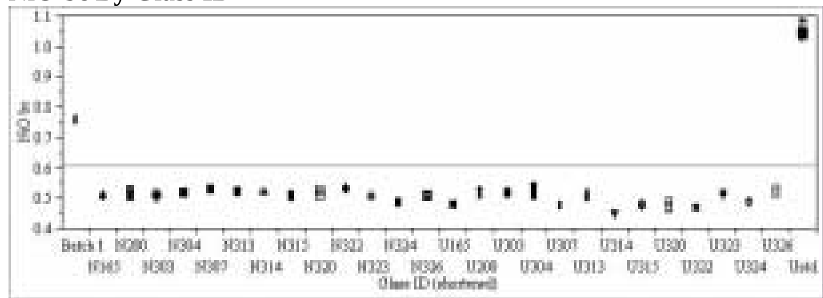


Exhibit E5. Plots of Oxide Concentrations by Shortened Glass ID for LM Method *(continued)*
(Concentrations in wt%'s, Plots for both Measured and Measured Bias-Corrected (bc) are shown)

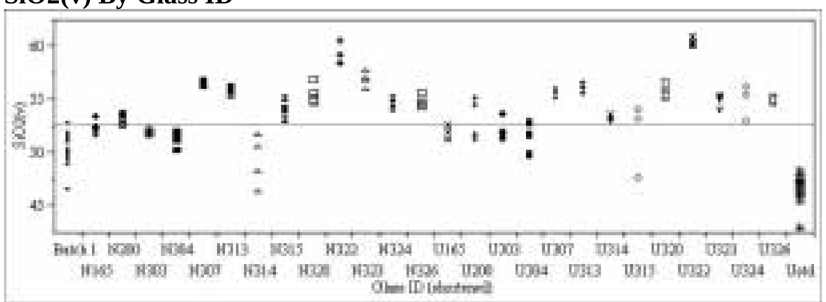
NiO(v) By Glass ID



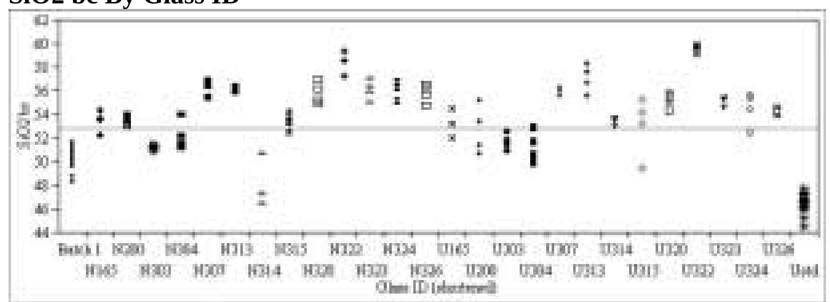
NiO bc By Glass ID



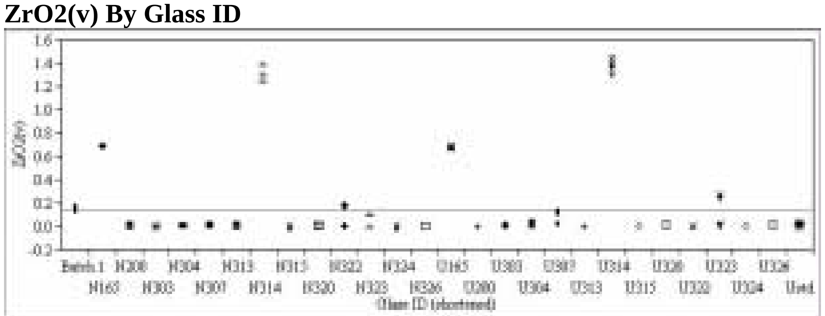
SiO2(v) By Glass ID



SiO2 bc By Glass ID



ZrO2(v) By Glass ID



ZrO2 bc By Glass ID

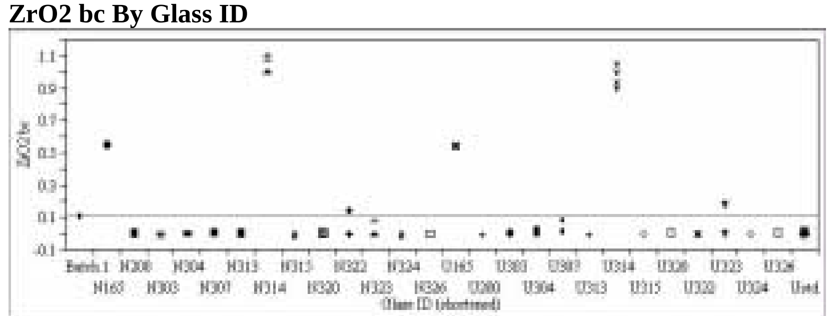
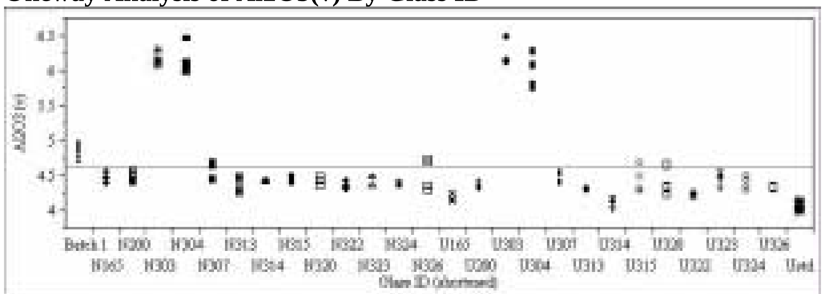
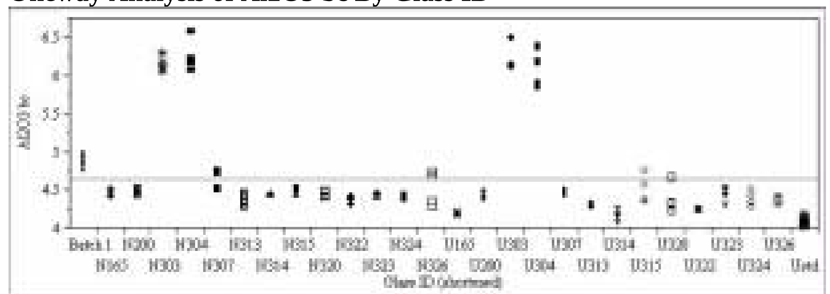


Exhibit E6. Plots of Oxide Concentrations by Shortened Glass ID for PF Method
(Concentrations in wt%'s, Plots for both Measured and Measured Bias-Corrected (bc) are shown)

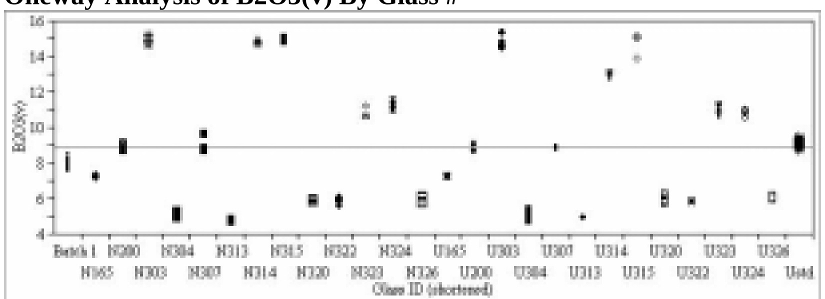
Oneway Analysis of Al2O3(v) By Glass ID



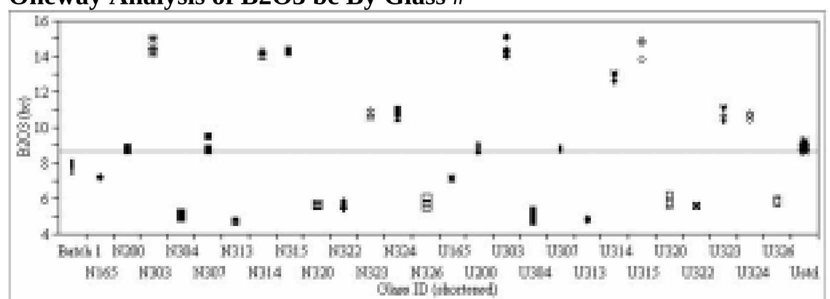
Oneway Analysis of Al2O3 bc By Glass ID



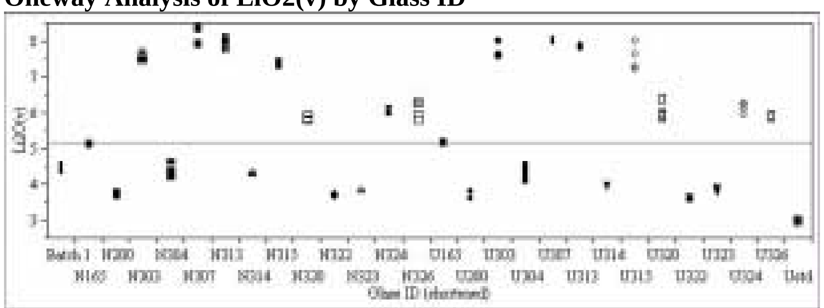
Oneway Analysis of B2O3(v) By Glass #



Oneway Analysis of B2O3 bc By Glass #



Oneway Analysis of LiO2(v) by Glass ID



Oneway Analysis of LiO2 bc by Glass ID

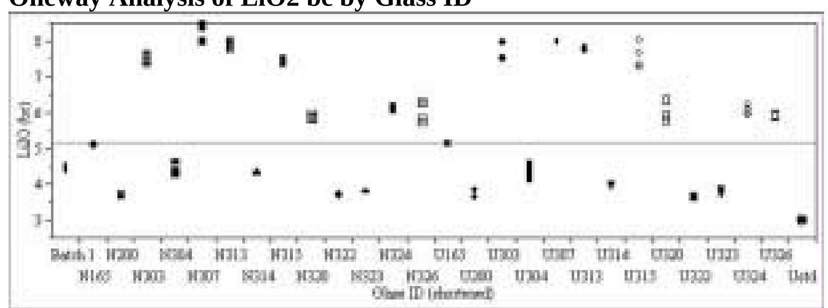
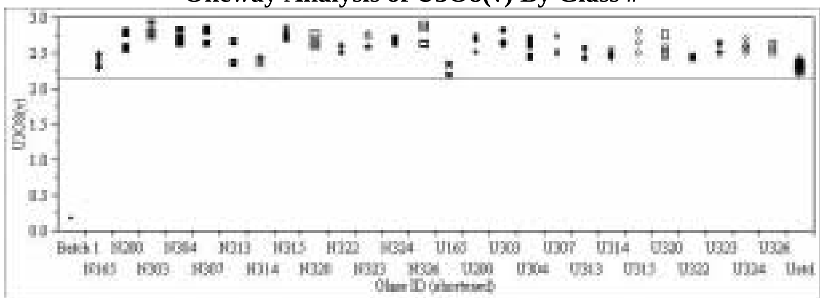


Exhibit E6. Plots of Oxide Concentrations by Shortened Glass ID for PF Method *(continued)*
(Concentrations in wt%'s, Plots for both Measured and Measured Bias-Corrected (bc) are shown)

Oneway Analysis of U3O8(v) By Glass #



Oneway Analysis of U3O8 bcBy Glass #

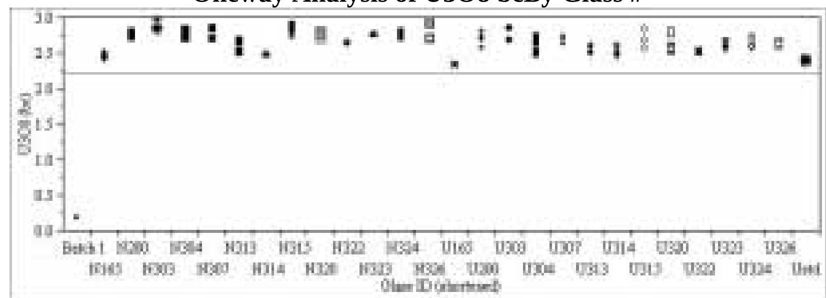
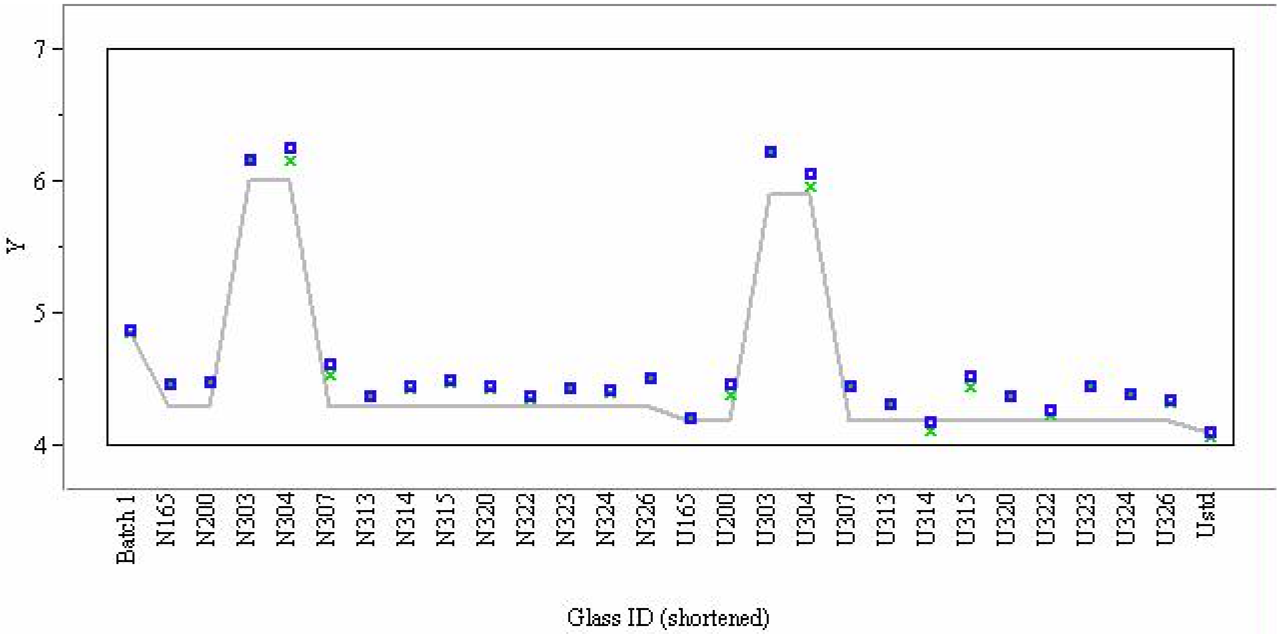


Exhibit E7. Comparisons of Measured versus Targeted Chemical Compositions
(Concentrations in wt%'s)

Al2O3



B2O3

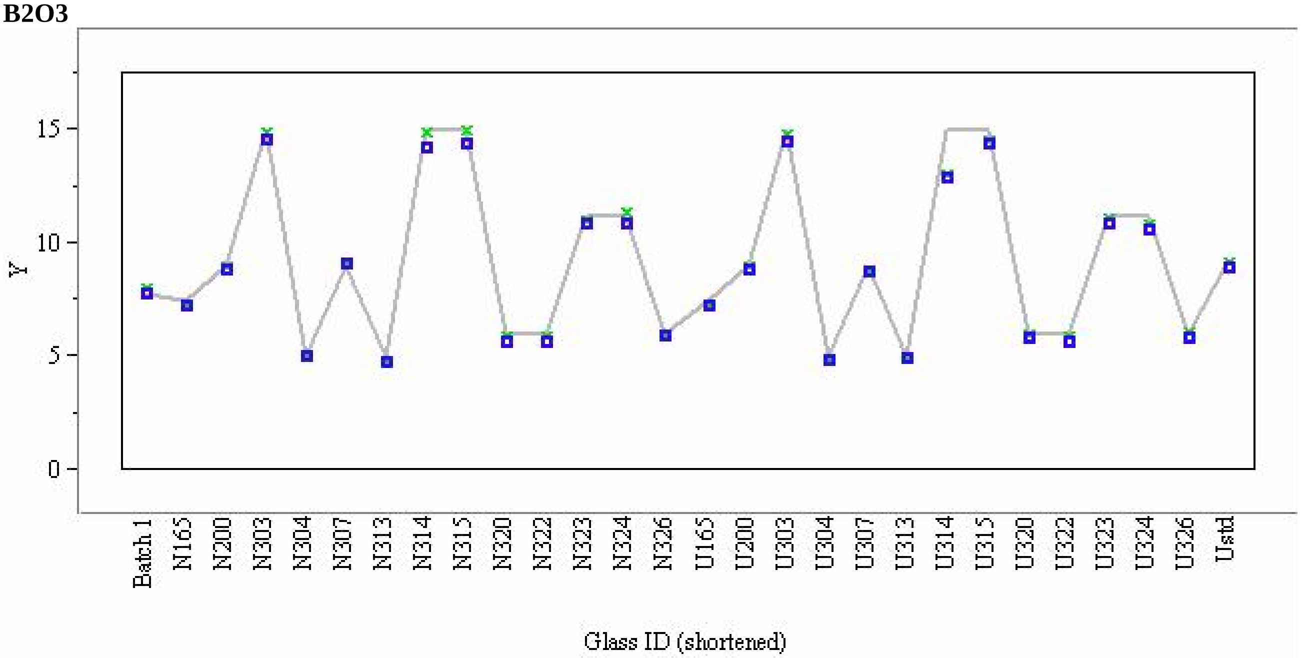
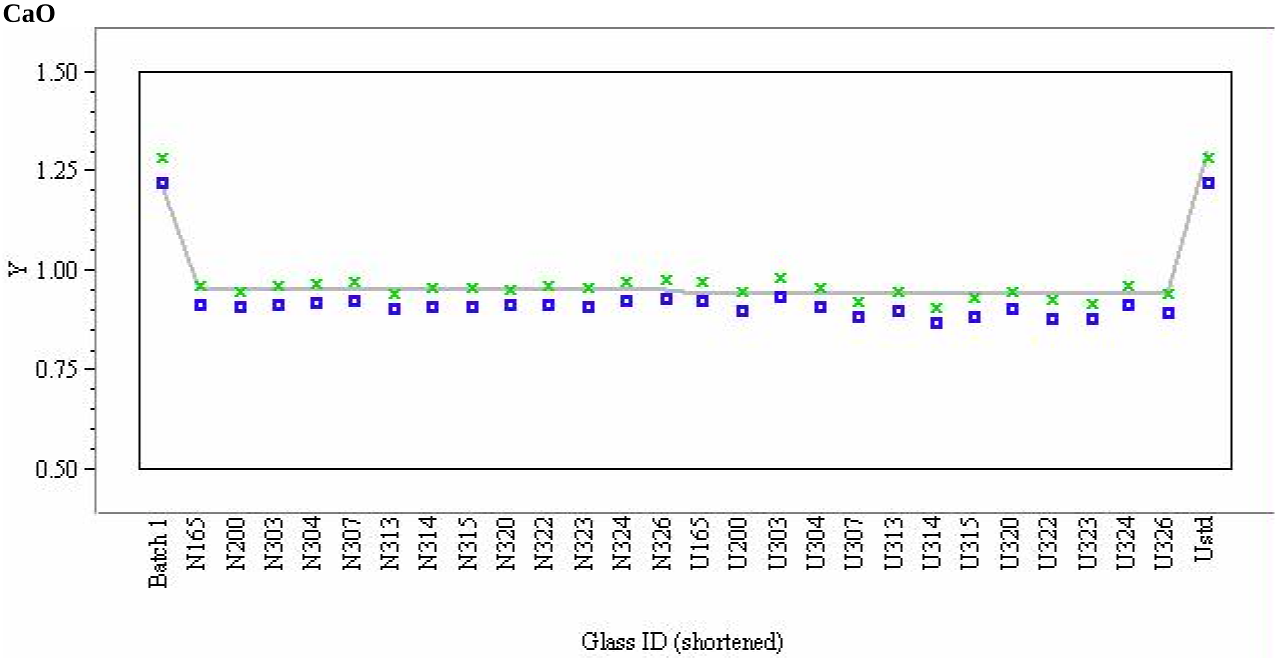
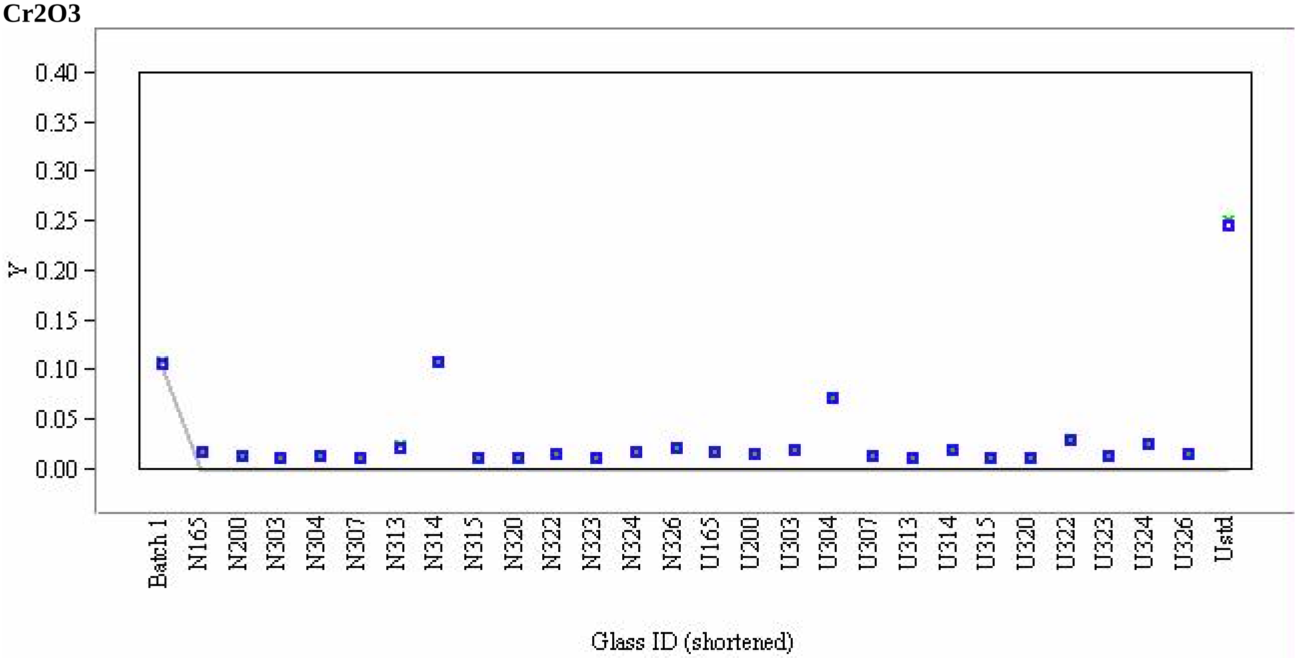


Exhibit E7. Comparisons of Measured versus Targeted Chemical Compositions
(Concentrations in wt%'s)

CaO



Cr2O3



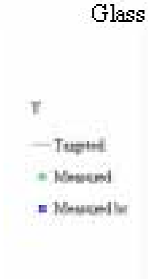
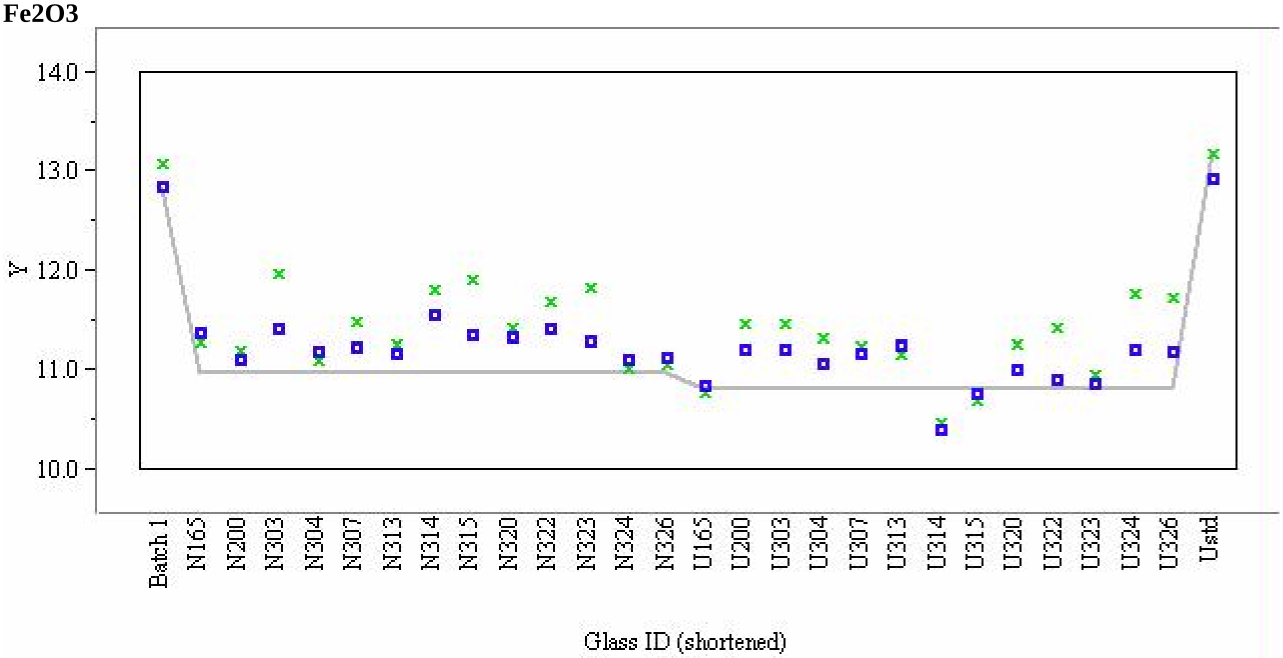
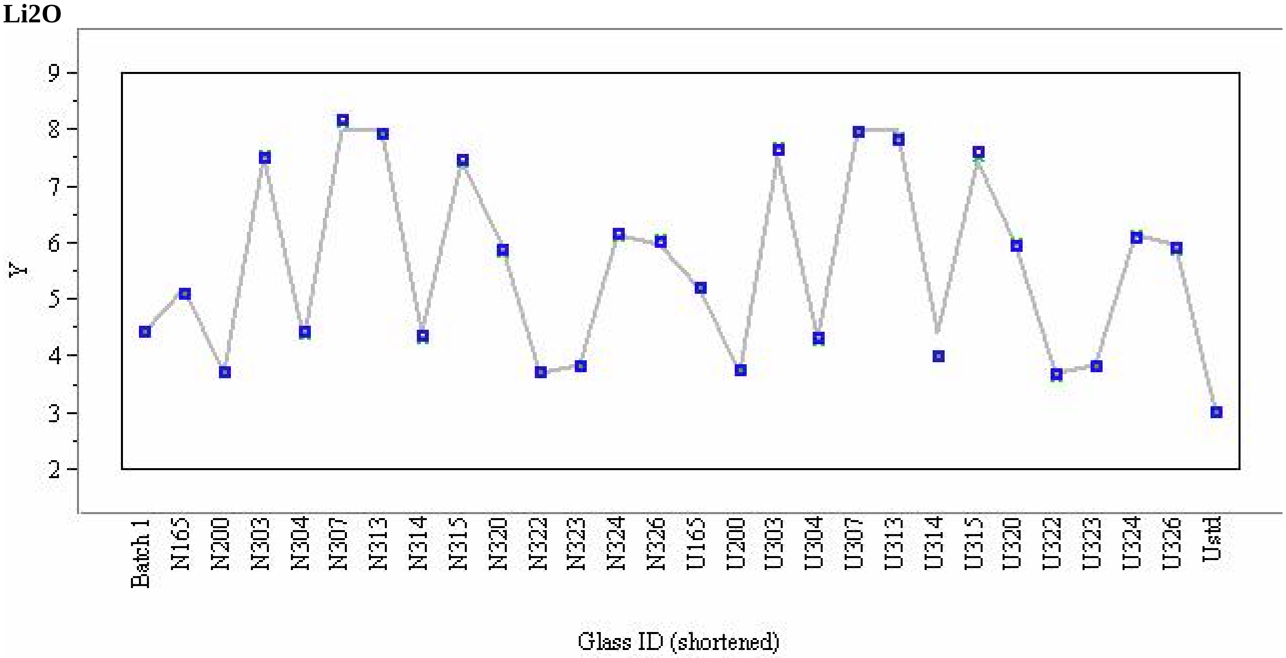


Exhibit E7. Comparisons of Measured versus Targeted Chemical Compositions
(Concentrations in wt%'s)

Fe2O3



Li2O



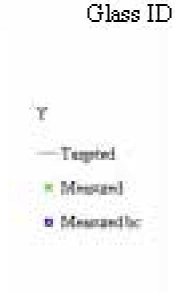
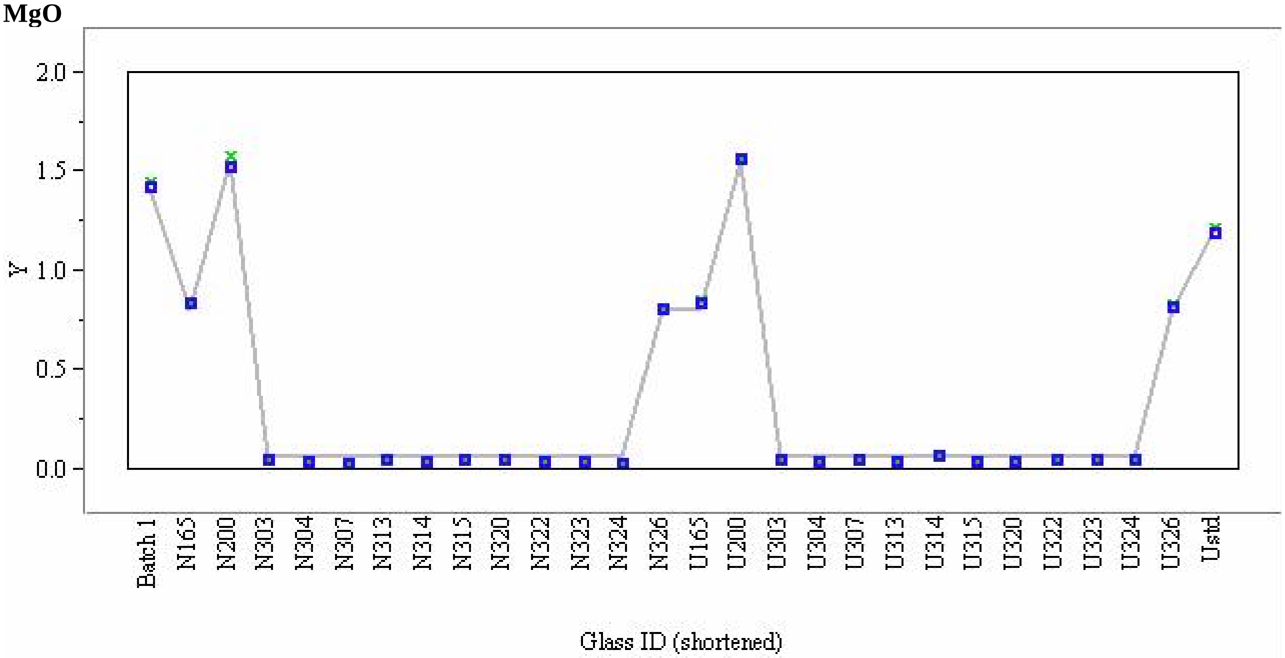
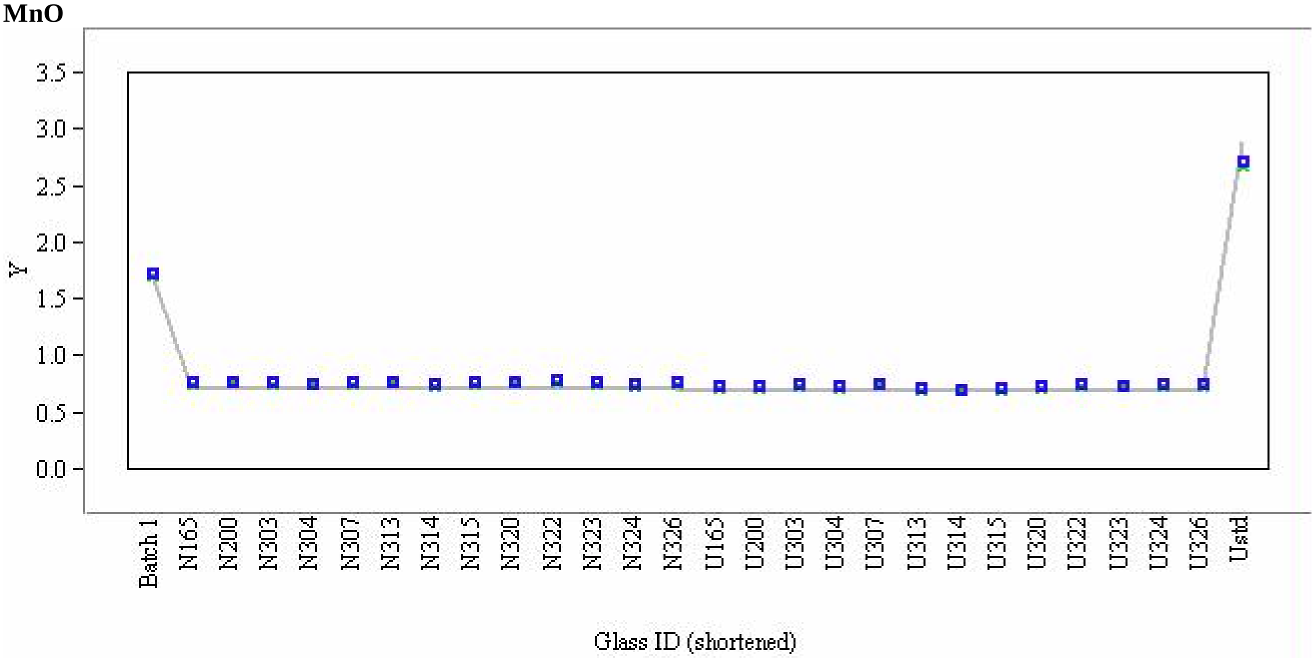


Exhibit E7. Comparisons of Measured versus Targeted Chemical Compositions
(Concentrations in wt%'s)

MgO



MnO



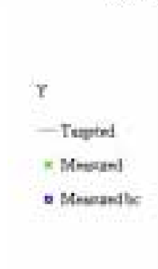
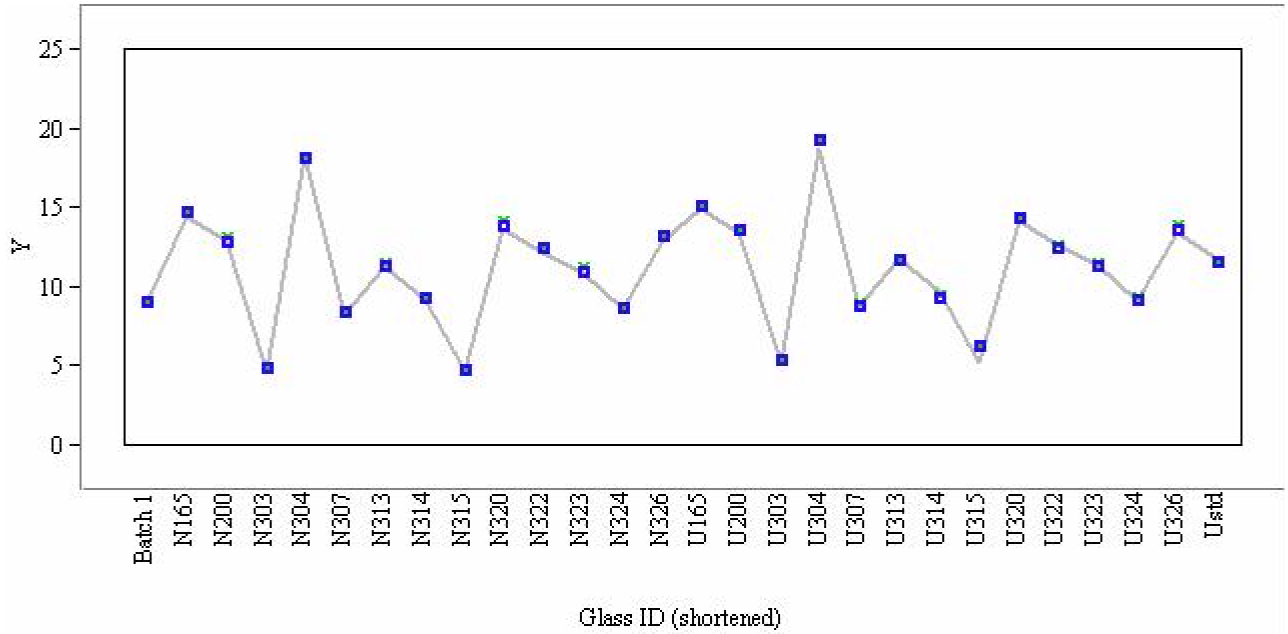


Exhibit E7. Comparisons of Measured versus Targeted Chemical Compositions
(Concentrations in wt%'s)

Na2O



NiO

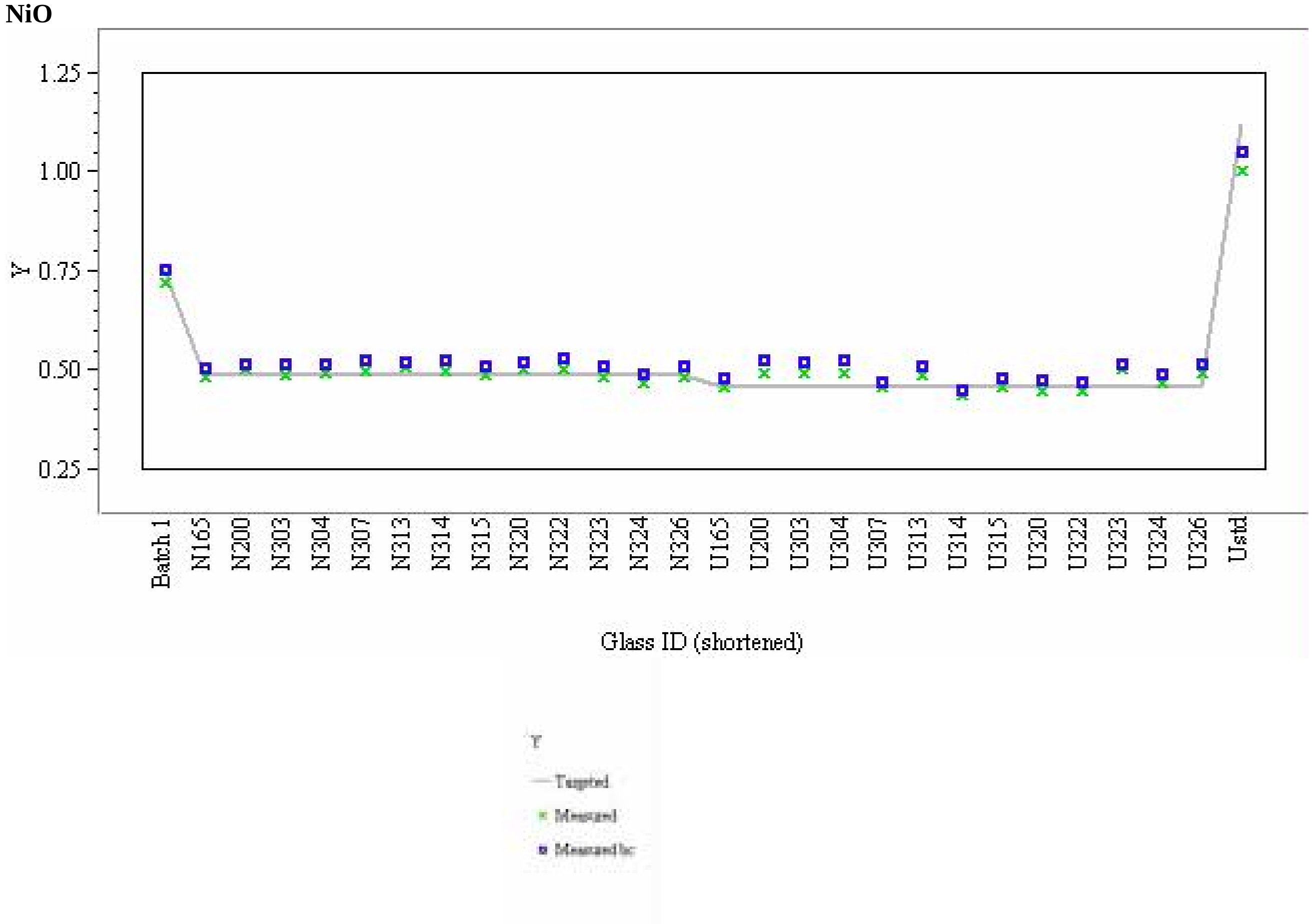
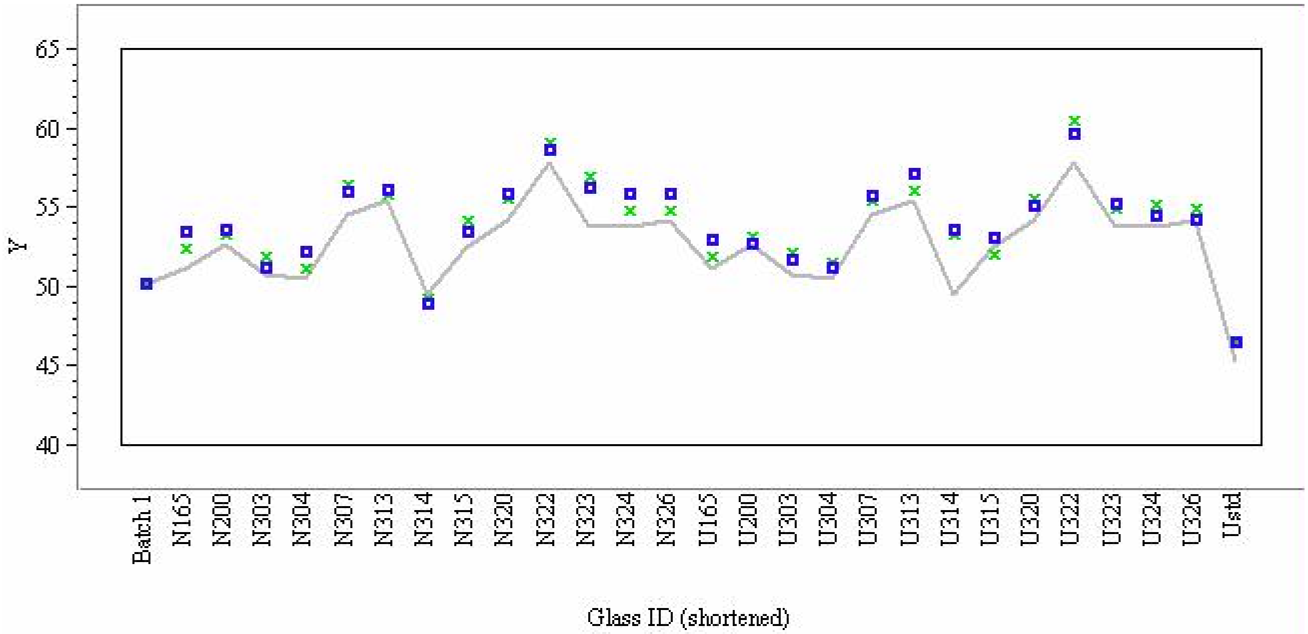
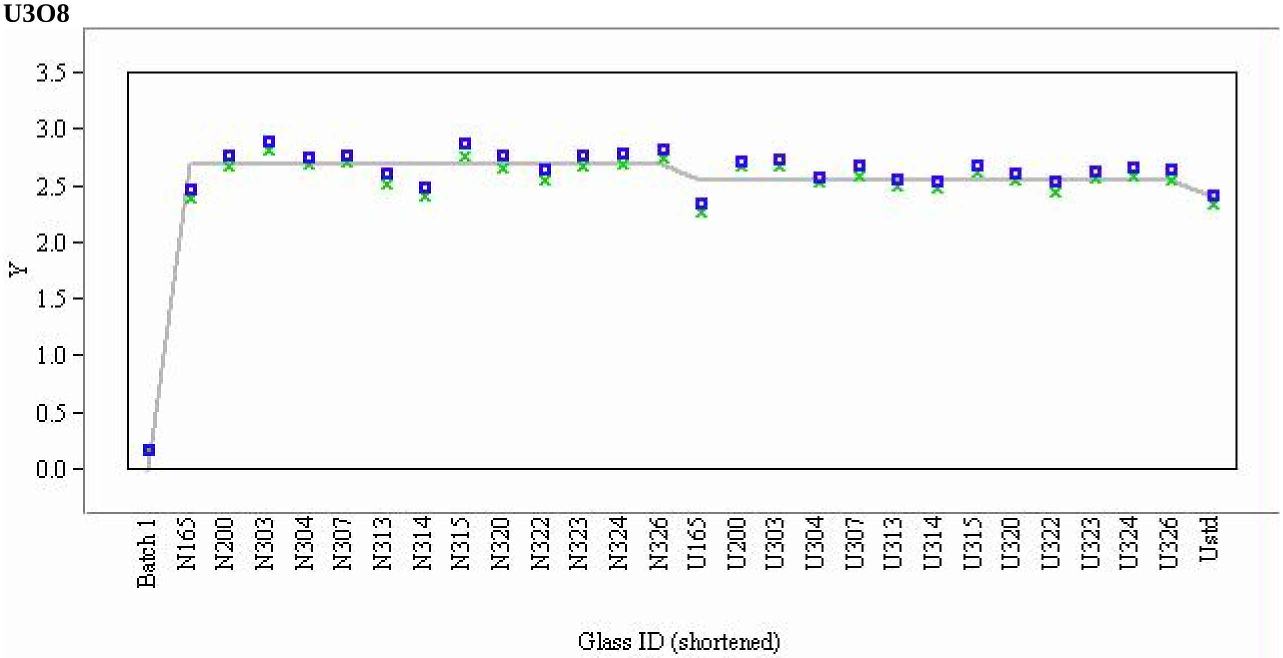


Exhibit E7. Comparisons of Measured versus Targeted Chemical Compositions
(Concentrations in wt%’s)

SiO2



U3O8



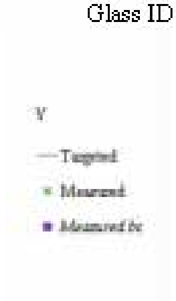
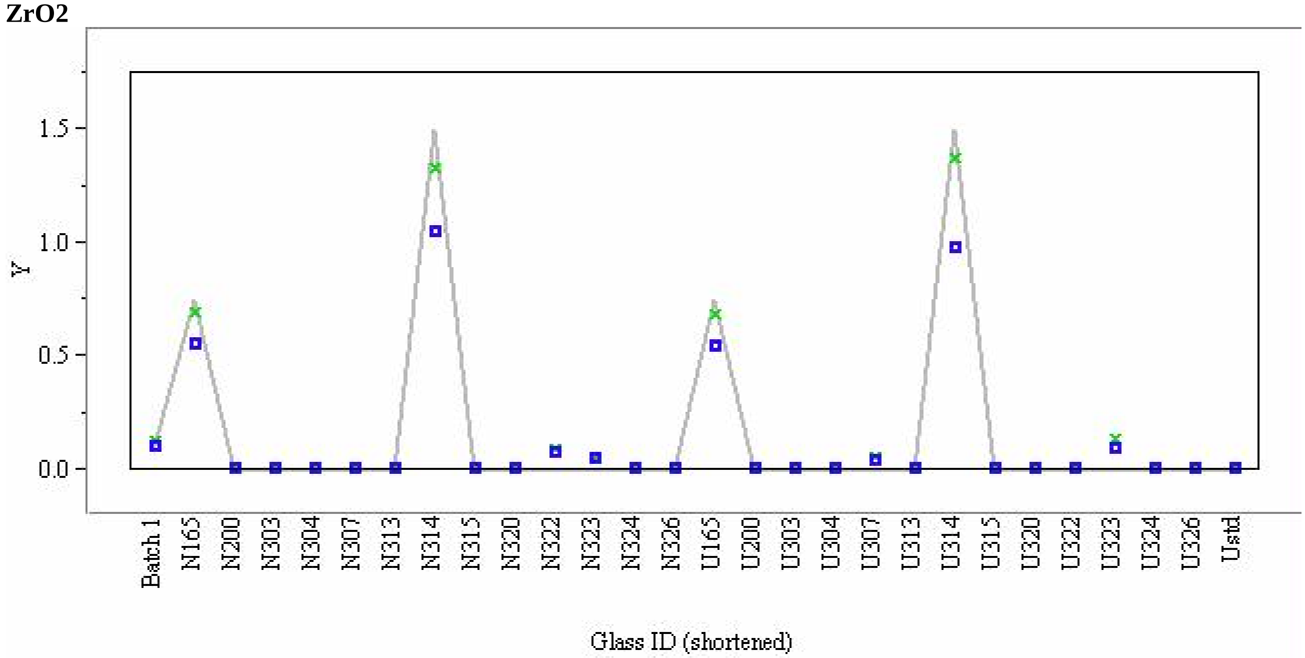
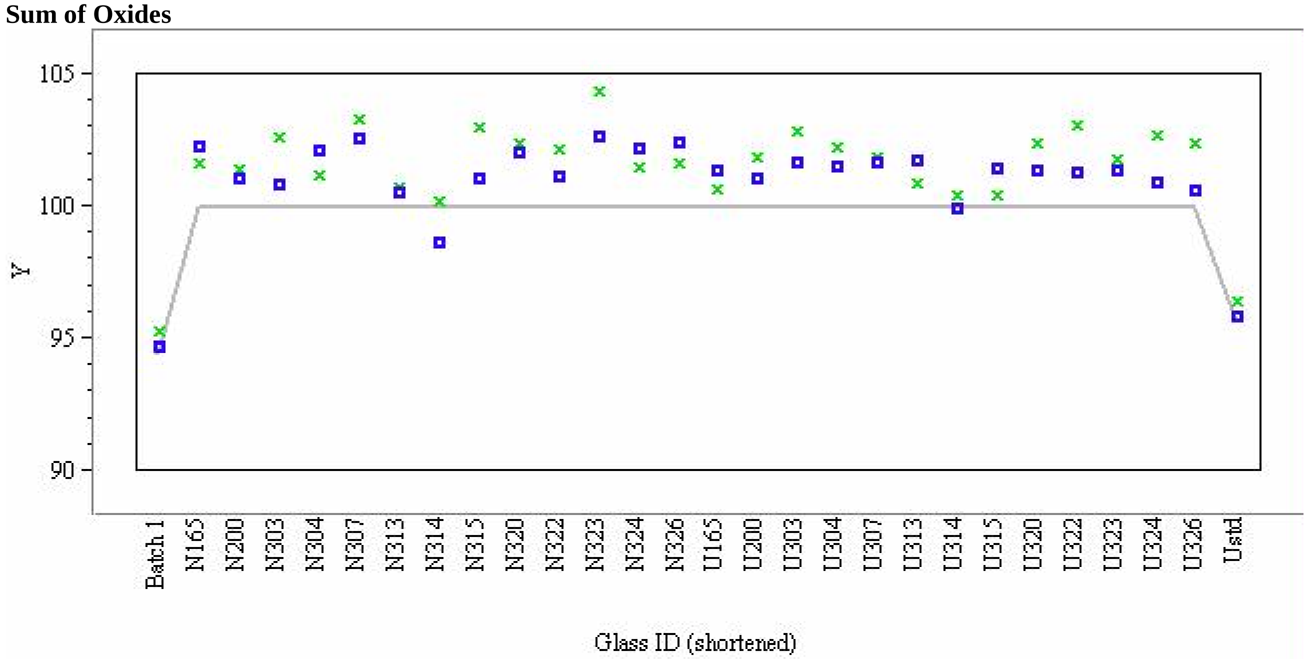


Exhibit E7. Comparisons of Measured versus Targeted Chemical Compositions
(Concentrations in wt%'s)

ZrO2



Sum of Oxides



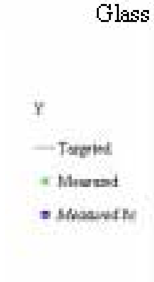
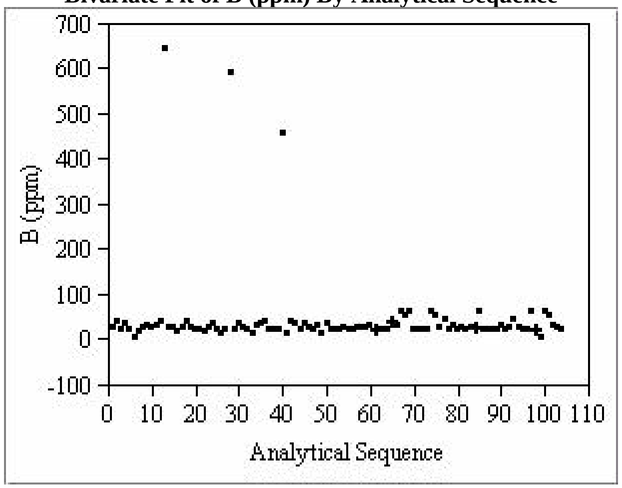
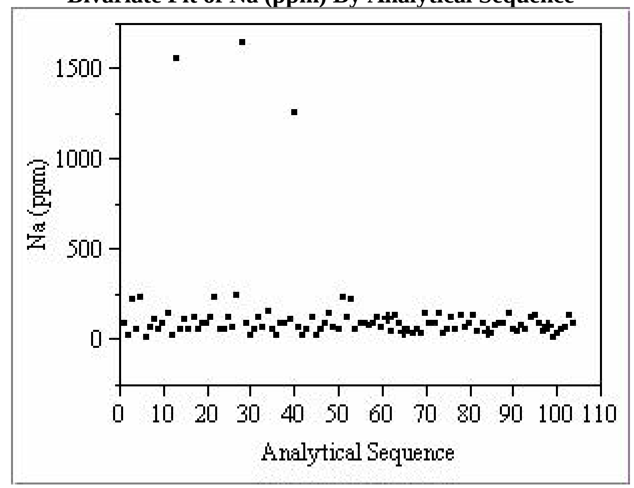


Exhibit E8. PCTs for Glasses from Nominally-Washed Sludge in Analytical Sequence
(with results for EA and Blanks)

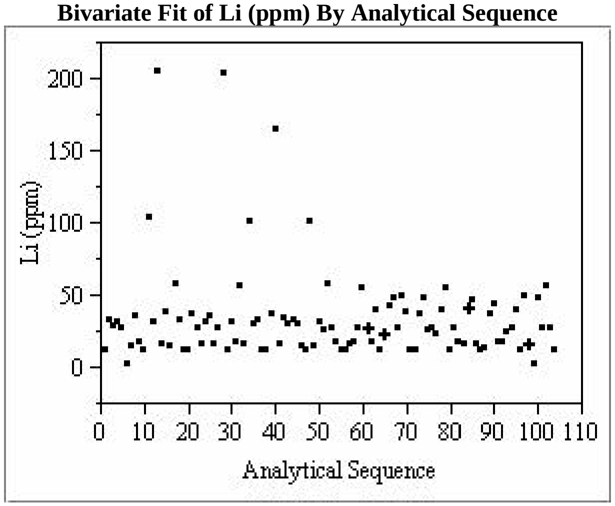
Bivariate Fit of B (ppm) By Analytical Sequence



Bivariate Fit of Na (ppm) By Analytical Sequence



Bivariate Fit of Li (ppm) By Analytical Sequence



Bivariate Fit of Si (ppm) By Analytical Sequence

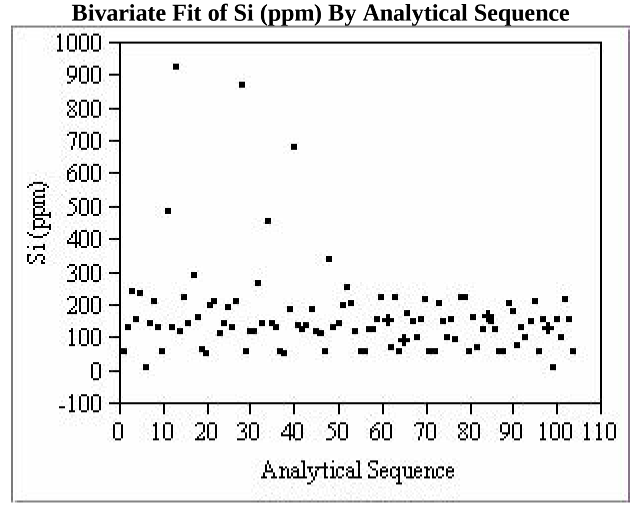
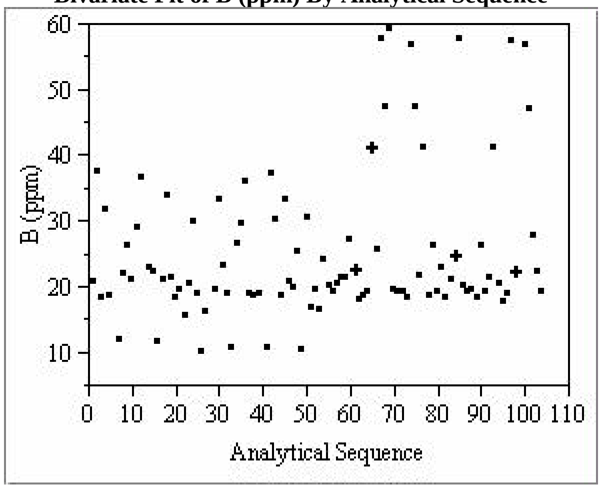
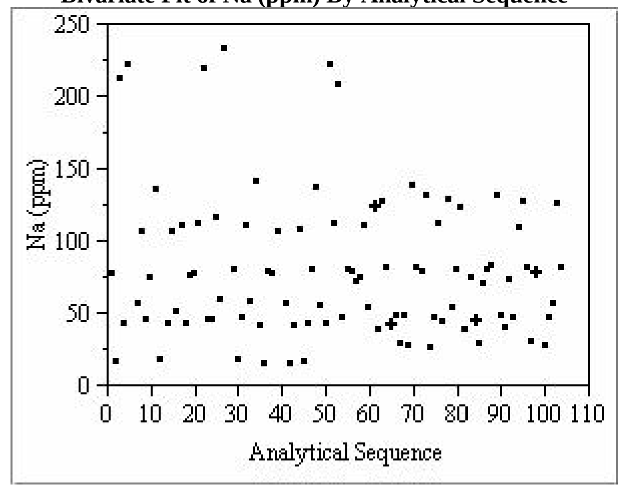


Exhibit E9. PCTs for Glasses from Nominally-Washed Sludge in Analytical Sequence
(without results for EA & Blanks)

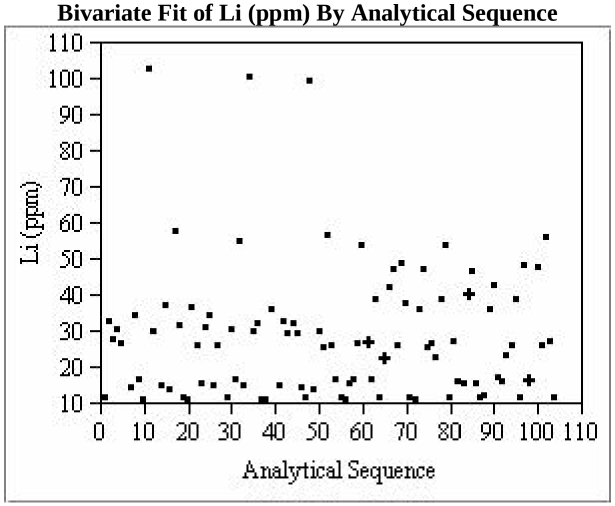
Bivariate Fit of B (ppm) By Analytical Sequence



Bivariate Fit of Na (ppm) By Analytical Sequence



Bivariate Fit of Li (ppm) By Analytical Sequence



Bivariate Fit of Si (ppm) By Analytical Sequence

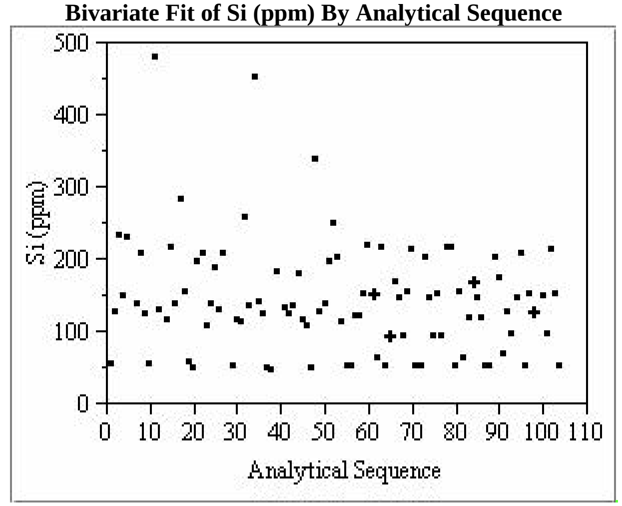
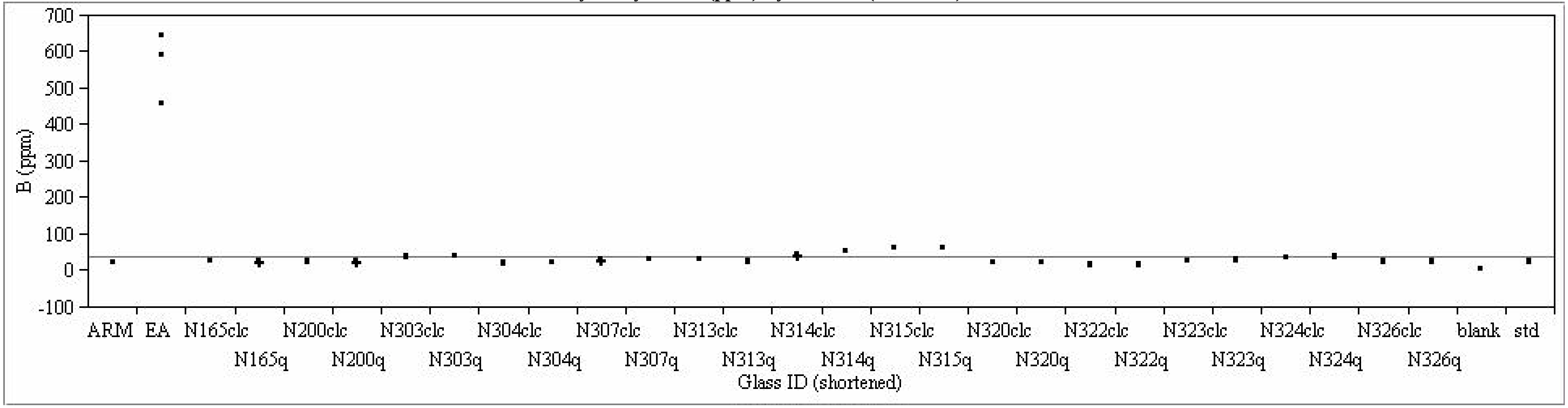


Exhibit E10. PCTs by Glass ID (Including EA and Blanks) for Nominally-Washed Sludge

Oneway Analysis of B (ppm) By Glass ID (shortened)



Oneway Analysis of Li (ppm) By Glass ID (shortened)

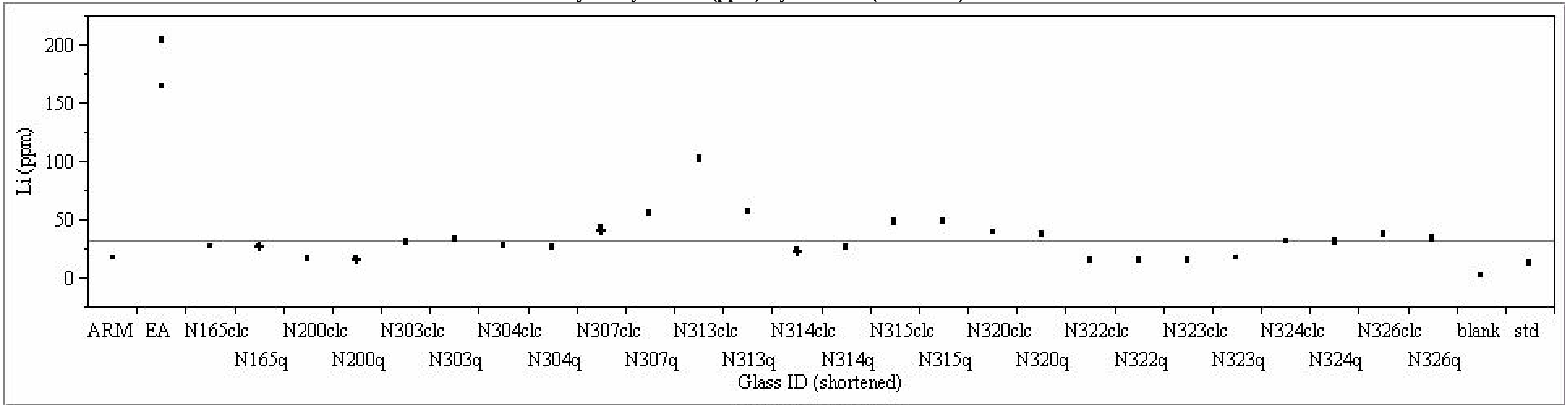
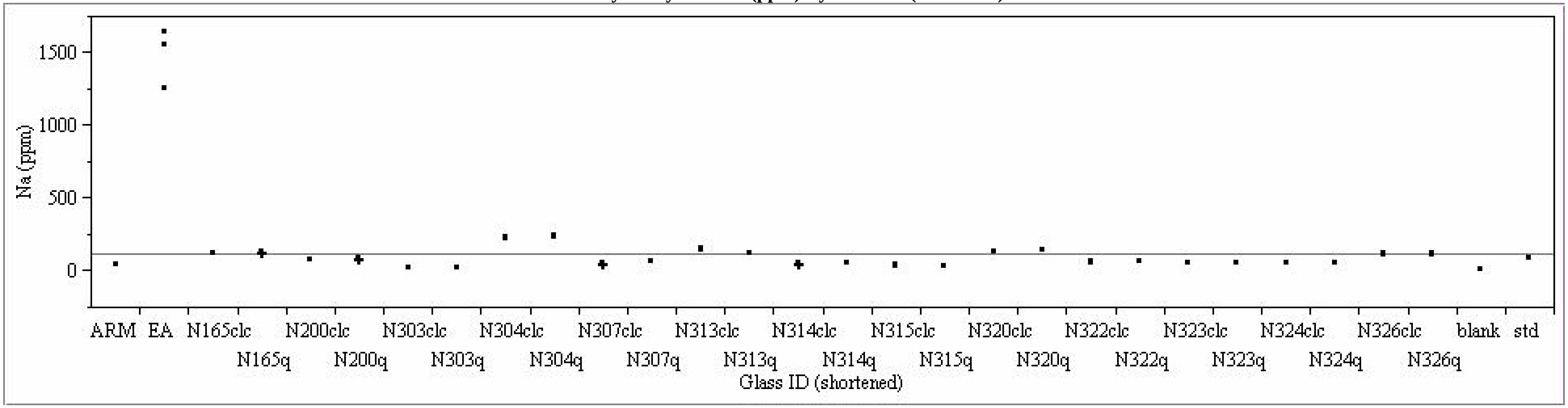


Exhibit E10. PCTs by Glass ID (Including EA and Blanks) for Nominally-Washed Sludge *(continued)*

Oneway Analysis of Na (ppm) By Glass ID (shortened)



Oneway Analysis of Si (ppm) By Glass ID (shortened)

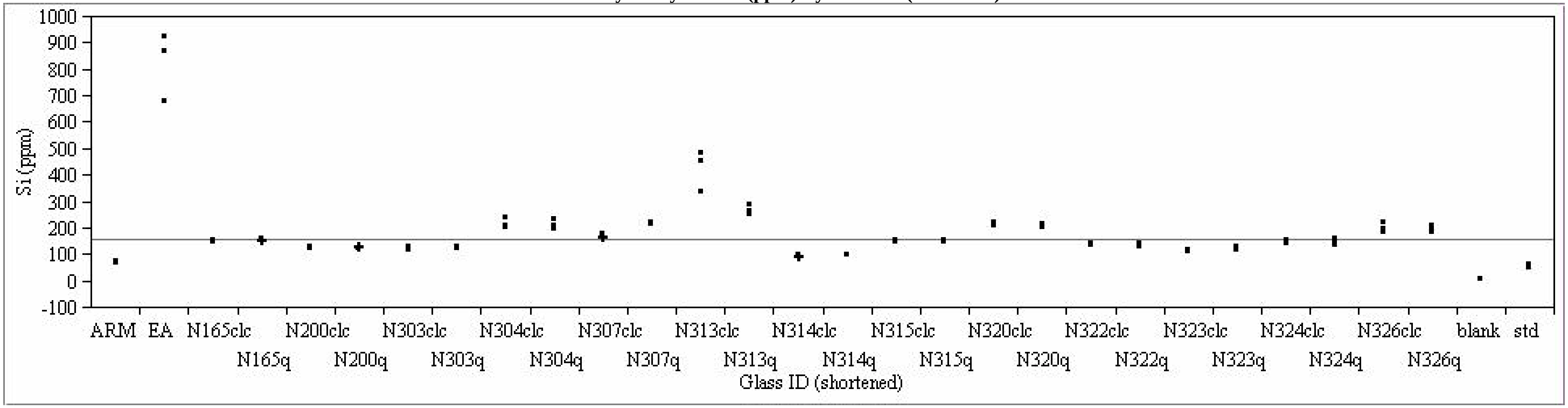
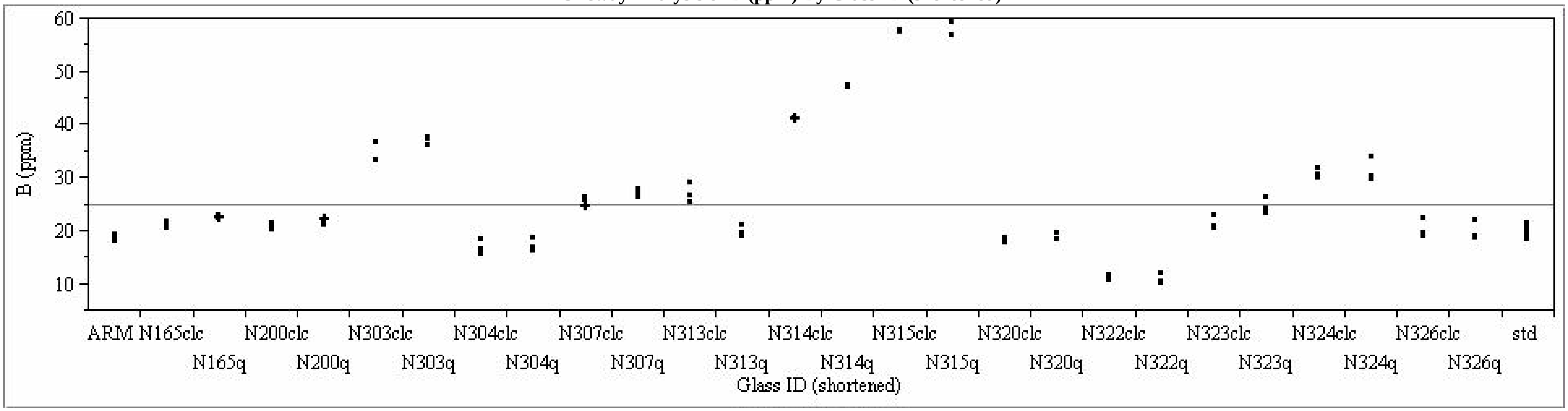


Exhibit E11. PCTs by Glass ID (Excluding EA and Blanks) for Nominally-Washed Sludge

Oneway Analysis of B (ppm) By Glass ID (shortened)



Oneway Analysis of Li (ppm) By Glass ID (shortened)

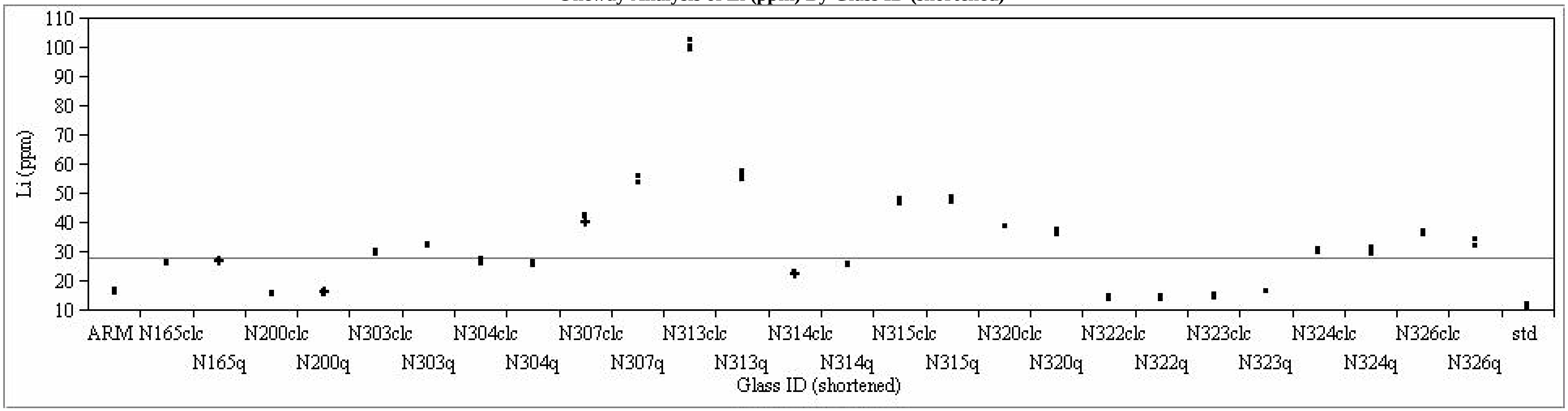
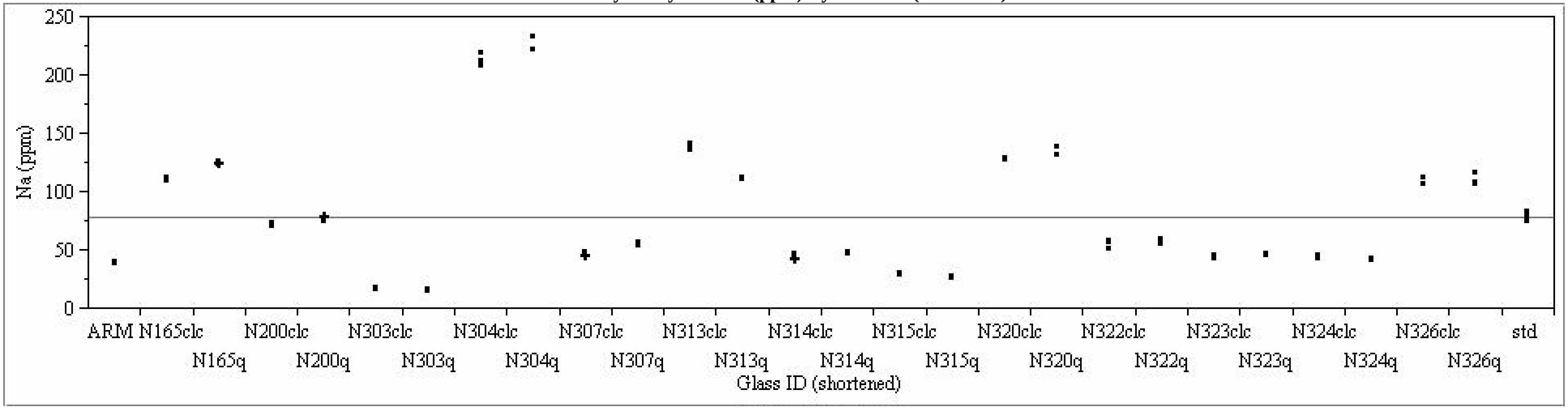


Exhibit E11. PCTs by Glass ID (Excluding EA and Blanks) for Nominally-Washed Sludge *(continued)*

Oneway Analysis of Na (ppm) By Glass ID (shortened)



Oneway Analysis of Si (ppm) By Glass ID (shortened)

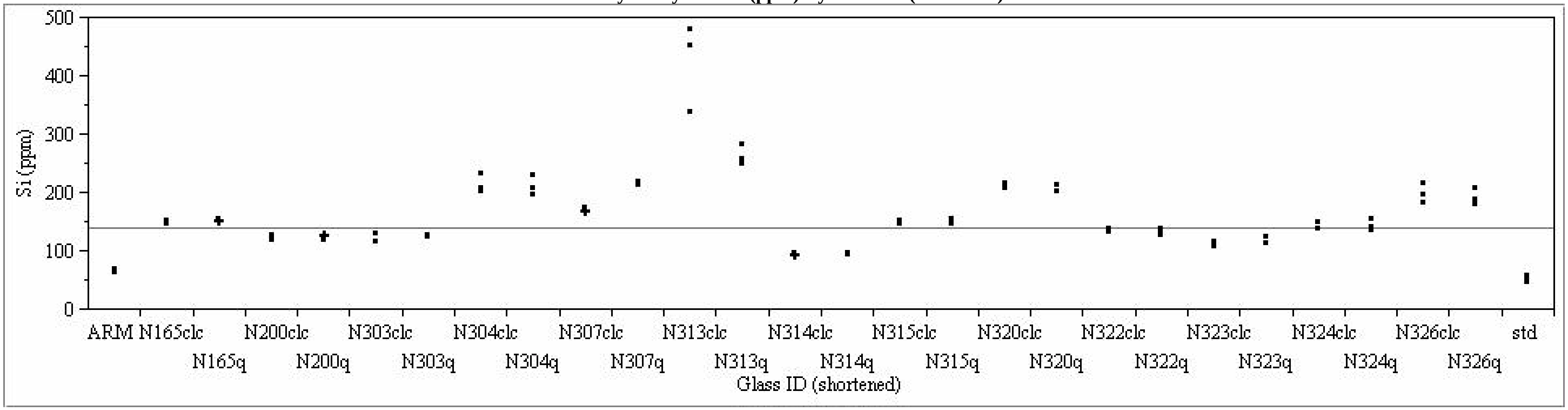
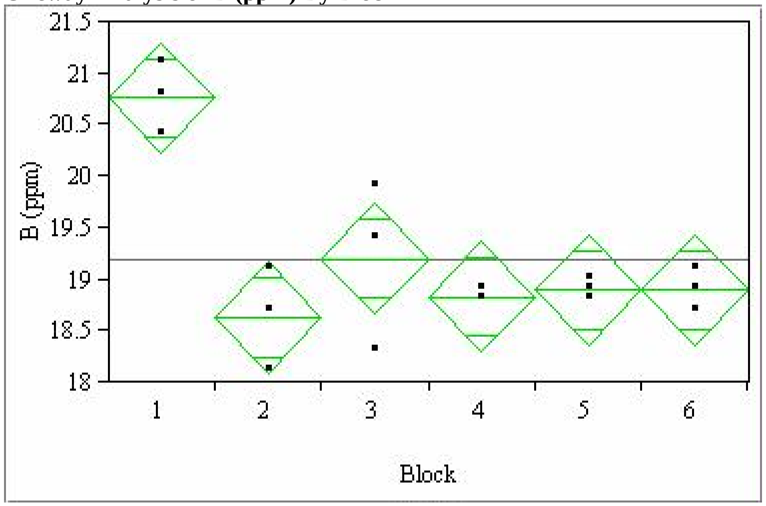


Exhibit E12. Measurements of the Solutions Standards by ICP Block for Nominally-Washed Analyses

Oneway Analysis of B (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	0.808186
Adj Rsquare	0.728264
Root Mean Square Error	0.428174
Mean of Response	19.20556
Observations (or Sum Wgts)	18

Analysis of Variance

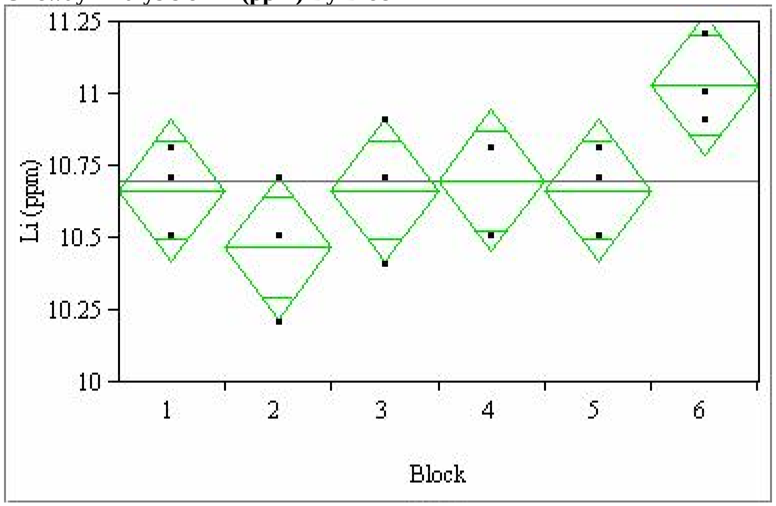
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	9.269444	1.85389	10.1121	0.0006
Error	12	2.200000	0.18333		
C. Total	17	11.469444			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	20.7667	0.24721	20.228	21.305
2	3	18.6333	0.24721	18.095	19.172
3	3	19.2000	0.24721	18.661	19.739
4	3	18.8333	0.24721	18.295	19.372
5	3	18.9000	0.24721	18.361	19.439
6	3	18.9000	0.24721	18.361	19.439

Std Error uses a pooled estimate of error variance

Oneway Analysis of Li (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	0.527778
Adj Rsquare	0.331019
Root Mean Square Error	0.194365
Mean of Response	10.7
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0.50666667	0.101333	2.6824	0.0749
Error	12	0.45333333	0.037778		
C. Total	17	0.96000000			

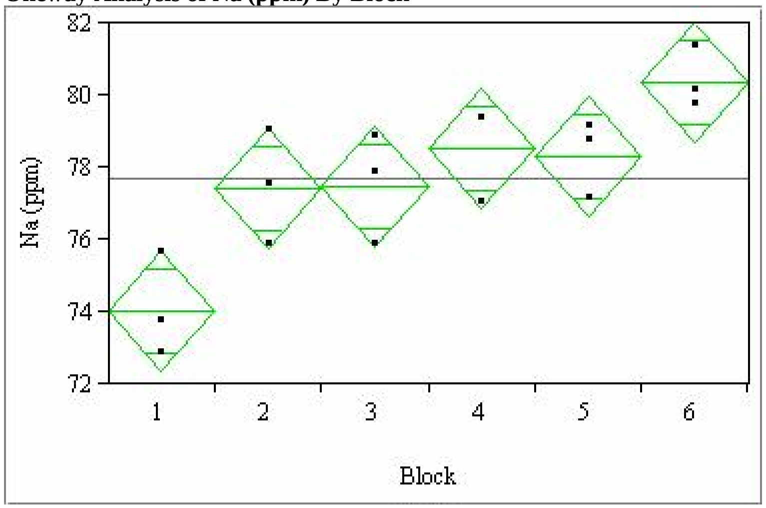
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	10.6667	0.11222	10.422	10.911
2	3	10.4667	0.11222	10.222	10.711
3	3	10.6667	0.11222	10.422	10.911
4	3	10.7000	0.11222	10.456	10.944
5	3	10.6667	0.11222	10.422	10.911
6	3	11.0333	0.11222	10.789	11.278

Std Error uses a pooled estimate of error variance

Exhibit E12. Measurements of the Solutions Standards by ICP Block for Nominally-Washed Analyses *(continued)*

Oneway Analysis of Na (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	0.756101
Adj Rsquare	0.654476
Root Mean Square Error	1.323925
Mean of Response	77.68889
Observations (or Sum Wgts)	18

Analysis of Variance

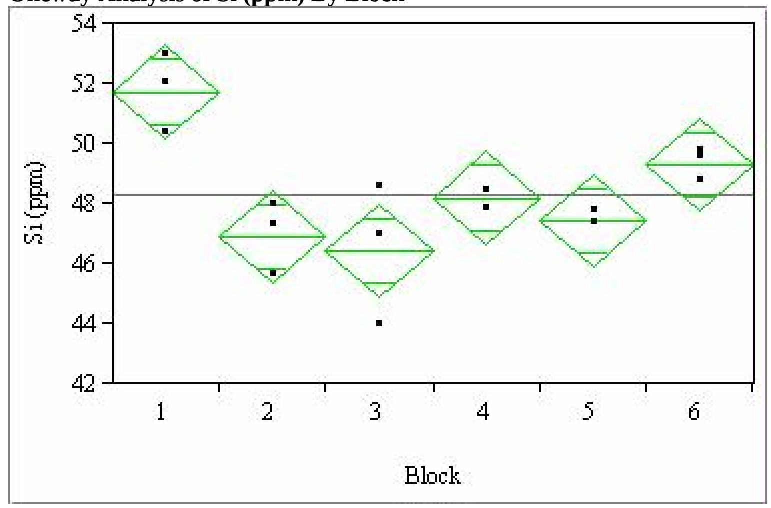
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	65.204444	13.0409	7.4401	0.0022
Error	12	21.033333	1.7528		
C. Total	17	86.237778			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	74.0333	0.76437	72.368	75.699
2	3	77.4333	0.76437	75.768	79.099
3	3	77.4667	0.76437	75.801	79.132
4	3	78.5333	0.76437	76.868	80.199
5	3	78.3000	0.76437	76.635	79.965
6	3	80.3667	0.76437	78.701	82.032

Std Error uses a pooled estimate of error variance

Oneway Analysis of Si (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	0.759062
Adj Rsquare	0.658671
Root Mean Square Error	1.227464
Mean of Response	48.33333
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	56.960000	11.3920	7.5611	0.0020
Error	12	18.080000	1.5067		
C. Total	17	75.040000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	51.7333	0.70868	50.189	53.277
2	3	46.9000	0.70868	45.356	48.444
3	3	46.4333	0.70868	44.889	47.977
4	3	48.2000	0.70868	46.656	49.744
5	3	47.4333	0.70868	45.889	48.977
6	3	49.3000	0.70868	47.756	50.844

Std Error uses a pooled estimate of error variance

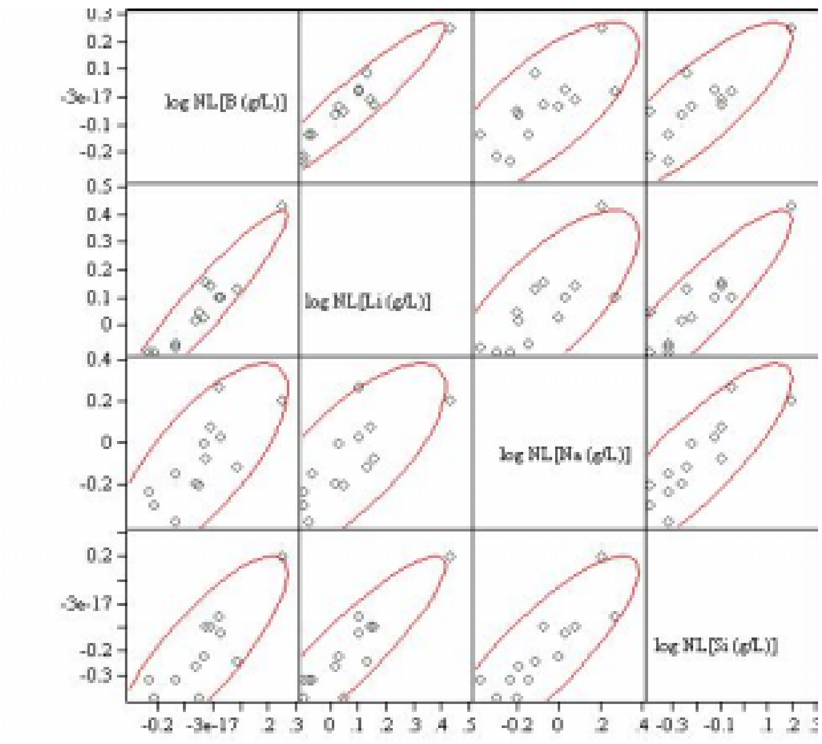
Exhibit E13. Correlations of PCTs for Nominally-Washed Case

Nominal-Measured Composition-clc

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	0.9478	0.7372	0.8286
log NL[Li (g/L)]	0.9478	1.0000	0.7495	0.9039
log NL[Na (g/L)]	0.7372	0.7495	1.0000	0.8453
log NL[Si (g/L)]	0.8286	0.9039	0.8453	1.0000

Scatterplot Matrix



Nominal-Measured Composition-quenched

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	0.9620	0.5915	0.6687
log NL[Li (g/L)]	0.9620	1.0000	0.6407	0.6932
log NL[Na (g/L)]	0.5915	0.6407	1.0000	0.8124
log NL[Si (g/L)]	0.6687	0.6932	0.8124	1.0000

Scatterplot Matrix

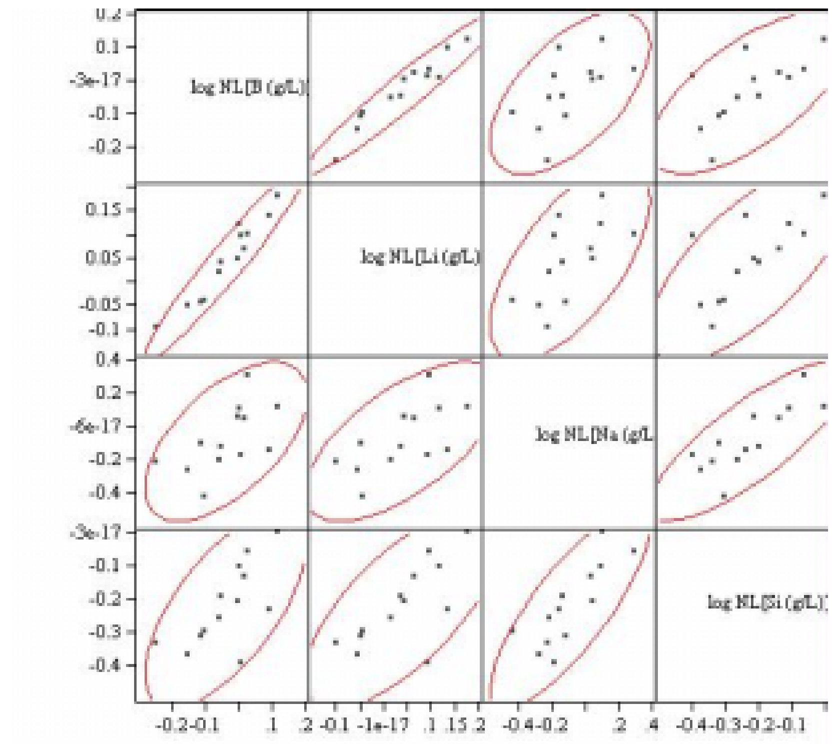
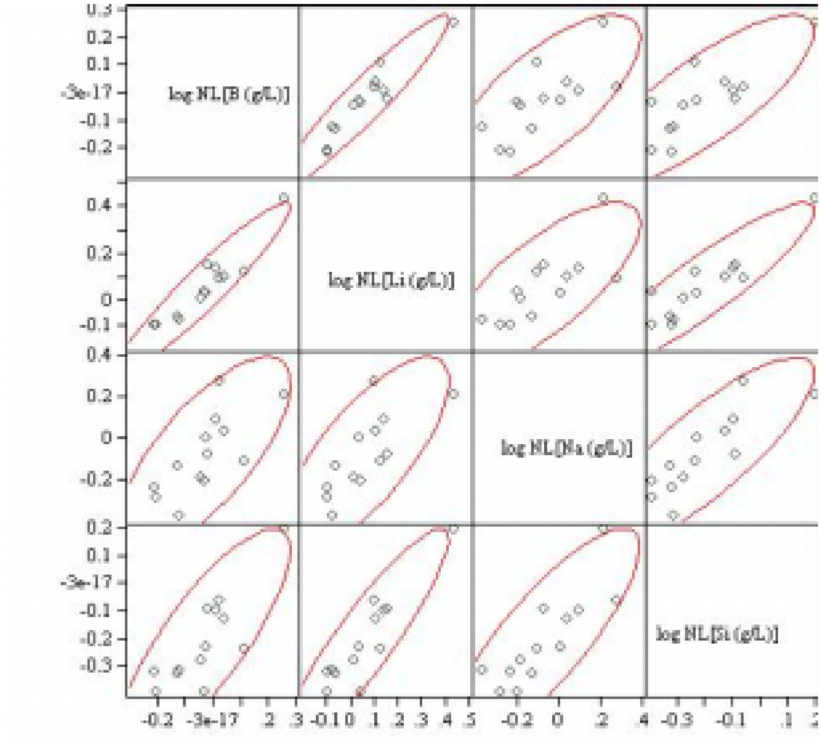


Exhibit E13. Correlations of PCTs for Nominally-Washed Case *(Continued)*

Nominal-Measured bc-clc 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	0.9456	0.7282	0.8151
log NL[Li (g/L)]	0.9456	1.0000	0.7519	0.9101
log NL[Na (g/L)]	0.7282	0.7519	1.0000	0.8380
log NL[Si (g/L)]	0.8151	0.9101	0.8380	1.0000

Scatterplot Matrix



Nominal-Measured bc-quenched 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	0.9717	0.5767	0.6501
log NL[Li (g/L)]	0.9717	1.0000	0.6443	0.7040
log NL[Na (g/L)]	0.5767	0.6443	1.0000	0.8040
log NL[Si (g/L)]	0.6501	0.7040	0.8040	1.0000

Scatterplot Matrix

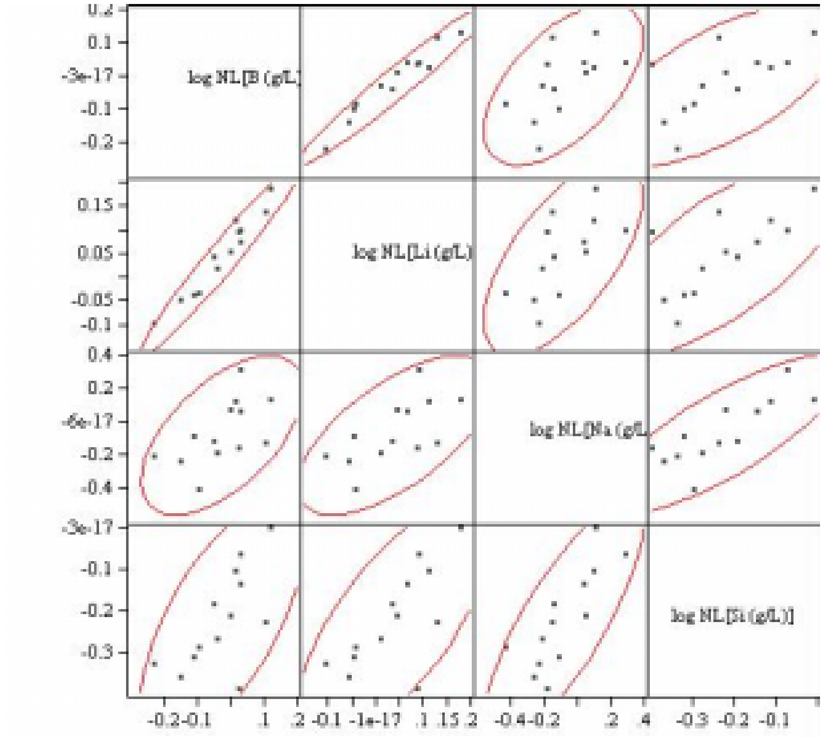


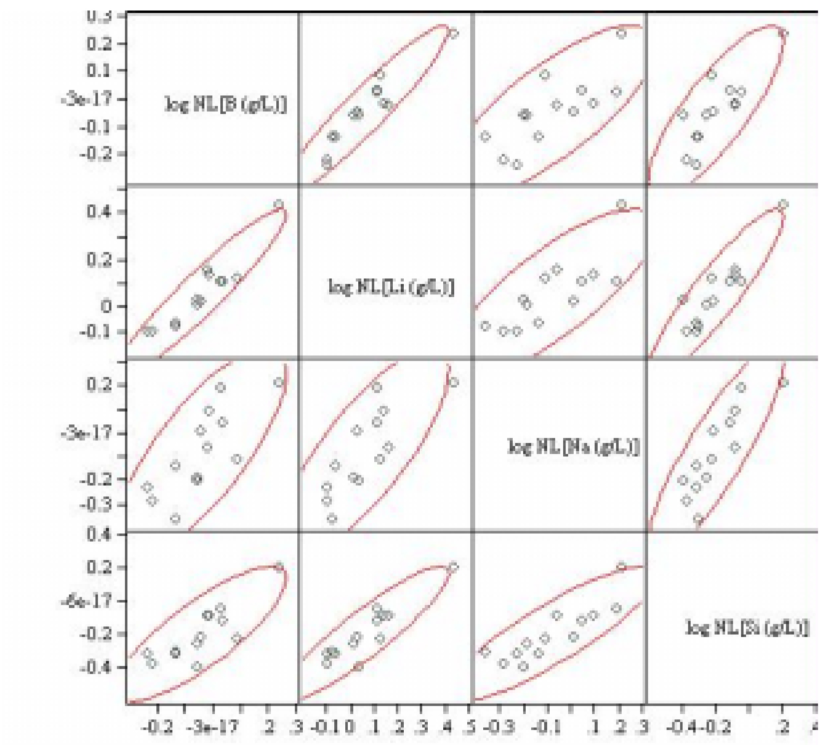
Exhibit E13. Correlations of PCTs for Nominally-Washed Case *(Continued)*

Nominal-Targeted-clc

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	0.9444	0.7708	0.8194
log NL[Li (g/L)]	0.9444	1.0000	0.7941	0.9082
log NL[Na (g/L)]	0.7708	0.7941	1.0000	0.8678
log NL[Si (g/L)]	0.8194	0.9082	0.8678	1.0000

Scatterplot Matrix



Nominal-Targeted-quenched

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	0.9639	0.6058	0.6549
log NL[Li (g/L)]	0.9639	1.0000	0.6712	0.7058
log NL[Na (g/L)]	0.6058	0.6712	1.0000	0.8185
log NL[Si (g/L)]	0.6549	0.7058	0.8185	1.0000

Scatterplot Matrix

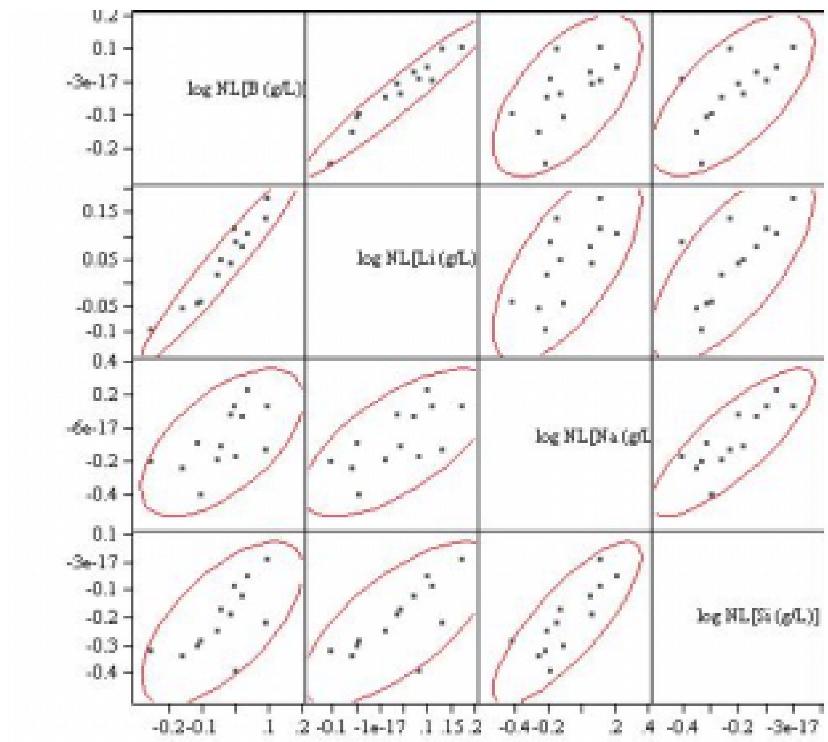
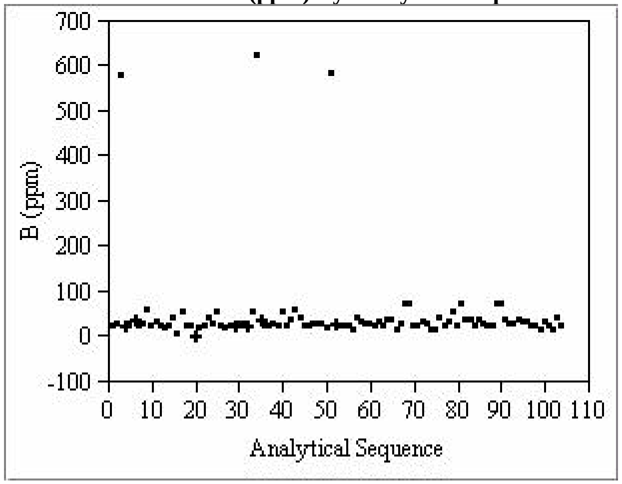
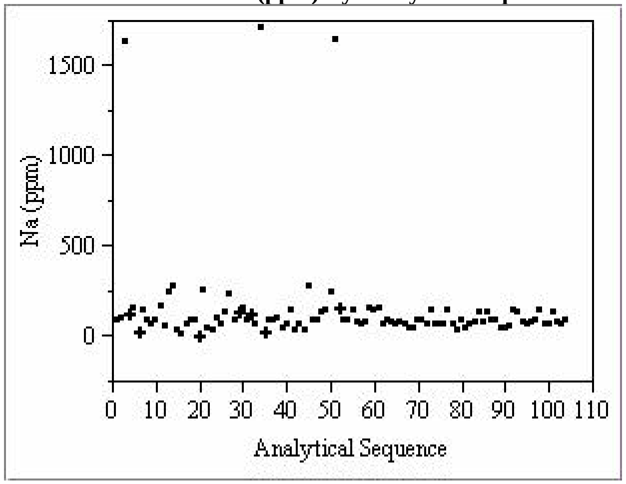


Exhibit E14. PCTs for Glasses from Underwashed Sludge in Analytical Sequence
(with results for EA and Blanks)

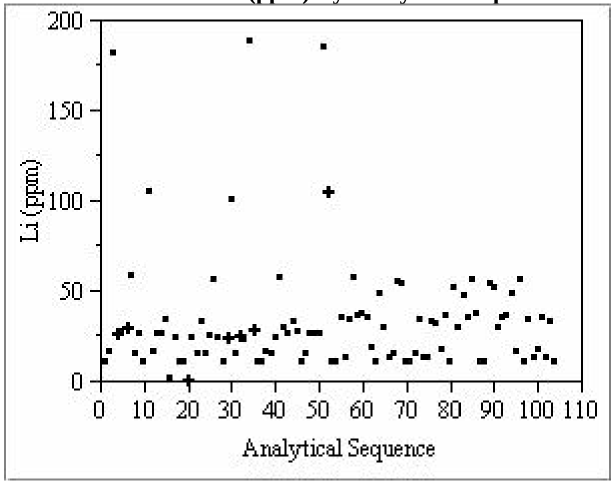
Bivariate Fit of B (ppm) By Analytical Sequence



Bivariate Fit of Na (ppm) By Analytical Sequence



Bivariate Fit of Li (ppm) By Analytical Sequence



Bivariate Fit of Si (ppm) By Analytical Sequence

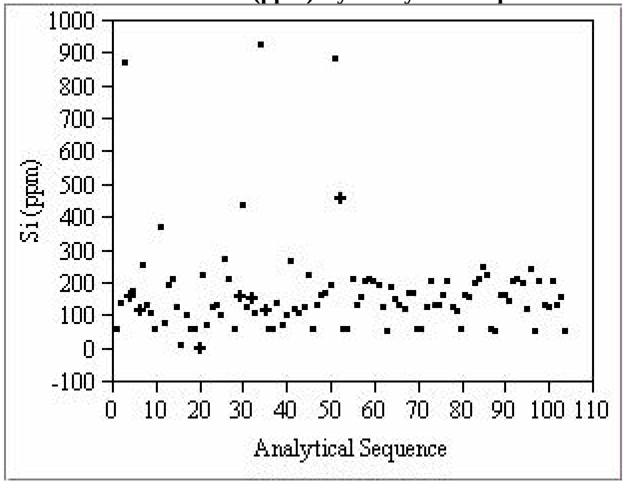
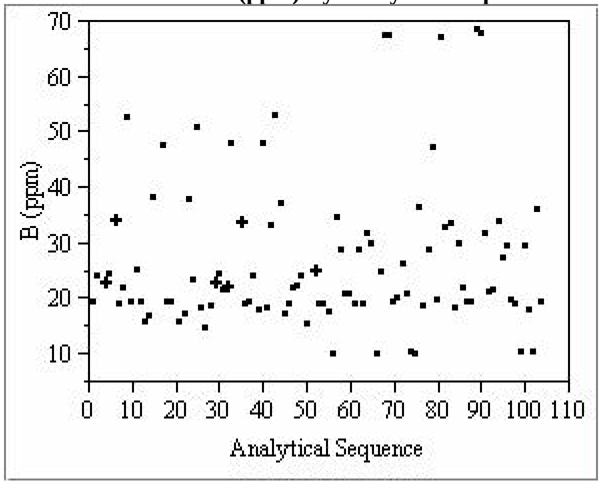
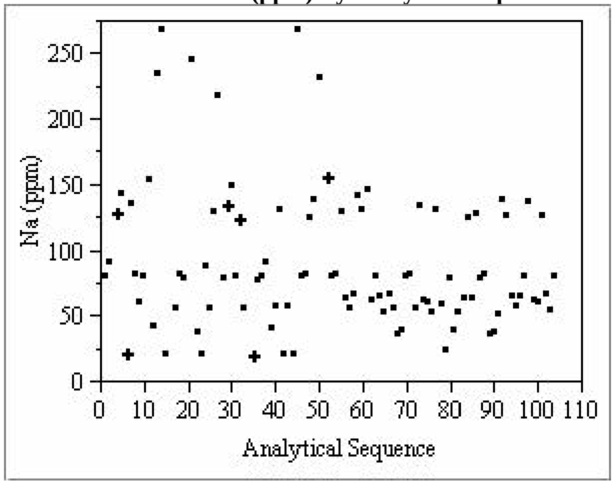


Exhibit E15. PCTs for Glasses from Underwashed Sludge in Analytical Sequence
(without results for EA and Blanks)

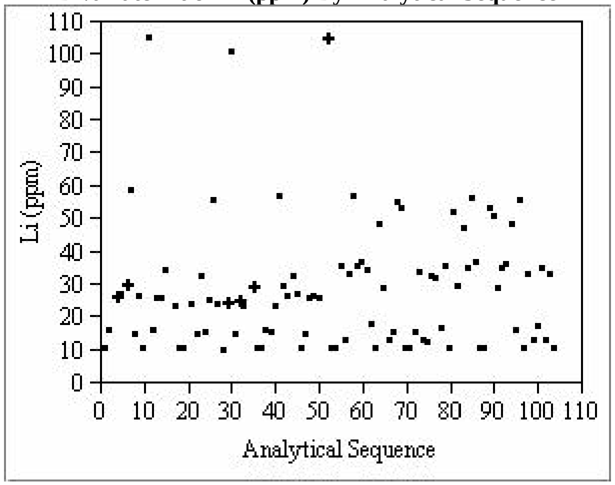
Bivariate Fit of B (ppm) By Analytical Sequence



Bivariate Fit of Na (ppm) By Analytical Sequence



Bivariate Fit of Li (ppm) By Analytical Sequence



Bivariate Fit of Si (ppm) By Analytical Sequence

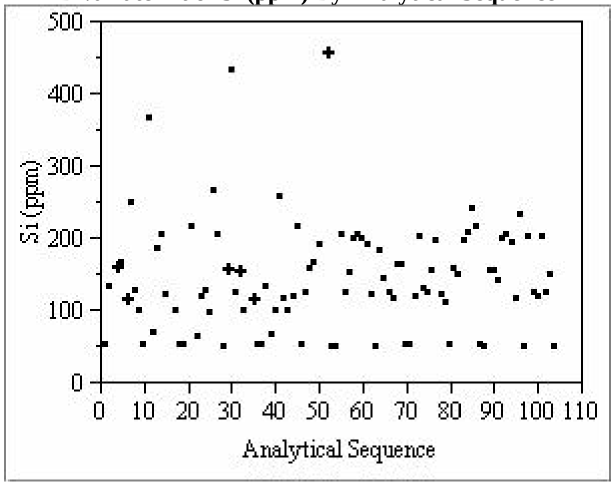
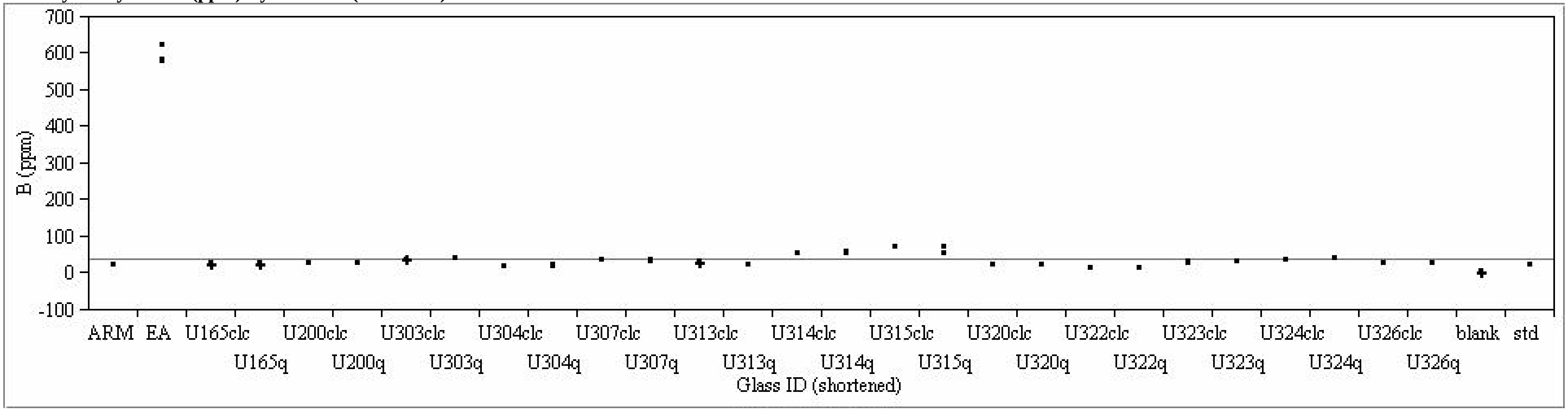


Exhibit E16. PCTs by Glass ID (Including EA and Blanks) for Underwashed Sludge

Oneway Analysis of B (ppm) By Glass ID (shortened)



Oneway Analysis of Li (ppm) By Glass ID (shortened)

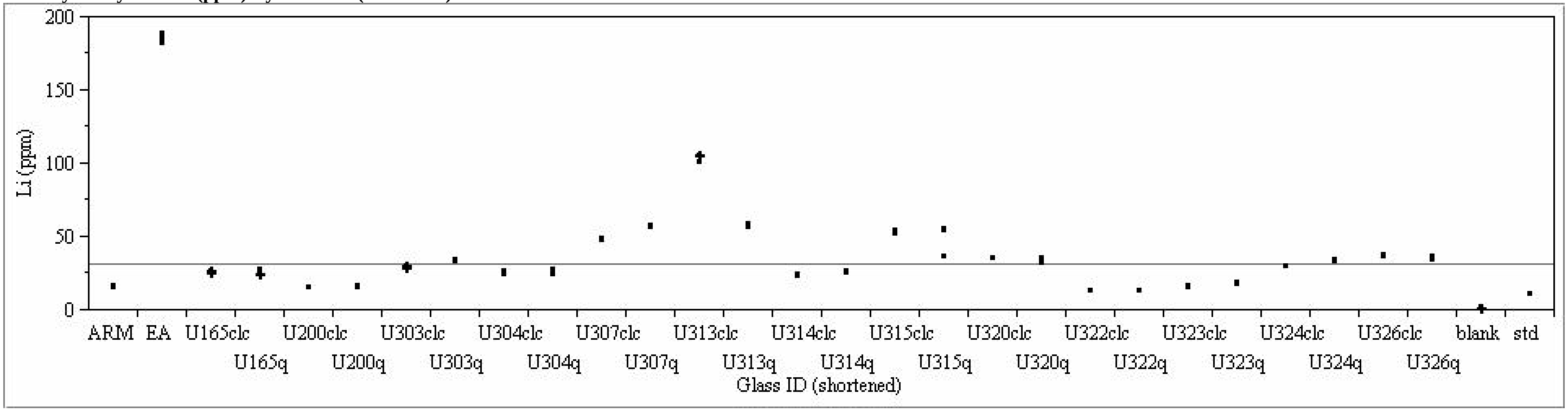
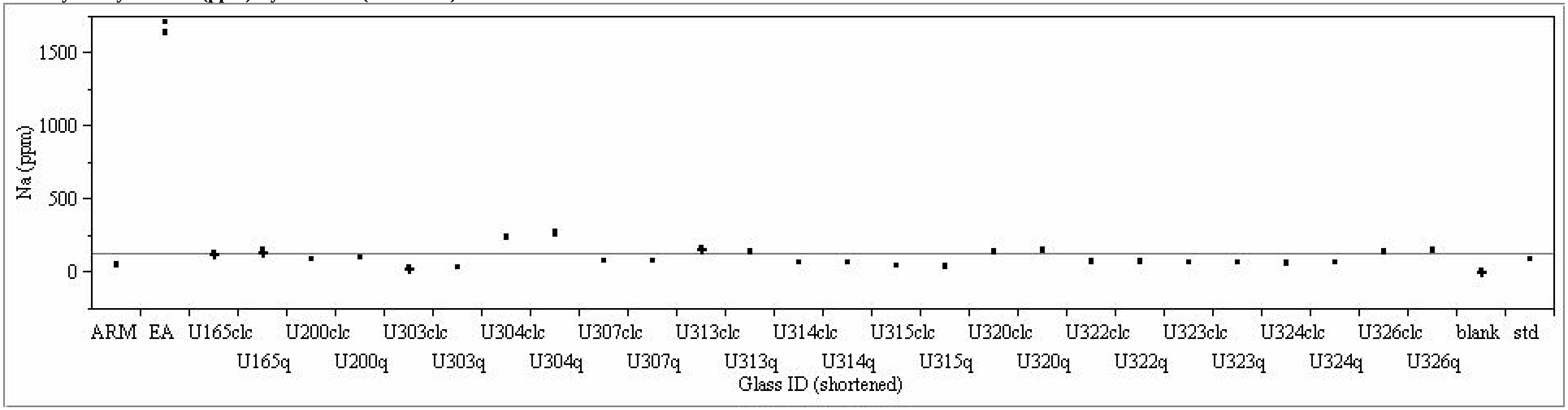


Exhibit E16. PCTs by Glass ID (Including EA and Blanks) for Underwashed Sludge *(continued)*

Oneway Analysis of Na (ppm) By Glass ID (shortened)



Oneway Analysis of Si (ppm) By Glass ID (shortened)

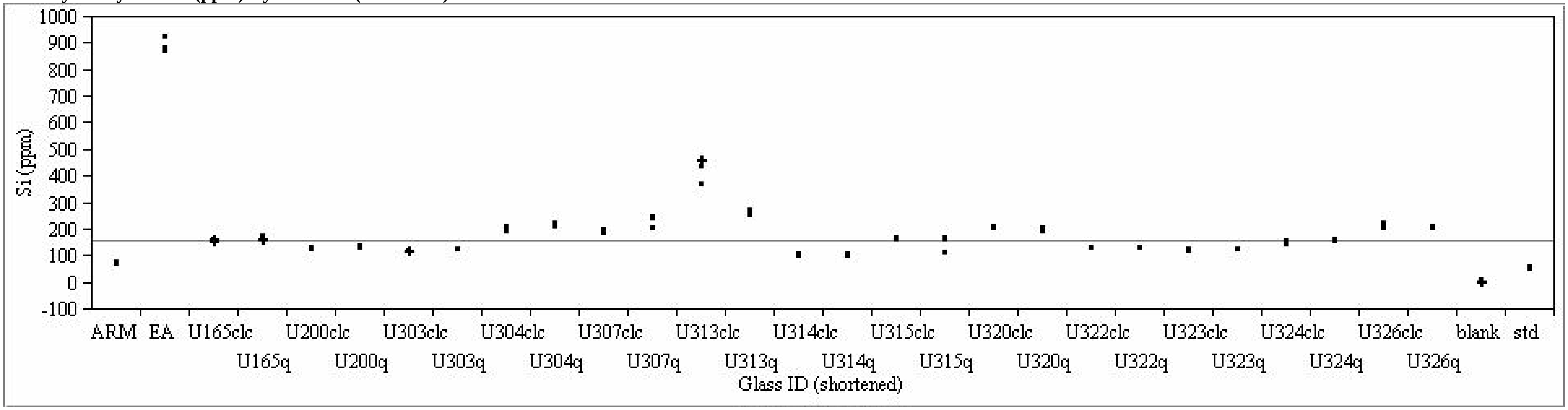
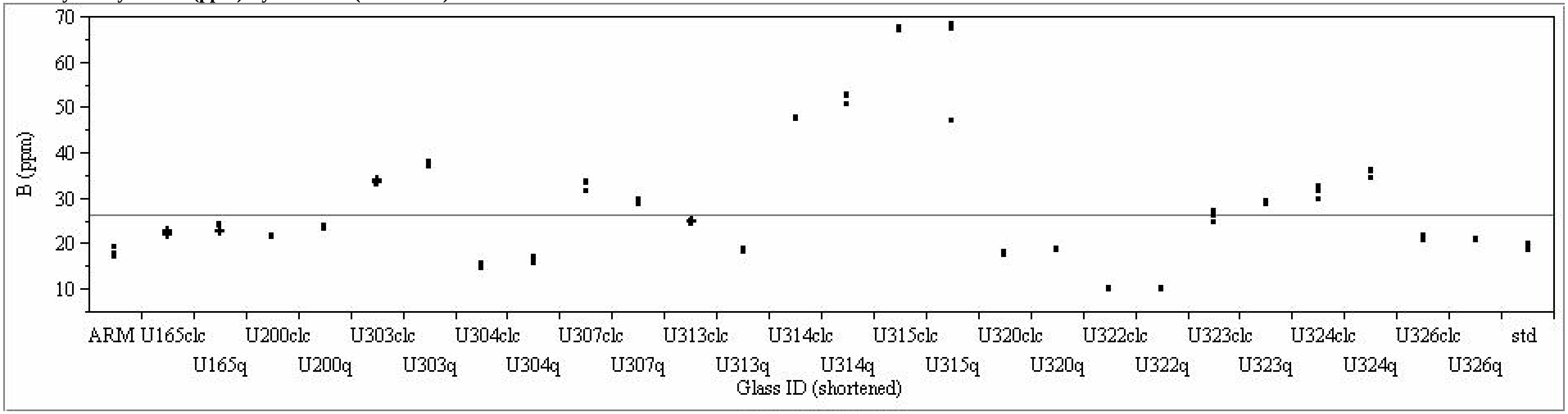


Exhibit E17. PCTs by Glass ID (Excluding EA and Blanks) for Underwashed Sludge

Oneway Analysis of B (ppm) By Glass ID (shortened)



Oneway Analysis of Li (ppm) By Glass ID (shortened)

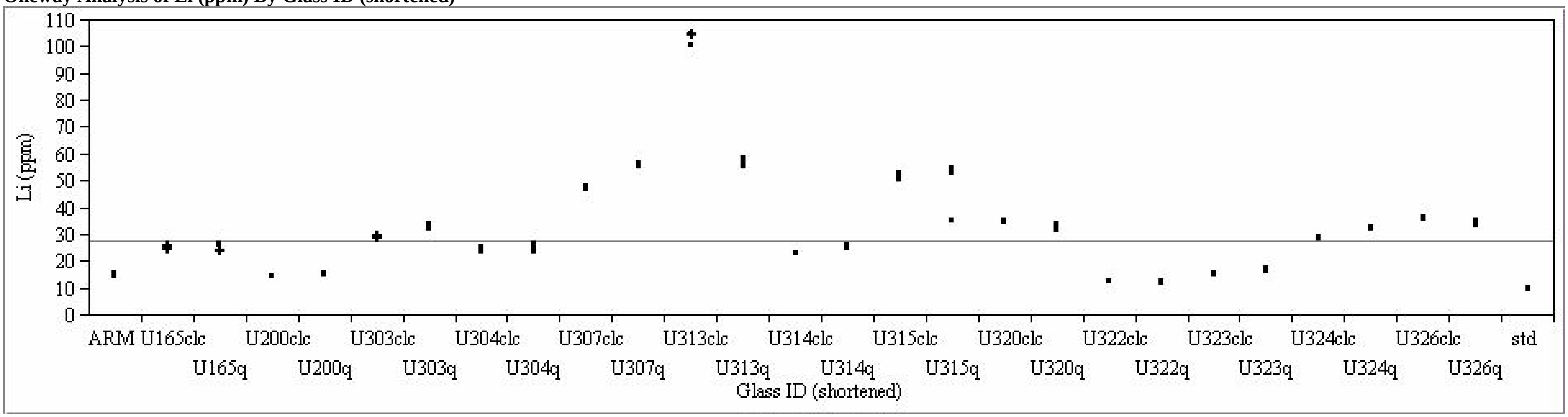
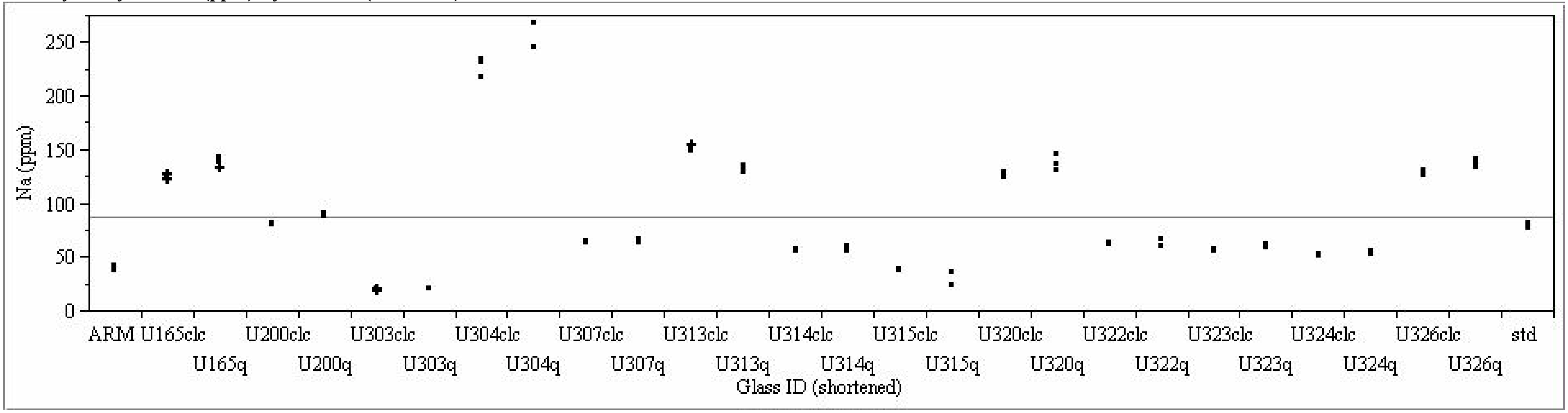


Exhibit E17. PCTs by Glass ID (Excluding EA and Blanks) for Underwashed Sludge *(continued)*

Oneway Analysis of Na (ppm) By Glass ID (shortened)



Oneway Analysis of Si (ppm) By Glass ID (shortened)

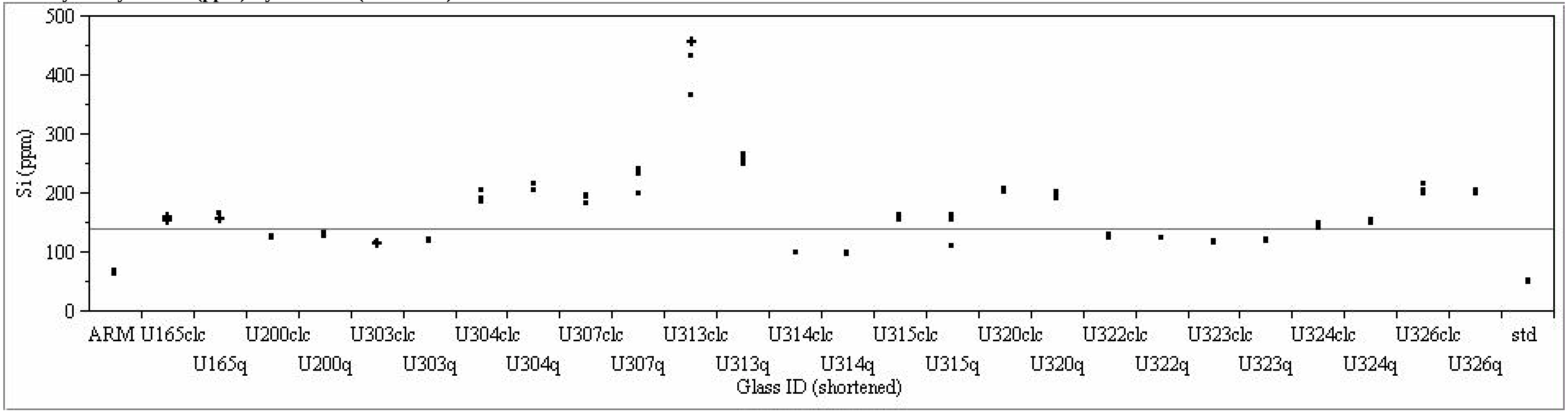
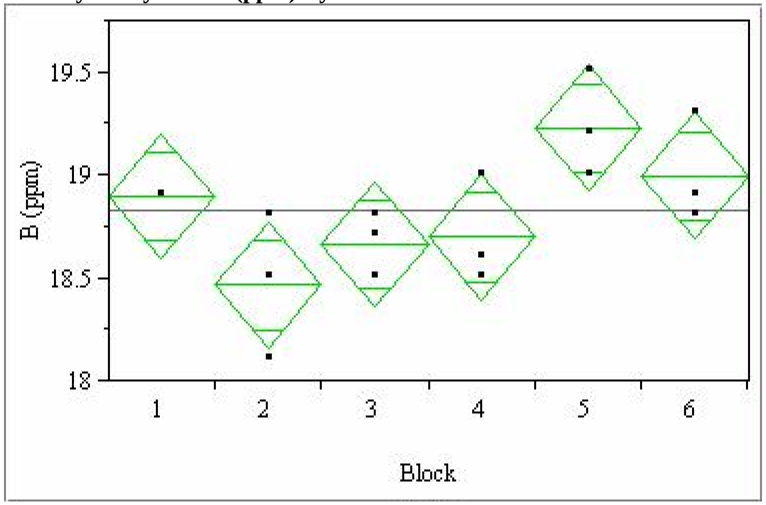


Exhibit E18. Measurements of the Solutions Standards by ICP Block for Underwashed Sludge Case

Oneway Analysis of B (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	0.614561
Adj Rsquare	0.453961
Root Mean Square Error	0.241523
Mean of Response	18.82778
Observations (or Sum Wgts)	18

Analysis of Variance

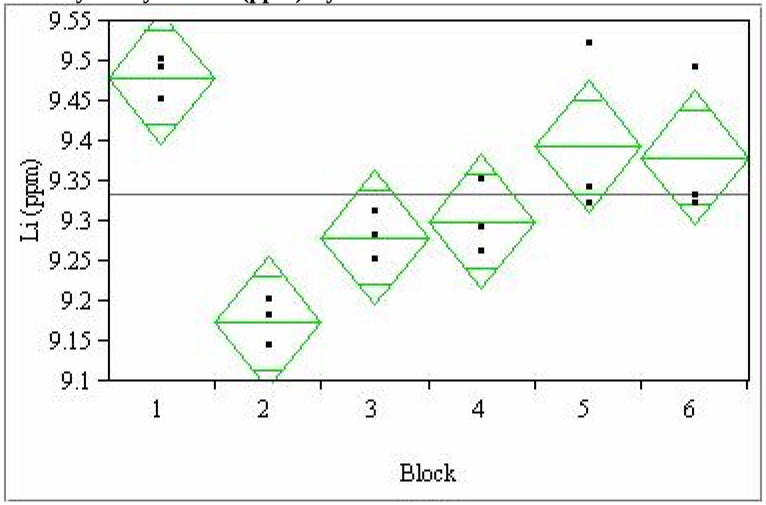
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	1.1161111	0.223222	3.8267	0.0264
Error	12	0.7000000	0.058333		
C. Total	17	1.8161111			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	18.9000	0.13944	18.596	19.204
2	3	18.4667	0.13944	18.163	18.770
3	3	18.6667	0.13944	18.363	18.970
4	3	18.7000	0.13944	18.396	19.004
5	3	19.2333	0.13944	18.930	19.537
6	3	19.0000	0.13944	18.696	19.304

Std Error uses a pooled estimate of error variance

Oneway Analysis of Li (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	0.767223
Adj Rsquare	0.670233
Root Mean Square Error	0.065659
Mean of Response	9.334444
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0.17051111	0.034102	7.9103	0.0017
Error	12	0.05173333	0.004311		
C. Total	17	0.22224444			

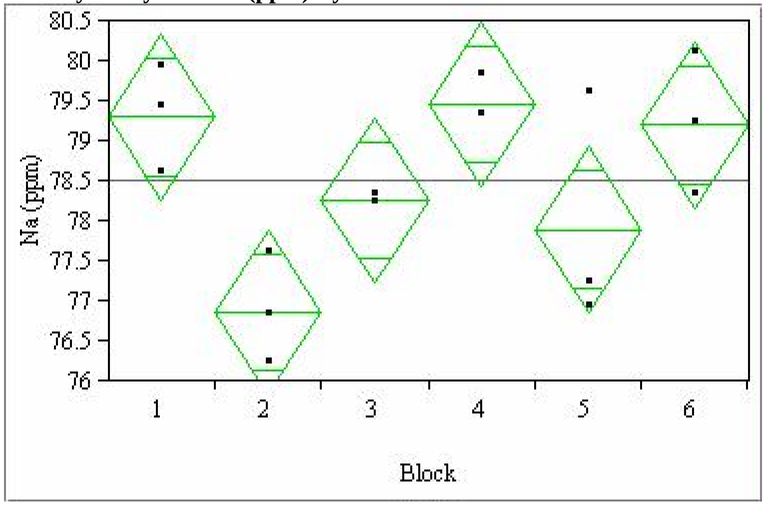
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	9.48000	0.03791	9.3974	9.5626
2	3	9.17333	0.03791	9.0907	9.2559
3	3	9.28000	0.03791	9.1974	9.3626
4	3	9.30000	0.03791	9.2174	9.3826
5	3	9.39333	0.03791	9.3107	9.4759
6	3	9.38000	0.03791	9.2974	9.4626

Std Error uses a pooled estimate of error variance

Exhibit E18. Measurements of the Solutions Standards by ICP Block for Underwashed Sludge Case *(continued)*

Oneway Analysis of Na (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	0.658142
Adj Rsquare	0.5157
Root Mean Square Error	0.817517
Mean of Response	78.5
Observations (or Sum Wgts)	18

Analysis of Variance

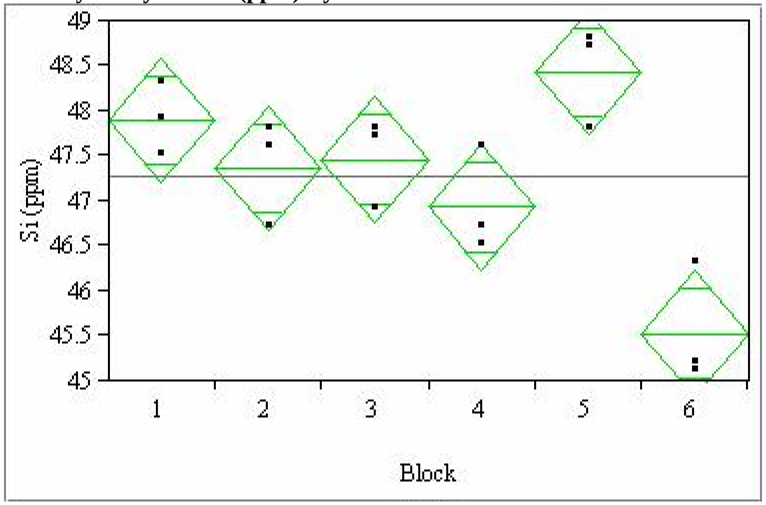
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	15.440000	3.08800	4.6204	0.0139
Error	12	8.020000	0.66833		
C. Total	17	23.460000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	79.3000	0.47199	78.272	80.328
2	3	76.8667	0.47199	75.838	77.895
3	3	78.2667	0.47199	77.238	79.295
4	3	79.4667	0.47199	78.438	80.495
5	3	77.9000	0.47199	76.872	78.928
6	3	79.2000	0.47199	78.172	80.228

Std Error uses a pooled estimate of error variance

Oneway Analysis of Si (ppm) By Block



Oneway Anova

Summary of Fit

Rsquare	0.800969
Adj Rsquare	0.71804
Root Mean Square Error	0.553273
Mean of Response	47.27222
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	14.782778	2.95656	9.6584	0.0007
Error	12	3.673333	0.30611		
C. Total	17	18.456111			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	47.9000	0.31943	47.204	48.596
2	3	47.3667	0.31943	46.671	48.063
3	3	47.4667	0.31943	46.771	48.163
4	3	46.9333	0.31943	46.237	47.629
5	3	48.4333	0.31943	47.737	49.129
6	3	45.5333	0.31943	44.837	46.229

Std Error uses a pooled estimate of error variance

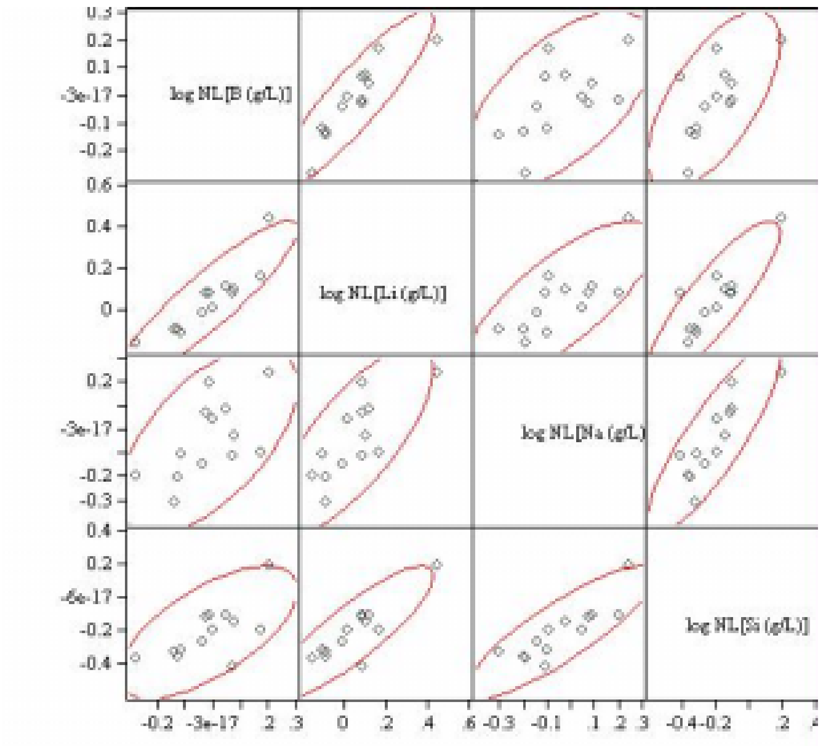
Exhibit E19. Correlations of PCTs for Underwashed Case

Under-Measured-clc

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	0.8999	0.5959	0.6516
log NL[Li (g/L)]	0.8999	1.0000	0.7558	0.8601
log NL[Na (g/L)]	0.5959	0.7558	1.0000	0.8566
log NL[Si (g/L)]	0.6516	0.8601	0.8566	1.0000

Scatterplot Matrix



Under-Measured-quenched

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	0.8843	0.3822	0.4092
log NL[Li (g/L)]	0.8843	1.0000	0.4988	0.6341
log NL[Na (g/L)]	0.3822	0.4988	1.0000	0.7977
log NL[Si (g/L)]	0.4092	0.6341	0.7977	1.0000

Scatterplot Matrix

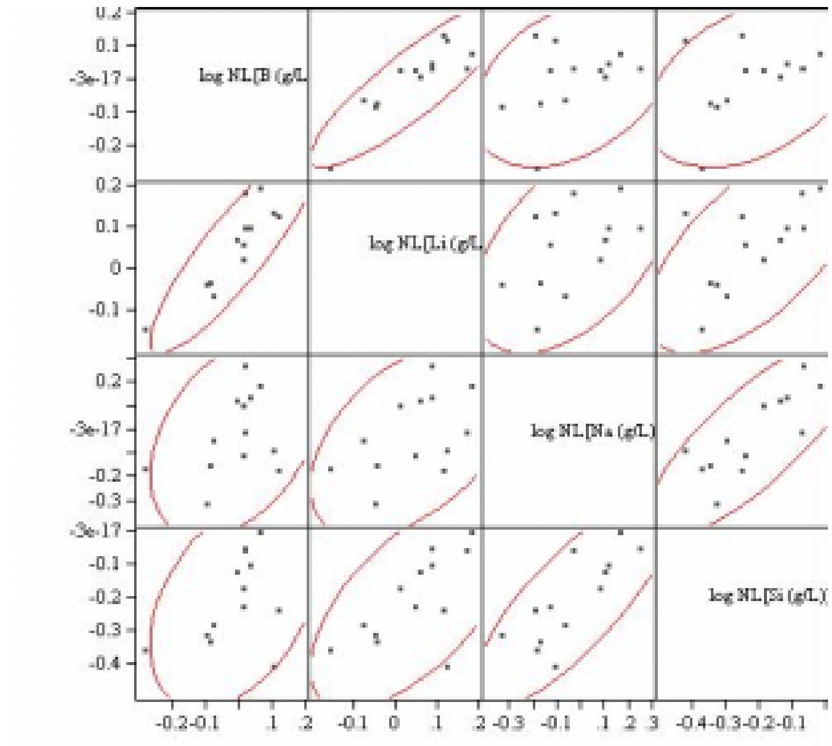
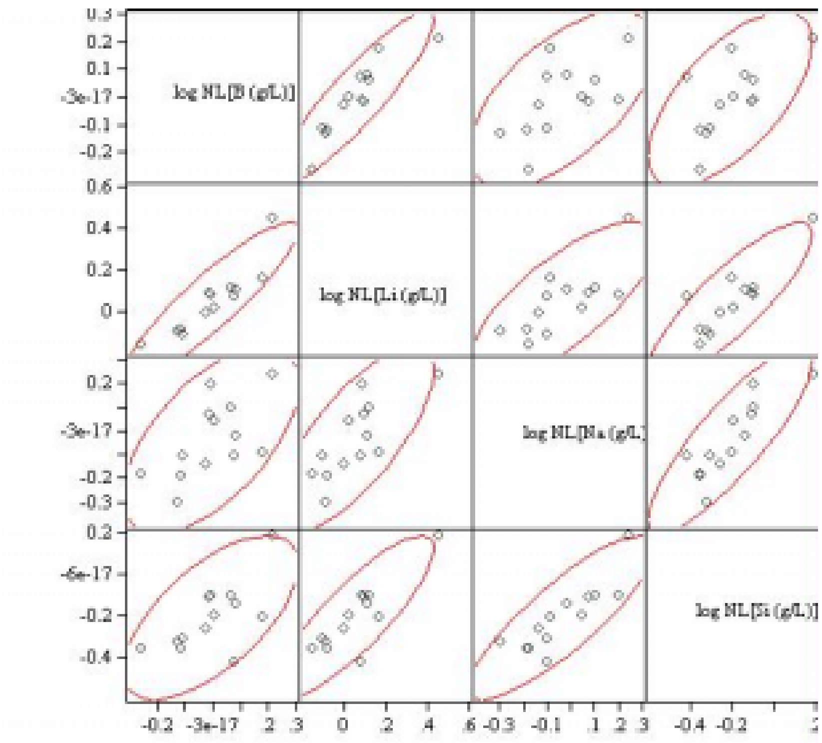


Exhibit E19. Correlations of PCTs for Underwashed Case *(Continued)*

Under-Measured bc-clc 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	0.9056	0.6033	0.6490
log NL[Li (g/L)]	0.9056	1.0000	0.7535	0.8535
log NL[Na (g/L)]	0.6033	0.7535	1.0000	0.8551
log NL[Si (g/L)]	0.6490	0.8535	0.8551	1.0000

Scatterplot Matrix



Under-Measured bc-quenched 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	0.8862	0.3887	0.4000
log NL[Li (g/L)]	0.8862	1.0000	0.4977	0.6233
log NL[Na (g/L)]	0.3887	0.4977	1.0000	0.7964
log NL[Si (g/L)]	0.4000	0.6233	0.7964	1.0000

Scatterplot Matrix

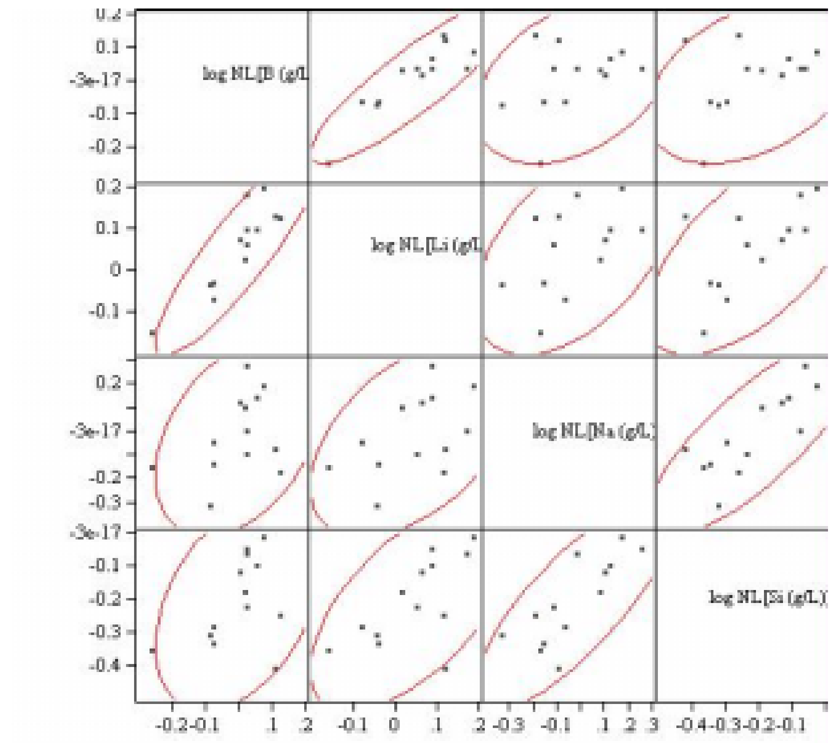


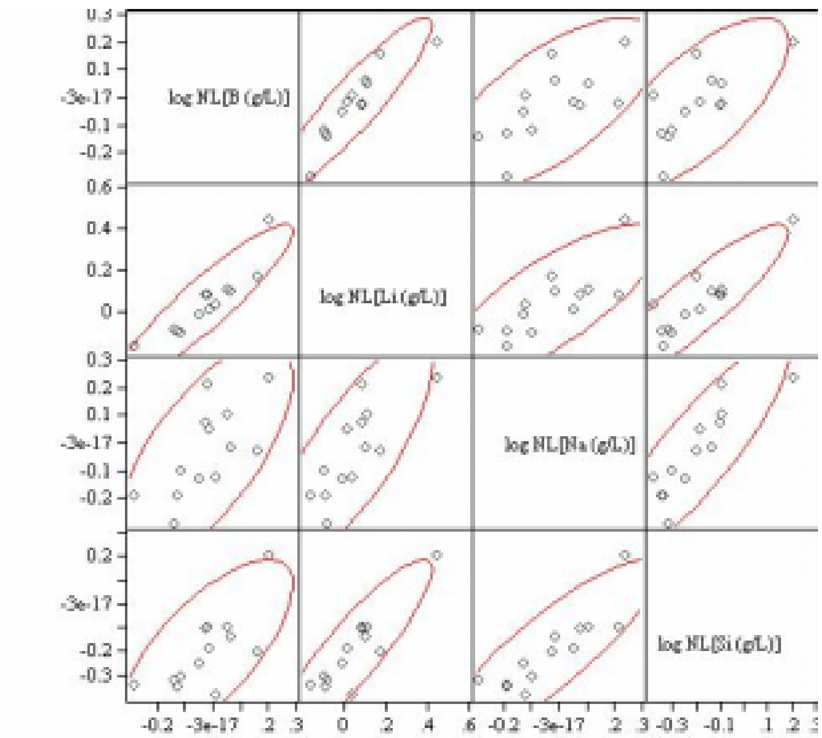
Exhibit AE19. Correlations of PCTs for Underwashed Case *(Continued)*

Under-Targeted-clc

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	0.9168	0.6828	0.7185
log NL[Li (g/L)]	0.9168	1.0000	0.7805	0.8932
log NL[Na (g/L)]	0.6828	0.7805	1.0000	0.8724
log NL[Si (g/L)]	0.7185	0.8932	0.8724	1.0000

Scatterplot Matrix



Under-Targeted-quenched

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	0.8920	0.4913	0.5085
log NL[Li (g/L)]	0.8920	1.0000	0.5402	0.7003
log NL[Na (g/L)]	0.4913	0.5402	1.0000	0.8346
log NL[Si (g/L)]	0.5085	0.7003	0.8346	1.0000

Scatterplot Matrix

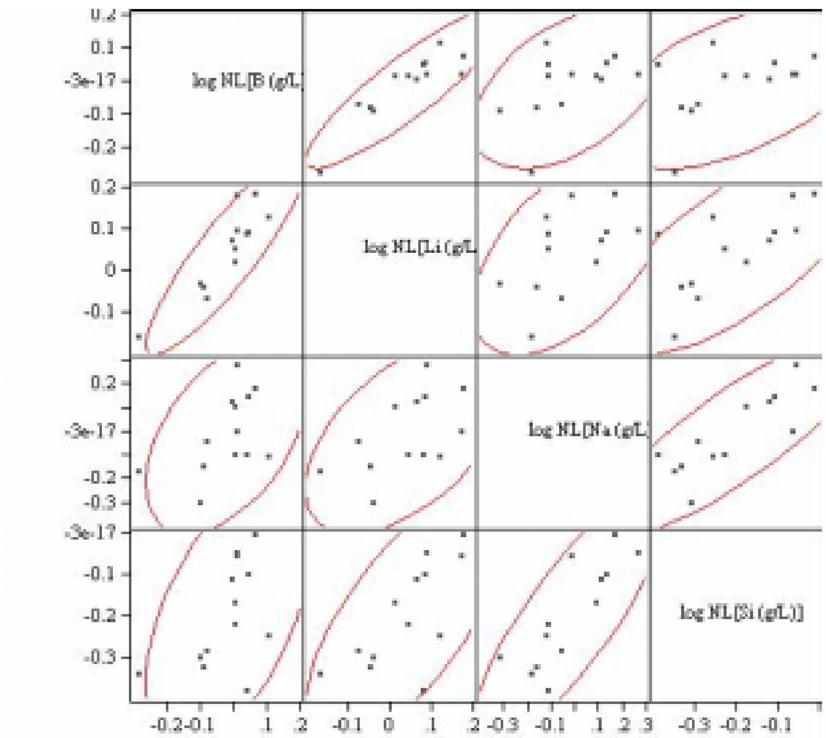
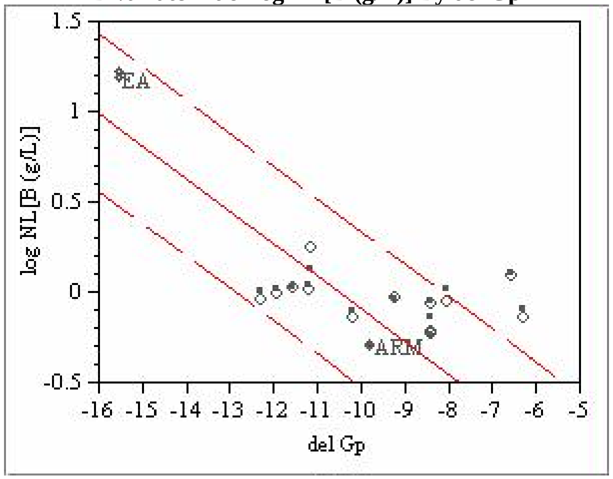
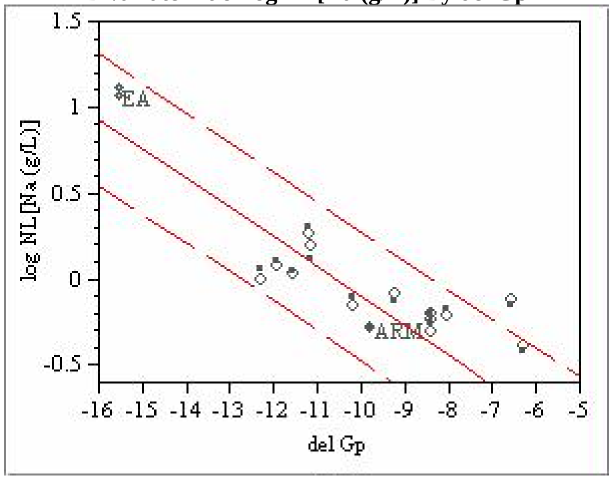


Exhibit E20. PCT vs Del Gp for Nominal-Washed Case; Measured Compositions

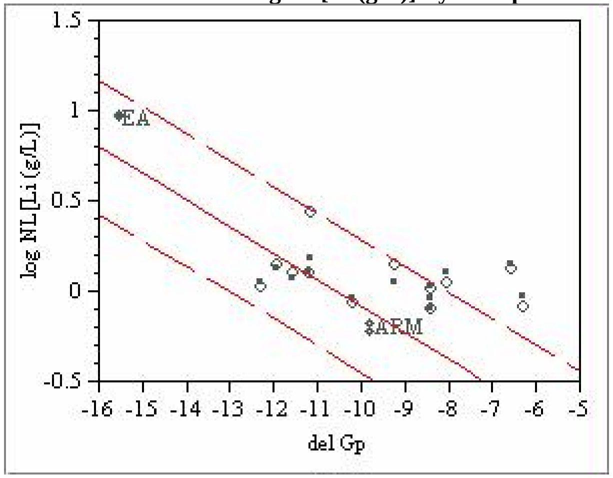
Bivariate Fit of log NL[B (g/L)] By del Gp



Bivariate Fit of log NL[Na (g/L)] By del Gp



Bivariate Fit of log NL[Li (g/L)] By del Gp



Bivariate Fit of log NL[Si (g/L)] By del Gp

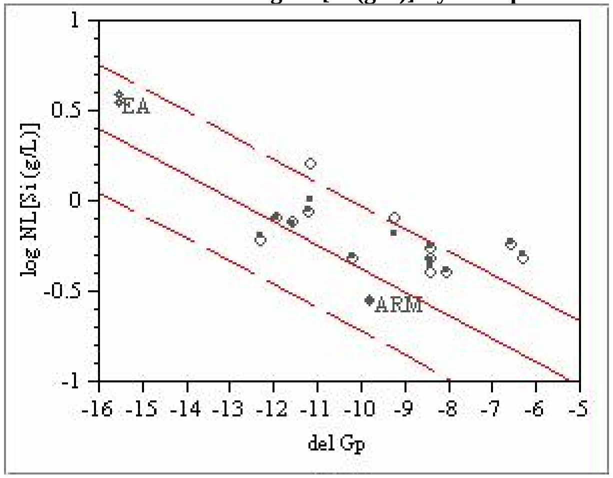
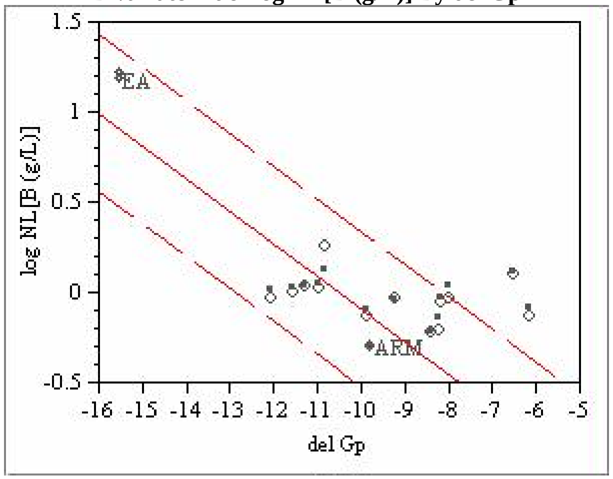
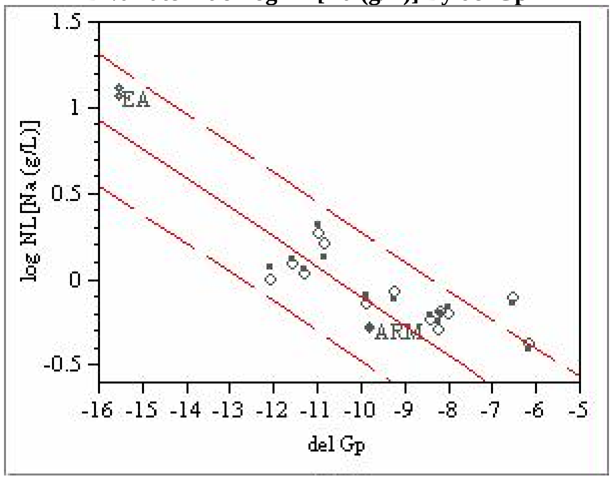


Exhibit E21. PCT vs Del Gp for Nominal-Washed Case; Measured Bias-Corrected Compositions

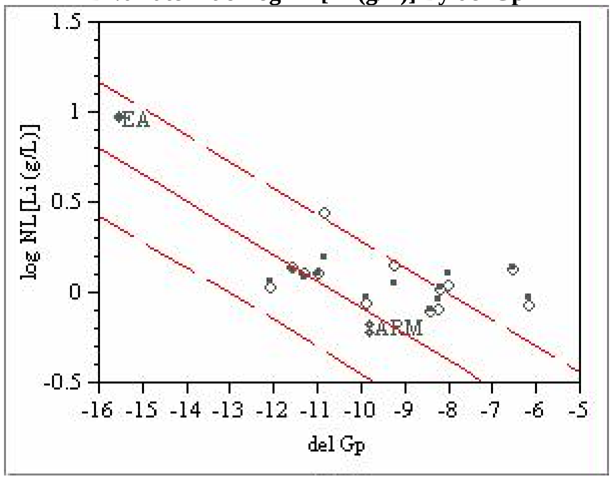
Bivariate Fit of log NL[B (g/L)] By del Gp



Bivariate Fit of log NL[Na (g/L)] By del Gp



Bivariate Fit of log NL[Li (g/L)] By del Gp



Bivariate Fit of log NL[Si (g/L)] By del Gp

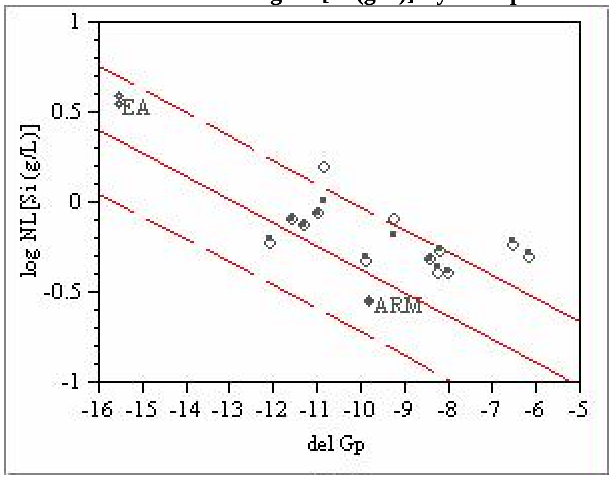
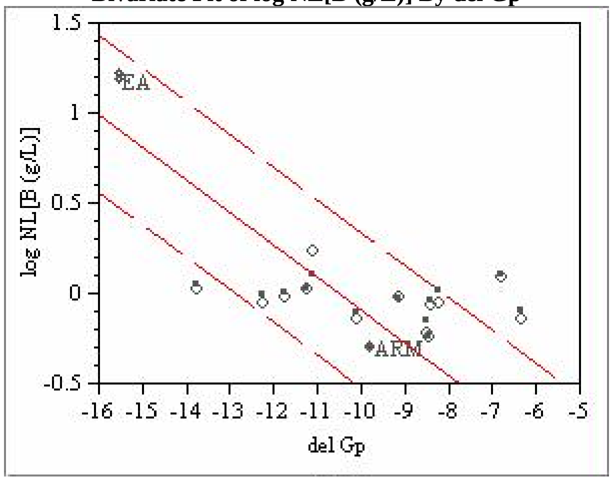
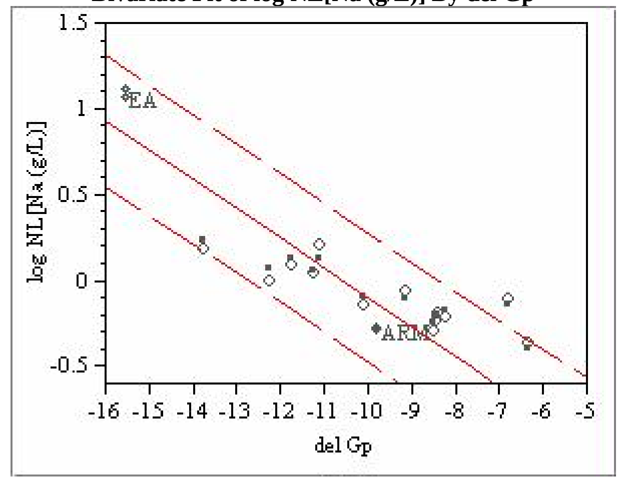


Exhibit E22. PCT vs Del Gp for Nominal-Washed Case; Targeted Compositions

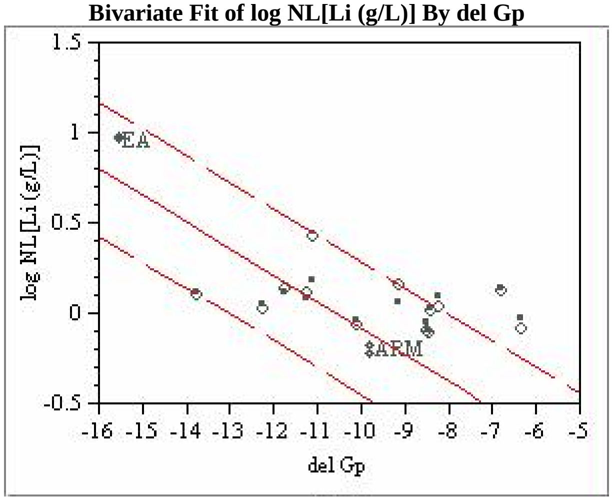
Bivariate Fit of log NL[B (g/L)] By del Gp



Bivariate Fit of log NL[Na (g/L)] By del Gp



Bivariate Fit of log NL[Li (g/L)] By del Gp



Bivariate Fit of log NL[Si (g/L)] By del Gp

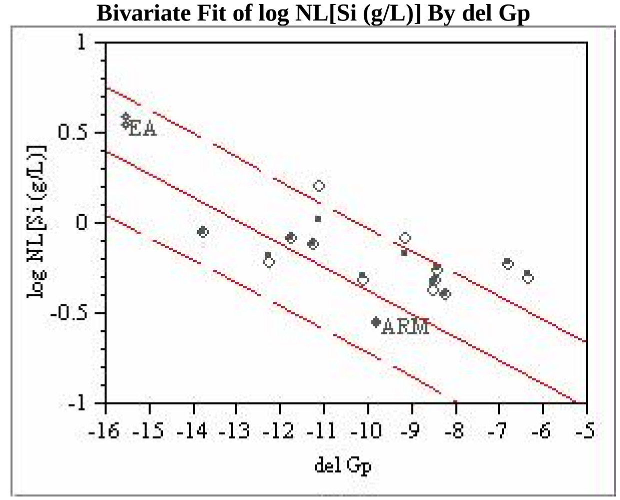
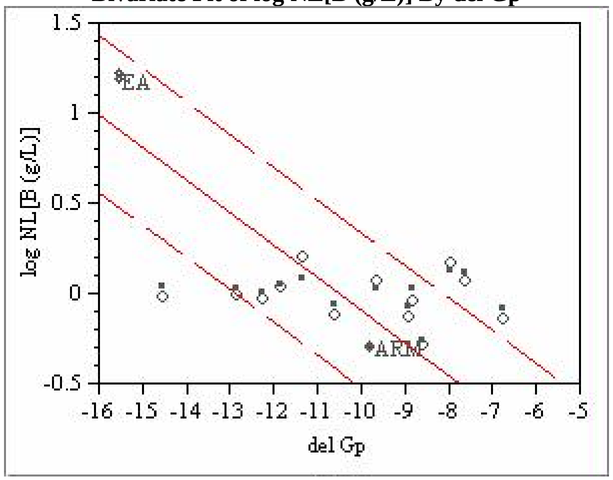
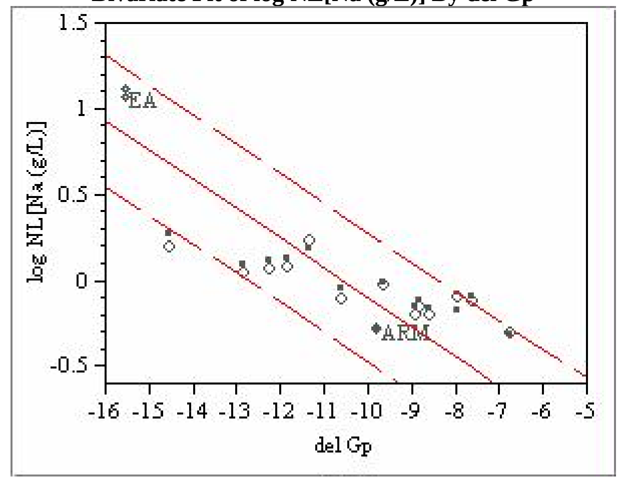


Exhibit E23. PCT vs Del Gp for Underwashed Case; Measured Compositions

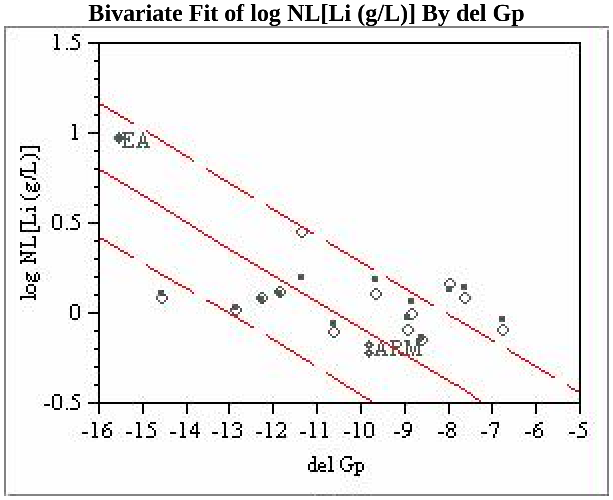
Bivariate Fit of log NL[B (g/L)] By del Gp



Bivariate Fit of log NL[Na (g/L)] By del Gp



Bivariate Fit of log NL[Li (g/L)] By del Gp



Bivariate Fit of log NL[Si (g/L)] By del Gp

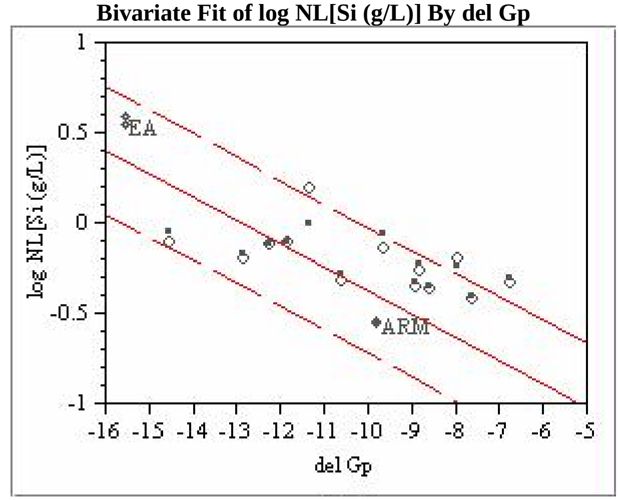
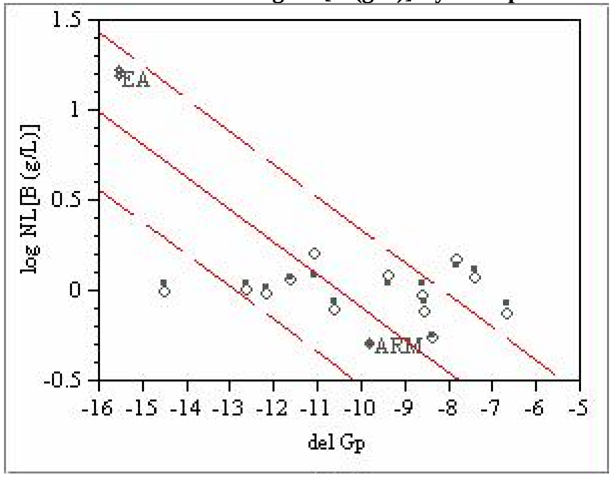
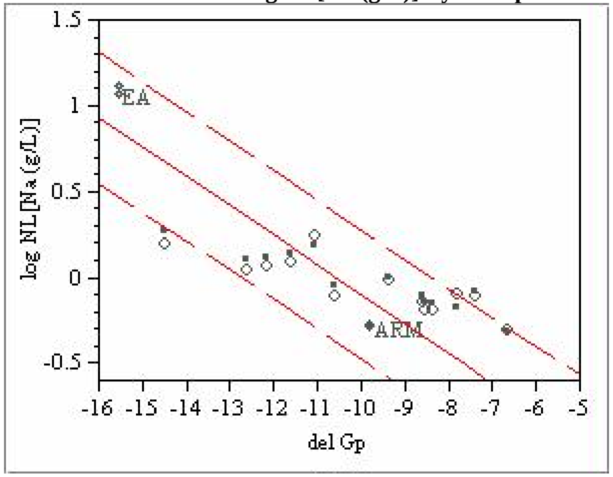


Exhibit E24. PCT vs Del Gp for Underwashed Case; Measured Bias-Corrected Compositions

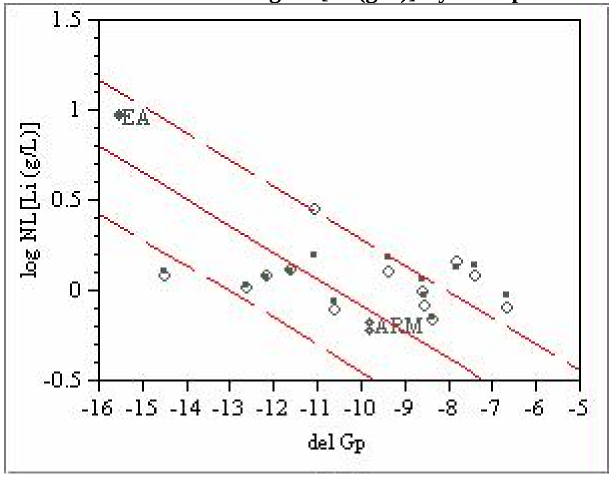
Bivariate Fit of log NL[B (g/L)] By del Gp



Bivariate Fit of log NL[Na (g/L)] By del Gp



Bivariate Fit of log NL[Li (g/L)] By del Gp



Bivariate Fit of log NL[Si (g/L)] By del Gp

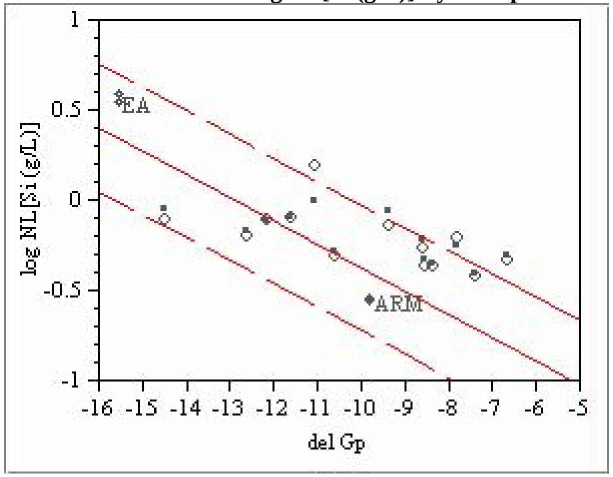
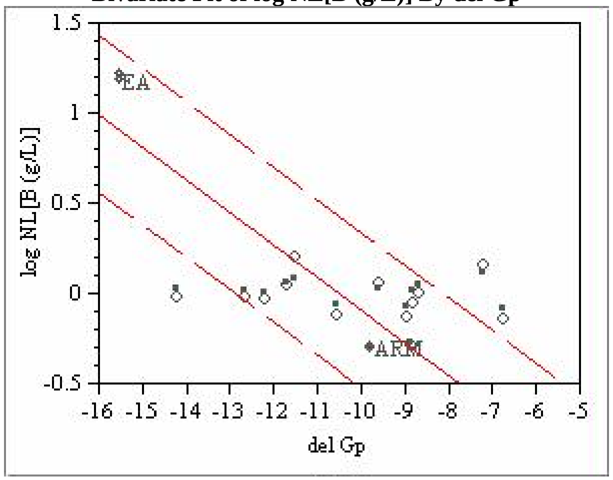
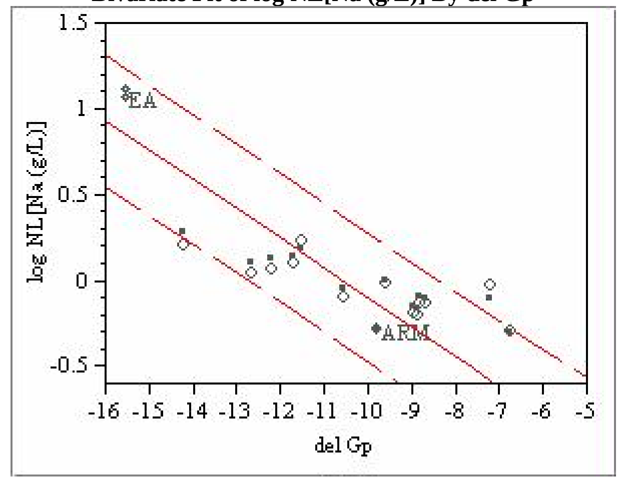


Exhibit E25. PCT vs Del Gp for Underwashed Case; Targeted Compositions

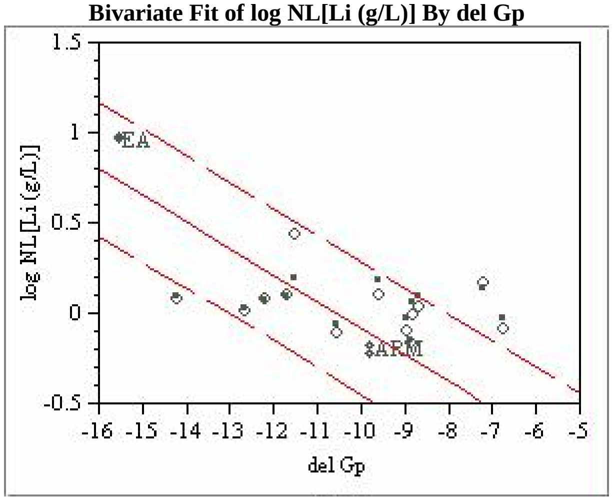
Bivariate Fit of log NL[B (g/L)] By del Gp



Bivariate Fit of log NL[Na (g/L)] By del Gp



Bivariate Fit of log NL[Li (g/L)] By del Gp



Bivariate Fit of log NL[Si (g/L)] By del Gp

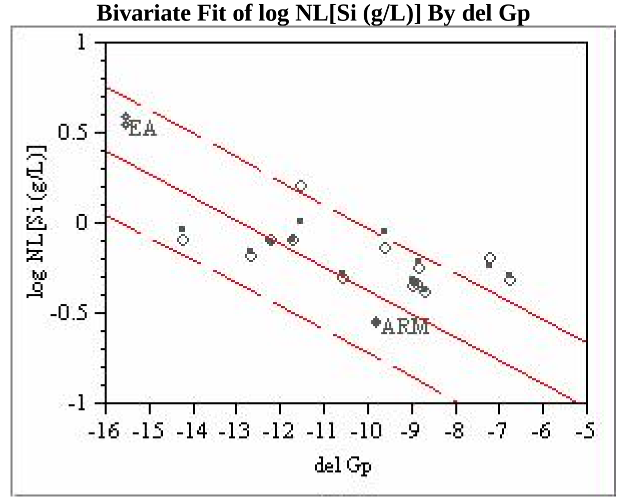
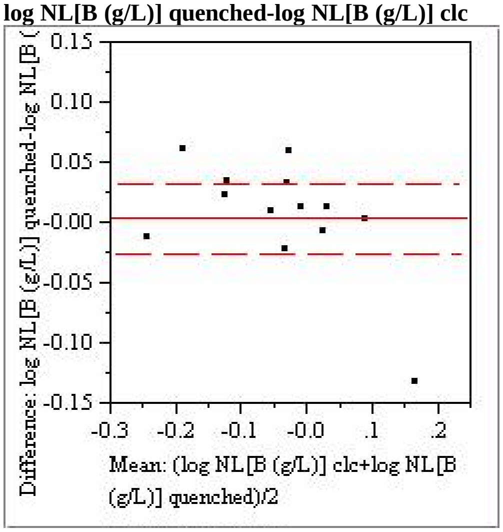


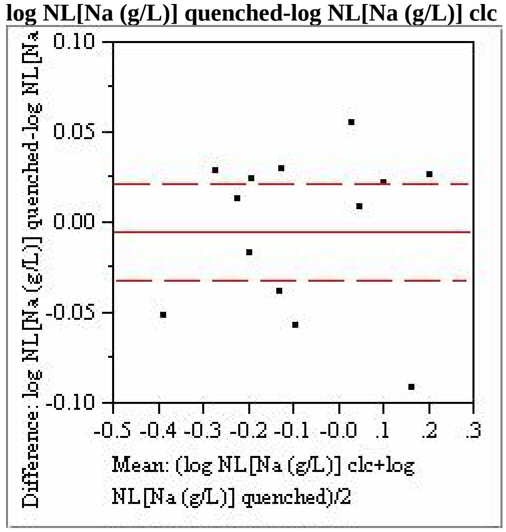
Exhibit E26. Quenched versus Centerline Cooled PCTs For Nominally-Washed Case

Difference:
log NL[B (g/L)] quenched-log NL[B (g/L)] clc



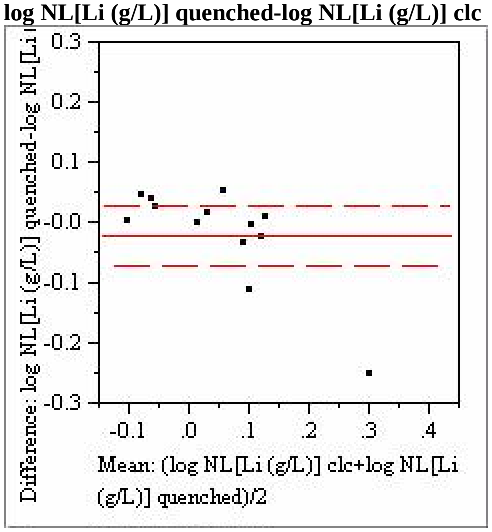
log NL[B (g/L)] quenched	-0.0377	t-Ratio	0.273934
log NL[B (g/L)] clc	-0.0414	DF	12
Mean Difference	0.0037	Prob > |t|	0.7888
Std Error	0.0135	Prob > t	0.3944
Upper95%	0.03312	Prob < t	0.6056
Lower95%	-0.0257		
N	13		
Correlation	0.93479		

Difference:
log NL[Na (g/L)] quenched-log NL[Na (g/L)] clc



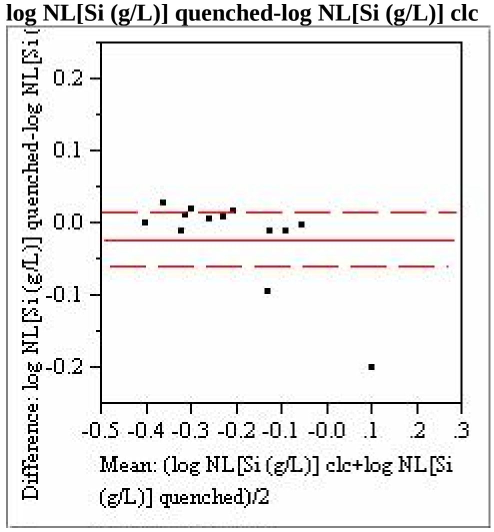
log NL[Na (g/L)] quenched	-0.0838	t-Ratio	-0.41586
log NL[Na (g/L)] clc	-0.0788	DF	12
Mean Difference	-0.005	Prob > |t|	0.6849
Std Error	0.01205	Prob > t	0.6576
Upper95%	0.02125	Prob < t	0.3424
Lower95%	-0.0313		
N	13		
Correlation	0.97112		

Difference:
log NL[Li (g/L)] quenched-log NL[Li (g/L)] clc



log NL[Li (g/L)] quenched	0.04012	t-Ratio	-0.9532
log NL[Li (g/L)] clc	0.06188	DF	12
Mean Difference	-0.0218	Prob > |t|	0.3593
Std Error	0.02282	Prob > t	0.8204
Upper95%	0.02797	Prob < t	0.1796
Lower95%	-0.0715		
N	13		
Correlation	0.88012		

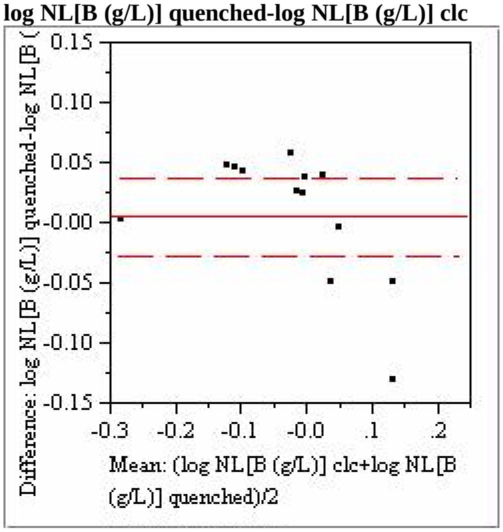
Difference:
log NL[Si (g/L)] quenched-log NL[Si (g/L)] clc



log NL[Si (g/L)] quenched	-0.2173	t-Ratio	-1.32738
log NL[Si (g/L)] clc	-0.1945	DF	12
Mean Difference	-0.0228	Prob > |t|	0.2091
Std Error	0.0172	Prob > t	0.8955
Upper95%	0.01465	Prob < t	0.1045
Lower95%	-0.0603		
N	13		
Correlation	0.95497		

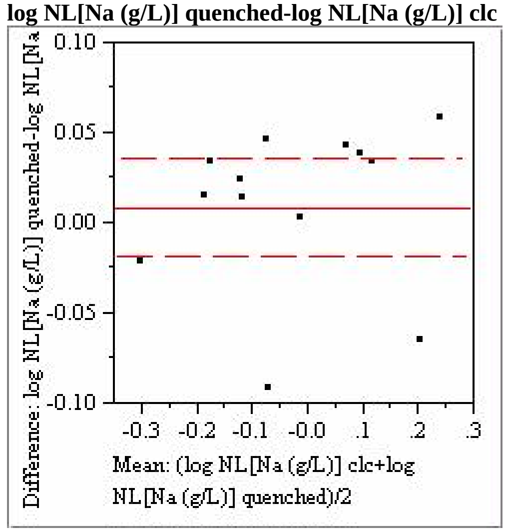
Exhibit E27. Quenched versus Centerline Cooled PCTs For Underwashed Case

Difference:
log NL[B (g/L)] quenched-log NL[B (g/L)] clc



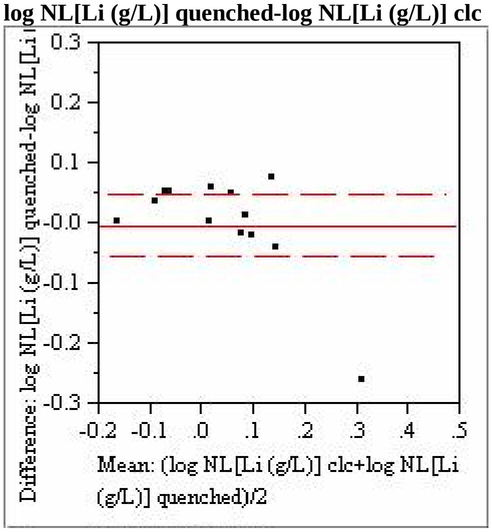
log NL[B (g/L)] quenched	-0.0185	t-Ratio	0.338677
log NL[B (g/L)] clc	-0.0236	DF	12
Mean Difference	0.00508	Prob > |t|	0.7407
Std Error	0.01499	Prob > t	0.3704
Upper95%	0.03774	Prob < t	0.6296
Lower95%	-0.0276		
N	13		
Correlation	0.92021		

Difference:
log NL[Na (g/L)] quenched-log NL[Na (g/L)] clc



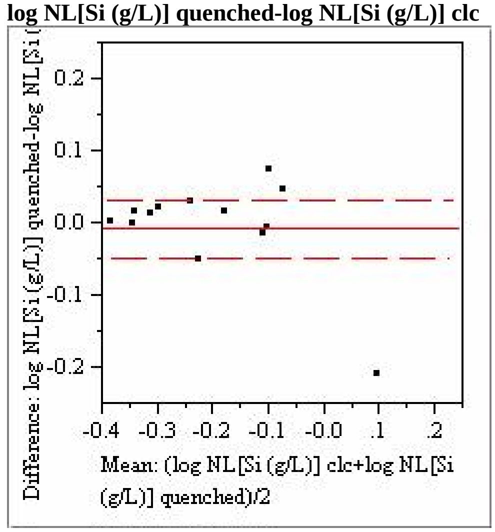
log NL[Na (g/L)] quenched	-0.0207	t-Ratio	0.719619
log NL[Na (g/L)] clc	-0.0296	DF	12
Mean Difference	0.00887	Prob > |t|	0.4855
Std Error	0.01233	Prob > t	0.2428
Upper95%	0.03573	Prob < t	0.7572
Lower95%	-0.018		
N	13		
Correlation	0.96374		

Difference:
log NL[Li (g/L)] quenched-log NL[Li (g/L)] clc



log NL[Li (g/L)] quenched	0.0412	t-Ratio	-0.1682
log NL[Li (g/L)] clc	0.0452	DF	12
Mean Difference	-0.004	Prob > |t|	0.8692
Std Error	0.02377	Prob > t	0.5654
Upper95%	0.04779	Prob < t	0.4346
Lower95%	-0.0558		
N	13		
Correlation	0.86204		

Difference:
log NL[Si (g/L)] quenched-log NL[Si (g/L)] clc



log NL[Si (g/L)] quenched	-0.2047	t-Ratio	-0.42016
log NL[Si (g/L)] clc	-0.1967	DF	12
Mean Difference	-0.008	Prob > |t|	0.6818
Std Error	0.01892	Prob > t	0.6591
Upper95%	0.03328	Prob < t	0.3409
Lower95%	-0.0492		
N	13		
Correlation	0.91053		

Distribution

W. D. Kerley, 704-S
J. F. Ortaldo, 704-S
R. E. Edwards, 704-3N
M. R. Norton, 704-27S
J. E. Occhipinti, 704-27S
J. F. Sproull, 704-30S
D. C. Iverson, 704-30S
R. J. O'Driscoll, 704-30S
L. M. Papouchado, 773-A
E. W. Holtzscheiter, 773-A
R. H. Spires, 773-A
D. A. Crowley, 773-43A
S. L. Marra, 704-1T
D. F. Bickford, 773-43A
C. M. Jantzen, 773-A
D. C. Witt, 704-1T
M. E. Stone, 704-1T
D. P. Lambert, 704-1T
M. F. Williams, 704-1T
D. C. Koopman, 704-1T
T. K. Snyder, 773-42A
J. J. Connelly, 773-41A
K. G. Brown, 704-1T
D. R. Best, 773-41A
D.K. Peeler, 773-43A
T.H. Lorier, 773-23A
D. H. Miller, 786-1A
T. B. Edwards, 773-42A
J.C. George, 773-43A
Records (4)
VT QA File