WSRC-TR-99-00055, Rev. 0

Composition/Property Relationships for the Phase 1 Am/Cm Glass Variability Study

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DOE Contract No. DE-AC09-96SR18500

This paper was prepared in connection with work done under the above contract number with the U. S. Department of Energy.

Immobilization Technology Section
Savannah River Technology Center
Westinghouse Savannah River Company

WSRC-TR-99-00055
Rev. 0

January 29, 1999

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Task Title: Am-Cm: SrABS Glass Variability Study	ITS Task Number: ITS-98-0099	TTR Number: NMSS/SE-005	Date:
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EXECUTIVE SUMMARY

The objective of this research was to evaluate the effect of compositional uncertainties on the primary processing and product performance criteria for potential glasses to stabilize the Tank 17.1 Am-Cm solution. Given the feed composition (and its anticipated ± 20% variation), the composition of the 25SrABS cullet, and the target feed loading range of 20 to 40 mass % (oxide basis) for the process, an experimental glass composition region (EGCR) for Phase 1 testing was defined. In this study, glasses were fabricated and both processing and product performance properties were measured as a function of glass composition. These properties were assessed against predefined constraints to define an acceptable glass composition region (AGCR) in which all property constraints were simultaneously satisfied.

As a result, an acceptable glass composition region (AGCR) has been identified in which glasses meet all processing and product performance criteria as currently defined. Therefore, if compositions within the AGCR are processed, the risks of process upsets are minimized and the probability of accepting the final glass product is increased. Based on the Phase 1 results, the operational window is rather limited given the current processing criteria (primarily due to the 1250°C liquidus temperature (T_L) constraint). However, if the T_L constraint was increased to 1300°C (or greater), the AGCR would expand but would still be limited by viscosity at the lower loadings (20 – 25 mass % feed loading).

Within the Phase 1 EGCR, most property / composition relationships are dependent upon the total lanthanide oxide (Ln_2O_3) content[a] in the glass. There was no indication that the distribution of the lanthanides impacts either the processing or product performance properties within the limits of the experimental design. The major observations for the Phase 1 variability study are summarized below:

HOMOGENEITY

(1) The AGCR is not restricted by homogeneity as defined by X-ray diffraction (XRD).

DURABILITY

(2) The AGCR is not restricted by durability as defined by the 7-Day Product Consistency Test (PCT), ASTM C-1285-94.
(3) PCT results indicate that the Phase 1 EGCR glasses are at least 2 orders of magnitude more durable than the Environmental Assessment (EA) glass based on normalized boron releases.

VISCOSITY

(4) The AGCR is restricted by the viscosity constraint of 3 – 24 Poise at 1350°C. Phase 1 glasses failing the constraint had viscosities greater than 24 Poise at 1350°C.
(5) The key indicator for complying with the viscosity constraint is the total lanthanide content in the glass. The viscosity data indicate that total lanthanide contents of ~45 mass % and ~42 mass %, based on targeted and "as-measured" respectively, should be targeted in the vitrification batch process to ensure a continuous pour.
(6) The fact that no glasses failed the viscosity constraint on the low side (i.e., < 3 Poise at 1350°C) provides the opportunity to increase waste loadings (or total lanthanide content) while maintaining adequate viscosity values.

[a] Throughout this report, the reference to lanthanide oxides (Ln_2O_3) refers to the oxides in the lanthanide (or rare earth) series (La, Ce, Pr, Nd, Sm, Eu, Gd, and Er) unless otherwise stated.

LIQUIDUS TEMPERATURE

(7) The AGCR is limited by the 1250°C liquidus temperature constraint.

(8) Within the EGCR, two primary phase fields were observed: a rare earth silicate (RES) phase and an aluminosilicate (AlS) phase.

(9) Within each primary phase field, the total lanthanide content can be used as the key indicator of T_L and trends in the T_L data. At low total Ln_2O_3 contents (or low loadings) the primary phase is an AlS and increases in Ln_2O_3 content decrease T_L. At higher Ln_2O_3 contents, the primary phase is a RES and increases in Ln_2O_3 content increase T_L. This phase field transition occurs at approximately 42.5 mass % total Ln_2O_3 content (on an "as-measured" basis) or ~25 – 30 mass % feed loading.

(10) Seven of the 31 Phase 1 glasses fail the 1250°C liquidus constraint. Unlike the viscosity constraint where only low loadings caused 10 glasses to be "unacceptable", both high and low loaded glasses (i.e., in both primary phase fields) fail the T_L constraint.

(11) Increasing the T_L constraint to 1300°C (or greater) would result in the "acceptance" of all Phase 1 glasses (ignoring uncertainties associated with the T_L measurement) and the AGCR would not be restricted by T_L.

CHEMICAL COMPOSITION

(12) Based on the chemical composition analysis, a statistically significant difference (at a 5% significance level) was observed between the targeted and "as-measured" compositions for all oxides except the bias-corrected B_2O_3, Er_2O_3, Gd_2O_3, Pr_2O_3, and Sm_2O_3. This was partially driven by the low sum of oxides obtained from the compositional analyses.

(13) Reproducibility of replicate samples on several properties raised issues regarding measurement uncertainty and/or homogeneity in chemical composition of subsamples. Recommendations have been proposed to minimize this issue in Phase 2.

ACRONYMS

ADS	Analytical Development Services
AGCR	Acceptable Glass Composition Region
AIS	Aluminosilicate
ARM	Approved Reference Material
ASTM	American Society for Testing and Materials
CIM	Cylindrical Induction Melter
DNFSB	Defense Nuclear Facility Safety Board
EA	Environmental Assessment
EGCR	Experimental Glass Composition Region
ICP-AES	Inductively Coupled Plasma – Atomic Emission Spectroscopy
NMS&S	Nuclear Materials Stabilization & Storage
MPPF	Multi-Purpose Processing Facility
ORNL	Oak Ridge National Laboratory
PCT	Product Consistency Test
PNNL	Pacific Northwest National Laboratory
RES	Rare-earth Silicate
SEM/EDS	Scanning Electron Microscopy / Energy Dispersive Spectroscopy
SrABS	$SrO-Al_2O_3-B_2O_3-SiO_2$
SRTC	Savannah River Technology Center
SRTC-ML	Savannah River Technology Center – Mobile Laboratory
T_L	Liquidus Temperature
TTR	Technical Task Request
VFT	Vogel-Tamman-Fulcher
XRD	X-Ray Diffraction

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INTRODUCTION

Approximately 11,000 liters (3,600 gallons) of solution containing isotopes of Am and Cm are currently stored in F-Canyon Tank 17.1. These isotopes were recovered during plutonium–242 production campaigns in the mid- and late-1970's. The continued storage of these isotopes was identified as an item of primary concern in the Defense Nuclear Facility Safety Board's (DNFSB) Recommendation 94-1 [1]. An analysis of several alternatives resulted in the recommendation to stabilize the Am-Cm solution in a high-lanthanide glass [2]. The Multi-Purpose Processing Facility (MPPF) in the F-Canyon will be used for the vitrification process. Pretreatment operations will be performed in existing canyon vessels to separate actinides and lanthanides from other impurities (primarily iron, aluminum, and sodium) prior to the vitrification operation.

The proposed baseline vitrification batch process involves precipitating the actinide materials with oxalic acid and washing the precipitate to lower the nitric acid concentration. The subsequent oxalate precipitate is then mixed with glass formers. The resultant mixture is then dried and heated to approximately 1450°C to produce a molten glass product in the Cylindrical Induction Melter (CIM). The glass is then poured through a drain tube into a stainless steel cylinder. Marra et al. [3] and Fellinger et al. [4] provided a more detailed summary of this baseline vitrification process.

For the vitrification campaign to be successful, a framework of knowledge sufficient to control the Am/Cm target glass composition within an acceptable processing window must be developed. Compositional control is essential to ensure that targeted glass compositions have properties that meet the MPPF melter processing requirements, the Oak Ridge National Laboratory (ORNL) processing capabilities for recovery of the americium and curium, and/or the product requirements for interim or long-term storage or disposal. To develop such a knowledge base, relationships between product and process properties and glass composition over the anticipated composition region for the MPPF vitrification process are being explored by the Savannah River Technology Center (SRTC).

In this study, glasses were fabricated and both processing and product performance properties were measured as a function of glass composition. These properties were assessed against predefined constraints to define an acceptable glass composition region (AGCR) in which all property constraints were simultaneously satisfied. The results of these property / composition relationships are described in this document. This study was developed [5,6] and executed by SRTC based on the Technical Task Request (TTR) [7] as defined by the Nuclear Materials Stabilization & Storage (NMS&S) Division.

OBJECTIVE STATEMENT

The objectives of this research are to evaluate the effect of compositional uncertainties on the primary processing and product performance properties for potential glasses to stabilize the Tank 17.1 Am-Cm solution and to identify the AGCR. Glasses in the AGCR will simultaneously meet both process and product performance criteria as defined for Phase 1 [6,7].

DEFINING THE EXPERIMENTAL GLASS COMPOSITIONAL REGION (EGCR)

Edwards [5] provides a detailed discussion on the definition of the experimental glass composition region (EGCR) [b], the objectives of the "phased" approach, and the strategy for selecting glasses within the multi-dimensional EGCR. In general, three primary factors define the Phase 1 EGCR:

(1) the composition of the Am/Cm containing feed (its average and likely variation),
(2) the composition of the selected frit, and
(3) the target range for the feed loading (i.e., the feed's percentage of the glass product).

The average composition of the feed has been estimated from the most recent measurement from Tank 17.1[c] and associated material balance calculations.[8] As stated in the TTR [7], the variation expected in each component of the feed is to be estimated at ± 20% of its average[d] and the loading of the feed in the glass is expected to fall within the interval of 20% to 40% on an oxide basis. The major characteristic of the actinide bearing feed (shown in Table I) is the high percentage of lanthanide oxides and actinide oxides (> 99.82 mass % of the feed). Given the high content of lanthanides and actinides, there are obviously very few "impurities" (e.g., Al_2O_3, Fe_2O_3, NiO, MnO, Cr_2O_3, etc) associated with this feed stream as a result of pretreatment processes.

The concentrations of several lanthanides (Tb_2O_3, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, and Lu_2O_3) in the feed are analyzed as less than 1 mass percent (mass %) on an individual basis. Although the components are shown on the most recent material balance flow sheets, their concentrations may be at or below the detection limits of the analytical equipment. Assuming that these oxide components are not present in the incoming actinide-bearing stream, one can distribute their questioned contribution (a total of 2.66 mass %) over the remaining major lanthanide oxides (Ln_2O_3) (i.e., normalize by increasing each of the seven major Ln_2O_3 concentrations by 0.38 mass %). Previous work has suggested that the total Ln_2O_3 concentration is critical, not the distribution.[9, 10] Based on these observations, the concentrations of the more prevalent Ln_2O_3's were normalized so that the total lanthanide concentration from the feed was represented by their values alone. The surrogate feed on which this study was based is also shown in Table I.

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[b] The composition region as specified by the TTR [7] is referred to as the experimental glass composition region (EGCR) throughout this report. In short, the EGCR bounds the compositional envelope in which glasses are expected to fall based on the feed composition (and its variability) from a 2-wash scenario, the frit composition, and the target loadings.

[c] Rare earth analyses (La, Ce, Pr, Nd, Sm, Eu and Gd) were obtained from a cc:mail memo from M.R. Nelson to W.H. Martin dated 4/23/98. Solution density, acid content and Fe, Ni and Cr analyses were obtained from a cc:mail memo from S.L. Maxwell to R.H. Spires (TSD-ALA-98-0011) dated 2/26/98. M.M. Jerath estimated the volume of solution in Tank 17.1 to be 10,551 liters from F-Canyon operating data.

[d] The ± 20% estimated by NMS&S takes into account the uncertainties associated with the 1993 and 1998 Tank 17.1 analyses, measurement errors associated with the ICP, and potential variations in each element/oxide (major or minor) due to inefficiencies in pretreatment.

Table I. Average Actinide-Bearing Feed Material and Surrogate Feed Material on an Oxide (mass %) Basis.

Oxide	Actinide-Bearing Feed Material (Tank 17.3E)	Surrogate Feed Material
Lanthanide Oxides		
La_2O_3	15.05	15.43
Ce_2O_3	12.94	13.32
Pr_2O_3	11.26	11.64
Nd_2O_3	32.80	33.18
Sm_2O_3	7.49	7.87
Eu_2O_3	1.56	1.94
Gd_2O_3	3.98	4.36
Tb_2O_3	0.36	-
Dy_2O_3	0.36	-
Ho_2O_3	0.36	-
Er_2O_3	0.35	12.08[e]
Tm_2O_3	0.53	-
Yb_2O_3	0.35	-
Lu_2O_3	0.35	-
Actinide Oxides		
Am_2O_3	9.70	-
Cm_2O_3	2.38	-
Np_2O_3	0.00	-
PuO_2	0.00	-
UO_3	0.00	-
Cs_2O	0.00	-
Metallic Oxides		
Al_2O_3	0.01	0.01
B_2O_3	0.00	-
CaO	0.00	-
Cr_2O_3	0.00	-
Fe_2O_3	0.03	0.03
K_2O	0.00	-
MnO	0.14	0.14
Na_2O	0.00	-
NiO	0.00	-
SiO_2	0.00	-
SrO	0.00	-
ZnO	0.00	-
ZrO_2	0.00	-
Total	100.00	100.00

[e] Er_2O_3 was substituted for both actinides (Am_2O_3 and Cm_2O_3) on a straight mass % basis. As with most programs involving radioactive materials, surrogates are used to expedite the development process and minimize cost and schedule impacts. The challenge is to choose a surrogate that mimics the chemical and physical response of the material properties of interest. Peeler and Reamer [9] provide a more detailed discussion of the surrogate selection.

The proposed frit composition for the vitrification process is based on a lanthanide borosilicate glass and is referred to as 25SrABS (SrO-Al_2O_3-B_2O_3-SiO_2). The targeted composition of the 25SrABS frit is given in Table II. The nomenclature or reference to 25 indicates that this frit contains 25 mass % La_2O_3. Therefore, La_2O_3 has contributions from both the feed (~15 mass %; Table I) and the 25SrABS frit (25 mass %; Table II).

Table II: Targeted 25SrABS Frit Composition (mass %).

Oxide	La_2O_3	Al_2O_3	B_2O_3	SiO_2	SrO
Mass Fraction	25.00	24.87	13.54	33.68	2.91

Given the feed composition (and its anticipated ± 20% variation), the 25SrABS frit composition, and the target feed loading range of 20 to 40 mass % for the process, the EGCR for Phase 1 testing was defined.[6] Table III provides the bounding concentrations for the Phase 1 EGCR.

Table III. Compositional Bounds for Phase 1 EGCR Definition (mass fraction).

	Mass Fraction Ranges	
Oxide	Lower	Upper
La_2O_3	0.1994	0.2363
Ce_2O_3	0.0213	0.0624
Pr_2O_3	0.0186	0.0544
Nd_2O_3	0.0531	0.1577
Sm_2O_3	0.0126	0.0363
Eu_2O_3	0.0031	0.0078
Gd_2O_3	0.0070	0.0194
Er_2O_3	0.0193	0.0580
Al_2O_3	0.1492	0.1990
B_2O_3	0.0812	0.1083
SiO_2	0.2021	0.2694
SrO	0.0175	0.0233

The bounding composition envelope represented by Table III ignored some trace, metallic oxides present in the material balance calculation (Al_2O_3, Fe_2O_3, and MnO as shown in Table I). These trace, metallic oxides are present in such small quantities (0.01, 0.03, and 0.14 mass %, respectively) in the feed they were assumed not to have a significant impact on the properties of interest in the Phase 1 design. As discussed in the next section, this assumption was evaluated with the insertion of five glasses using a minor component "spike".

SELECTING PHASE 1 GLASS COMPOSITIONS

The strategy for selecting glass compositions for the Phase 1 variability study EGCR has been described by Edwards [5]. Statistically, Phase 1 had two primary goals. The first was to establish the measurement procedures (and their uncertainties) that are to be used to measure the properties of interest throughout this study. The second was to assess the impact of compositional uncertainties on the primary processing and product performance properties of glasses that cover the EGCR. This second objective may be more precisely stated as the goal of answering the question; "Is there any indication that the properties of interest are unacceptable over any portion of the anticipated experimental glass composition region?"

Table IV identifies the 31 glasses selected for the Phase 1 design.[f] The use of the AC1 nomenclature identifies this as Phase 1 of the Am/Cm variability study. There are 16 unique compositions (AC1-01 through AC1-16) that span the Phase 1 EGCR. Five glasses (AC1-17 through AC1-21) are replicates of AC1-04, AC1-07, AC1-10, AC1-13, and AC1-16, respectively.

To evaluate the effect of minor metallic oxides on the primary processing and product performance properties of interest, five additional glasses were added to the overall EGCR design. AC1-22 through AC1-26 are essentially replicates of AC1-17 through AC1-21 (and their counterparts), respectively, with the exception that these glasses have been "spiked" with maximum levels of various metallic oxides (as shown in Table V). These glasses are identified by an "*" in Table IV. The level of each minor component spike is considered as an upper or bounding value that the process may receive at the highest feed loading evaluated in Phase 1 (i.e., 40 mass %).

Table V. Level of Metallic Oxides "Spiked" in Select Glasses (mass %).

Oxide	Fe_2O_3	NiO	Cr_2O_3	CaO	Na_2O	K_2O	MnO
Mass %	0.010	0.005	0.005	0.005	0.005	0.005	0.050

AC1-27 through AC1-31 represent specific glass compositions within the EGCR being evaluated for the baseline process at the time this study was initiated. These glasses are based on the nominal feed composition but vary in loading (ranging from 31 – 36 mass %). These glasses also have trace amounts of both MnO and Fe_2O_3. As the properties of interest are explored for this EGCR, the behavior of the spiked glasses relative to their non-spiked replicates will be investigated.

Figure 1 shows the Phase 1 EGCR as defined by the 31 glasses within a compositional ternary. The three components of the ternary represent the total targeted La_2O_3 content (La_2O_3 contributions from both the feed and the frit), other frit, and other feed. Property / composition relationships within the EGCR (represented by the outlined "box" in Figure 1) are the focus of this study. That is, is there any indication that the properties of interest are unacceptable with respect to the predefined criteria over any portion of this EGCR?

[f] The Phase 1 EGCR was based on a total of 31 glasses: 16 unique compositions, 5 replicates, 5 "minor" component spiked glasses, and an additional 5 glasses representing specific glass formulations under consideration by the Am/Cm development team. Due to preliminary viscosity and liquidus temperature results, a replicate of AC1-19 (referred to as AC1-19B) was subsequently added.

Table IV: Targeted Phase 1 Glass Compositions (mass fraction).

Glass ID	La_2O_3	Ce_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3	Eu_2O_3	Gd_2O_3	Er_2O_3	Al_2O_3	B_2O_3	SiO_2	SrO
AC1-01	0.2177	0.0415	0.0361	0.1001	0.0245	0.0055	0.0134	0.0378	0.1731	0.0949	0.2350	0.0205
AC1-02	0.2363	0.0312	0.0272	0.0531	0.0126	0.0039	0.0070	0.0288	0.1990	0.1083	0.2694	0.0233
AC1-03	0.2247	0.0312	0.0272	0.0645	0.0126	0.0039	0.0070	0.0290	0.1990	0.1083	0.2694	0.0233
AC1-04,-17,-22*	0.2304	0.0262	0.0229	0.0695	0.0152	0.0035	0.0083	0.0241	0.1990	0.1083	0.2694	0.0233
AC1-05	0.2184	0.0390	0.0233	0.0943	0.0158	0.0044	0.0104	0.0320	0.1865	0.1016	0.2526	0.0218
AC1-06	0.2328	0.0266	0.0340	0.0782	0.0192	0.0044	0.0121	0.0302	0.1865	0.1016	0.2526	0.0218
AC1-07,-18,-23*	0.2255	0.0327	0.0286	0.0868	0.0190	0.0044	0.0104	0.0301	0.1865	0.1016	0.2526	0.0218
AC1-08	0.2294	0.0394	0.0279	0.0884	0.0272	0.0047	0.0145	0.0435	0.1741	0.0948	0.2358	0.0204
AC1-09	0.2120	0.0320	0.0408	0.1183	0.0272	0.0049	0.0107	0.0292	0.1741	0.0948	0.2358	0.0204
AC1-10,-19,-24*	0.2206	0.0393	0.0343	0.1042	0.0228	0.0052	0.0125	0.0361	0.1741	0.0948	0.2358	0.0204
AC1-11	0.2057	0.0428	0.0326	0.1380	0.0317	0.0054	0.0170	0.0393	0.1617	0.0880	0.2189	0.0189
AC1-12	0.2260	0.0521	0.0476	0.0929	0.0220	0.0068	0.0170	0.0482	0.1617	0.0880	0.2189	0.0189
AC1-13,-20,-25*	0.2157	0.0458	0.0401	0.1216	0.0266	0.0061	0.0146	0.0421	0.1617	0.0880	0.2189	0.0189
AC1-14	0.1994	0.0426	0.0543	0.1577	0.0284	0.0062	0.0194	0.0419	0.1492	0.0812	0.2021	0.0175
AC1-15	0.2225	0.0624	0.0372	0.1314	0.0252	0.0062	0.0167	0.0483	0.1492	0.0812	0.2021	0.0175
AC1-16,-21,-26*	0.2108	0.0524	0.0458	0.1389	0.0304	0.0070	0.0167	0.0481	0.1492	0.0812	0.2021	0.0175
AC1-27	0.2207	0.0407	0.0356	0.1015	0.0241	0.0133	0.0059	0.0370	0.1727	0.0940	0.2338	0.0202
AC1-28	0.2190	0.0431	0.0377	0.1074	0.0255	0.0141	0.0063	0.0391	0.1682	0.0916	0.2278	0.0197
AC1-29	0.2165	0.0466	0.0407	0.1161	0.0276	0.0153	0.0068	0.0423	0.1617	0.0880	0.2189	0.0189
AC1-30	0.2155	0.0480	0.0420	0.1196	0.0284	0.0157	0.0070	0.0435	0.1591	0.0866	0.2154	0.0186
AC1-31	0.2213	0.0400	0.0349	0.0995	0.0236	0.0131	0.0058	0.0362	0.1741	0.0948	0.2358	0.0204

(1) AC1-22 through AC1-26 are replicates of AC1-17 through AC1-21 (and their counterparts), respectively, with the exception that these glasses have been "spiked" with levels of various metallic oxides (as shown in Table V). The level of minor component spiked is considered to be the upper or bounding value that the vitrification process may receive at a 40% feed loading. These glasses are identified by an "*" in Table IV.

(2) The minor components associated with AC1-27 through AC1-31 are Fe_2O_3 and MnO at the 0.01 mass % and 0.05 mass % levels.

(3) AC1-31 has also been referred to as Am/Cm-1, which represents the baseline glass composition at the time this study was initiated. AC1-31 (or Am/Cm-1) is a 30 mass % loaded glass based on the nominal feed stream composition.

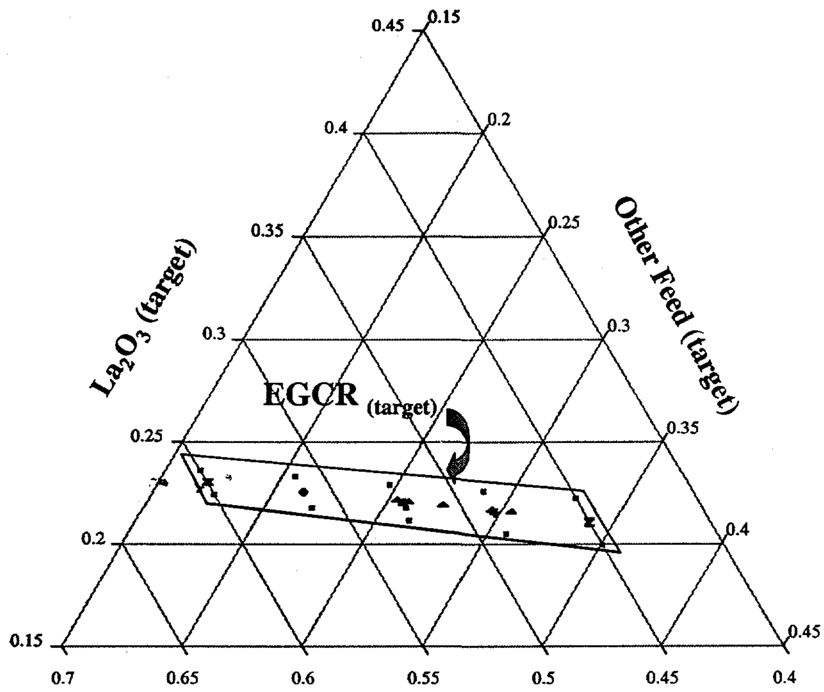

Figure 1. Targeted Glass Compositions (mass fraction) Defining the Phase 1 EGCR.

PREDEFINED ACCEPTANCE CRITERIA

To ensure that the glass is both processable and meets product performance specifications, criteria were established and implemented for the Phase 1 study.[7] These criteria focus on processing (liquidus temperature and viscosity) and product performance (homogeneity, durability, and recoverability) issues and were used to evaluate each of the 31 Phase 1 glasses in an effort to define the AGCR. That is, for a glass to be "acceptable", it must comply with or meet all constraints simultaneously. Each Phase 1 acceptance criteria is briefly discussed below.

PROCESSING CRITERIA

VISCOSITY

This constraint has been defined by a viscosity (η) range (3 – 24 Poise) at a given temperature (1350°C) based on thermal modeling and calculations of continuous and non-continuous pour streams.[g] Viscosities outside this range at a fixed temperature will be considered less than optimal due to the potential to result in a non-continuous pour stream (considered to be ≤ 8 kg/hr).

LIQUIDUS TEMPERATURE (T_L)

Liquidus temperature is defined as the maximum temperature at which equilibrium exists between the molten glass and its primary crystalline phase.[11] If the nominal melt temperature

[g] The relationship between flow rate and glass viscosity was obtained from an isothermal model of the drain tube based on the extended Bernoulli and Poiseuille's equations. The viscosity required to give an 8 kg/hr flow rate was obtained for a given glass density, glass pool depth (head) and drain tube diameter and length.

is above T_L, crystallization will not occur eliminating potentially negative impacts to melter processing. If the nominal melt temperature is below T_L (or "cold" spots exist within the melter), crystallization may occur and can impact processing (i.e., crystals may plug the drain tube) or affect product performance (i.e., durability) if crystals are present in the final glass product. The nominal CIM operating temperatures are in the range of 1350° - 1450°C. To avoid the potential negative effects of crystallization within the melter, a liquidus temperature criteria of 1250°C was used for Phase 1. This provides a 100°C differential between the nominal lower melter operating temperature (1350°C based on a 30 mass % loaded glass) and the liquidus temperature. Therefore AC1 lanthanide-based glasses with T_L's ≤ 1250°C will be considered processable within the CIM.[h]

PRODUCT PERFORMANCE CRITERIA

HOMOGENEITY

Homogeneity will be evaluated to ensure that undissolved solids or crystallization is not present in the glass upon initial fabrication that could potentially restrict the AGCR. However, it should be noted that these glasses were produced from reagent grade oxide raw materials; not an oxalate / frit mixture that will be utilized in the CIM. Different reaction pathways between the various starting materials may lead to conflicting results. Glasses within and near the boundaries of the Phase 1 EGCR have been successfully processed in the CIM using an oxalate / frit mixture (e.g., Am/Cm-1 (AC1-31) at 30% loaded glass) resulting in a homogeneous (non-crystalline) glass product.

DURABILITY

Durability of the final waste form can also limit the composition space over which glasses should be produced. That is, glass within a certain compositional space may be processable but may result in a non-durable product thus reducing the likelihood of acceptance. To minimize this potential, durability as defined by the Product Consistency Test (PCT) will also be used to define the AGCR. The PCT (ASTM C 1285-94) [12] will be used to distinguish between durable and non-durable glasses. The acceptance criteria will be based on a comparison of the normalized release rates of various AC1 glass components to those limits of the Environmental Assessment (EA) [13] (with the appropriate confidence limits applied). Normalized boron (B) release will be used as the key indicator of durability although the release of other components will also be tracked. Typically, Na and Li are also tracked, but the SrABS frit does not contain either Na or Li and only Na exists in the waste stream and at an extremely low concentration.

RECOVERABILITY

To ensure that the product meets the current programmatic objective (i.e., recoverability of Am/Cm at ORNL), a recoverability criterion was also defined. The recoverability criterion is 98% of the total lanthanides must be recovered within 2 hours using 8M nitric acid with glass ground to ~60 mesh and heated to 110°C [14].

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[h] The liquidus temperature constraint (1250°C) for Phase 1 was defined based on the nominal processing temperature (1350°C) for the Am/Cm-1 (AC1-31) glass (30 mass % feed loading). Although this glass is processable at 1350°C, higher processing temperatures are within the capability of the CIM. This capability allows for the relaxation of this initial liquidus temperature constraint if T_L becomes a limiting factor in the definition of the AGCR.

Table VI summarizes the processing and product performance criteria to be used to define the AGCR for Phase 1.

Table VI. Property Constraints to Define the Phase 1 AGCR.

Property	Phase 1 Constraint
Processing	
Viscosity (η)	3 – 24 Poise at 1350°C
Liquidus Temperature (T_L)	≤ 1250°C
Product Performance	
Homogeneity	Homogeneous as defined by XRD
Durability	NL [B] < 16.695 - 2σ (EA limits) As defined by the PCT
Recoverability	98% recovery of total lanthanides under specific processing conditions

EXPERIMENTAL

The data generated for the Phase 1 variability study were accomplished via a joint effort between the SRTC and the Pacific Northwest National Laboratory (PNNL). This work was performed according to applicable DOE/RW-0333P Quality Assurance Criteria[i] at both laboratories. Data collected and reported from PNNL were acquired under a PNNL Quality Assurance (QA) Program, SNF-70-001. A specific QA Plan Checklist for PNNL Project 30306, High Temperature Viscosity and T_L for Am-Cm Variability Study, was developed and utilized by PNNL in the performance of this study. The QA Plan Checklist contains the QA implementing procedures, part of the PNNL Spent Fuel Nuclear Fuel QA Program which applied to this study. This section describes the experimental procedures, test equipment, and application of standards to generate the required data.

GLASS FABRICATION

Table IV identified the 31 AC1 Phase 1 glasses prepared for this study as well as the unique nomenclatures used (i.e., AC1 series). Each batch was prepared (to produce 450 grams of glass[j]) from the proper proportions of reagent grade chemicals using SRTC technical procedure "Glass Batch Preparation Procedure – GTOP-3-003".[15] Weigh sheets were filled out as the materials were weighed. It should be noted that the use of reagent grade chemicals will not allow for an evaluation of certain processing issues that have been of interest in the development program (i.e., volume expansion and/or high temperature bubble formation which typically require oxalate precipitate and frit as raw material sources).[3,4] These issues will be evaluated in separate tests performed in the CIM pilot facility.

[i] As defined by the DOE/RW-0333P Quality Assurance Program.

[j] The 450 gram batch would produce enough glass from which all processing and product performance properties could be measured. The use of a single batch would minimize uncertainties associated with batch to batch variations if smaller individual batches were produced for each property measurement. Glasses supplied to Monarch Analytical Laboratories for high temperature density measurements (discussed in subsequent sections) were batched and melted separately due to the quantity of glass required.

Once batched, these glasses were melted according to SRTC technical procedure "Glass Melting Procedure – GTOP-3-004" [15] using a standard thermal heat treatment. In general, the raw materials were thoroughly mixed and placed into a Platinum / 5% Rhodium 500 ml crucible. The batch was subsequently placed into a high temperature furnace and the temperature was increased at 4°C/minute to 1350°C. After an isothermal hold at 1350°C for 0.5 hour, the crucible was removed and the glass was poured onto a clean stainless steel plate and allowed to air cool. Approximately 400 grams of glass was removed (poured) from the crucible while ~ 50 grams remained in the crucible along the walls. The pour patty was divided into the appropriate quantities for each property measurement. Glasses were stored in marked containers (using the unique AC1 nomenclature as defined by Edwards [5]) and either shipped to PNNL (for viscosity, density, and liquidus temperature measurements) or retained at SRTC (for homogeneity, chemical composition, density, and PCT measurements).

PROPERTY MEASUREMENTS

CHEMICAL COMPOSITION ANALYSIS

To confirm that the "as-fabricated" glasses corresponded to the defined targeted compositions (as shown in Table IV), a representative sample from each "as-fabricated" AC1 glass was submitted to the SRTC Mobile Laboratory (SRTC-ML) for chemical analysis. Edwards [16] provided an analytical plan that accompanied these samples. This plan identified the cations to be analyzed as well as specifying the dissolution techniques (i.e., sodium peroxide fusion or lithium-metaborate flux) to be used. Each glass was prepared in duplicate by each of the dissolution techniques. Concentrations (as mass %) for the cations of interest were measured by Inductively Coupled Plasma – Atomic Emission Spectroscopy (ICP – AES). The analytical plan was developed in such a way as to provide the opportunity to evaluate potential sources of error. The results were evaluated to confirm that the targeted glass compositions were adequately met.

HOMOGENEITY

Although visual observations for homogeneity were performed and documented[k], representative samples from each "as-fabricated" glass were submitted to SRTC Analytical Department Service (ADS) for X-ray diffraction (XRD) analysis. This analysis would be used to confirm visual observations of homogeneity within a given detection limit based on the run conditions of the diffractometer. Samples from the Phase 1 test matrix were run under conditions allowing an approximate 1.0 vol% detection limit. That is, if crystals (or undissolved solids) are present at 1.0 vol% (or greater) the diffractometer will not only be able to detect these crystals but will also allow a qualitative measure (i.e., determine the type of crystal present). Otherwise, a characteristic amorphous hump indicative of a glass product results.

DENSITY

SRTC measured room temperature density for each Phase 1 glass. Glass density was measured by buoyancy (Archimedes method) in water using SRTC technical procedure "Glass Density Using the Mettler AT400 Balance – GTOP-3-105".[15] Representative glass samples (approximately 5 gram samples) were selected from the original pour patty for this measurement.

PNNL measured density of each Phase 1 glass using a gas pycnometer following PNNL technical procedure APEL-PIP-4, "Gas Pycnometer Method for Apparent Specific Gravity Determination of Consolidated Solids." Glass that had been ground, sieved and washed for T_L determination was used for

[k] For visual observations of homogeneity refer to WSRC-NB-98-00208.

density measurement. When sieved samples were not available, pieces from the "as received" glass were ultrasonically washed, then dried at 90°C and used for the density measurement.

High temperature and annealed (room temperature) density measurements were performed on a limited number of glasses (AC1-04, AC1-07, AC1-10, AC1-13, and AC1-16) by Monarch Analytical Laboratories, Inc. to support thermal modeling efforts.[1] Samples were annealed at 650°C for 30 minutes and the "annealed" glass density was measured using ASTM C 693.[17] Molten glass density was determined as described by Shartsis and Spinner [18]. In general, the determination of molten glass density for all five samples was limited at the lower temperatures by viscosity. At the higher temperatures, the glasses deposited gas bubbles (e.g., oxygen liberated from the high temperature reduction of CeO_2) on the test bob limiting the higher temperature to which the samples could be tested. An additional problem with samples AC1-13 and AC1-16 was the formation of a surface "scum" (reported by Monarch as a "probable crystalline material") at temperatures below 2200°F (or approximately 1200°C). Monarch also measured surface tension of these 5 AC1 glasses.

VISCOSITY

High temperature viscosity (η) measurements were performed by PNNL. Viscosities were measured as functions of temperature (T) using a spindle viscometer for each of the Phase 1 AC1 glasses. The measurements were obtained with the PNNL technical procedure, "Standard Viscosity Measurement for Vitrified Nuclear Waste – GDL-VIS, Rev. 1," which is in compliance with the ASTM C 965 [19] procedure. The spindle viscometer was calibrated according to the PNNL technical procedure, "Standard Viscosity Calibration Procedure – GDL-VSC, Rev. 1."

Glass η – T data were fitted to the Vogel-Tamman-Fulcher (VTF) model [20]:

$$\ln \eta = A + \frac{B}{T - T_0},$$

where A, B, and T_0 are temperature independent coefficients. The fitted VTF model was then used to calculate the T values at fixed η points (T_η) and the η value at 1350°C (η_{1350}) for each glass.

High temperature viscosity 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 the maximum operating temperature of the furnace (1500°C), the detection limit of the Brookfield viscometer, or effects of volatilization. PNNL also incorporated a standard viscosity glass (NBS-710) into these measurements to check accuracy and precision.

LIQUIDUS TEMPERATURE (T_L)

Liquidus temperature was measured for each Phase 1 glass following Method B of PNNL technical procedure GDL-LQT, "Standard Test Methods for Determining the Liquidus Temperature (T_L) of Waste Glasses and Simulated Waste Glasses." A run-order was not used for determining T_L for individual samples due to time constraints, but samples were grouped together in furnaces operating at a specific

[1] These five glasses were batched and melted separately from the Phase 1 glasses. Therefore, small batch-to-batch chemical variations may be expected relative to their counterpart Phase 1 glasses. The Monarch work scope was not performed under the Quality Assurance criteria of RW-0333P since these data were only to be used to support thermal modeling efforts and were not used to define the AGCR.

temperature. The final measurements used to determine T_L were confined to one of two validated furnaces to prevent differences of calibration between furnaces from biasing results.

As glass samples were received by PNNL from SRTC, the majority of each sample was split out for viscosity measurement. The remaining sample was crushed in a tungsten carbide milling chamber, sieved to capture 0.5 to 4.0 mm grains, ultrasonically washed for two minutes in ethanol, and dried at 90°C according to the technical procedure. Each glass sample had its own platinum crucible (1.27 cm^3) and lid, which were cleaned between heat treatments. Samples were heat treated in calibrated and temperature-profiled furnaces for 24 ± 2 h.

Each glass was initially tested with 4 to 5 heat treatments, which narrowed the temperature range in which T_L would be determined and reported. The first heat treatments were at 1100°C which resulted in crystallization in all samples (i.e., T_L > 1100°C for all Phase 1 glasses). Subsequent subsamples were heat treated at progressively higher temperatures (in roughly 50°C intervals) until the heat treated sample was crystal-free. The use of the 50°C temperature intervals would have met the specifications as defined in the IWO SOW[m] (i.e. T_L to be defined ± 50°C). However, T_L was measured to a much narrower temperature interval. Based on the 50°C interval results, the temperature difference between the lowest temperature at which samples did not form crystals (T_A) and the highest temperature at which samples did form crystals (T_C) was narrowed by additional heat treatments. Data were then collected on the samples tested near the temperature region of T_L. Some of the samples that were used for XRD and SEM came from the initial heat treatments because the samples near T_L did not have sufficient crystal number density and crystal size for useful analytical analysis.

Two Deltech® furnaces were used for final T_L determination. The furnaces were profiled for temperature differences in the hot zone where samples were heat treated using calibrated temperature measurement equipment. An accuracy check of the equipment was performed by heat treating SRM-773 Liquidus Temperature Glass from the National Institute of Standards and Technology at the beginning, middle, and end of the test period.

Crystal identification was made by optical microscopy, XRD, and Scanning Electron Microscopy (SEM) accompanied by Energy Dispersive Spectroscopy (EDS) to characterize chemical composition of analyzed samples. XRD and SEM/EDS were used for phase identification of those crystals observed by optical microscopy. Phases with the similar morphology as observed by optical microscopy were not repeatedly characterized with XRD or SEM.

DURABILITY

The Product Consistency Test (PCT) was performed on each glass to assess chemical durability using SRTC technical procedure "Nuclear Waste Glass Product Consistency Test (PCT) Method – GTOP-3-025".[15] The PCT was conducted in triplicate for each of the Phase 1 glasses as described by Edwards [5, 21]. Also included in this experimental test matrix were the Environmental Assessment (EA) glass, the Approved Reference Material (ARM-1) glass, and blanks. Samples were ground, washed, and prepared according to procedure. Fifteen (15) ml of ASTM water was added to 1.5 grams of glass in stainless steel vessels. The vessels were closed, sealed, and placed into an oven at 90°C. For each glass sample, one triplicate was randomly placed on one of three shelves in the PCT oven. The location of each sample was recorded and documented in the appropriate notebook. Samples were left at 90°C for 7

[m] PNNL work scope was defined in the IWO SOW – US Department of Energy Interoffice Work Order (Amendment # IWORLD98111) Statement of Work.

days. The resulting solutions were sampled, labeled (according to the analytical plan), and analyzed.[n] Edwards [21] provided an analytical plan for the SRTC-ML analysis. The overall philosophy of this plan was to provide an opportunity to assess the consistency (repeatability) of the PCT and analytical procedures in the effort to evaluate chemical durability of the Phase 1 glasses. Normalized release rates were calculated based on both targeted and "as-measured" compositions.

RECOVERABILITY

Although recoverability is a product performance criterion, it was not measured for the Phase 1 glasses. This decision was based on two factors. The first was the issuance of a document by Rudisill [14] stating that full recovery of the lanthanides was essentially independent of glass composition within the bounds of the two lanthanide borosilicate systems tested (of which the 25SrABS frit composition was utilized). The other contributing factor was that higher waste loadings were being evaluated when the recoverability portion of this task was scheduled to be performed. That is, the baseline process is now based on a 47 mass % loaded glass (i.e., outside the EGCR for Phase 1) as opposed to a 30 mass % loaded glass. Based on these primary factors, the recoverability measurements were not performed on the Phase 1 glasses. It is assumed in this report that the recoverability will not limit the AGCR. However, recoverability will be measured during Phase 2, which will include select glasses from Phase 1.

RESULTS AND DISCUSSION

CHEMICAL COMPOSITION

The measured compositions for the Phase 1 glasses, along with standards (EA and ARM-1) that were included in the plan used by the SRTC-ML [16] in conducting these analyses, are provided in Appendix A. Table A.1 provides the results (raw data) for Al, Ca, Ce, Cr, Er, Eu, Fe, Gd, K, La, Mn, Na, Nd, Pr, Si, Sm, and Sr that were obtained using the lithium-metaborate dissolution method. Based on a preliminary review of these data, a few of these analytical results (in particular for Ce, Fe, La, Ni, and Sm) were seen as probable outliers. A review of these values with the SRTC-ML led to some corrections being made (no Ni values were changed). Both the original and corrected cation concentrations are presented in Table A.1 (Appendix A) with the corrected values shaded.

Table A.2 in Appendix A provides the results for B and Li, which were obtained using the peroxide fusion dissolution method. The measured cation concentrations and the target (or "known") oxide concentrations are provided.

In addition, a column of bias-corrected B_2O_3 values is also shown in Table A.2. The average boron cation concentration for EA for each of the analytical blocks was computed and compared to the "known" boron concentration for this standard glass. For each analytical block, the factor that would bring the average measured values to this "known" value was determined. These factors were then used to adjust the boron cation concentrations for the other glasses within the respective analytical blocks. The adjusted values were then converted to oxide concentrations, and it is these B_2O_3 values that are presented in the "bias corrected" column of Table A.2. Both sets of these boron values were investigated where appropriate, as part of this study, and the results will be included in the discussions that follow.

Plots of the oxide measurements derived using lithium-metaborate preps are provided in Exhibit A.1 in Appendix A, and those derived using the peroxide fusion in Exhibit A.2. No obvious outliers are seen in

[n] Initiation of the PCT can be found in WSRC-NB-98-00208, p. 122. Termination of the PCT and sample submittal can be found on pages 129 and 133, respectively.

these data, and, thus, all concentration values for each oxide were averaged to determine the concentration of that oxide in a given glass. Table A.3 in Appendix A provides the average measured concentrations for the oxides of interest for each glass along with their target values and the percent relative differences between the measured and target.

Exhibit A.3 provides the details of a statistical (paired) comparison of the target versus measured values for all of the glasses of this test (including EA and ARM-1) for the following oxides: Al_2O_3, B_2O_3 (with and without the bias correction), SiO_2 and SrO. Exhibit A.4 provides the results of the same approach applied to the Phase 1 glasses for the lanthanides (i.e., Ce_2O_3, Er_2O_3, Eu_2O_3, Gd_2O_3, La_2O_3, Nd_2O_3, Pr_2O_3, and Sm_2O_3). The results indicate a statistically significant difference (at a 5% significance level) between the measured and targeted compositions for all oxides except the bias-corrected B_2O_3, Er_2O_3, Gd_2O_3, Pr_2O_3, and Sm_2O_3. Some of the glasses with widely differing target and measured values are labeled in these plots. Once again, Table A.3 provides the details of these comparisons for each glass including percent relative differences.

An important indicator of the reliability of these measurements is the sum of oxides, and for the Phase 1 glasses, an additional indicator is the sum of lanthanides (Ln_2O_3). These values are provided in the last columns of Table A.3. A histogram of the sum of oxides for all of the Phase 1 glasses is provided in Figure 2. A substantial portion of these values is below 95%, a value often used as the lower bound for reliable measurements.

Figure 3 provides a closer look (in the form of a paired-comparison) at the sum of oxides (derived using the lithium-metaborate prep) for all of the glasses. The results indicate a statistically significant difference between the targeted and "as-measured" sum of oxides using the lithium-metaborate dissolution method. On average, the measured sum is 4 mass % below the targeted value.

Figure 4 provides the details of a comparison of the target lanthanide concentrations versus the measured for the Phase 1 glasses. Note that all lanthanide measurements were conducted on glass samples prepared using the lithium-metaborate dissolution method. A statistically significant difference (at the 5% significance level) is indicated by these results with the targeted value exceeding the measured, on average, by 2 mass %. Five glasses have been highlighted in Figure 4: AC1-02, AC1-20, and AC1-26 have measured values substantially larger than their targets while the opposite is true for glasses AC1-17 and AC1-22.

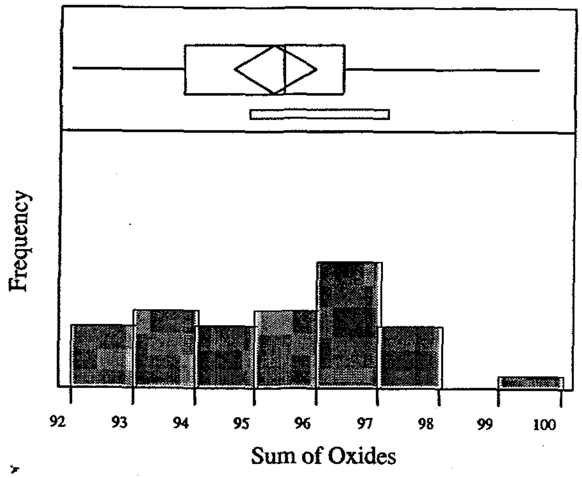
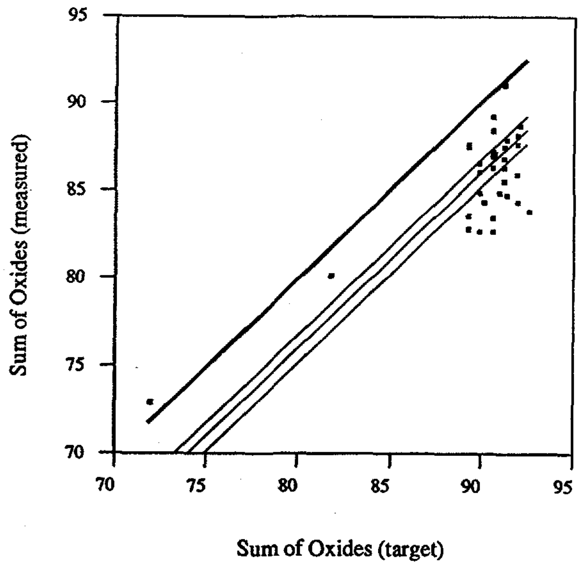


Figure 2. Histogram of Sum of Oxides for All Phase 1 Glasses.
(sum of oxides = 100% of the glass)

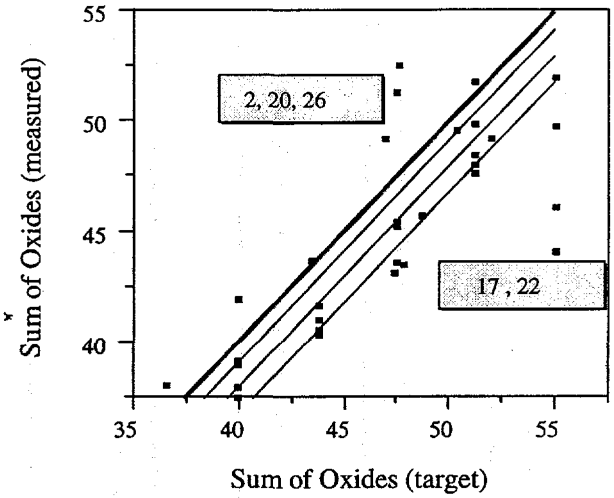


Paired t-Test

Sum of Oxides (t) - Sum of Oxides (m)

Mean Difference	4.118727	Prob > |t|	< 0.0001
Std Error	0.400747	Prob > t	< 0.0001
t-Ratio	10.27762	Prob < t	1.0000
DF	32		

Figure 3. Comparison of Targeted Versus "As-Measured" Sum of Oxides
(Lithium-metaborate Dissolution).



Paired t-Test

Sum of Lanthanides (t) - Sum of Lanthanides (m)			
Mean Difference	2.068697	Prob > |t|	0.0011
Std Error	0.574829	Prob > t	0.0006
t-Ratio	3.598804	Prob < t	0.9994
DF 30			

Figure 4. Comparison of Targeted and "As-Measured" Sum of Lanthanide (Ln_2O_3) Concentrations.

Exhibit A.5 in Appendix A provides comparisons of the compositions of the duplicate glasses of Phase 1. There are five sets of duplicate glasses as indicated in Table IV. These sets were sequentially numbered 1 through 5 for the analysis in this exhibit. The fifth group includes 4 instead of 3 glasses; this group includes the late addition AC1-19B (labeled as 19.5 in Exhibit A.5). For each oxide (even the minors) a plot of the measured concentrations is provided, and "pooled" estimates of the standard deviation and percent relative standard deviation of the repeats are calculated. Table VII provides a summary of these relative standard deviations for the lanthanides, alumina, boron, and silica.

Table VII. Summary of the Relative Standard Deviations for the Ln_2O_3, Al_2O_3, B_2O_3, SiO_2, and SrO.

Oxide	% Relative Standard Deviation from Duplicates
Al_2O_3	5.9%
B_2O_3	4.9%
Ce_2O_3	10.5%
Er_2O_3	10.4%
Eu_2O_3	9.7%
Gd_2O_3	9.6%
La_2O_3	2.6%
Nd_2O_3	11.0%
Pr_2O_3	9.9%
SiO_2	5.2%
Sm_2O_3	25.1%
SrO	5.3%

The results for Al_2O_3, B_2O_3, SiO_2, and SrO are typical of those seen in previous studies.[o] The results for the lanthanides indicate more variation in these measurements with the exception of La_2O_3 as compared to the other oxides in Table VII. Based on the chemical composition results, two recommendations are made for consideration prior to the Phase 2 work scope. These include:

(1) Review of the Phase 1 sum of oxide data with the SRTC-ML will be a priority since a substantial portion of these data are below the 95% level. Although chemical composition gradients between subsamples may have resulted in differences between targeted and "as-measured" values (see recommendation #2), the sum of oxides in each samples should be 100 ± 5% regardless of subsample chemical homogeneity to provide a high degree of measurement confidence. Discussions will also include the "as-measured" total lanthanide (Ln_2O_3) contents.

(2) Compositional gradients assumed to exist in the original pour sample from which subsamples were taken for each property measurement may have impacted these results. This may explain property value differences for the replicate glasses (as discussed later). Regardless of its potential impact in the Phase 1 results, this effect should be minimized (if not eliminated) in the Phase 2 task. This will be accomplished by a change in the melting procedure.

[o] See for example: Edwards, T.B., and K.G. Brown, "A Statistical Review of the Data from the SRTC Mobile Laboratory: Addressing the Issues of Accuracy and Precision (U)", WSRC-RP-98-00430, Rev. 0, June 15, 1998.

Another means of comparing the target versus "as-measured" compositions of the Phase 1 glasses is provided in Figure 5, a ternary plot in measured-space of La_2O_3, the other feed components, and the other frit components. In this ternary, the target EGCR is outlined, but the plotted points are based on measured compositions of the Phase 1 glasses (see Figure 1 for a comparison with targeted compositions).

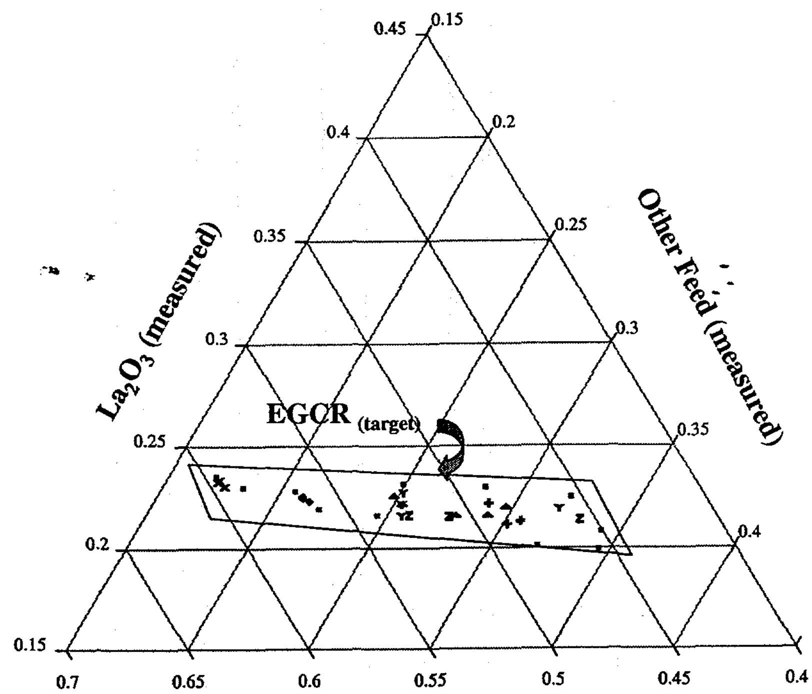


Figure 5. EGCR as Defined by Measured Phase 1 Glass Compositions (mass fraction).

HOMOGENEITY

"As-fabricated" Phase 1 glasses were submitted to X-ray diffraction (XRD) to confirm visual observations of homogeneity. All 32 Phase 1 glasses (including AC1-19B) were homogeneous based on the XRD results.[p] The XRD patterns for AC1-17 (20% loaded, replicate of AC1-04), AC1-06 (25% loaded), AC1-24 (30% loaded), AC1-11 (35% loaded), and AC1-14 (40% loaded) are shown in Figures 6 – 10, respectively. All five of these XRD patterns show the characteristic amorphous hump indicative of a homogeneous (non-crystalline) product. That is, if undissolved solids and/or crystallization were present in the sample, well defined or distinct peaks would be observed which could be used to identify the crystalline phase. It should be noted that the X-ray diffractometer used in this study has a detection limit of approximately 1.0 vol% in glass. Undissolved solids and/or crystallization present below this limit remain undetected by the XRD unit.

[p] XRD patterns for all 32 Phase 1 glasses (including AC1-19B) are documented in WSRC-NB-98-00208, pp. 154 – 164 and p. 171. All 32 patterns are characterized by an amorphous hump indicative of a glassy, homogeneous product within the detection limits of the x-ray diffractometer. Note, the absence of well defined peaks does not provide an indication of chemical homogeneity, but simply the absence of crystalline material.

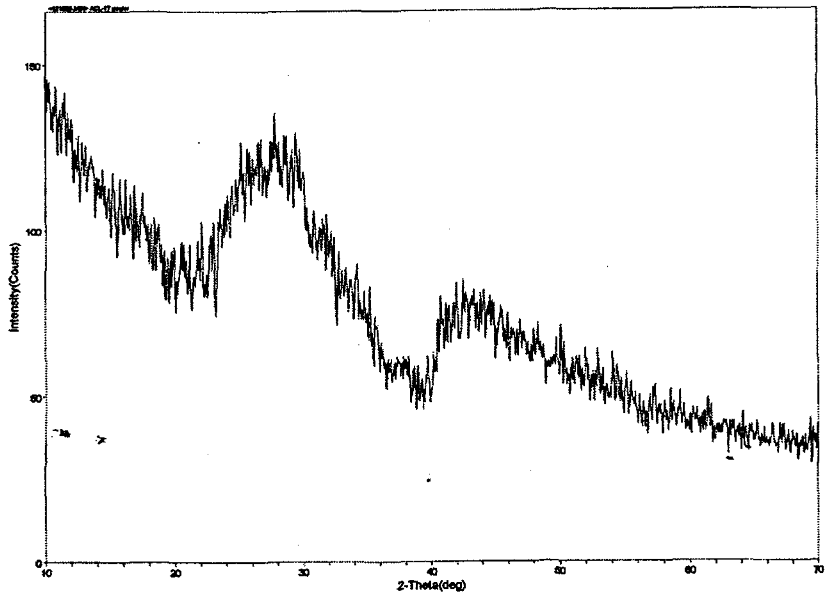


Figure 6. XRD Pattern of AC1-17 (20% loading).

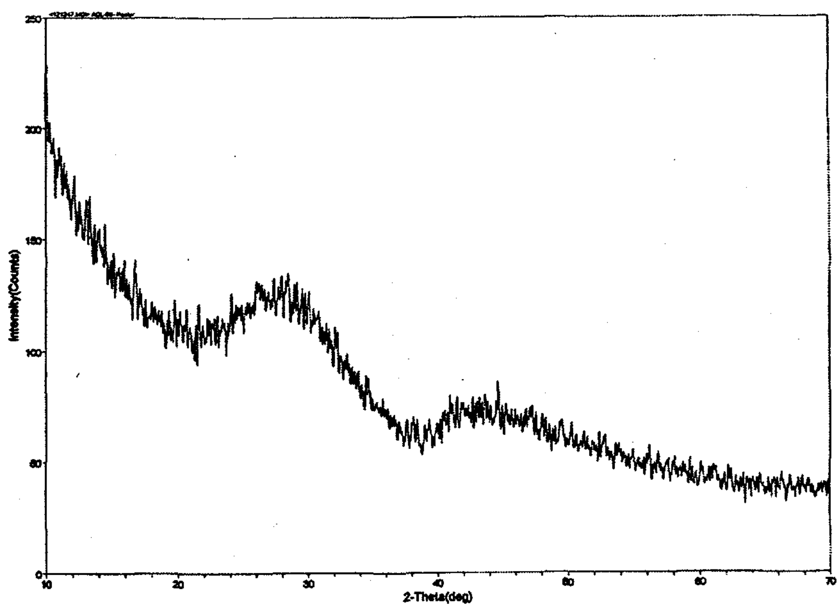


Figure 7. XRD Pattern of AC1-06 (25% loading).

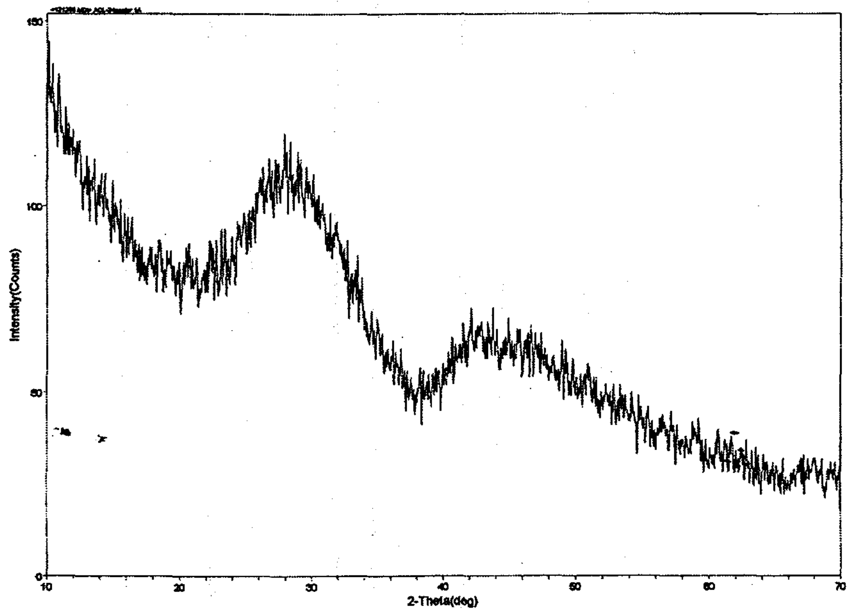


Figure 8. XRD Pattern of AC1-24 (30% loading).

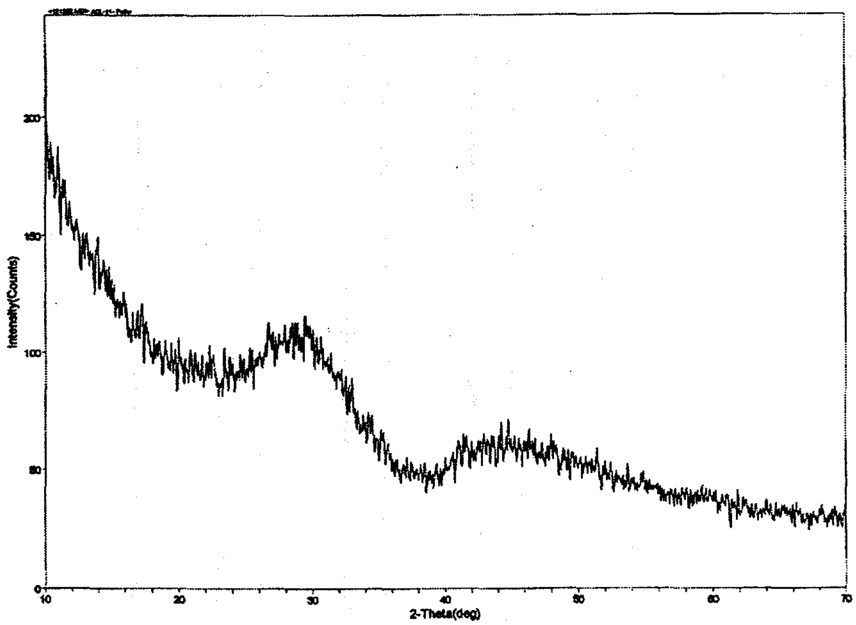


Figure 9. XRD Pattern of AC1-11 (35% loading).

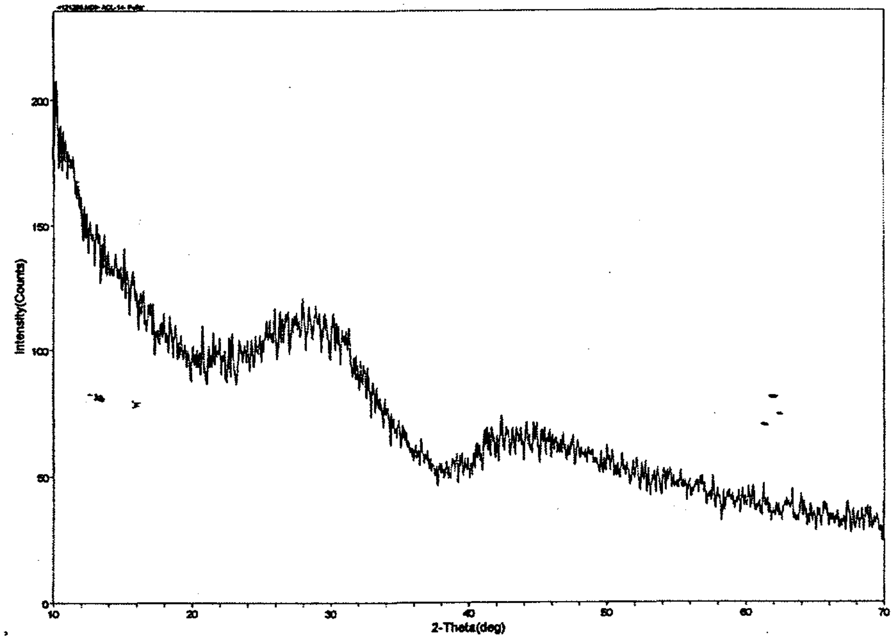


Figure 10. XRD Pattern of AC1-14 (40% loading).

Based on the XRD results, the AGCR is not restricted by homogeneity. As previously noted, these glasses were produced from reagent grade oxide raw materials not the oxalate / frit mixture that will be utilized in the Cylindrical Induction Melter (CIM). Different reaction pathways between the various starting materials may lead to different results although glasses within the Phase 1 EGCR have been successfully processed in the CIM (e.g., Am/Cm-1 a 30% loaded glass) resulting in a homogeneous (non-crystalline) glass product. Note, the absence of well defined peaks does not provide an indication of chemical homogeneity, but simply the absence of crystalline material.

DENSITY

Room temperature density was determined for the Phase 1 glasses by two techniques: buoyancy (measured by SRTC) and gas pycnometry (measured by PNNL). The results are shown in Table VIII. Density values based on buoyancy are individual measurements. Values based on the gas pycnometer technique are an average of five consecutive measurements on the same sample automatically performed by the program-driven gas pycnometer. Also shown in Table VIII, are duplicate pycnometry measurements performed on a limited number of glasses (AC1-10, AC1-16, AC1-21, AC1-24, AC1-26 (triplicate analysis), and AC1-19B). These replicate measurements were based on different subsamples from the original pour patty.

Table VIII. Density of Phase 1 Glasses by Buoyancy and Gas Pycnometry.

	Buoyancy	Gas Pycnometer Density		
Glass	(g/cm^3)	(g/cm^3)	(g/cm^3)	(g/cm^3)
AC1-01	4.0486	4.1025	-	-
AC1-02	3.4235	3.4510	-	-
AC1-03	3.4287	3.4488	-	-
AC1-04	3.4641	3.4527	-	-
AC1-05	3.6090	3.5982	-	-
AC1-06	3.5211	3.5422	-	-
AC1-07	3.6435	3.5851	-	-
AC1-08	3.7184	3.7703	-	-
AC1-09	3.7077	3.7607	-	-
AC1-10	**3.7163**	**3.8201**	3.8289	-
AC1-11	4.0622	4.0601	-	-
AC1-12	3.9076	3.9104	-	-
AC1-13	3.8401	3.8883	-	-
AC1-14	3.9345	3.9453	-	-
AC1-15	4.1581	4.0902	-	-
AC1-16	3.8114	3.7284	3.7316	-
AC1-17	3.4262	3.4350	-	-
AC1-18	3.5724	3.5910	-	-
AC1-19	4.0425	4.0167	-	-
AC1-20	3.8940	3.9597	-	-
AC1-21	3.7744	3.7577	3.7434	-
AC1-22	3.4662	3.4482	-	-
AC1-23	3.6111	3.5920	-	-
AC1-24	3.7407	3.7500	3.7562	-
AC1-25	3.9071	3.9154	-	-
AC1-26	**4.0992**	**3.9098**	4.1319	4.1169
AC1-27	3.8026	3.7568	-	-
AC1-28	3.8213	3.8341	-	-
AC1-29	3.8933	3.9588	-	-
AC1-30	3.9602	3.9512	-	-
AC1-31	3.7803	3.7485	-	-
AC1-19B	3.7427	3.7502	3.7394	-

Figure 11 shows a comparison of the SRTC buoyancy and PNNL gas pycnometry density data. Only two glasses (AC1-10 and AC1-26 - **bolded** in Table VIII) appear to be "outliers" (e.g., they differ by more than 2.5%), statistically there is no significant difference between the two techniques based on a paired t-test.

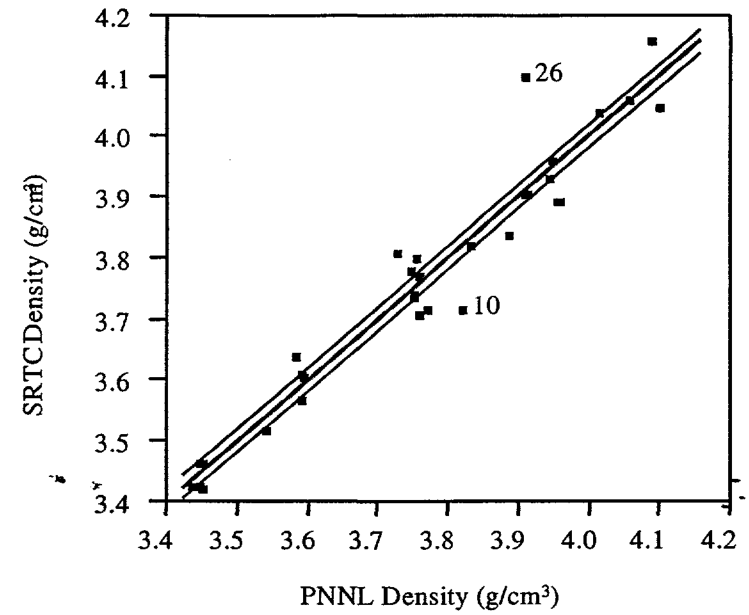


Figure 11. Buoyancy Versus Gas Pycnometry Density Measurements.

The variation of density as determined by pycnometry of the three AC1-26 subsamples is also of interest (e.g., 3.9098, 4.1319, and 4.1169 g/cm^3). The three independent measurements indicate that there may be differences in chemical composition of the three different subsamples selected from the "as-fabricated" pour patty. The potential impact of chemical non-uniformity within the "as-fabricated" sample could play a role in those property measurements that involve relatively small subsamples (e.g., chemical composition, density, liquidus temperature, and durability). For those properties which utilize a relatively large quantity of material (e.g., viscosity) this effect should be minimal.

Figures 12 and 13 show the SRTC buoyancy density data as a function of total lanthanide content on both a targeted and "as-measured" basis. Figures 14 and 15 show the PNNL gas pycnometry density data as a function of total lanthanide content on both a targeted and "as-measured" basis. The data indicate an excellent correlation of density with the total lanthanide content. As the total lanthanide content (or loading since the feed stream is highly lanthanide based) increases, the measured density (regardless of measurement technique) increases. There appears to be more scatter in the targeted data relative to the "as-measured" data for both techniques. The SRTC buoyancy and PNNL gas pycnometry data based on "as-measured" compositions have very little scatter.

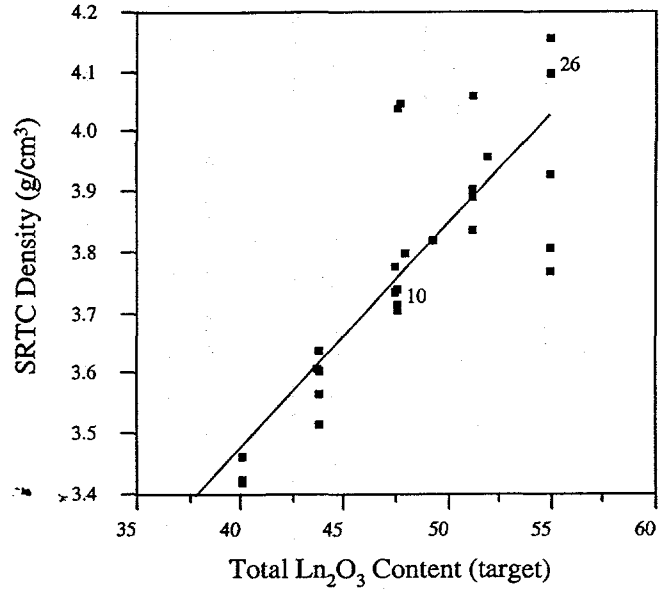


Figure 12. SRTC Buoyancy Density Versus Targeted Total Ln_2O_3 Content.

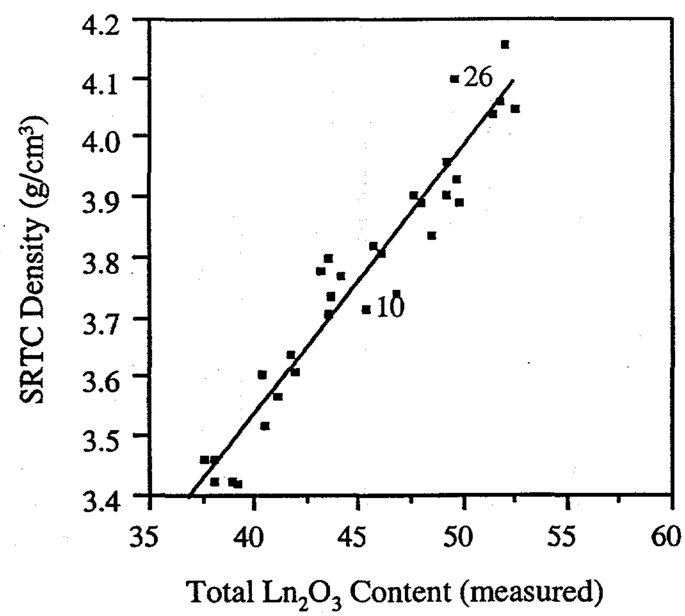


Figure 13. SRTC Buoyancy Density Versus "As-Measured" Total Ln_2O_3 Content.

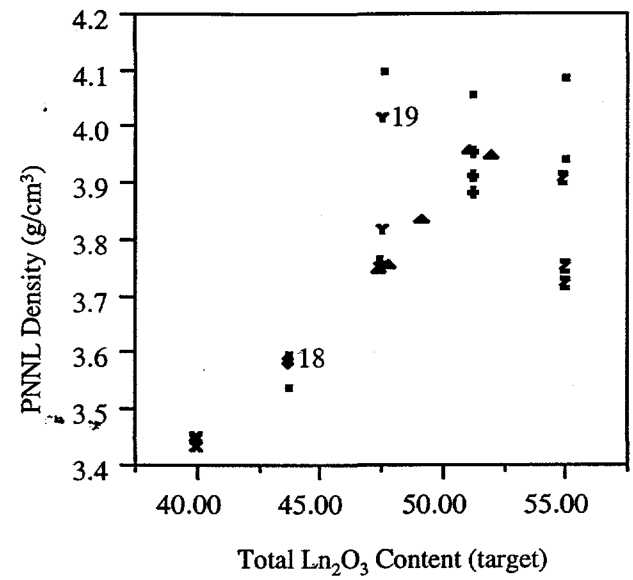


Figure 14. PNNL Gas Pycnometry Density Versus Targeted Total Ln_2O_3 Content.

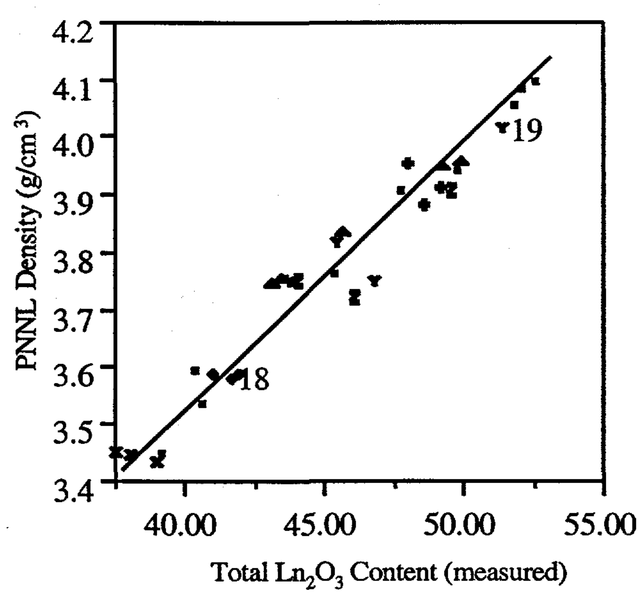


Figure 15. PNNL Gas Pycnometry Density Versus "As-Measured" Total Ln_2O_3 Content.

A review of the density measurements of the duplicate glasses for both techniques is provided in Figures 16 and 17. The first of these figures considers the SRTC densities as measured by buoyancy. A pooled standard deviation (0.1134 g/cm^3) was estimated across all five sets of replicates, and using the overall mean of these measurements (3.7345 g/cm^3), a % relative standard deviation was determined (3.0%). These data also provide an indication of the potential chemical composition differences among subsamples (in particular AC1-19 and AC1-26 and their respective replicates).

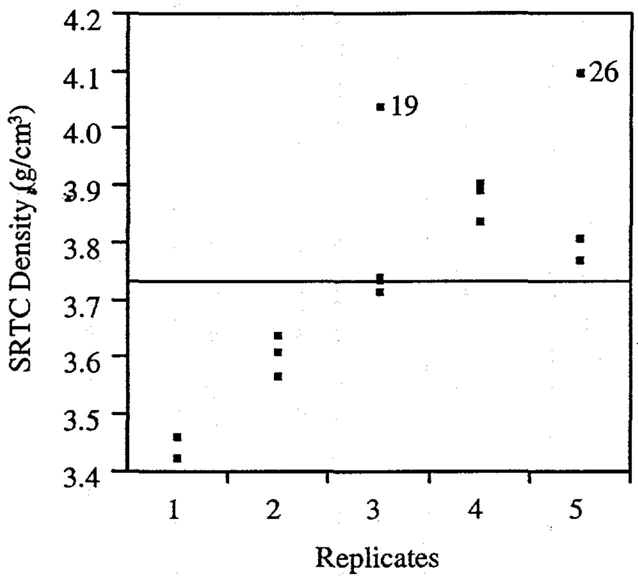


Figure 16: SRTC Density (g/cm^3) as Measured by Buoyancy for Replicates.

The relationship between total lanthanide content (or loading) and density demonstrated in Figures 12 – 15 is also observed in Figure 16. That is, as the total lanthanide content (or loading) increases (from Replicates #1 to #5), increases in density should be observed. Given this trend, one would question the measured values of AC1-19, AC1-16, and AC1-21. The latter two being replicates of AC1-26. Again, this could be the result of subsample compositional differences.

Using the same approach for PNNL gas pycnometry densities results in a % relative standard deviation of 2.1% for an overall mean density of 3.725 g/cm^3 and "pooled" standard deviation of 0.0794 g/cm^3.

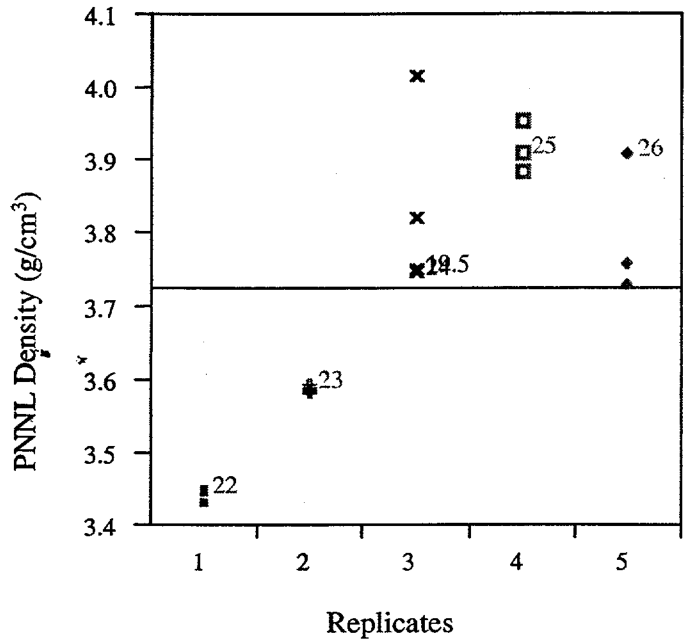


Figure 17: PNNL Density (g/cm^3) As Measured by Gas Pycnometry for Replicates.

High-temperature and annealed (room temperature) density measurements were performed on a limited number of glasses (AC1-04, AC1-07, AC1-10, AC1-13, and AC1-16) by Monarch Analytical Laboratories, Inc. to support thermal modeling efforts.[q] These five glasses span the 20 – 40% loading range (in 5% increments) used in the Phase 1 EGCR development. Annealed densities, as measured by ASTM C 693 [17], as a function of loading and total Ln_2O_3 content are shown in Table IX and plotted in Figure 18. Density increases can be directly attributed to increases in total lanthanide content as previously shown in Figures 12 – 15. A plot of the annealed density data versus the "as-measured" total lanthanide content is not shown since these glasses were produced from separate batches and subsequent chemical analysis was not performed.

Table IX. Annealed Density of Select Phase 1 Glasses
as Measured By Monarch Laboratories Using ASTM C 693.

Glass	Loading (mass %)	Total Lanthanide Content	Annealed Density (g/cm^3)
AC1-04	20	40.01	3.472
AC1-07	25	43.75	3.608
AC1-10	30	47.50	3.775
AC1-13	35	51.26	3.928
AC1-16	40	55.01	4.100

[q] These five glasses were batched and melted separately from the Phase 1 glasses used to evaluate the primary processing and product performance properties. Since these data were only to be used to support thermal modeling efforts, this work was not performed under the Quality Assurance criteria of RW-0333P.

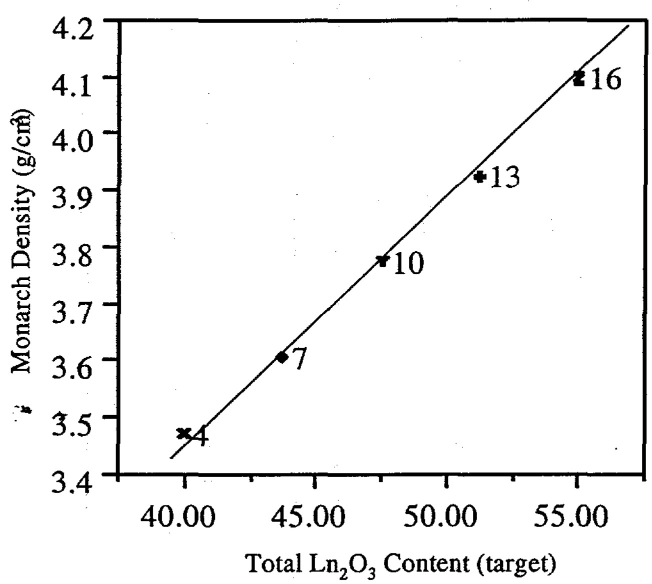


Figure 18. Monarch Density Versus Targeted Total Ln_2O_3 Content.

Tables X – XIV summarize the high temperature density measurements performed by Monarch Laboratories for AC1-04, AC1-07, AC1-10, AC1-13, and AC1-16, respectively. A rigorous data reduction was not performed on the high temperature density data. However, the data do indicate a reduction in high temperature density with increasing temperature. An increase in molten glass density with increased total lanthanide content (at similar temperature) also is observed.

In general, the determination of molten glass density for all five samples was limited at the lower temperatures by viscosity. At the higher temperatures, the glasses deposited gas bubbles (e.g., oxygen liberated from high temperature reduction of CeO_2) on the test bob limiting the higher temperature to which the samples could be tested. An additional problem with samples AC1-13 and AC1-16 was the formation of a surface "scum" (reported by Monarch as a probable crystalline material) at temperatures below 2200°F (or approximately 1200°C). The formation of a crystalline scum layer is indicative of the impact of liquidus temperature and the kinetics of devitrification (i.e., crystals are thermodynamically favorable below T_L). Monarch also measured surface tension of these five glasses (see Table XV).

Table X. High Temperature Density Data for AC1-04.

Temperature (°C)	Molten Density (g/cm^3)
1093	3.325
1121	3.320
1148	3.315
1201	3.306
1255	3.299
1281	3.295
1309	3.292
1336	3.288

Table XI. High Temperature Density Data for AC1-07.

Temperature (°C)	Molten Density (g/cm^3)
1095	3.480
1122	3.473
1148	3.469
1202	3.461
1256	3.452
1282	3.449
1310	3.445

Table XII. High Temperature Density Data for AC1-10.

Temperature (°C)	Molten Density (g/cm^3)
1096	3.585
1123	3.578
1150	3.573
1176	3.567
1203	3.564
1230	3.558
1256	3.552
1284	3.549

Table XIII. High Temperature Density Data for AC1-13.

Temperature (°C)	Molten Density (g/cm^3)
1092	3.735
1120	3.728
1146	3.723
1199	3.711
1253	3.701
1281	3.696
1308	3.688
1336	3.683

Table XIV. High Temperature Density Data for AC1-16.

Temperature (°C)	Molten Density (g/cm^3)
1148	3.903
1199	3.893
1253	3.881
1281	3.876
1308	3.870
1336	3.864

Table XV. Surface Tension Data for Select Phase 1 Glasses.

Glass	Surface Tension (dynes/cm)
AC1-04	288
AC1-07	298
AC1-10	312
AC1-13	332
AC1-16	338

VISCOSITY

Viscosity measurements were made according to the schedule given in Table XVI.[22] The NBS-710 glass is a standard glass with a certified η-T relationship. The η data are summarized in Appendix B (Table B.1), where a number of data points are highlighted. Those data points typed in **bold** font are suspected of being influenced by crystallization at lower T's or volatility at higher T's. Data points were assigned a **bold** font if the spindle torque failed to reach a steady value when held at constant speed and temperature for five minutes. This assignment does not invalidate the data it only calls attention to them.

Table XVI. Tracking and Run Order Numbers for Phase 1 Glasses.

Run order	Tracking #	Run order	Tracking #	Run order	Tracking #
1	NBS-710a	13	AC1-21	25	AC1-13
2	AC1-29	14	AC1-03	26	AC1-08
3	AC1-19	15	AC1-07	27	AC1-01
4	AC1-02	16	AC1-10	28	AC1-27
5	AC1-18	17	NBS-710b	29	AC1-30
6	AC1-22	18	AC1-16	30	AC1-26
7	AC1-28	19	AC1-20	31	AC1-12
8	AC1-25	20	AC1-31	32	AC1-09
9	AC1-04	21	AC1-11	33	AC1-06
10	AC1-23	22	AC1-14	34	NBS-710c
11	AC1-05	23	AC1-17	35	AC1-19B
12	AC1-15	24	AC1-24		

Viscosity-T data were fitted to the Vogel-Tamman-Fulcher (VTF) model [20, 22] for each glass. Occasionally data points were omitted from the VTF fit in order to obtain lower standard error on the three VTF coefficients (A, B, and T_0). The omitted points (a subset of the **bold** points discussed above) are listed in Table B.1 (Appendix B) with a line drawn through them. The impact of data point removal is best described with an example. Figure 19 shows the η-T data from AC1-11 fitted to a VTF model with all data. Figure 20 shows the η-T data from AC1-11 fitted to a VTF model with three data points removed. It is clear by comparing the two figures that the latter fit yields a model that better estimates actual η-T behavior of the glass. The errors associated with each coefficient (see inserts within figures) are far lower in the second figure. The viscosities calculated using the "all data" and "limited data" for AC1-1 results in an ~4 Poise difference at 1350°C for AC1-11.

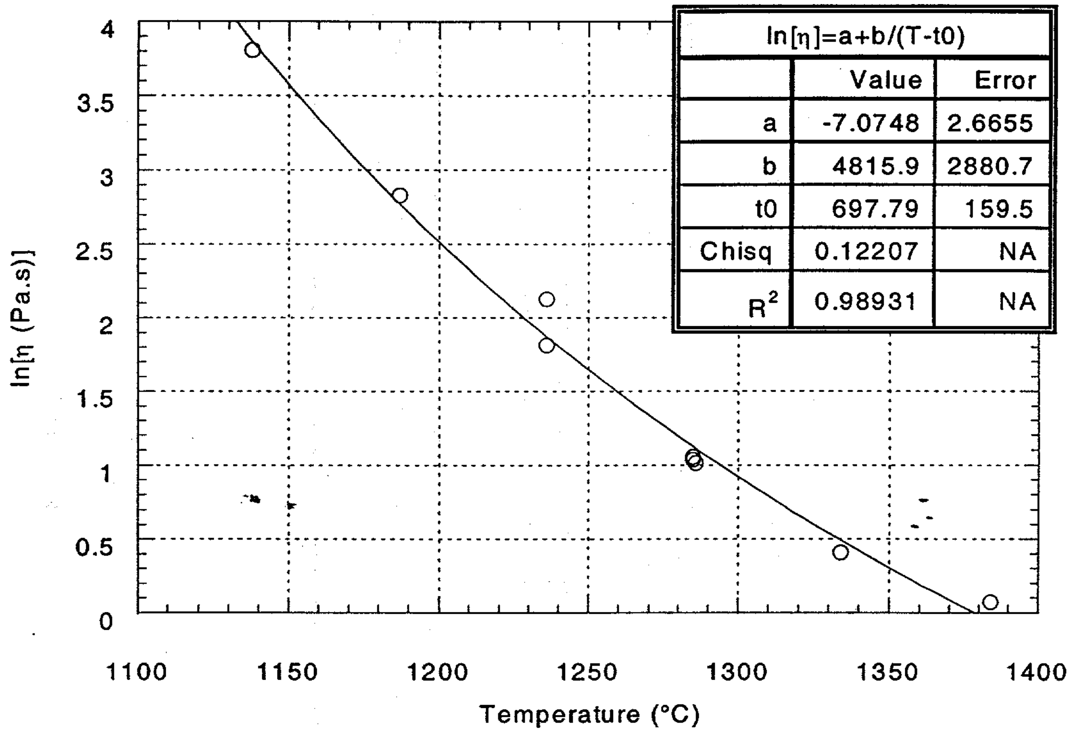


Figure 19. Plot of AC1-11 η-T Data Fitted to the VTF Model with All Data Included.

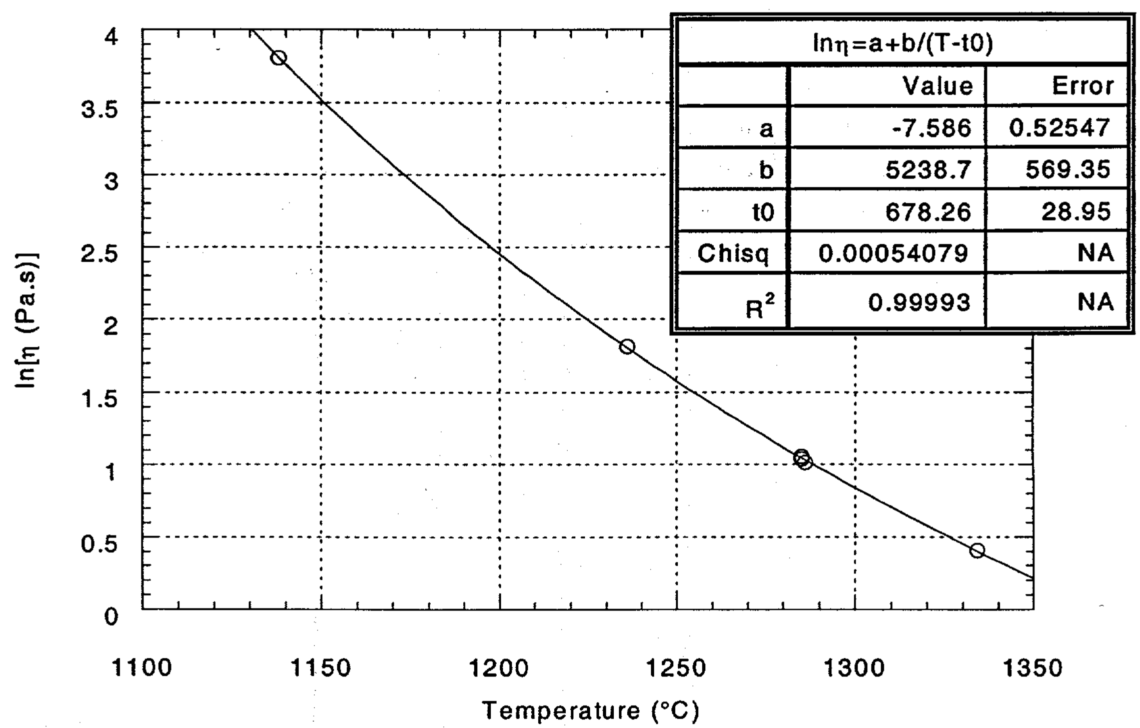


Figure 20. Plot of AC1-11 η-T Data Fitted to the VTF Model with Three Data Points Removed.

The fitted VTF coefficients are listed in Table XVII for each Phase 1 glass. These VTF models were used to calculate the T values at four fixed viscosity points – 0.3, 2, 2.4, and 5 Pa·s (corresponding to ln[η (Pa·s)] values of –1.2, 0.69, 0.88, and 1.61, respectively), which are also listed in Table XVII. These η values correspond to points of interest in glass formulation and melter operation efforts. The η at 1350°C (both Pa·s and Poise) was also calculated using the VTF model for each glass and is listed in Table XVII. The η at 1350°C is one of the primary processing constraints to be used to define the AGCR (constraint of 3 – 24 Poise at 1350°C).

The measured viscosity at 1350°C as a function of targeted and "as-measured" total lanthanide content are shown in Figures 21 and 22, respectively. Again, the total lanthanide (Ln_2O_3) content is the key indicator in both figures. The data indicate that as the total Ln_2O_3 content (or feed loading) increases the viscosity decreases. Also evident from the data is a set of glasses that do not meet the upper viscosity limit (≤ 24 Poise at 1350°C). Those glasses failing this constraint (**bolded** in Table XVIII) have low total Ln_2O_3 content which translates into a viscosity higher than 24 Poise at 1350°C. For those glasses failing the viscosity constraint, total targeted lanthanide content is 43.75 mass % or less (corresponding to 25 mass % feed loading or less). Based on "as-measured" Ln_2O_3 content, glasses containing at least 42 mass % total Ln_2O_3 meet the viscosity constraint. There are no Phase 1 glasses that fail the viscosity constraint on the low side (i.e., < 3 Poise).

The data indicate the AGCR is restricted to feed loadings of greater than ~ 30 mass % (the true line of demarcation is between 25 and 30 mass %). This latter statement assumes that the glass coming through the drain tube contains at least 30 mass % feed (or approximately 42 – 44 mass % total lanthanide content). The fact that no glasses failed the viscosity constraint on the low side (i.e., < 3 Poise at 1350°C) provides the opportunity to increase waste loadings (or total lanthanide content) while maintaining adequate viscosity values (other properties not being considered).

Table XVII. VTF Coefficients, T's at Fixed η Points, and η at 1350°C for Each Phase 1 Glass.

Glass	A	B (K)	T_0 (°C)	$T_{0.3}$ (°C)	T_2 (°C)	$T_{2.4}$ (°C)	T_5 (°C)	η_{1350} (Pa.s)	η_{1350} (Poise)
AC1-01	-4.532	2434.9	846.74	1578	1313	1297	1243	1.36	13.6
AC1-02	-7.102	5802.5	660.67	1644	1405	1388	1327	3.73	37.3
AC1-03	-6.820	5558.5	669.68	1659	1410	1392	1329	3.86	38.6
AC1-04	-8.124	7104.5	598.88	1626	1405	1388	1329	3.80	38.0
AC1-05	-6.827	5372.1	671.46	1627	1386	1369	1308	2.97	29.7
AC1-06	-7.090	5802.7	649.27	1635	1395	1378	1316	3.29	32.9
AC1-07	-6.964	5561.2	659.97	1625	1386	1369	1309	2.99	29.9
AC1-08	-6.625	4880.1	694.64	1595	1361	1345	1287	2.27	22.7
AC1-09	-5.931	4227.5	727.71	1622	1366	1349	1288	2.37	23.7
AC1-10	-6.790	5119.5	676.92	1593	1361	1345	1286	2.26	22.6
AC1-11	-7.586	5238.7	678.26	1499	1311	1297	1248	1.24	12.4
AC1-12	-6.616	4658.7	698.95	1560	1336	1321	1265	1.72	17.2
AC1-13	-6.689	4815.0	688.42	1566	1341	1325	1269	1.80	18.0
AC1-14	-6.638	4648.4	701.39	1557	1335	1320	1265	1.70	17.0
AC1-15	-4.966	2762.9	823.25	1558	1312	1296	1243	1.32	13.2
AC1-16	-6.867	5157.5	674.86	1586	1357	1341	1283	2.16	21.6
AC1-17	-7.083	5910.8	652.25	1658	1412	1395	1332	4.01	40.1
AC1-18	-6.752	5280.1	674.38	1626	1384	1367	1306	2.90	29.0
AC1-19	-5.706	3461.8	776.80	1546	1318	1303	1250	1.40	14.0
AC1-20	-6.698	4797.1	688.73	1562	1338	1322	1266	1.75	17.5
AC1-21	-6.572	4853.4	689.05	1593	1357	1341	1282	2.16	21.6
AC1-22	-7.975	6907.0	603.62	1624	1400	1384	1324	3.59	35.9
AC1-23	-6.657	5135.4	682.79	1625	1381	1365	1304	2.83	28.3
AC1-24	-6.762	5052.8	679.31	1588	1357	1341	1283	2.16	21.6
AC1-25	-6.386	4394.3	713.25	1561	1334	1318	1263	1.67	16.7
AC1-26	-5.387	3128.4	801.30	1549	1316	1301	1248	1.37	13.7
AC1-27	-6.547	4810.0	692.15	1592	1357	1340	1282	2.15	21.5
AC1-28	-6.612	4788.8	692.08	1578	1348	1332	1275	1.95	195
AC1-29	-6.548	4614.5	697.24	1561	1335	1319	1263	1.68	16.8
AC1-30	-6.083	4038.2	732.15	1560	1328	1312	1257	1.57	15.7
AC1-31	-6.684	4966.8	685.80	1592	1359	1343	1285	2.21	22.1
AC1-19B	-5.815	4080.8	736.56	1622	1364	1347	1286	2.31	23.1

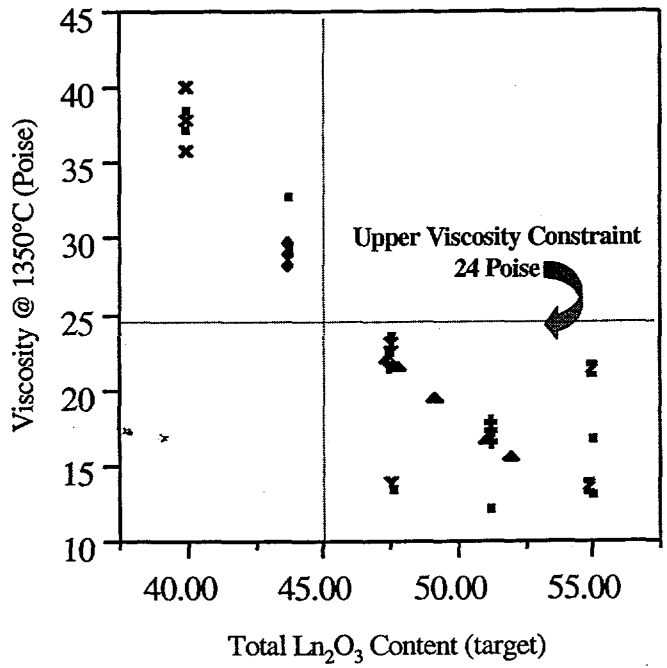


Figure 21. Viscosity (1350°C) Versus Targeted Total Ln_2O_3 Content.

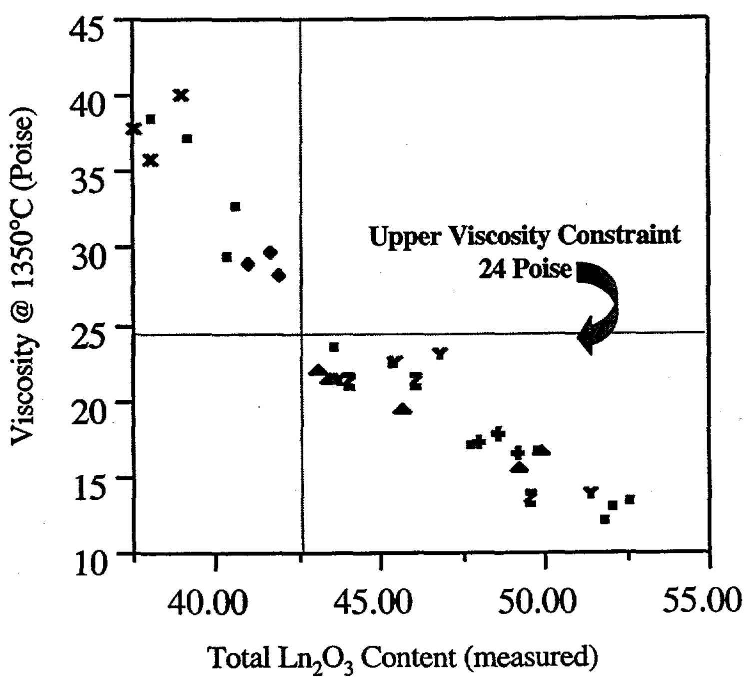


Figure 22. Viscosity (1350°C) Versus "As-Measured" Total Ln_2O_3 Content.

Table XVIII. Calculated Viscosity (η_{1350}) as a Function of Loading and Total Ln_2O_3 Content.

Glass	η_{1350} (Poise)	Loading	Total Ln_2O_3 Content (as targeted)	Total Ln_2O_3 Content (as measured)
AC1-01	13.6	~30*	47.66	52.59
AC1-02	**37.3**	**20**	**40.01**	**39.18**
AC1-03	**38.6**	**20**	**40.01**	**38.04**
AC1-04	**38.0**	**20**	**40.01**	**37.57**
AC1-05	**29.7**	**25**	**43.76**	**40.38**
AC1-06	**32.9**	**25**	**43.75**	**40.57**
AC1-07	**29.9**	**25**	**43.75**	**41.68**
AC1-08	22.7	30	47.50	45.33
AC1-09	23.7	30	47.51	43.60
AC1-10	22.6	30	47.50	45.44
AC1-11	12.4	35	51.25	51.82
AC1-12	17.2	35	51.26	47.70
AC1-13	18.0	35	51.26	48.55
AC1-14	17.0	40	54.99	49.77
AC1-15	13.2	40	54.99	52.04
AC1-16	21.6	40	55.01	46.15
AC1-17	**40.1**	**20**	**40.01**	**38.99**
AC1-18	**29.0**	**25**	**43.75**	**41.06**
AC1-19	14.0	30	47.50	51.39
AC1-20	17.5	35	51.26	48.03
AC1-21	21.6	40	55.01	44.09
AC1-22	**35.9**	**20**	**39.97**	**38.08**
AC1-23	**28.3**	**25**	**43.71**	**41.99**
AC1-24	21.6	30	47.45	43.71
AC1-25	16.7	35	51.21	49.21
AC1-26	13.7	40	54.96	49.64
AC1-27	21.5	31	47.88	43.53
AC1-28	19.5	32	49.22	45.71
AC1-29	16.8	35	51.19	49.92
AC1-30	15.7	36	51.97	49.26
AC1-31	22.1	30	47.44	43.17
AC1-19B	23.1	30	47.50	46.78

* AC1-01 has a feed loading of ~30 mass % and ~40 mass % based on targeted and "as-measured" total lanthanide content calculations respectively.

Isolating just the duplicate glasses (including those that were spiked with the minor components) and plotting their viscosities leads to Figure 23. The "pooled" estimate of the standard deviation of these measurements is 3 Poise (with or without including the glasses with the minor components). Each of the 95% confidence intervals for the means of these five sets of repeats contains its respective spiked "duplicate" indicating no statistically significant impact on viscosities due to the minor components (at least not within the EGCR evaluated for Phase 1).

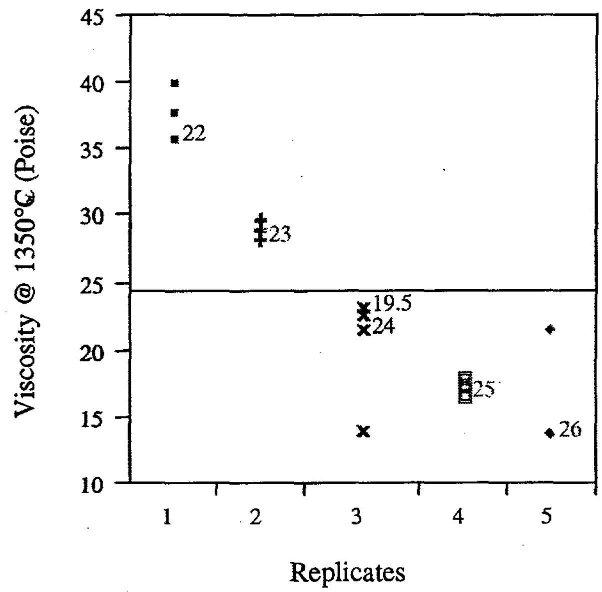


Figure 23: Viscosity (Poise) @ 1350°C for Replicates.

VISCOSITY DATA VALIDATION

The NBS-710 glass was tested three times to check measurement accuracy and precision. Viscometer calibration was performed using a different standard glass -- NBS-711 glass. Table XIX summarizes the results for these standard glass measurements. Here, like in Appendix B, data points were assigned a **bold** font if the spindle torque failed to reach a steady value when held at constant speed and temperature for five minutes.

Table XIX. Summary of NBS-710 Standard Glass Viscosity Measurement Data, T in °C, η in Pa·s

	1st pt	2nd pt	3rd pt	4th pt	5th pt	6th pt	7th pt	8th pt	9th pt	10th pt
NBS-710a T	**1529**	1480	1430	**1381**	1332	**1282**	1233	1184	1135	1529
NBS-710a η	**5.669**	6.834	10.000	**15.156**	22.348	**35.080**	58.194	99.543	183.635	5.072
NBS-710b T	**1531**	1482	1433	1383	1334	1284	1235	1185	1136	1531
NBS-710b η	**5.747**	6.869	10.19	15.45	22.814	35.589	59.573	102.759	191.488	5.158
NBS-710c T	**1531**	1482	1433	1384	1334	1284	1235	1186	**1136**	1531
NBS-710c η	**5.556**	7.215	10.485	15.709	23.346	36.097	60.798	104.443	**194.509**	5.375

The η-T data from these glasses were fitted to Equation (1) and the raw viscosity data were then calculated according to:

$$\log_{10}\eta = -1.626 + \frac{4236.118}{T(°C) - 266}, \qquad (1a)$$

for comparison purposes. Figure 24 shows the reported glass viscosity (calculated using Equation 1a) and the measured η-T data for NBS-710a, b, and c glasses. The ln[η(Pa·s)] curves calculated for all three NBS-710 glasses (NBS-710a, NBS-710b, and NBS-710c) are within ±2% of the reported curve given by Equation (1a) over the temperature interval measured.

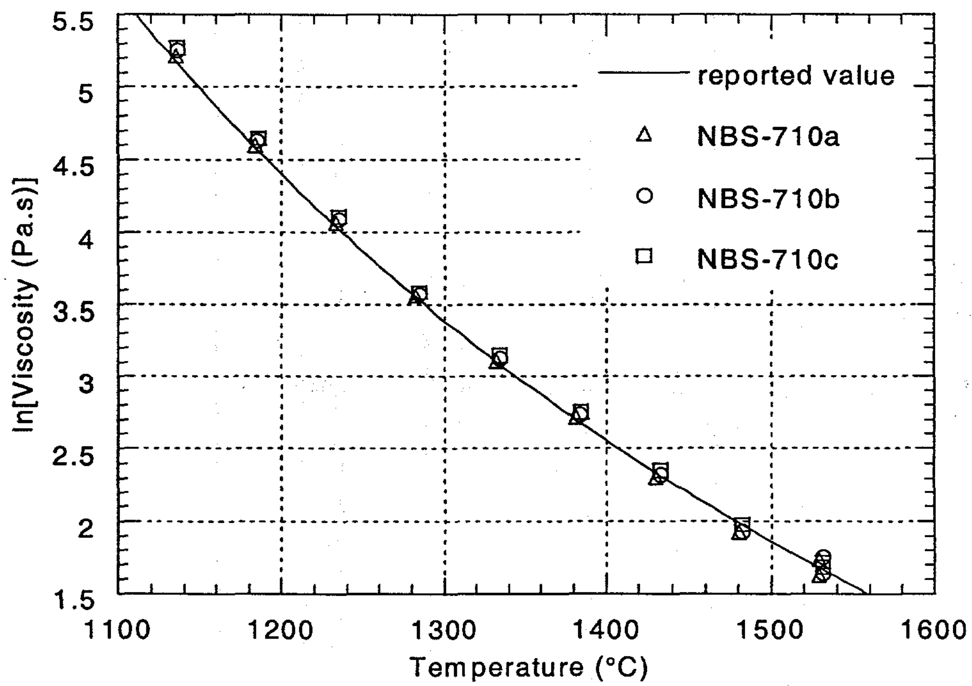


Figure 24. Plot of Measured NBS-710a, b, and c Glass η-T Data with Reported Values.

LIQUIDUS TEMPERATURE (T_L)

Liquidus temperatures for the 32 glasses (including AC1-19B) were between 1163 and 1298°C (AC1-24 and AC1-26 respectively).[23] One of two crystal types was identified as the primary phase: a rare earth silicate (RES) phase or an aluminosilicate (AlS) phase. The T_L data are summarized in Table XX and include the primary crystalline phase, T_L, T_A and T_C.

Rare earth silicate was the primary phase in 22 of the 32 glasses; however, morphology of the RES crystals was different between glasses. Three crystal shapes of RES crystals were observed by optical microscopy: needle-like, hair-like and plate-like. Each crystal shape was analyzed using XRD and SEM. SEM/EDS scans showed Si, La, Nd, O (major elements), Ce, Sm, Er (minor elements), Pr may be present but is obscured by a large La peak, and Al is present in some crystals but not in others (minor element). Chemically the RES crystals are the same regardless of morphology, even in the hair-like crystals. Samples analyzed by XRD had the crystal structure (closest match with the software used[r]) neodymium germanium borate silicate ($Nd_3BGe_{1.08}Si_{0.92}O_{10}$). In this crystal structure, germanium could be replaced by silicon and neodymium replaced by rare earth (RE) elements to form $RE_3BSi_2O_{10}$, the crystal type that is probably present in these samples.

[r] Material Data, Inc., Jade 3.1 Software with International Centre for Diffraction Database (Release 1998).

Table XX. T_L and Primary Crystalline Phase for the Phase 1 Glasses.

Glass	T_L (°C)	Primary Phase	T_C^* (°C)	T_A^* (°C)
AC1-01	1272	RES	1270	1278
AC1-02	1255	AIS	1249	1259
AC1-03	1246	AIS	1242	1249
AC1-04	1255	AIS	1249	1259
AC1-05	1164	AIS	1161	1166
AC1-06	1230	AIS	1228	1235
AC1-07	1187	AIS	1183	1191
AC1-08	1184	RES	1183	1189
AC1-09	1212	RES	1209	1213
AC1-10	1216	RES	1213	1219
AC1-11	1267	RES	1264	1270
AC1-12	1238	RES	1235	1241
AC1-13	1241	RES	1240	1241
AC1-14	1240	RES	1235	1241
AC1-15	1254	RES	1249	1256
AC1-16	1195	RES	1192	1197
AC1-17	1246	AIS	1242	1249
AC1-18	1197	AIS	1193	1199
AC1-19	1246	RES	1241	1248
AC1-20	1247	RES	1241	1250
AC1-21	1180	RES	1174	1183
AC1-22	1224	AIS	1213	1225
AC1-23	1201	AIS	1199	1209
AC1-24	1163	RES	1159	1166
AC1-25	1244	RES	1240	1248
AC1-26	1298	RES	1295	1300
AC1-27	1168	RES	1166	1169
AC1-28	1208	RES	1205	1209
AC1-29	1259	RES	1256	1261
AC1-30	1242	RES	1241	1248
AC1-31	1186	RES	1183	1188
AC1-19B	1165	RES	1161	1168

* T_A is the lowest temperature at which samples did not form crystals
T_C is the highest temperature at which samples did form crystals.

The RES crystals observed as needle-shaped crystals commonly clustered at a focal point with the needles pointing out in all directions (Figure 25 and 26a). The size of the crystals had a wide range in length from <0.1 mm to >1.0 mm, and thickness of approximately 1 μm to >10 μm.

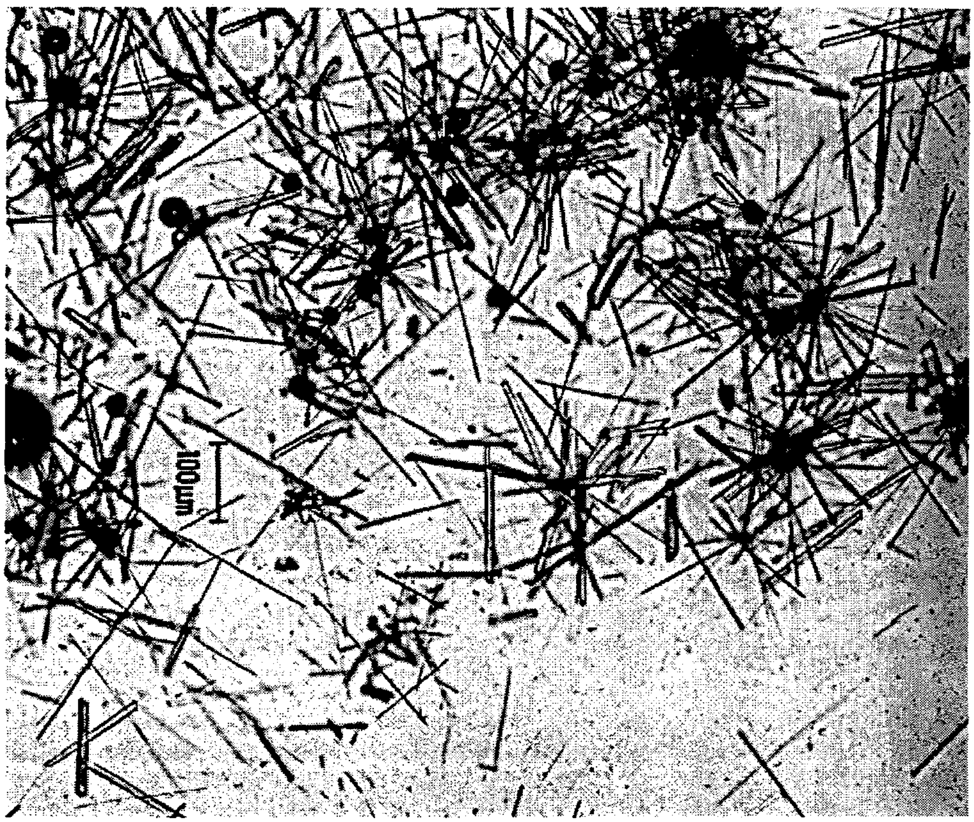


Figure 25. AC1-28 (1180°C), 100x, transmitted light.
Example of needle-like RES crystal phase.

Associated with the needle-like crystals are hair-like crystals which were found in or near the vicinity of the needle clusters (Figure 26a and 26b). These crystals are very thin (<0.5 μm) and long (>100 μm) and curved like an eyebrow and occasionally observed in a coil. These crystals may be straight also, but they are so thin that they are difficult to observe by optical microscopy, but are very distinct when they curve or coil. SEM /EDS scans indicated very similar chemical composition for both needle- and hair-like RES crystals.

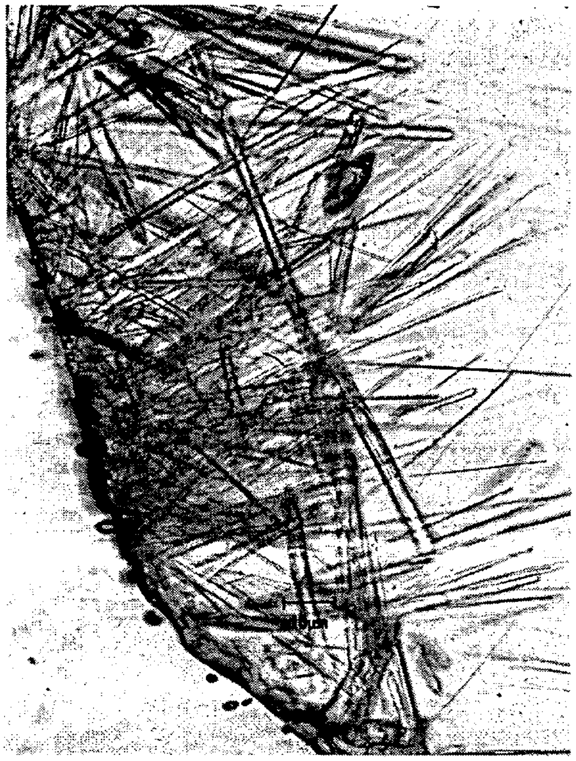


Figure 26a – AC1-31 (1159°C), 100x, polarized light. RES needle-like crystals (major) with thin, hair-like crystals.

Figure 26b – AC1-24 (1150°C), SEM, 500x, all phases are RES crystals including thin, curved hair-line crystal on left side of photomicrograph.

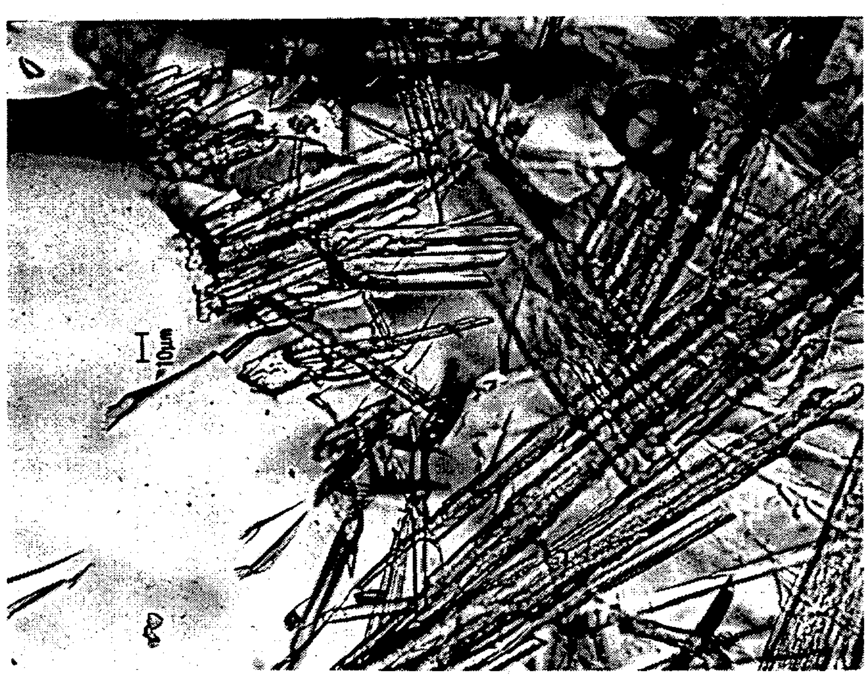


Figure 27. AC1-09 (1199°C), 50x, polarized light, plate-like RES crystals.

Plate-like, RE silicate crystals (Figure 27) were also found in many of the samples (i.e., AC1-20, 26 and 30). This morphology seems to develop as needle-shaped RES crystals join side-by-side to form plate-like formations. The plate-like crystals were also observed in samples with needle-like crystals (e.g., AC1-14 (1206°C) and AC1-16 (1180°C)).

Aluminosilicate crystals as the primary phase were found in 10 Phase 1 glasses (Table XX, AlS). This crystal type was observed mainly on the surface of the samples but was also found in the glass bulk near T_L in clusters of very fine (thin), clear crystals that extended from a central location (Figure 28a and b). These clusters were small and difficult to observe using optical microscopy and appeared as small white clouds. SEM/EDS identified the crystals as high in aluminum and oxygen and low in silicon. The structure that matched the phase closest was mullite ($Al_6Si_2O_{13}$) when analyzed by XRD. The dense core of the cluster caused the clouds, but the outer area was invisible to transmitted light. Polarized light was essential for observing these crystals near T_L.

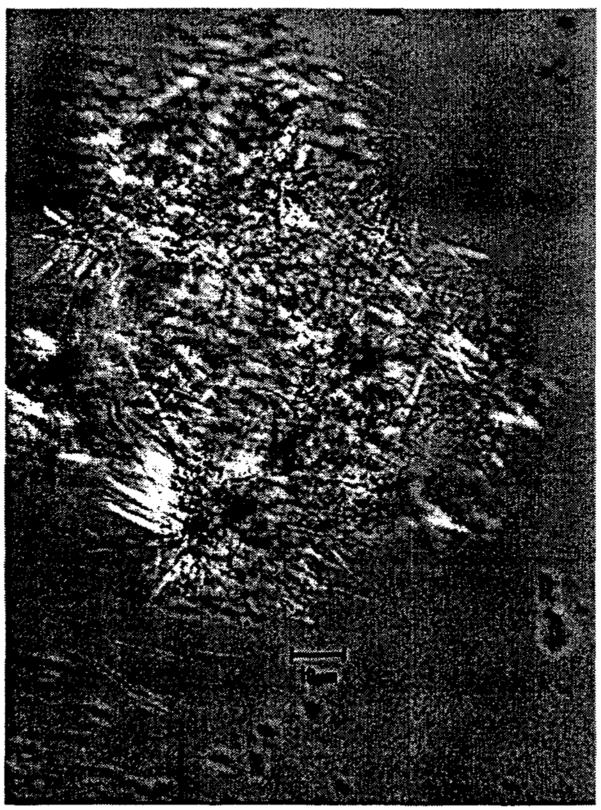


Figure 28a – AC1-17 (1228°C), 100x, polarized light, cloud-like cluster of AlS crystals.

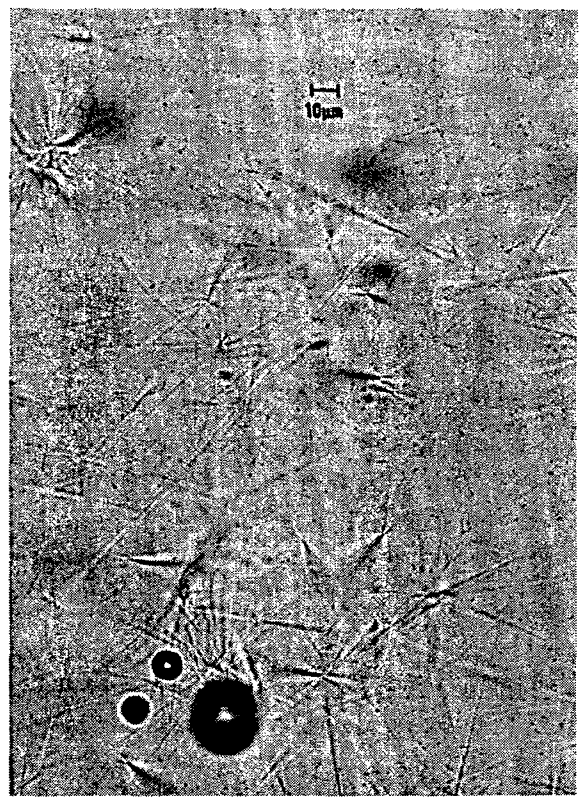


Figure 28b – AC1-18 (1100°C), 500x, transmitted light, AlS crystals barely visible.

Determining T_L of those glasses with AlS crystals as the primary phase was difficult. At temperatures less than 60°C below T_L, surface crystals were observed. The surface crystals would diminish with samples heat treated at temperatures closer to T_L, until only small areas in the meniscus contained surface crystals. However, the bulk would still have clusters of aluminosilicate (see Figure 28a). Heat treatments were needed to about 40 to 50°C above this change before the clusters in the bulk disappeared at T_L. Often there would be only a few very small clusters of crystals even at 20°C below T_L, but several heat treatments at temperatures close to T_L confirmed the presence of crystals.

Figures 29 – 30 show the measured T_L (from Table XX) versus targeted total Ln_2O_3 and "as-measured" total Ln_2O_3 contents, respectively. The two primary phases are represented by unique symbols: ✚ and ■ represent the rare earth silicate (RES) and aluminosilicate (AlS) primary phases respectively. There is a clear distinction between the primary phase fields based on total lanthanide content alone (see Figure 29 or 30). That is, at low total Ln_2O_3 (or low loadings) the primary phase is an AlS and as loadings increase (or total lanthanides increase) the primary phase transitions into the RES field. Glasses with low loadings are frit "dominated". With Al_2O_3 being a major player in the frit composition (24.87 mass %; Table II), it is not surprising that an AlS phase dictates T_L at low loadings. As loadings increase, rare-earth contents increase and the transition to the RES primary phase occurs. This transition occurs at approximately 45 mass % total Ln_2O_3 (targeted) content (or roughly 25 – 30 mass % feed loading). Based on the targeted total Ln_2O_3 content (Figure 29) there does not appear to be a trend in the T_L data. However, when T_L's are plotted against the "as-measured" total Ln_2O_3 contents, a trend does emerge (see Figure 30). As total lanthanide contents increase from ~ 38 mass % up to ~ 42.5 mass %, a gradual decrease in T_L is observed. This trend continues until a second primary phase field is encountered (i.e., transition from the AlS to the RES phase field). In the RES phase field (> 42.5 mass % total Ln_2O_3 "as-measured"), as total Ln_2O_3 contents (or loadings) increase T_L increases as well.

With respect to the 1250°C liquidus constraint, 7 of the 32 Phase 1 glasses fail this constraint. These glasses are **bolded** in Table XXI. Unlike the viscosity constraint where only low loadings caused 10 glasses to be "unacceptable", both high and low loaded glasses (i.e., in both primary phase fields) fail the T_L constraint. The total lanthanide content within each primary phase field can be used as a key indicator to define the Phase 1 AGCR. Within the AlS primary phase field, 2 (AC1-02 and AC1-04) of the 4 glasses at the 20% loading have T_L's > 1250°C (both reported to be 1255°C). Therefore, the AGCR should not include glasses with a 20% feed loading based on the 1250°C constraint.

In the RES primary phase field, AC1-01, AC1-11, AC1-15, AC1-26, and AC1-29 all have T_L's > 1250°C. One would hope that these glasses would be a part of a single targeted loading (i.e., 40%) but that is not the case. These glasses span the loading range of 35 – 40% that translates into a further reduction of the AGCR. It should be noted that AC1-01 has a targeted loading of ~30 mass % but based on the "as-measured" total lanthanide content it loadings would be ~40 mass %. Thus it is not surprising to see the high T_L associated with this glass. Given the restrictions in both primary phase fields, the Phase 1 AGCR is grossly reduced in size based solely on the 1250°C T_L constraint. Only glasses falling within the 25 – 30 mass % feed loading range are deemed acceptable. The AGCR has been defined ignoring the uncertainties of the T_L measurement (1σ = 24°C based on the Phase 1 results). However, the 100°C temperature differential between the lower nominal operating temperature (1350°C) and the 1250°C constraint should be adequate to account for any measurement uncertainty based on the Phase 1 results.

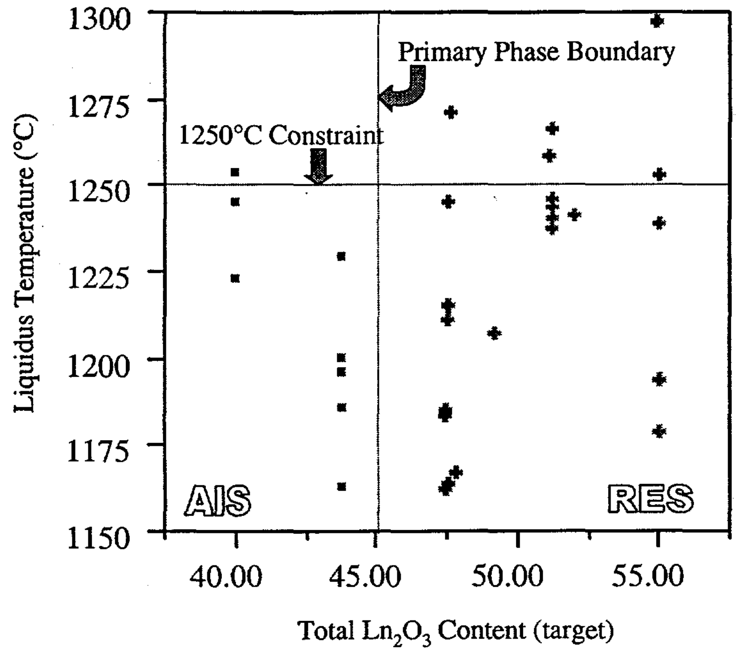


Figure 29. Liquidus Temperature Versus Targeted Total Ln_2O_3 Content.

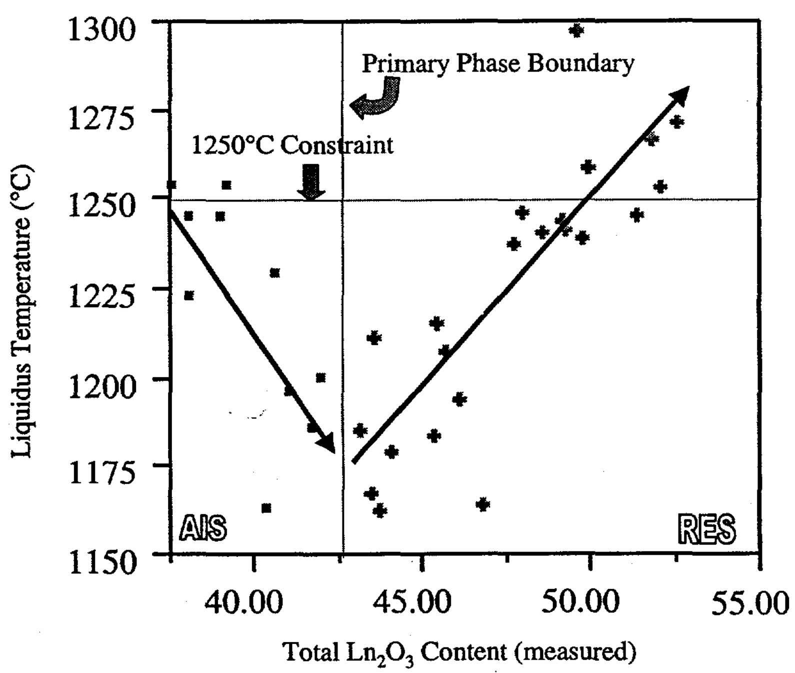


Figure 30. Liquidus Temperature Versus "As-Measured" Total Ln_2O_3 Content.

Table XXI. Liquidus Temperature and Primary Phase as a Function of Loading and Total Ln_2O_3 Content.

Glass	T_L (°C)	Primary Phase	Loading	Total Ln_2O_3 Content (targeted)	Total Ln_2O_3 Content ("as-measured")
AC1-01	**1272**	**RES**	**~30***	**47.66**	**52.59**
AC1-02	**1255**	**AIS**	**20**	**40.01**	**39.18**
AC1-03	1246	AIS	20	40.01	38.04
AC1-04	**1255**	**AIS**	**20**	**40.01**	**37.57**
AC1-05	1164	AIS	25	43.76	40.38
AC1-06	1230	AIS	25	43.75	40.57
AC1-07	1187	AIS	25	43.75	41.68
AC1-08	1184	RES	30	47.50	45.33
AC1-09	1212	RES	30	47.51	43.60
AC1-10	1216	RES	30	47.50	45.44
AC1-11	**1267**	**RES**	**35**	**51.25**	**51.82**
AC1-12	1238	RES	35	51.26	47.70
AC1-13	1241	RES	35	51.26	48.55
AC1-14	1240	RES	40	54.99	49.77
AC1-15	**1254**	**RES**	**40**	**54.99**	**52.04**
AC1-16	1195	RES	40	55.01	46.15
AC1-17	1246	AIS	20	40.01	38.99
AC1-18	1197	AIS	25	43.75	41.06
AC1-19	1246	RES	30	47.50	51.39
AC1-20	1247	RES	35	51.26	48.03
AC1-21	1180	RES	40	55.01	44.09
AC1-22	1224	AIS	20	39.97	38.08
AC1-23	1201	AIS	25	43.71	41.99
AC1-24	1163	RES	30	47.45	43.71
AC1-25	1244	RES	35	51.21	49.21
AC1-26	**1298**	**RES**	**40**	**54.96**	**49.64**
AC1-27	1168	RES	31	47.88	43.53
AC1-28	1208	RES	32	49.22	45.71
AC1-29	**1259**	**RES**	**35**	**51.19**	**49.92**
AC1-30	1242	RES	36	51.97	49.26
AC1-31	1186	RES	30	47.44	43.17
AC1-19B	1165	RES	30	47.50	46.78

* AC1-01 has a feed loading of ~30 mass % and ~40 mass % based on targeted and "as-measured" total lanthanide content calculations respectively.

Isolating just the duplicate glasses (including those that were spiked with the minor components) and plotting their liquidus temperature measurements leads to Figure 31. The "pooled" estimate of the standard deviation of these measurements is 35°C with the spiked glasses and 24°C without. Glass AC1-26 appears very different than its duplicates in this measurement-space again raising questions of chemical homogeneity. Removing it from consideration leads to an estimate of the "pooled" standard deviation of the remaining values of 23.8°C. In addition to glass AC1-26, AC1-24 is worth noting. It is very different from its original duplicates (AC1-10 and AC1-19) but its measured liquidus temperature is very near that of AC1-19B.

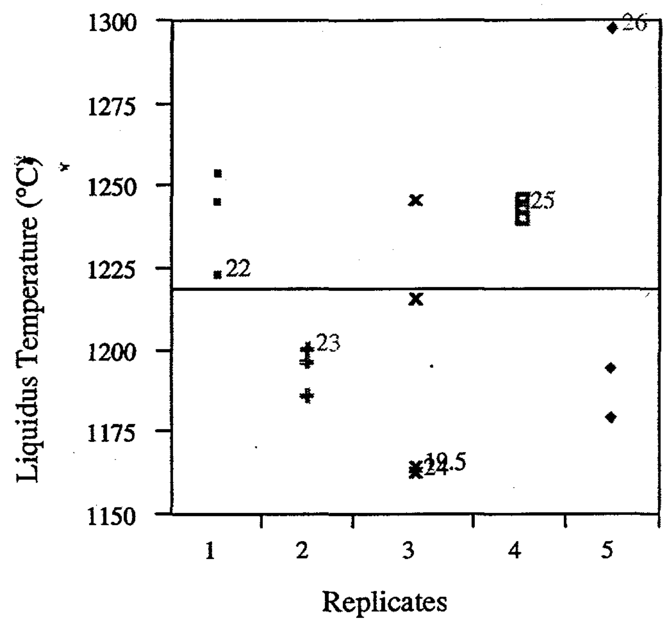


Figure 31. Liquidus Temp (T_L in °C) for Replicates.

The data shown in Figure 31 suggest that the measurement error associated with the liquidus temperature measurements is approximately 24°C at the 1σ level. This assumes that the glasses were initially homogeneous and the subsamples selected were also compositionally identical. Reference has been made to the potential for chemical composition gradients within the "as-fabricated" pour patty from which liquidus temperature subsamples were selected. Therefore, one can not distinguish from this data where the source of the rather large ΔT in terms of replicate measurements originates (errors from both may also propagate). The presence of undissolved and/or crystalline material in the "as received" samples may also have impacted the reported T_L results (discussed in a subsequent section).

VALIDATION OF FURNACES TEMPERATURES WITH SRM-773 GLASS

The Deltech® furnaces were checked initially, in the middle, and at the end of the test period using SRM-773 glass to validate the accuracy of the furnaces and the temperature measurement equipment used for T_L determination. SRM-773 glass has a reported T_L of 988°C ± 3°C for Method A and 991°C ± 5°C Method B. Since neither method was used for T_L measurement, both ranges were considered to validate the furnaces.

Furnace #8 had T_L of 992 (beginning), 995 (mid), and 994°C (final), and Furnace #5 had T_L of 993 (beginning), 993 (mid), and 997°C (final) for SRM-773 glass. In Furnace #5 on January 14, 1999, a crucible came in contact with the measurement thermocouple and the lid welded itself to the tip of the thermocouple. This may have been the cause for the shift in T_L of the SRM-773 glass from 993 to 997°C. Following this event, the furnace was used to measure the T_L of glasses AC1-02 (T_A=1259°C), AC1-03 (T_C=1242°C), AC1-04 (T_C=1249°C and T_A=1259°C), AC1-06 (T_C=1228°C and T_A=1235°C), AC1-17 (T_C=1242°C), and AC1-29 (T_A=1261°C).

INCLUSIONS IN "AS RECEIVED" GLASSES

"As received" glass was analyzed by optical microscopy to determine if crystalline or immiscible liquid phases existed. Three glasses, AC1-02, 17 and 22, were found to have clusters of AlS crystals present (Figure 32). The total amount of crystal fraction is not known but is estimated to be below 1 vol%. Note that these glasses are loaded at the 20% level and lie within the AlS primary phase field. Within this field the lower loadings typically pose higher T_L values (see Figure 30). The detection of AlS clusters in the "as-fabricated" samples suggest that the kinetics of devitrification are rather rapid. It should also be noted that the degree of devitrification is small since these samples were submitted to XRD for a measure of homogeneity prior to these glasses being shipped to PNNL. As discussed in a previous section, the x-ray diffractometer has a detection limit of approximately 1.0 vol%. All XRD patterns were characterized by an "amorphous hump" indicating that the "as-fabricated" glasses were homogeneous at that detection limit.

The presence of crystals in the "as received" glass may have had an effect on T_L. Small sample sizes used for measurement and changes in chemical composition due to inhomogeneity in the glass, especially if areas of the glass had clusters of crystals used for sample measurement, can contribute to differences in T_L.

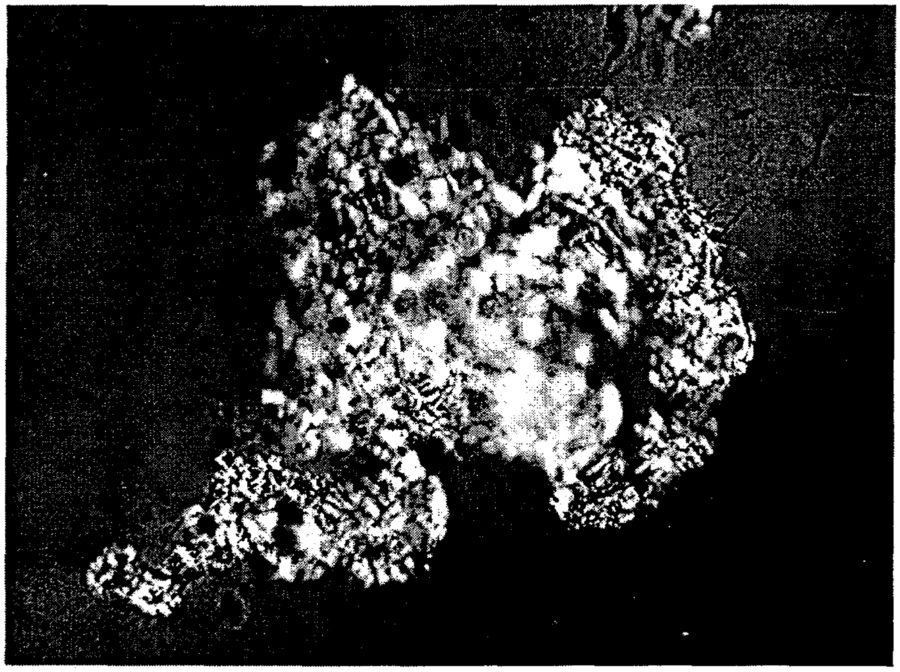


Figure 32. AC1-17 "As Received" Glass Showing Cluster of AlS Crystals.
(100x, polarized light)

Glasses AC1-22, -23 and -24 were received with inclusions. These glasses were 3 of the 5 Phase 1 glasses that were spiked with minor components (refer to Table IV). The inclusions were first noticed while examining samples of AC1-23 glass near T_L (Figure 33a and b). A sample was sent for SEM/EDS. The crystalline material that formed the inclusion was high in aluminum, chromium, and oxygen. There were also several crystals high in aluminum and oxygen and low in silicon. These inclusions were small (15-30 μm) and rounded; they probably formed during the initial chemical batch to melt reaction process and were slowly dissolving, indicative of the round shape of the inclusion.

Figure 33a – Inclusion in "As Received" AC1-23 (1156°C) Glass, SEM, 500x.

Figure 33b – Increased magnification of Figure 33a, 2000x.

DURABILITY

The extent of corrosion is usually defined as the amount of glass dissolved per unit volume of solution or the fraction of glass that has entered the solution per unit surface area. It is conveniently measured using a tracer, which is a glass component that does not participate at secondary reactions. Thus all the tracer released from glass is found in the solution. For borosilicate glasses, boron (B) is usually chosen because it is present in the glass in a sufficiently high concentration and is unlikely to precipitate or be absorbed from the solution.

The PCT (ASTM C-1285-94) [12] was conducted, in triplicate, for each of the Phase 1 glasses as a measure of durability (or resistance to aqueous corrosion). In addition, samples of EA glass, ARM-1 glass, and blanks were also included in this test. The solutions from these tests were submitted to the SRTC-ML for concentration measurements of B, Si, Na, Li, Al, and La. Along with the various solutions, a multi-element standard solution was run within each analytical block. Table C.1 in Appendix C shows the raw data obtained from the SRTC-ML corrected for the dilution factor (5/3) and blanks.

A typical expression for leachate concentrations is as normalized elemental losses released from the glass in grams of glass per liter of leachate (g/L). This value is computed by taking the elemental concentration (as ppm) in the PCT leachate and dividing it by the product of the cation concentration (as a mass percent) in the glass and 10.

However, it is the common logarithm of this normalized loss (NL) that is of primary interest in modeling glass durability. This value is computed by first taking the common logarithm of each available measurement (elemental concentrations in the leachate and cation concentrations in the glass), averaging the appropriate transformed values, and then subtracting one from the difference between the averages of the transformed leachate concentrations and the transformed cation concentrations.

Tables XXII and XXIII summarize the normalized releases (NL) and the common logarithm of the normalized release (log NL) for the Phase 1 glasses, respectively. Release rates of both the EA and ARM glass are also included. Note that Na was present only in the spiked glasses (AC1-22 – AC1-26) at very low target concentrations (refer to Tables IV and V). Propagating analytical errors associated with the PCT and chemical composition measurements causes the Na release values (based on "as-measured" values) to be extremely high.

Table XXII. Normalized Release (g/L) for the Phase 1 Glasses.

	Normalized Release Rate (g/L)					
Glass	B	Si	Na	Al	La	pH
ARM-1	0.559	0.313	0.594	0.000	0.000	10.21
EA	16.702	4.469	15.221	0.000	0.000	12.00
AC1-01	0.013	0.011	0.000	0.001	0.001	8.67
AC1-02	0.022	0.016	0.000	0.001	0.002	7.82
AC1-03	0.020	0.020	0.000	0.007	0.001	8.01
AC1-04	0.032	0.015	0.000	0.002	0.002	7.57
AC1-05	0.020	0.018	0.000	0.005	0.001	7.99
AC1-06	0.024	0.014	0.000	0.004	0.001	7.88
AC1-07	0.009	0.024	0.000	0.001	0.002	7.56
AC1-08	0.019	0.013	0.000	0.003	0.000	7.67
AC1-09	0.017	0.012	0.000	0.002	0.002	7.46
AC1-10	0.018	0.013	0.000	0.004	0.001	7.65
AC1-11	0.011	0.011	0.000	0.001	0.002	7.41
AC1-12	0.013	0.012	0.000	0.002	0.002	7.34
AC1-13	0.011	0.015	0.000	0.003	0.004	7.31
AC1-14	0.014	0.010	0.000	0.003	0.001	7.69
AC1-15	0.016	0.012	0.000	0.002	0.001	7.67
AC1-16	0.013	0.010	0.000	0.008	0.000	8.11
AC1-17	0.015	0.016	0.000	0.002	0.003	7.52
AC1-18	0.017	0.013	0.000	0.002	0.001	7.41
AC1-19	0.007	0.011	0.000	0.002	0.001	7.47
AC1-20	0.026	0.011	0.000	0.002	0.001	7.43
AC1-21	0.022	0.014	0.000	0.001	0.002	7.38
AC1-22	0.018	0.013	17.783	0.003	0.001	7.55
AC1-23	0.012	0.015	11.910	0.000	0.002	7.54
AC1-24	0.017	0.013	16.315	0.001	0.002	7.47
AC1-25	0.012	0.012	16.630	0.001	0.001	7.42
AC1-26	0.013	0.011	17.109	0.002	0.001	7.40
AC1-27	0.013	0.011	0.000	0.001	0.001	7.54
AC1-28	0.016	0.014	0.000	0.005	0.005	7.44
AC1-29	0.005	0.013	0.000	0.003	0.002	7.43
AC1-30	0.012	0.012	0.000	0.003	0.002	7.54
AC1-31	0.008	0.015	0.000	0.000	0.003	7.44
AC1-19B	0.041	0.022	0.000	0.012	0.001	7.91

Table XXIII. Common Logarithm of Normalized Release Rates (g/L).

	Log Normalized Release Rate (g/L)				
Glass	B	Si	Na	Al	La
ARM-1	-0.254	-0.505	-0.227	0.000	0.000
EA	1.222	0.650	1.182	0.000	0.000
AC1-01	-1.938	-1.978	0.000	-3.235	-2.826
AC1-02	-1.664	-1.787	0.000	-3.010	-2.737
AC1-03	-1.735	-1.725	0.000	-2.282	-3.207
AC1-04	-1.498	-1.831	0.000	-2.918	-2.761
AC1-05	-1.731	-1.764	0.000	-2.617	-2.958
AC1-06	-1.613	-1.864	0.000	-2.656	-3.117
AC1-07	-2.059	-1.638	0.000	-3.264	-2.779
AC1-08	-1.731	-1.878	0.000	-2.596	-3.371
AC1-09	-1.786	-1.913	0.000	-2.894	-2.787
AC1-10	-1.752	-1.883	0.000	-2.680	-3.117
AC1-11	-2.060	-1.954	0.000	-3.134	-2.797
AC1-12	-1.929	-1.923	0.000	-3.125	-2.773
AC1-13	-1.999	-1.831	0.000	-2.760	-2.533
AC1-14	-1.861	-2.009	0.000	-2.977	-3.208
AC1-15	-1.870	-1.929	0.000	-2.825	-3.097
AC1-16	-1.938	-1.990	0.000	-2.125	-3.334
AC1-17	-1.871	-1.807	0.000	-2.692	-2.588
AC1-18	-1.793	-1.890	0.000	-2.938	-2.963
AC1-19	-2.176	-1.967	0.000	-2.607	-2.993
AC1-20	-1.590	-1.960	0.000	-3.113	-2.941
AC1-21	-1.673	-1.867	0.000	-3.148	-2.757
AC1-22	-1.743	-1.870	1.207	-2.822	-2.953
AC1-23	-1.908	-1.835	1.076	-3.551	-2.797
AC1-24	-1.767	-1.876	1.184	-3.161	-2.762
AC1-25	-1.959	-1.908	1.189	-3.142	-2.864
AC1-26	-1.924	-1.958	1.197	-3.074	-2.953
AC1-27	-1.939	-1.962	0.000	-3.177	-2.835
AC1-28	-1.798	-1.874	0.000	-2.679	-2.453
AC1-29	-2.260	-1.892	0.000	-2.523	-2.612
AC1-30	-1.966	-1.924	0.000	-2.790	-2.816
AC1-31	-2.165	-1.829	0.000	-3.521	-2.604
AC1-19B	-1.395	-1.652	0.000	-1.910	-3.053

To define the AGCR, a comparison of the normalized release rates of various glass components for the Phase 1 glasses was made to those limits of the Environmental Assessment (EA) [13] (with the appropriate confidence limits applied) as shown in Table XXIV. Normalized boron release (NL [B]) was used as the key indicator of durability as previously described. The average NL [B] for the EA glass tested in this study was 16.702 g/L (shown in Table XXII) which is very consistent with the reported standard NL [B] release rate of 16.695 g/L (shown in Table XXIV).[13] This provides a high degree of confidence that the PCT was conducted appropriately.

Table XXIV. Leachate Concentrations (ppm), Normalized Release (g/L), and Log Normalized Release Rates (g/L) for the Environmental Assessment (EA) Glass.

	Leachate Concentrations [13]			
	B (ppm)	Li (ppm)	Na (ppm)	Si (ppm)
Mean	587	190	1662	893
Standard Deviation	43	14.5	112	86
	Normalized Release (NL) [13]			
	B (g/L)	Li (g/L)	Na (g/L)	Si (g/L)
Mean	16.695	9.565	13.346	3.922
Standard Deviation	1.222	0.735	0.902	0.376
	Log Normalized Release (log NL)			
	B (g/L)	Li (g/L)	Na (g/L)	Si (g/L)
	1.223	0.981	1.125	0.594

Exhibit C.2 in Appendix C provides a series of plots showing the log NL's of interest versus total lanthanide content. Various combinations of target and measured values are considered; that is, PCT normalized by target as well as measured compositions and each of these plotted versus both targeted and "as-measured" (total) lanthanide content in the glass. As indicated by these plots, there is a tendency for durability of the glass to increase (indicated by a downward slope in the plots of Exhibit C.2) as the lanthanide content in the glass increases (over the Phase 1 ECGR). The relationships that are statistically significant (at the 5% significance level) are provided in Table XXV.

Table XXV. PCT Results Showing a Statistically Significant Relationship With the Total Ln_2O_3 Content. (Significance Level at 5%)

Log[NL(B) g/L] (target)	Versus	Lanthanide (measured)
Log[NL(Si) g/L] (target)	Versus	Lanthanide (target)
Log[NL(Si) g/L] (target)	Versus	Lanthanide (measured)
Log[NL(B) g/L] (measured)	Versus	Lanthanide (target)
Log[NL(B) g/L] (measured)	Versus	Lanthanide (measured)
Log[NL(B) g/L] (bias-corrected)	Versus	Lanthanide (target)
Log[NL(B) g/L] (bias-corrected)	Versus	Lanthanide (measured)
Log[NL(Si) g/L] (measured)	Versus	Lanthanide (target)
Log[NL(Si) g/L] (measured)	Versus	Lanthanide (measured)

The durabilities of the duplicate glasses are contrasted in Exhibit C.3 of Appendix C. First, Log PCT plots determined using the target compositions of these glasses are presented then similar plots of these values determined using the measured compositions. Note that Na was present only in the spiked glasses and at very low target concentrations in these glasses. This accounts for the behavior displayed in the Na plots. The overall mean (over all duplicates) of the Log PCT for each element of interest is determined along with the "pooled" standard deviation. A great deal of variation is seen in each of these plots (even for those based on the target compositions) as evidenced by the large estimated standard deviation for the repeatability of each element's measurements.

Two other observations regarding Exhibit C.3 are worth noting. There is no obvious pattern to the behavior of the PCT's of the spiked glasses relative to the PCT's of their non-spiked replicates. The PCT's (for each element presented in this exhibit) appear to be relatively insensitive to the compositional variation introduced over these 5 sets of duplicate glasses. In most instances, all of the values in each plot fall within 2-sigma (where sigma is the "pooled" standard deviation) of their overall mean value.

Figures 34 and 35 summarize the results of the Phase 1 study of the ECGR for durability. They show the relationships among the boron durabilities (based on target and "as-measured" compositions) of the Phase 1 glasses, ARM-1, and EA. Clearly, the AGCR is not limited by durability based on the results from this Phase 1 study as compared to the EA glass limits for B. All Phase 1 glasses are roughly two orders of magnitude more durable (as defined by the PCT) than the EA glass.

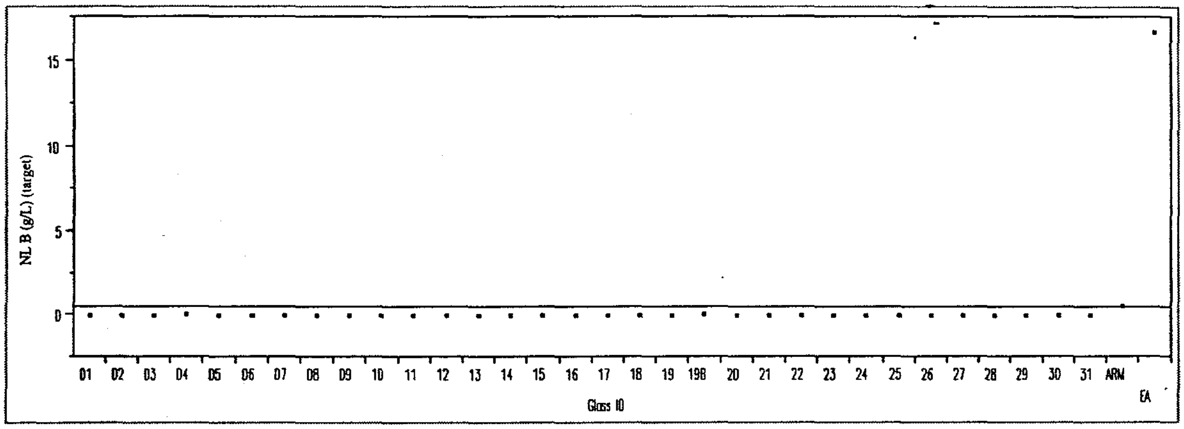


Figure 34. NL B (g/L) Based on Targeted Compositions By Glass ID.

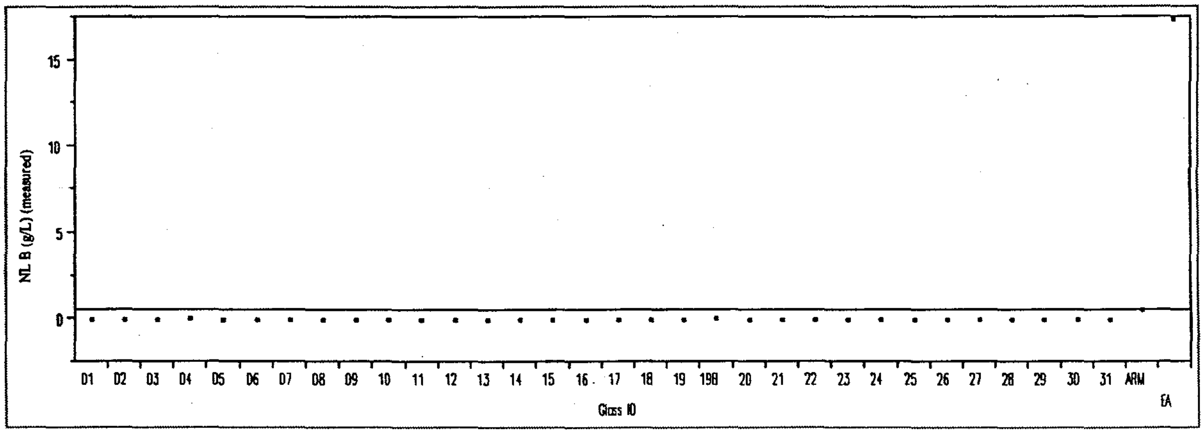


Figure 35. NL B (g/L) Based on "As-Measured" Compositions By Glass ID.

DEFINITION OF AGCR

Figure 36 identifies the Phase 1 AGCR based on targeted compositions. Glasses within the AGCR simultaneously meet all processing and performance constraints as defined for Phase 1. Glasses to the left of the AGCR (i.e., lower total lanthanide contents or loadings) do not meet either the viscosity constraint and/or the liquidus constraint. Glasses lying to the right of the AGCR fail the 1250°C liquidus constraint. Several other Phase 1 glasses have properties that meet all the specifications but due to a T_L of 1261°C for AC1-29, the AGCR cannot be extended to higher loadings. Although a compositional or operational window does exist based on targeted compositions, it is rather limited.

Figure 37 shows the same compositional ternary with the Phase 1 glasses identified by their "as-measured" compositions. A continuous overlap exists of glasses in which one or more of the property constraints are not met. Subsequently, an AGCR can not be defined based on "as-measured" compositions. The lack of an AGCR based on "as-measured" compositions is primarily a function of three potential issues: (1) measurement uncertainty associated with the chemical composition analysis in particular the sum of oxides, (2) potential chemical composition gradients within the subsamples, and (3) uncertainties associated with measuring the liquidus temperature that may be linked to issue #2.

However, if the liquidus temperature constraint were "relaxed" to at least 1300°C (i.e., accept glasses having a $T_L \leq 1300$°C) and uncertainties associated with the liquidus temperature measurements are ignored ($1\sigma = 24$°C), all Phase 1 glasses with feed loadings of at least 30 mass % would define the AGCR (see Figure 38). This would increase the operational window for the batch vitrification process relative to that shown in either Figure 36 or 37. An increase in the liquidus temperature constraint to at least 1300°C is logical since the CIM is typically operated at temperatures of ~1450°C.

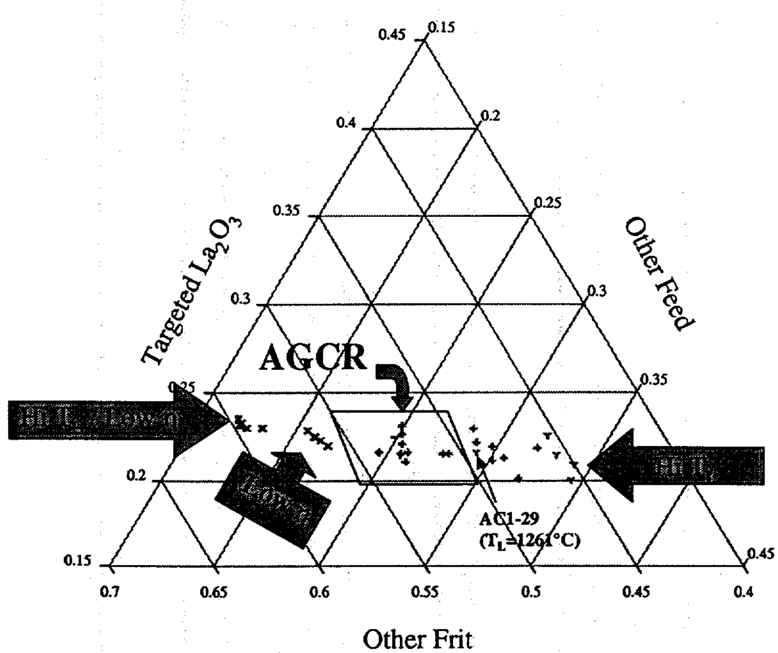


Figure 36. Definition of Phase 1 AGCR Based on Targeted Compositions.

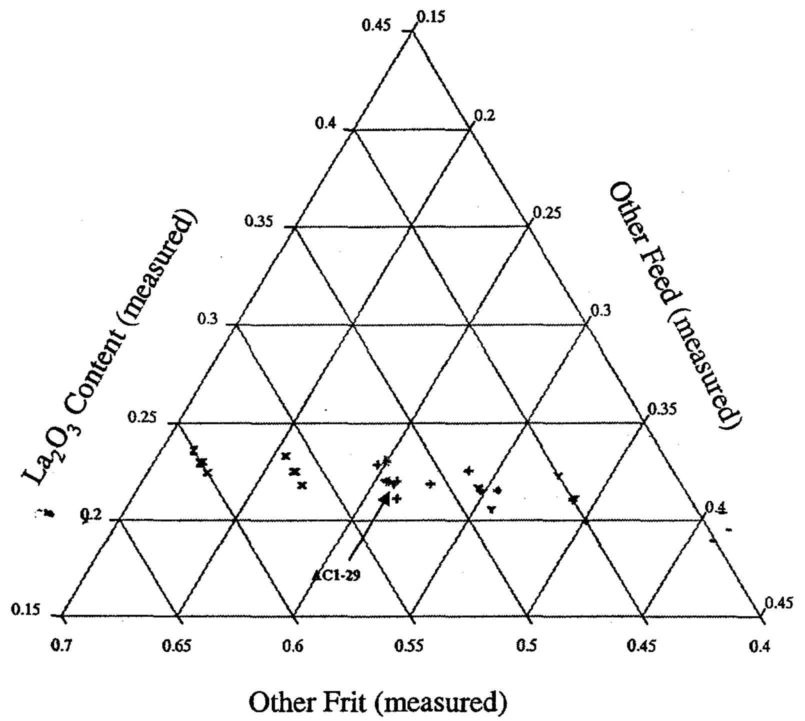


Figure 37. Undefined Phase 1 AGCR Using "As-Measured" Compositions.

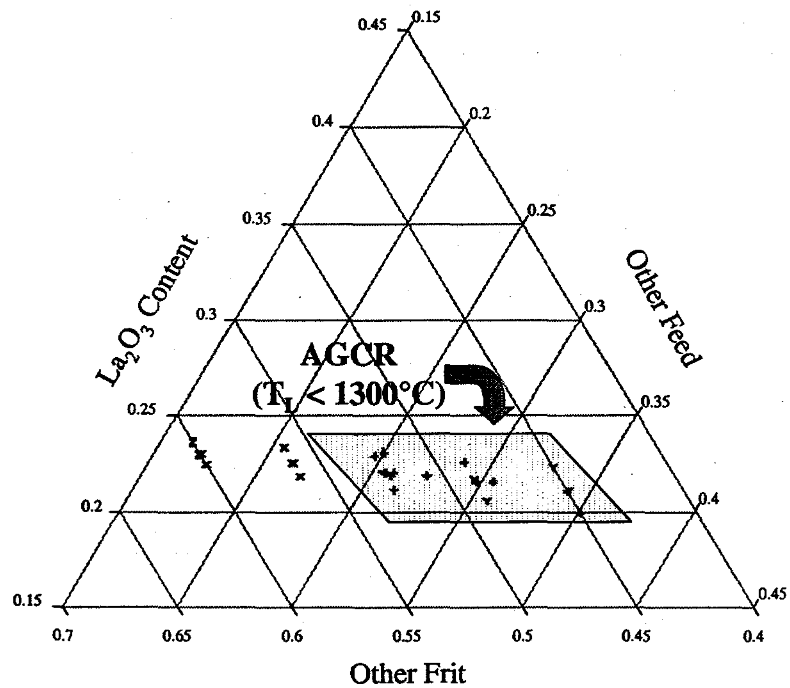


Figure 38. Definition of Phase 1 AGCR Given T_L Constraint Increase.

CONCLUSIONS

The objective of this research was to evaluate the effect of compositional uncertainties on the primary processing and product performance criteria for potential glasses to be processed in the MPPF. Given the feed composition (and its anticipated ± 20% variation), the composition of 25SrABS, and the target feed loading range of 20 to 40 mass % for the process, an experimental glass composition region (EGCR) for Phase 1 testing was defined. In this study, glasses were fabricated and both processing and product performance properties were measured as a function of glass composition. These properties were assessed against predefined constraints to define an acceptable glass composition region (AGCR) in which all property constraints were simultaneously satisfied.

As a result, an acceptable glass composition region (AGCR) has been identified in which glasses meet all processing and product performance criteria as currently defined. The operational window is rather small given the current processing and product performance criteria but can be expanded significantly by raising the liquidus temperature constraint. Given that the T_L constraint could safely be increased to 1300°C, the operational window or AGCR for the Phase 1 Variability study is only limited by glasses at a 20 – 25 mass% loading. Those glasses do not meet the viscosity specification as currently defined. In other words, all glasses with feed loadings of > 25 mass % would be acceptable from both a processing and product performance perspective within the limits that the study was developed. The risks of process upsets are minimized and the acceptance of the final glass product is increased.

The AGCR is not restricted by either product performance constraint evaluated: homogeneity and durability. All Phase 1 glasses defining the EGCR were "acceptable" based on the homogeneity criteria as defined by XRD. PCT results indicate that the Phase 1 EGCR produces glasses that are at least 2 orders of magnitude more durable than the Environmental Assessment (EA) glass based on normalized boron releases.

However, the Phase 1 AGCR is restricted by processing criteria (namely viscosity and liquidus). All Phase 1 glasses failing the current viscosity constraint (3 – 24 Poise at 1350°C) have viscosities greater than 24 Poise at 1350°C. The key indicator for complying with the viscosity specification is the total lanthanide content in the glass. For those glasses failing the viscosity constraint, total targeted lanthanide contents are ≤ 43.75 mass % (corresponding to ≤ 25 mass % feed loading). Based on "as-measured" Ln_2O_3 content, glasses containing at least 42 mass % total Ln_2O_3 meet the viscosity constraint. There are no glasses that fail the constraint on the low viscosity side (i.e., < 3 Poise).

The viscosity data indicate that feed loadings of at least 30 mass % should be targeted in the vitrification batch process. The fact that no glasses failed the viscosity constraint on the low side (i.e., < 3 Poise at 1350°C) provides the opportunity to increase waste loadings (or total lanthanide content) while maintaining adequate viscosity values (other properties not being considered or adjusted).

The AGCR is also restricted based on the 1250°C liquidus constraint. Two primary phases were observed in the EGCR: (1) a rare earth silicate (RES) phase and (2) an aluminosilicate (AlS) phase. A clear distinction between these two primary phase fields can be based on total lanthanide content alone. That is, at low total Ln_2O_3 (or low loadings) the primary phase is an AlS and as loadings increase (or total lanthanides increase) the primary phase transitions into the RES field. This transition occurs at approximately 45 mass % total Ln_2O_3 content (or roughly 25 – 30 mass % feed loading based on targeted compositions). When T_L's are plotted against the "as-measured" total Ln_2O_3 contents, an obvious trend does emerge. As the total lanthanide content increases from ~ 30 mass % up to ~ 43 mass %, a gradual decrease in T_L is observed. This trend continues within the AlS primary phase field until the RES primary phase field is encountered. In the RES phase field (> 43 mass % total Ln_2O_3 "as-measured"), as total Ln_2O_3 contents (or loadings) increase, T_L increases as well.

With respect to the 1250°C liquidus constraint, 7 of the 32 Phase 1 glasses fail this constraint. Unlike the viscosity constraint where only low loadings caused glasses to be "unacceptable", both high and low loaded glasses (i.e., in both primary phase fields) fail the Phase 1 T_L constraint. The total lanthanide content alone cannot be used as the key indicator. However, one can use the total lanthanide content within each primary phase field. Based on the data within the AIS primary phase field, one would lean toward eliminating the fabrication of 20 mass % loaded glasses based on the 1250°C constraint.

In the RES primary phase field, one would hope that glasses failing the 1250°C constraint would be a part of a single targeted loading (i.e., 40%). Unfortunately, this is not the case. Glasses deemed "unacceptable" within the RES primary phase field based on the current T_L criterion span feed loadings from 35 – 40 mass %. The exception is AC1-01 which has a measured total lanthanide content of 52.59 mass % which may explain the high T_L. If one were to utilize the fairly restrictive constraint (1250°C), a relatively large portion of the EGCR would be eliminated to define the AGCR. However, if the T_L constraint is increased to 1300°C (or greater), all Phase 1 glasses would pass and the AGCR would encompass the entire Phase 1 EGCR based solely on T_L (again ignoring uncertainties associated with the T_L measurement).

Given that the T_L constraint could safely be increased to 1300°C, the operational window or AGCR for the Phase 1 variability study would be expanded to include all glasses within the EGCR with feed loadings of > 25 mass %. In other words, all glasses with feed loadings of > 25% would be acceptable from both a processing and product performance perspective within the limits that the study was developed. The risks of process upsets are minimized and the acceptance of the final glass product is increased within the AGCR. Those glasses at lower loadings do not meet the viscosity specification as currently defined.

RECOMMENDATIONS FOR PHASE 2 DESIGN AND TESTING

The strategy proposed by Edwards [5] to evaluate the effect of compositional upsets on the primary processing and product performance properties is based on a "phased approach". That is, Phase 1 would be developed, executed, and the resulting data analyzed (as described in this document). The Phase 1 results would provide insight into the Phase 2 design and perhaps experimental implementation considerations and/or precautions to minimize negative impacts on data interpretation.

Based on the Phase 1 results discussed, several items are of interest to consider in the development of the Phase 2 EGCR. These items are listed below with a brief discussion:

(1) The Phase 1 EGCR was developed with the Am/Cm-1 glass (AC1-31) used essentially as a centroid in terms of loading. The Phase 1 loadings ranged from 20% - 40% and the results suggest that lower loadings should be avoided due to high viscosity values (insufficient total lanthanide content). Since the development of Phase 1, the baseline composition has shifted to higher loadings (47% feed loading; referred to as Am/Cm-1a). The new baseline composition is outside the Phase 1 EGCR. Therefore, in the development of the Phase 2 matrix, one should consider the new loading boundaries in light of the Phase 1 data. If higher loadings are considered, the liquidus temperature constraint must be "relaxed" (i.e., increased to at least 1300°C or 1350°C).

(2) The Phase 2 test matrix should provide some degree of overlap (in terms of loading) with the Phase 1 design. The upper loading of the Phase 2 design should be closely correlated with liquidus temperature requirements in conjunction with the upper nominal processing temperature of the CIM (allowing some temperature delta to overcome an "off-normal" event). Based on the Phase 1 data, predicted liquidus temperature as a function of loading should be considered when defining both the upper and lower total lanthanide content bounds for Phase 2.

(3) The expected variation of each feed component for the Phase 1 design (i.e., ±20% of its average) did not appear to be an issue for any of the processing or product performance properties within the design limitations. Given this knowledge, it is recommended that NMS&S expand the variation of each element in the Phase 2 design (i.e., ±30% or ±40% of the average). A layered design may be feasible where the layers could evaluate different variations although this would increase the number of glasses to be tested. This decision should be based on the expected uncertainties associated with the Tank 17.1 analysis and potential variations that pretreatment precipitations may have on the resulting feed stream.

(4) Minor components appear to have a minimal impact on the processing properties of interest and no effect on the product performance issue. If the quantity of the minor components in the feed stream is a function of the number of pretreatment steps (i.e., number of washes), allowing a higher percentage of "minor" components in the feed may be a consideration for the Phase 2 design. This may allow a reduction in both the pretreatment cycle time and costs.

(5) To minimize potential chemical composition gradients within each "as-fabricated" glass, the Phase 2 glasses should be fabricated, crushed, and remelted to ensure homogeneity. This will minimize the impacts of small compositional gradients for those properties which require a limited sample size.

(6) The Phase 1 testing program did evaluate liquidus temperatures over the anticipated range of processing. However, the T_L measurement does not provide an indication of the devitrification kinetics as a function of loading. This measurement is critical to reducing risks of plugging the drain tube during the vitrification thermal cycle given that a glass remains in the drain tube from the previous run. It is recommended that devitrification kinetics of various glasses (as a function of total lanthanide content) be evaluated through time-temperature-transformation (TTT) studies.

(7) Phase 2 could include specific compositions in the design (e.g., similar to AC1-27 – AC1-31 in Phase 1). These compositions should be chosen in such a manner to represent potential processing scenarios.

(8) Studies to address the reaction pathway or conversion of the oxalate/frit mixtures into a glass product are recommended. Such studies may provide insight into the chemical composition differences that have been observed in the laboratory melts as well as the CIM.

The issues listed and discussed above are for consideration as the Phase 2 work scope is being defined. These issues do not have to be fully addressed in a single study but may take the form of a multi-phased approach.

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Appendix A – Chemical Composition Data for the Phase 1 Glasses

Table A.1: Measured and Target Compositions (Lithium-metaborate Dissolution Method)

Block	Run Order	Glass ID	Glass #	Lab #	Lab ID	Al	Ca	Orig Ce	Cor Ce	Cr	Er	Eu	Orig Fe	Cor Fe	Gd	K	Orig La	Cor La	Mn	Na	Nd	Ni	Pr	Si	Orig Sm	Cor Sm	Sr
1-1	1	EA	0	0	elm111	2.03	0.796	<0.500	<0.500	<0.100	0.617	<0.010	6.04	6.04	<0.050	<0.150	0.396	0.396	0.993	12.2	<0.100	0.499	<0.100	21.6	<0.100	<0.100	0.017
1-1	2	AC1-10	10	28	w28-lm21	9.3	0.017	3.57	3.57	<0.100	3.39	0.475	0.037	0.037	1.1	<0.150	18.6	18.6	<0.010	<0.150	9.05	<0.020	3.04	10.5	1.98	1.98	1.74
1-1	3	AC1-19	19	30	w30-lm11	8.24	0.016	4.18	4.18	<0.100	4.18	0.583	0.036	0.036	1.35	<0.150	18.2	18.2	<0.010	<0.150	10.8	<0.020	3.87	9.68	2.17	2.17	1.52
1-1	4	AC1-17	17	22	w22-lm21	10.6	0.018	2.26	2.26	<0.100	2.16	0.32	0.043	0.043	0.759	<0.150	19.8	19.8	<0.010	<0.150	5.92	0.061	2.04	11.7	1.34	1.34	2.06
1-1	5	AC1-09	9	23	w23-lm11	9.56	0.018	2.74	2.74	<0.100	2.64	0.422	0.045	0.045	0.824	<0.150	18.5	18.5	<0.010	<0.150	9.92	0.037	3.4	10.8	1.69	1.69	1.75
1-1	6	AC1-20	20	20	w20-lm21	8.78	0.017	4.07	4.07	<0.100	3.98	0.57	0.037	0.037	1.26	<0.150	18.7	18.7	<0.010	<0.150	10.2	<0.020	3.61	9.62	1.82	1.82	1.61
1-1	7	AC1-18	18	31	w31-lm11	10.1	0.022	2.9	2.9	<0.100	2.6	0.375	0.039	0.039	0.869	<0.150	19.3	19.3	<0.010	<0.150	7.02	<0.020	2.6	11.2	1.56	1.56	1.79
1-1	8	AC1-09	9	23	w23-lm21	9.22	0.016	2.62	2.62	<0.100	2.46	0.411	0.035	0.035	0.806	<0.150	17.4	17.4	<0.010	<0.150	9.52	<0.020	3.27	10.3	1.68	1.68	1.68
1-1	9	AC1-08	8	24	w24-lm11	9.45	0.031	3.41	3.41	<0.100	3.9	0.415	0.042	0.042	1.32	<0.150	20.1	20.1	<0.010	<0.150	7.6	0.168	2.58	10.3	2.55	2.55	1.72
1-1	10	EA	0	0	elm112	2.04	0.803	<0.500	<0.500	<0.100	0.584	<0.010	5.95	5.95	<0.050	<0.150	0.387	0.387	0.978	12.2	<0.100	0.471	<0.100	20.8	<0.100	<0.100	0.017
1-1	11	AC1-20	20	20	w20-lm11	8.19	0.014	3.66	3.66	<0.100	3.54	0.515	0.047	0.047	1.16	<0.150	17.4	17.4	<0.010	<0.150	9.48	0.041	3.46	9.07	1.74	1.74	1.57
1-1	12	AC1-18	18	31	w31-lm21	9.34	0.016	2.66	2.66	<0.100	2.45	0.374	0.04	0.04	0.819	<0.150	18.1	18.1	<0.010	<0.150	6.8	0.188	2.42	11.4	1.44	1.44	1.72
1-1	13	AC1-17	17	22	w22-lm11	10.4	0.022	2.18	2.18	<0.100	2.04	0.296	0.044	0.044	0.692	<0.150	18.3	18.3	<0.010	0.356	5.78	<0.020	1.92	12	1.29	1.29	1.89
1-1	14	AC1-16	16	27	w27-lm21	8.5	0.016	3.37	3.37	<0.100	3.1	0.463	0.036	0.036	1.2	<0.150	17.2	17.2	<0.010	<0.150	8.69	0.067	3.05	9.69	2.65	2.65	1.64
1-1	15	AC1-16	16	27	w27-lm11	8.9	0.017	3.54	3.54	<0.100	3.34	0.476	0.03	0.03	1.23	<0.150	17.6	17.6	<0.010	<0.150	8.88	<0.020	3	9.93	2.78	2.78	1.66
1-1	16	AC1-19	19	30	w30-lm21	7.71	0.015	3.97	3.97	<0.100	3.77	0.558	0.032	0.032	1.27	<0.150	17.6	17.6	<0.010	<0.150	10.6	<0.020	3.82	8.88	2.09	2.09	1.47
1-1	17	AC1-08	8	24	w24-lm21	8.38	0.019	3.28	3.28	<0.100	3.46	0.373	0.038	0.038	1.21	<0.150	18.1	18.1	<0.010	0.245	7.01	0.048	2.35	9.71	2.24	2.24	1.58
1-1	18	AC1-10	10	28	w28-lm11	8.78	0.016	3.09	3.09	<0.100	2.95	0.413	0.035	0.035	0.949	<0.150	17.7	17.7	<0.010	<0.150	7.91	<0.020	2.75	9.91	1.82	1.82	1.6
1-1	19	EA	0	0	elm113	1.86	0.742	<0.500	<0.500	<0.100	0.549	<0.010	5.38	5.38	<0.050	<0.150	0.363	0.363	0.931	12.3	<0.100	0.453	<0.100	20	<0.100	<0.100	0.016
1-2	20	EA	0	0	elm121	2.02	0.777	<0.500	<0.500	<0.100	0.601	<0.010	5.96	5.96	<0.050	<0.150	0.362	0.362	0.932	12.4	<0.100	0.416	<0.100	20.4	<0.100	<0.100	<0.010
1-2	21	AC1-19	19	30	w30-lm22	8.14	<0.010	3.93	3.93	<0.100	4.08	0.59	0.047	0.047	1.32	<0.150	18.4	18.4	0.016	<0.150	9.83	0.03	3.72	9.83	1.77	1.77	1.51
1-2	22	AC1-17	17	22	w22-lm12	10.8	<0.010	2.06	2.06	<0.100	2.11	0.312	0.065	0.065	0.743	<0.150	19.8	19.8	0.016	<0.150	5.24	0.027	2.07	12.2	1.07	1.07	2.02
1-2	23	AC1-10	10	28	w28-lm12	9.2	<0.010	2.96	2.96	<0.100	3.12	0.442	0.053	0.053	1.05	<0.150	19.5	19.5	0.015	<0.150	7.55	0.22	2.98	11	1.64	1.64	1.71
1-2	24	AC1-17	17	22	w22-lm22	10.9	<0.010	1.98	1.98	<0.100	2.1	0.312	0.054	0.054	0.686	<0.150	19.8	19.8	0.016	<0.150	5.02	0.084	1.92	12.1	1.14	1.14	1.86
1-2	25	AC1-20	20	20	w20-lm12	8.71	<0.010	3.37	3.37	<0.100	3.54	0.519	0.061	0.061	1.18	<0.150	18.1	18.1	0.016	<0.150	8.69	0.061	3.4	9.95	1.44	1.44	1.56
1-2	26	AC1-08	8	24	w24-lm22	8.95	<0.010	3.01	3.01	<0.100	3.69	0.403	0.055	0.055	1.24	<0.150	18.9	18.9	0.016	0.281	6.07	0.071	2.43	11.1	2.17	2.17	1.67
1-2	27	AC1-09	9	23	w23-lm12	9	<0.010	2.5	2.5	<0.100	2.32	0.389	0.059	0.059	0.738	<0.150	17	17	0.016	<0.150	8.2	0.059	3.09	11	1.37	1.37	1.58
1-2	28	AC1-10	10	28	w28-lm22	8.72	<0.010	3.11	3.11	<0.100	3.02	0.453	0.051	0.051	1.02	<0.150	18.5	18.5	0.016	<0.150	7.21	0.028	2.78	10.8	1.55	1.55	1.56
1-2	29	EA	0	0	elm122	1.91	0.761	<0.500	<0.500	<0.100	0.575	<0.010	5.69	5.69	<0.050	<0.150	0.34	0.34	0.932	12	<0.100	0.435	<0.100	21.2	<0.100	<0.100	<0.010
1-2	30	AC1-08	8	24	w24-lm12	8.81	<0.010	3.02	3.02	<0.100	3.68	0.387	0.056	0.056	1.2	<0.150	18.7	18.7	0.016	<0.150	6.09	0.2	2.39	10.8	2.08	2.08	1.66
1-2	31	AC1-20	20	20	w20-lm22	8.17	<0.010	3.26	3.26	<0.100	3.49	0.498	0.054	0.054	1.11	<0.150	17.7	17.7	0.016	<0.150	8.52	0.039	3.28	10.2	1.34	1.34	1.51
1-2	32	AC1-18	18	31	w31-lm12	9.42	<0.010	2.34	2.34	<0.100	2.38	0.359	0.055	0.055	0.8	<0.150	18.2	18.2	0.017	<0.150	5.9	0.026	2.34	11.5	1.27	1.27	1.69
1-2	33	AC1-16	16	27	w27-lm12	8.5	<0.010	2.89	2.89	<0.100	3.14	0.446	0.049	0.049	1.16	<0.150	17.6	17.6	0.016	<0.150	7.63	0.024	2.94	10.1	2.38	2.38	1.59
1-2	34	AC1-09	9	23	w23-lm22	8.89	<0.010	2.3	2.3	<0.100	2.22	0.386	0.049	0.049	0.762	<0.150	17.6	17.6	0.016	<0.150	7.64	0.023	3.16	11.2	1.33	1.33	1.62
1-2	35	AC1-18	18	31	w31-lm22	9.47	<0.010	2.81	2.81	<0.100	2.41	0.363	0.057	0.057	0.797	<0.150	17.9	17.9	0.017	<0.150	6.89	0.213	2.35	11.7	1.21	1.21	1.67
1-2	36	AC1-16	16	27	w27-lm22	8.69	<0.010	3.53	3.53	<0.100	3.09	0.462	0.055	0.055	1.18	<0.150	17.3	17.3	0.016	<0.150	8.6	0.084	2.94	10.1	2.3	2.3	1.57
1-2	37	AC1-19	19	30	w30-lm12	7.82	<0.010	4.39	4.39	<0.100	3.67	0.549	0.051	0.051	1.24	<0.150	17.8	17.8	0.016	<0.150	10.5	0.029	3.59	9.12	1.77	1.77	1.42
1-2	38	EA	0	0	elm123	1.86	0.731	<0.500	<0.500	<0.100	0.562	<0.010	6	6	<0.050	<0.150	0.328	0.328	0.933	12	<0.100	0.441	<0.100	21.6	<0.100	<0.100	<0.010
2-1	39	EA	0	0	elm211	2.02	0.833	<0.500	<0.500	<0.100	0.636	<0.010	6.27	6.27	<0.050	<0.150	0.367	0.367	0.946	12	<0.100	0.441	<0.100	22	<0.100	<0.100	0.016
2-1	40	AC1-06	6	25	w25-lm11	10.2	0.043	2.27	2.27	<0.100	2.72	0.386	<0.010	<0.010	1.05	<0.150	18.1	18.1	<0.010	<0.150	5.86	<0.020	2.91	11.3	2.02	2.02	1.84
2-1	41	AC1-28	28	32	w32-lm11	8.15	0.041	3.16	3.16	<0.100	3.29	1.14	<0.010	<0.010	0.556	<0.150	18	18	0.021	0.168	8.24	<0.020	3.13	10.1	2.42	2.42	1.57
2-1	42	AC1-06	6	25	w25-lm21	9.01	0.042	2.15	2.15	<0.100	2.45	0.357	<0.010	<0.010	1.02	<0.150	17.8	17.8	<0.010	<0.150	5.32	<0.020	2.62	10.9	1.97	1.97	1.74
2-1	43	AC1-30	30	14	w14-lm11	8.33	0.041	4.07	4.07	<0.100	3.95	1.38	<0.010	<0.010	0.567	<0.150	18.1	18.1	0.028	0.155	9.4	<0.020	3.73	10.1	1.8	1.8	1.58
2-1	44	AC1-28	28	32	w32-lm21	8.26	0.041	3.24	3.24	<0.100	3.26	1.17	<0.010	<0.010	0.528	<0.150	16.7	16.7	0.022	<0.150	8.13	<0.020	3.08	9.44	2.35	2.35	1.54
2-1	45	AC1-30	30	14	w14-lm21	7.85	0.038	3.82	3.82	<0.100	3.68	1.28	<0.010	<0.010	0.556	<0.150	17.5	17.5	0.024	<0.150	9.1	<0.020	3.57	9.28	1.75	1.75	1.45
2-1	46	AC1-25	25	17	w17-lm21	8.66	0.044	3.87	3.87	<0.100	3.59	0.502	<0.010	<0.010	1.21	<0.150	16.8	16.8	0.027	<0.150	9.84	<0.020	3.42	9.72	2.38	2.38	1.63
2-1	47	AC1-02	2	29	w29-lm11	10.6	0.043	2.52	2.52	<0.100	2.69	0.339	<0.010	<0.010	0.63	<0.150	20.2	20.2	<0.010	<0.150	4.23	<0.020	2.45	12.8	1.28	1.28	1.87
2-1	48	EA	0	0	elm212	2.01	0.796	<0.500	<0.500	<0.100	0.596	<0.010	<0.010	6.34	<0.050	<0.150	0.378	0.378	0.9	11.9	<0.100	<0.020	<0.100	21.2	<0.100	<0.100	0.017
2-1	49	AC1-29	29	21	w21-lm21	8.83	0.041	4.07	4.07	<0.100	3.54	1.3	<0.010	<0.010	0.525	<0.150	17.8	17.8	0.027	0.176	9.69	<0.020	3.87	10.4	1.88	1.88	1.75
2-1	50	AC1-29	29	21	w21-lm11	9.13	0.05	4.1	4.1	<0.100	3.9	1.35	<0.010	<0.010	0.574	<0.150	19.2	19.2	0.029	0.151	9.51	<0.020	3.83	10.6	1.95	1.95	1.69
2-1	51	AC1-24	24	18	w18-lm11	9.03	0.044	3.24	3.24	<0.100	3.11	0.46	<0.010	<0.010	1.01	<0.150	18.5	18.5	0.026	<0.150	8.51	<0.020	3.23	10.7	2	2	1.68
2-1	52	AC1-25	25	17	w17-lm11	7.9	0.046	3.6	3.6	<0.100	3.37	0.511	<0.010	<0.010	1.21	<0.150	16.9	16.9	0.024	0.187	9.03	0.023	3.26	9.44	2.26	2.26	1.53

Orig - original values; Cor - Corrected (shaded) Values; < implies less than the indicated detection limit. Concentrations are expressed as weight percents.

Table A.1: Measured and Target Compositions (Lithium-metaborate Dissolution Method)

Block	Run Order	Glass ID	Glass #	Lab #	Lab ID	Al	Ca	Orig Ce	Cor Ce	Cr	Er	Eu	Orig Fe	Cor Fe	Gd	K	Orig La	Cor La	Mn	Na	Nd	Ni	Pr	Si	Orig Sm	Cor Sm	Sr
2-1	53	AC1-24	24	18	w18-lm21	8.37	0.04	2.81	2.81	<0.100	2.88	0.395	<0.010	<0.010	0.947	<0.150	15.5	15.5	0.023	<0.150	7.32	0.044	2.8	9.97	1.8	1.8	1.52
2-1	54	AC1-01	1	26	w26-lm11	7.68	0.04	3.94	3.94	<0.100	4.2	0.586	<0.010	<0.010	1.45	<0.150	16.8	16.8	<0.010	0.196	10.6	<0.020	3.99	9.45	3.11	3.11	1.39
2-1	55	AC1-02	2	29	w29-lm21	10.4	0.041	2.74	2.74	<0.100	2.67	0.348	<0.010	<0.010	0.636	<0.150	20.5	20.5	<0.010	<0.150	4.38	<0.020	2.51	12.1	1.29	1.29	1.96
2-1	56	AC1-01	1	26	w26-lm21	7.8	0.043	3.91	3.91	<0.100	4.32	0.568	<0.010	<0.010	1.46	<0.150	17.2	17.2	<0.010	0.18	10.6	0.067	4.06	9.24	3.2	3.2	1.44
2-1	57	EA	0	0	elm213	1.92	0.73	<0.500	<0.500	<0.100	0.594	<0.010	6.23	6.23	<0.050	<0.150	0.377	0.377	0.905	11.6	<0.100	0.423	<0.100	21	<0.100	<0.100	0.016
2-2	58	EA	0	0	elm221	2	0.783	<0.500	<0.500	<0.100	0.587	<0.010	5.82	5.82	<0.050	<0.150	0.372	0.372	0.991	12.3	<0.100	0.504	<0.100	22	<0.100	<0.100	<0.010
2-2	59	AC1-30	30	14	w14-lm22	8.12	<0.010	3.84	3.84	<0.100	3.5	1.27	0.041	0.041	0.526	<0.150	18.3	18.3	0.017	0.151	9.55	0.03	3.43	9.8	1.58	1.58	1.52
2-2	60	AC1-01	1	26	w26-lm22	7.61	<0.010	3.81	3.81	<0.100	4.01	0.566	0.038	0.038	1.41	<0.150	17.2	17.2	<0.010	0.161	11	0.093	3.68	9.14	3.03	3.03	1.35
2-2	61	AC1-29	29	21	w21-lm12	8.33	0.021	3.9	3.9	<0.100	3.66	1.26	0.051	0.051	0.561	<0.150	17.9	17.9	0.019	<0.150	9.53	0.02	3.43	10.5	1.77	1.77	1.58
2-2	62	AC1-01	1	26	w26-lm12	7.67	<0.010	4.01	4.01	<0.100	4.08	0.597	0.037	0.037	1.45	<0.150	17.5	17.5	<0.010	0.195	10.9	0.028	4	9.67	3.1	3.1	1.41
2-2	63	AC1-02	2	29	w29-lm22	9.97	0.01	2.61	2.61	<0.100	2.38	0.315	0.042	0.042	0.621	<0.150	19.8	19.8	<0.010	<0.150	4.47	0.03	2.28	12.9	1.18	1.18	1.98
2-2	64	AC1-30	30	14	w14-lm12	8.24	<0.010	3.81	3.81	<0.100	3.76	1.28	0.049	0.049	0.55	<0.150	18.2	18.2	0.021	<0.150	9.77	0.025	3.49	10.5	1.71	1.71	1.51
2-2	65	AC1-29	29	21	w21-lm22	8.27	<0.010	3.76	3.76	<0.100	3.65	1.26	0.048	0.048	0.525	<0.150	18.2	18.2	0.021	0.173	9.25	0.022	3.54	10.7	1.78	1.78	1.53
2-2	66	AC1-24	24	18	w18-lm22	8.76	<0.010	3.14	3.14	<0.100	3.05	0.426	0.047	0.047	0.987	<0.150	17.7	17.7	0.019	<0.150	8.58	0.084	2.8	10.7	1.9	1.9	1.62
2-2	67	EA	0	0	elm222	1.94	0.775	<0.500	<0.500	<0.100	0.59	<0.010	6.15	6.15	<0.050	<0.150	0.366	0.366	1.03	12.4	<0.100	0.515	<0.100	21.4	<0.100	<0.100	<0.010
2-2	68	AC1-28	28	32	w32-lm12	8.76	<0.010	3.3	3.3	<0.100	3.14	1.15	0.045	0.045	0.541	<0.150	17.7	17.7	0.014	0.187	8.9	0.026	3.11	10.2	2.41	2.41	1.56
2-2	69	AC1-02	2	29	w29-lm12	9.52	<0.010	2.4	2.4	<0.100	2.32	0.298	0.039	0.039	0.571	<0.150	18	18	<0.010	<0.150	4.27	0.029	2.12	12.5	1.08	1.08	1.82
2-2	70	AC1-24	24	18	w18-lm12	8.45	<0.010	2.98	2.98	<0.100	2.88	0.412	0.047	0.047	0.946	<0.150	17.2	17.2	0.017	<0.150	7.78	0.036	2.68	10.7	1.78	1.78	1.5
2-2	71	AC1-06	6	25	w25-lm12	9.21	0.01	2.07	2.07	<0.100	2.42	0.361	0.041	0.041	0.945	<0.150	18.7	18.7	<0.010	<0.150	5.51	0.053	2.64	11.1	1.87	1.87	1.66
2-2	72	AC1-28	28	32	w32-lm22	8.37	<0.010	3.28	3.28	<0.100	3.04	1.07	0.043	0.043	0.527	<0.150	1.64	16.4	0.013	<0.150	8.43	0.028	2.92	9.86	2.34	2.34	1.5
2-2	73	AC1-06	6	25	w25-lm22	9.78	0.012	2.24	2.24	<0.100	2.6	0.363	0.04	0.04	1.03	<0.150	19	19	<0.010	<0.150	5.61	0.024	2.61	11.5	1.97	1.97	1.76
2-2	74	AC1-25	25	17	w17-lm12	8.33	0.019	3.69	3.69	<0.100	3.7	0.532	0.054	0.054	1.28	<0.150	18	18	0.021	0.166	9.53	0.064	3.52	10.3	2.46	2.46	1.6
2-2	75	AC1-25	25	17	w17-lm22	8.6	0.011	3.74	3.74	<0.100	3.59	0.536	0.053	0.053	1.3	<0.150	18.4	18.4	0.022	<0.150	10.6	<0.020	3.56	10.7	2.5	2.5	1.56
2-2	76	EA	0	0	elm223	2	0.798	<0.500	<0.500	<0.100	0.644	<0.010	6.86	6.86	<0.050	<0.150	0.404	0.404	1.13	11.8	<0.100	0.581	<0.100	24.6	<0.100	<0.100	<0.010
3-1	77	EA	0	0	elm311	1.91	0.742	<0.500	<0.500	<0.100	0.574	<0.010	5.86	5.86	<0.050	<0.150	0.419	0.419	0.968	12.2	<0.100	0.424	<0.100	20.1	<0.100	<0.100	<0.010
3-1	78	AC1-13	13	12	w12-lm21	7.85	0.011	3.34	3.34	<0.100	3.36	0.517	0.027	0.027	1.29	<0.150	16.8	16.8	0.01	<0.150	8.4	0.025	3.17	9.3	3.3	3.3	1.49
3-1	79	AC1-12	12	15	w15-lm11	8.14	<0.010	3.8	3.8	<0.100	3.66	0.513	0.018	0.018	1.24	<0.150	18.4	18.4	<0.010	<0.150	6.69	0.029	3.7	9.1	1.32	1.32	1.41
3-1	80	AC1-15	15	19	w19-lm21	7.54	<0.010	4.83	4.83	<0.100	3.75	0.498	0.028	0.028	1.22	<0.150	17.4	17.4	<0.010	<0.150	9.69	0.034	3.21	8.83	1.44	1.44	1.34
3-1	81	AC1-22	22	7	w07-lm11	9.9	0.011	2.13	2.13	<0.100	1.93	0.283	0.03	0.03	0.659	<0.150	18.3	18.3	0.04	<0.150	5.28	0.034	2.01	11.2	0.989	0.989	1.77
3-1	82	AC1-12	12	15	w15-lm21	8.05	0.011	4.1	4.1	<0.100	3.89	0.538	0.03	0.03	1.25	<0.150	17.9	17.9	<0.010	<0.150	7.1	0.1	3.89	9.18	1.42	1.42	1.46
3-1	83	AC1-22	22	7	w07-lm21	9.75	0.021	2.18	2.18	<0.100	2.08	0.289	0.036	0.036	0.67	<0.150	18.6	18.6	0.041	<0.150	5.62	0.03	2.01	11.4	1.03	1.03	1.79
3-1	84	AC1-21	21	2	w02-lm11	8.69	<0.010	3.26	3.26	<0.100	3.03	0.42	0.021	0.021	1.07	<0.150	16.7	16.7	<0.010	0.16	7.36	0.034	2.98	9.89	16.7	1.74	1.54
3-1	85	AC1-23	23	9	w09-lm11	9.35	0.013	<0.500	2.41	<0.100	2.61	0.349	0.029	0.029	0.844	<0.150	17.8	17.8	0.044	<0.150	6.42	0.026	2.32	10.7	1.52	1.52	1.64
3-1	86	EA	0	0	elm 312	1.95	0.77	<0.500	<0.500	<0.100	0.559	<0.010	6.07	6.07	<0.050	<0.150	0.38	0.38	1.04	13.7	<0.100	0.459	<0.100	20.9	<0.100	<0.100	<0.010
3-1	87	AC1-14	14	16	w16-lm11	8.02	<0.010	3.35	3.35	<0.100	3.19	0.445	0.024	0.024	1.44	<0.150	16.1	16.1	<0.010	<0.150	10.8	0.059	3.1	9.37	2.63	2.63	1.41
3-1	88	AC1-15	15	19	w19-lm11	7.8	<0.010	4.84	4.84	<0.100	3.8	0.506	0.02	0.02	1.27	<0.150	18.1	18.1	<0.010	<0.150	10.1	0.032	3.21	8.59	1.46	1.46	1.3
3-1	89	AC1-11	11	3	w03-lm21	7.91	0.01	3.25	3.25	<0.100	3.38	0.493	0.025	0.025	1.53	<0.150	15.9	15.9	<0.010	<0.150	11.9	0.06	3.9	8.94	2.46	2.46	1.28
3-1	90	AC1-21	21	2	w02-lm21	8.64	<0.010	3.22	3.22	<0.100	3.2	0.44	0.023	0.023	1.05	<0.150	17.6	17.6	<0.010	<0.150	7.33	0.042	2.89	10.2	1.8	1.8	1.51
3-1	91	AC1-23	23	9	w09-lm21	9.66	0.012	2.74	2.74	<0.100	2.43	0.352	0.027	0.027	0.865	<0.150	17.8	17.8	0.045	<0.150	6.51	0.028	2.32	11.4	1.47	1.47	1.72
3-1	92	AC1-13	13	12	w12-lm11	7.69	<0.010	3.46	3.46	<0.100	3.28	0.474	0.026	0.026	1.24	<0.150	16.6	16.6	<0.010	<0.150	8.45	0.072	3.07	9.33	3.13	3.13	1.37
3-1	93	AC1-11	11	3	w03-lm11	7.13	0.01	3.21	3.21	<0.100	3.37	0.457	0.018	0.018	1.53	<0.150	16	16	<0.010	<0.150	11.6	0.025	3.73	8.82	2.33	2.33	1.28
3-1	94	AC1-14	14	16	w16-lm21	8.09	0.01	3.35	3.35	<0.100	3.14	0.446	0.021	0.021	1.4	<0.150	16.3	16.3	<0.010	<0.150	10.6	0.025	2.9	9.56	2.59	2.59	1.32
3-1	95	EA	0	0	elm313	1.88	0.746	<0.500	<0.500	<0.100	0.577	<0.010	6.29	6.29	<0.050	<0.150	0.364	0.364	1.02	12.4	<0.100	0.465	<0.100	20.7	<0.100	<0.100	<0.010
3-2	96	EA	0	0	elm321	2.02	0.83	<0.500	<0.500	<0.100	0.619	<0.010	6.36	6.36	<0.050	<0.150	0.379	0.379	1.05	12.9	<0.100	0.435	<0.100	22.6	<0.100	<0.100	0.017
3-2	97	AC1-13	13	12	w12-lm22	8.64	0.025	3.52	3.52	<0.100	3.8	0.577	0.01	0.01	1.39	<0.150	18.1	18.1	<0.010	<0.150	9.82	<0.020	3.56	10.3	3.99	3.99	1.56
3-2	98	AC1-12	12	15	w15-lm12	8.41	0.02	4.21	4.21	<0.100	4.09	0.578	<0.010	<0.010	1.41	<0.150	18.9	18.9	<0.010	<0.150	7.48	<0.020	4.08	10	1.55	1.55	1.57
3-2	99	AC1-11	11	3	w03-lm12	7.74	0.022	3.48	3.48	<0.100	3.81	0.537	<0.010	<0.010	1.85	<0.150	17.2	17.2	<0.010	<0.150	13.5	<0.020	4.46	9.52	2.78	2.78	1.53
3-2	100	AC1-14	14	16	w16-lm22	8.29	0.025	3.57	3.57	<0.100	3.48	0.514	<0.010	<0.010	1.65	<0.150	17.8	17.8	<0.010	<0.150	12.8	<0.020	3.39	10.3	3.12	3.12	1.64
3-2	101	AC1-14	14	16	w16-lm12	7.95	0.02	3.33	3.33	<0.100	3.28	0.444	<0.010	<0.010	1.5	<0.150	16.1	16.1	<0.010	<0.150	11.8	0.033	3.14	9.41	2.91	2.91	1.58
3-2	102	AC1-23	23	9	w09-lm12	10.1	0.029	2.83	2.83	<0.100	2.74	0.413	0.015	0.015	0.961	<0.150	19.6	19.6	0.03	<0.150	7.61	<0.020	2.65	12.1	1.72	1.72	1.89
3-2	103	AC1-15	15	19	w19-lm12	7.71	0.021	4.75	4.75	<0.100	4.4	0.56	<0.010	<0.010	1.45	<0.150	18.6	18.6	<0.010	<0.150	11.2	<0.020	3.56	9.7	1.67	1.67	1.49
3-2	104	AC1-21	21	2	w02-lm22	8.69	0.02	3.39	3.39	<0.100	3.19	0.458	<0.010	<0.010	1.13	<0.150	17.4	17.4	<0.010	0.151	8.02	<0.020	3.01	10.3	1.92	1.92	1.65

Orig - original values; Cor - Corrected (shaded) Values;   < implies less than the indicated detection limit   Concentrations are expressed as weight percents.

Block	Run Order	Glass ID	Glass #	Lab #	Lab ID	Al	Ca	Orig Ce	Cor Ce	Cr	Er	Eu	Orig Fe	Cor Fe	Gd	K	Orig La	Cor La	Mn	Na	Nd	Ni	Pr	Si	Orig Sm	Cor Sm	Sr
3-2	105	EA	0	0	elm322	1.95	0.767	<0.500	<0.500	<0.100	0.584	<0.010	6.58	6.58	<0.050	<0.150	0.366	0.366	1.03	13.5	<0.100	0.431	<0.100	22.3	<0.100	<0.100	0.017
3-2	106	AC1-13	13	12	w12-lm12	7.85	0.019	3.5	3.5	<0.100	3.43	0.526	<0.010	<0.010	1.39	<0.150	17	17	<0.010	<0.150	9.17	0.038	3.22	9.74	3.56	3.56	1.48
3-2	107	AC1-11	11	3	w03-lm22	7.45	0.021	3.23	3.23	<0.100	3.63	0.536	<0.010	<0.010	1.7	<0.150	16.3	16.3	<0.010	<0.150	12.8	0.03	4.12	9.37	2.68	2.68	1.41
3-2	108	AC1-12	12	15	w15-lm22	8.23	0.022	4.21	4.21	<0.100	4.09	0.564	<0.010	<0.010	1.38	<0.150	18.4	18.4	<0.010	<0.150	7.55	0.08	4.05	9.73	1.53	1.53	1.59
3-2	109	AC1-23	23	9	w09-lm22	9.54	0.025	2.65	2.65	<0.100	2.65	0.377	<0.010	<0.010	0.905	<0.150	18.7	18.7	0.026	<0.150	7.15	<0.020	2.46	11.6	1.64	1.64	1.83
3-2	110	AC1-22	22	7	w07-lm22	10.3	0.035	2.25	2.25	<0.100	2.21	0.307	0.011	0.011	0.705	<0.150	19.1	19.1	0.026	0.172	6.06	<0.020	2.11	12.4	1.13	1.13	1.86
3-2	111	AC1-15	15	19	w19-lm22	7.99	0.023	4.71	4.71	<0.100	4.25	0.567	<0.010	<0.010	1.44	<0.150	19.7	19.7	<0.010	<0.150	11.1	<0.020	3.39	9.58	1.68	1.68	1.5
3-2	112	AC1-22	22	7	w07-lm12	9.73	0.023	2.05	2.05	<0.100	2.09	0.307	<0.010	<0.010	0.686	<0.150	18.6	18.6	0.024	<0.150	5.69	<0.020	1.93	12	1.06	1.06	1.87
3-2	113	AC1-21	21	2	w02-lm12	8.44	0.022	3.23	3.23	<0.100	3.13	0.462	<0.010	<0.010	1.13	<0.150	17.6	17.6	<0.010	0.259	8.12	<0.020	2.91	10.5	1.9	1.9	1.64
3-2	114	EA	0	0	elm323											<0.150				12.6							
4-1	115	EA	0	0	elm411	1.91	0.698	<0.500	<0.500	<0.100	0.657	<0.010	5.28	5.28	<0.050	<0.150	0.679	0.679	0.918	11.8	<0.100	0.385	<0.100	19.4	<0.100	<0.100	0.011
4-1	116	ARM	100	10	w10-lm21	2.82	1.58	1.06	1.06	<0.100	2.96	0.017	0.032	0.032	0.173	<0.150	0.105	0.105	<0.010	7.03	4.54	0.027	0.182	19.9	<0.100	<0.100	0.367
4-1	117	AC1-07	7	8	w08-lm21	9.42	0.012	2.65	2.65	<0.100	2.71	0.373	0.037	0.037	1	<0.150	18.3	18.3	<0.010	<0.150	6.95	0.022	2.42	11.2	1.41	1.41	1.9
4-1	118	AC1-26	26	5	w05-lm11	6.94	0.014	4.12	4.12	<0.100	4.17	0.573	0.046	0.046	1.41	<0.150	17.2	17.2	0.02	<0.150	10.4	<0.020	3.46	8.77	2.04	2.04	1.46
4-1	119	AC1-31	31	1	w01-lm11	8	<0.010	3.28	3.28	<0.100	3.23	1.02	0.046	0.046	0.608	<0.150	16.8	16.8	<0.010	0.225	7.04	0.05	2.61	9.61	0.836	0.836	1.6
4-1	120	AC1-27	27	11	w11-lm21	7.82	0.012	3.35	3.35	<0.100	3.17	1	0.038	0.038	0.572	<0.150	16.4	16.4	0.01	<0.150	7.38	<0.020	2.69	9.57	1.67	1.67	1.55
4-1	121	AC1-03	3	13	w13-lm11	8.42	<0.010	2.53	2.53	<0.100	2.59	0.293	0.037	0.037	0.676	<0.150	16.7	16.7	<0.010	0.155	4.74	<0.020	2	10.2	0.957	0.957	1.84
4-1	122	AC1-05	5	6	w06-lm11	8.49	<0.010	3.13	3.13	<0.100	2.84	0.338	0.036	0.036	0.93	<0.150	16.3	16.3	<0.010	<0.150	7.3	<0.020	1.87	10.5	0.949	0.949	1.83
4-1	123	AC1-04	4	4	w04-lm11	9.13	0.01	2.07	2.07	<0.100	1.96	0.274	0.048	0.048	0.813	<0.150	18	18	<0.010	<0.150	5.46	0.22	1.77	11.3	1.17	1.17	1.88
4-1	124	EA	0	0	elm412	1.89	0.716	<0.500	<0.500	<0.100	0.668	<0.010	5.4	5.4	<0.050	<0.150	0.739	0.739	0.961	11.2	<0.100	0.417	<0.100	19.5	<0.100	<0.100	0.01
4-1	125	ARM	100	10	w10-lm11	3.2	1.78	1.14	1.14	<0.100	3.05	0.016	0.034	0.034	0.203	<0.150	0.088	0.088	<0.010	6.85	4.96	<0.020	0.211	22.7	<0.100	<0.100	0.422
4-1	126	AC1-07	7	8	w08-lm11	9.96	0.013	2.62	2.62	<0.100	2.61	0.413	0.043	0.043	1.09	<0.150	19.3	19.3	<0.010	<0.150	7.67	0.031	2.52	12.1	1.56	1.56	2.1
4-1	127	AC1-04	4	4	w04-lm21	10.1	0.014	2.14	2.14	<0.100	2.02	0.311	0.04	0.04	0.873	<0.150	19.1	19.1	<0.010	0.188	5.85	<0.020	1.97	11.9	1.38	1.38	2.04
4-1	128	AC1-03	3	13	w13-lm21	9.54	0.014	2.53	2.53	<0.100	2.62	0.341	0.049	0.049	0.763	<0.150	19.3	19.3	<0.010	<0.150	5.38	0.045	2.34	12.6	0.829	0.829	2.02
4-1	129	AC1-05	5	6	w06-lm21	9.08	0.011	3.14	3.14	<0.100	2.81	0.37	0.034	0.034	0.958	<0.150	17.5	17.5	<0.010	<0.150	7.36	<0.020	2.01	10.6	0.933	0.933	1.83
4-1	130	AC1-31	31	1	w01-lm21	8.27	0.01	3.36	3.36	<0.100	3.21	1.02	0.042	0.042	0.642	<0.150	17.6	17.6	0.011	<0.150	7.88	<0.020	2.81	10.2	0.78	0.78	1.67
4-1	131	AC1-27	27	11	w11-lm11	8.19	0.011	3.34	3.34	<0.100	3.09	1.08	0.038	0.038	0.622	<0.150	17.8	17.8	0.013	<0.150	7.83	<0.020	2.82	10.1	1.6	1.6	1.69
4-1	132	AC1-26	26	5	w05-lm21	7.02	0.015	4	4	<0.100	4.14	0.541	0.047	0.047	1.45	<0.150	16.2	16.2	0.019	<0.150	10.5	0.024	3.44	8.64	2.12	2.12	1.44
4-1	133	EA	0	0	elm413	2.04	0.739	<0.500	<0.500	<0.100	0.652	<0.010	5.38	5.38	<0.050	<0.150	0.749	0.749	0.964	11.4	0.246	0.411	<0.100	20.4	<0.100	<0.100	0.014
4-2	134	EA	0	0	elm421	2.03	0.765	<0.500	<0.500	<0.100	0.632	<0.010	5.91	5.91	<0.050	<0.150	0.736	0.736	0.959	12.3	0.206	0.405	<0.100	21	<0.050	<0.050	0.036
4-2	135	AC1-26	26	5	w05-lm22	7.44	<0.010	4.31	4.31	<0.100	4.03	0.551	0.04	0.04	1.31	<0.150	17.5	17.5	0.018	0.153	10.1	<0.020	3.85	8.82	1.89	1.89	1.42
4-2	136	AC1-05	5	6	w06-lm22	9.55	<0.010	3.15	3.15	<0.100	2.76	0.356	0.024	0.024	0.828	<0.150	17.9	17.9	<0.010	<0.150	7.34	<0.020	2.13	10.7	0.952	0.952	1.94
4-2	137	AC1-31	31	1	w01-lm22	8.7	<0.010	3.32	3.32	<0.100	3.07	1.07	0.014	0.014	0.501	<0.150	18.1	18.1	0.011	<0.150	7.52	<0.020	2.92	9.99	1.35	1.35	1.72
4-2	138	ARM	100	10	w10-lm12	3.02	1.66	1.19	1.19	<0.100	3.04	<0.010	0.02	0.02	<0.050	<0.150	0.076	0.076	<0.010	7.4	4.34	<0.020	0.124	20.4	<0.050	<0.050	0.398
4-2	139	AC1-04	4	4	w04-lm12	9.84	<0.010	2.08	2.08	<0.100	2.05	0.269	0.035	0.035	0.668	<0.150	19.2	19.2	<0.010	0.16	5.22	0.226	1.76	11.4	0.605	0.605	1.99
4-2	140	AC1-03	3	13	w13-lm22	10.1	<0.010	2.62	2.62	<0.100	2.58	0.32	0.035	0.035	0.586	<0.150	19.3	19.3	<0.010	0.319	5.21	<0.020	2.25	12	1	1	1.99
4-2	141	AC1-04	4	4	w04-lm22	10.1	<0.010	2.1	2.1	<0.100	2.14	0.286	0.023	0.023	0.669	<0.150	18.6	18.6	<0.010	0.168	5.28	<0.020	1.84	11.8	0.654	0.654	1.99
4-2	142	AC1-27	27	11	w11-lm22	8.76	<0.010	3.46	3.46	<0.100	3.14	1.11	<0.010	<0.010	0.482	<0.150	18.1	18.1	0.012	<0.150	7.86	<0.020	2.72	11.2	0.894	0.894	1.62
4-2	143	EA	0	0	elm422	2.13	0.757	<0.500	<0.500	<0.100	0.662	<0.010	5.29	5.29	<0.050	<0.150	0.75	0.75	0.993	12.4	0.22	0.438	<0.100	21.5	<0.050	<0.050	0.039
4-2	144	AC1-31	31	1	w01-lm12	8.54	<0.010	3.17	3.17	<0.100	3.04	1.01	0.033	0.033	0.454	<0.150	18.3	18.3	0.01	<0.150	7.35	0.046	2.73	10.3	1.26	1.26	1.65
4-2	145	AC1-03	3	13	w13-lm12	9.25	<0.010	2.37	2.37	<0.100	2.4	0.298	0.031	0.031	0.545	<0.150	18	18	<0.010	<0.150	5.02	<0.020	2.2	11	0.944	0.944	1.92
4-2	146	AC1-07	7	8	w08-lm12	9.46	<0.010	2.5	2.5	<0.100	2.52	0.355	0.029	0.029	0.744	<0.150	18.4	18.4	<0.010	<0.150	7	<0.020	2.2	11.7	1.43	1.43	1.83
4-2	147	AC1-27	27	11	w11-lm12	8.44	<0.010	3.11	3.11	<0.100	3.23	1.02	0.028	0.028	0.432	<0.150	17.5	17.5	0.012	<0.150	7.42	<0.020	2.66	10.5	1.59	1.59	1.55
4-2	148	ARM	100	10	w10-lm22	2.87	1.5	1.01	1.01	<0.100	2.92	<0.010	0.021	0.021	<0.050	<0.150	0.104	0.104	<0.010	7.23	4.13	<0.020	0.118	20.1	0.081	0.081	0.371
4-2	149	AC1-05	5	6	w06-lm12	9.35	<0.010	2.94	2.94	<0.100	2.62	0.34	0.021	0.021	0.769	<0.150	17.8	17.8	<0.010	<0.150	6.89	<0.020	1.88	10.7	0.922	0.922	1.81
4-2	150	AC1-26	26	5	w05-lm12	7.42	<0.010	3.89	3.89	<0.100	3.8	0.522	0.029	0.029	1.19	<0.150	16.3	16.3	0.018	<0.150	9.72	<0.020	3.65	8.62	1.81	1.81	1.36
4-2	151	AC1-07	7	8	w08-lm22	9.3	<0.010	2.56	2.56	<0.100	2.46	0.341	0.025	0.025	0.787	<0.150	18	18	<0.010	<0.150	6.37	<0.020	2.23	10.7	1.24	1.24	1.79
4-2	152	EA	0	0	elm 423	2.03	0.733	<0.500	<0.500	<0.100	0.595	<0.010	5.2	5.2	<0.050	<0.150	0.735	0.735	0.957	11.2	0.173	0.403	<0.100	20.1	<0.050	<0.050	0.035

Table A.1: Measured and Target Compositions (Lithium-metaborate Dissolution Method)

The oxide values were computed using the corrected cation concentations.

Block	Run Order	Glass ID	Glass #	Lab #	Lab ID	Al2O3	CaO	Ce2O3	Cr2O3	Er2O3	Eu2O3	Fe2O3	Gd2O3	K2O	La2O3	MnO	Na2O	Nd2O3	NiO	Pr2O3	SiO2	Sm2O3	SrO
1-1	1	EA	0	0	elm111	3.836	1.114	0.293	0.073	0.706	0.006	8.635388	0.029	0.09	0.464	2.897	16.446	0.058	0.635	0.059	46.209	0.058	0.02
1-1	2	AC1-10	10	28	w28-lm21	17.572	0.024	4.182	0.073	3.876	0.55	0.052899	1.268	0.09	21.814	0.015	0.101	10.556	0.013	3.558	22.463	2.296	2.058
1-1	3	AC1-19	19	30	w30-lm11	15.569	0.022	4.896	0.073	4.78	0.675	0.051469	1.556	0.09	21.345	0.015	0.101	12.597	0.013	4.529	20.708	2.516	1.798
1-1	4	AC1-17	17	22	w22-lm21	20.029	0.025	2.647	0.073	2.47	0.371	0.061477	0.875	0.09	23.221	0.015	0.101	6.905	0.078	2.387	25.03	1.554	2.436
1-1	5	AC1-09	9	23	w23-lm11	18.064	0.025	3.209	0.073	3.019	0.489	0.064336	0.95	0.09	21.697	0.015	0.101	11.571	0.047	3.979	23.104	1.96	2.07
1-1	6	AC1-20	20	20	w20-lm21	16.59	0.024	4.767	0.073	4.551	0.66	0.052899	1.452	0.09	21.931	0.015	0.101	11.897	0.013	4.225	20.58	2.11	1.904
1-1	7	AC1-18	18	31	w31-lm11	19.084	0.031	3.397	0.073	2.973	0.434	0.055758	1.002	0.09	22.635	0.015	0.101	8.188	0.013	3.043	23.96	1.809	2.117
1-1	8	AC1-09	9	23	w23-lm21	17.421	0.022	3.069	0.073	2.813	0.476	0.05004	0.929	0.09	20.407	0.015	0.101	11.104	0.013	3.827	22.035	1.948	1.987
1-1	9	AC1-08	8	24	w24-lm11	17.856	0.043	3.994	0.073	4.46	0.481	0.060047	1.521	0.09	23.573	0.015	0.101	8.865	0.214	3.019	22.035	2.957	2.034
1-1	10	EA	0	0	elm112	3.855	1.124	0.293	0.073	0.668	0.006	8.506715	0.029	0.09	0.454	2.854	16.446	0.058	0.599	0.059	44.497	0.058	0.02
1-1	11	AC1-20	20	20	w20-lm11	15.475	0.02	4.287	0.073	4.048	0.596	0.067196	1.337	0.09	20.407	0.015	0.101	11.057	0.052	4.049	19.403	2.018	1.857
1-1	12	AC1-18	18	31	w31-lm21	17.648	0.022	3.116	0.073	2.802	0.433	0.057188	0.944	0.09	21.228	0.015	0.101	7.932	0.239	2.832	24.388	1.67	2.034
1-1	13	AC1-17	17	22	w22-lm11	19.651	0.031	2.553	0.073	2.333	0.343	0.062907	0.798	0.09	21.462	0.015	0.48	6.742	0.013	2.247	25.672	1.496	2.235
1-1	14	AC1-16	16	27	w27-lm21	16.061	0.022	3.947	0.073	3.545	0.536	0.051469	1.383	0.09	20.172	0.015	0.101	10.136	0.085	3.569	20.73	3.073	1.939
1-1	15	AC1-16	16	27	w27-lm11	16.817	0.024	4.146	0.073	3.819	0.551	0.042891	1.418	0.09	20.641	0.015	0.101	10.358	0.013	3.511	21.243	3.224	1.963
1-1	16	AC1-19	19	30	w30-lm21	14.568	0.021	4.65	0.073	4.311	0.646	0.04575	1.464	0.09	20.641	0.015	0.101	12.364	0.013	4.471	18.997	2.424	1.738
1-1	17	AC1-08	8	24	w24-lm21	15.834	0.027	3.842	0.073	3.957	0.432	0.054329	1.395	0.09	21.228	0.015	0.33	8.176	0.061	2.75	20.773	2.598	1.869
1-1	18	AC1-10	10	28	w28-lm11	16.59	0.022	3.619	0.073	3.373	0.478	0.05004	1.094	0.09	20.759	0.015	0.101	9.226	0.013	3.218	21.2	2.11	1.892
1-1	19	EA	0	0	elm113	3.514	1.038	0.293	0.073	0.628	0.006	7.691786	0.029	0.09	0.426	2.716	16.58	0.058	0.576	0.059	42.786	0.058	0.019
1-2	20	EA	0	0	elm121	3.817	1.087	0.293	0.073	0.687	0.006	8.521012	0.029	0.09	0.425	2.719	16.715	0.058	0.529	0.059	43.642	0.058	0.006
1-2	21	AC1-19	19	30	w30-lm22	15.381	0.007	4.603	0.073	4.665	0.683	0.067196	1.521	0.09	21.58	0.047	0.101	11.466	0.038	4.354	21.029	2.052	1.786
1-2	22	AC1-17	17	22	w22-lm12	20.407	0.007	2.413	0.073	2.413	0.361	0.09293	0.856	0.09	23.221	0.047	0.101	6.112	0.034	2.423	26.099	1.241	2.389
1-2	23	AC1-10	10	28	w28-lm12	17.383	0.007	3.467	0.073	3.568	0.512	0.075774	1.21	0.09	22.87	0.044	0.101	8.806	0.28	3.487	23.532	1.902	2.022
1-2	24	AC1-17	17	22	w22-lm22	20.596	0.007	2.319	0.073	2.401	0.361	0.077204	0.791	0.09	23.221	0.047	0.101	5.855	0.107	2.247	25.886	1.322	2.2
1-2	25	AC1-20	20	20	w20-lm12	16.458	0.007	3.947	0.073	4.048	0.601	0.087212	1.36	0.09	21.228	0.047	0.101	10.136	0.078	3.979	21.286	1.67	1.845
1-2	26	AC1-08	8	24	w24-lm22	16.911	0.007	3.526	0.073	4.22	0.467	0.078633	1.429	0.09	22.166	0.047	0.379	7.08	0.09	2.844	23.746	2.516	1.975
1-2	27	AC1-09	9	23	w23-lm12	17.005	0.007	2.928	0.073	2.653	0.45	0.084352	0.851	0.09	19.938	0.047	0.101	9.564	0.075	3.616	23.532	1.589	1.869
1-2	28	AC1-10	10	28	w28-lm22	16.476	0.007	3.643	0.073	3.453	0.525	0.072915	1.176	0.09	21.697	0.047	0.101	8.41	0.036	3.253	23.104	1.797	1.845
1-2	29	EA	0	0	elm122	3.609	1.065	0.293	0.073	0.658	0.006	8.134993	0.029	0.09	0.399	2.719	16.176	0.058	0.554	0.059	45.353	0.058	0.006
1-2	30	AC1-08	8	24	w24-lm12	16.646	0.007	3.537	0.073	4.208	0.448	0.080063	1.383	0.09	21.931	0.047	0.101	7.103	0.255	2.797	23.104	2.412	1.963
1-2	31	AC1-20	20	20	w20-lm22	15.437	0.007	3.818	0.073	3.991	0.577	0.077204	1.279	0.09	20.759	0.047	0.101	9.938	0.05	3.839	21.821	1.554	1.786
1-2	32	AC1-18	18	31	w31-lm12	17.799	0.007	2.741	0.073	2.722	0.416	0.078633	0.922	0.09	21.345	0.05	0.101	6.882	0.033	2.739	24.602	1.473	1.999
1-2	33	AC1-16	16	27	w27-lm12	16.061	0.007	3.385	0.073	3.591	0.516	0.070055	1.337	0.09	20.641	0.047	0.101	8.9	0.031	3.441	21.607	2.76	1.88
1-2	34	AC1-09	9	23	w23-lm22	16.798	0.007	2.694	0.073	2.539	0.447	0.070055	0.878	0.09	20.641	0.047	0.101	8.911	0.029	3.698	23.96	1.542	1.916
1-2	35	AC1-18	18	31	w31-lm22	17.894	0.007	3.291	0.073	2.756	0.42	0.081493	0.919	0.09	20.993	0.05	0.101	8.036	0.271	2.75	25.03	1.403	1.975
1-2	36	AC1-16	16	27	w27-lm22	16.42	0.007	4.135	0.073	3.533	0.535	0.078633	1.36	0.09	20.289	0.047	0.101	10.031	0.107	3.441	21.607	2.667	1.857
1-2	37	AC1-19	19	30	w30-lm12	14.776	0.007	5.142	0.073	4.197	0.636	0.072915	1.429	0.09	20.876	0.047	0.101	12.247	0.037	4.201	19.51	2.052	1.679
1-2	38	EA	0	0	elm123	3.514	1.023	0.293	0.073	0.643	0.006	8.5782	0.029	0.09	0.385	2.722	16.176	0.058	0.561	0.059	46.209	0.058	0.006
2-1	39	EA	0	0	elm211	3.817	1.166	0.293	0.073	0.727	0.006	8.964219	0.029	0.09	0.43	2.76	16.176	0.058	0.561	0.059	47.065	0.058	0.019
2-1	40	AC1-06	6	25	w25-lm11	19.273	0.06	2.659	0.073	3.11	0.447	0.007149	1.21	0.09	21.228	0.015	0.101	6.835	0.013	3.406	24.174	2.342	2.176
2-1	41	AC1-28	28	32	w32-lm11	15.399	0.057	3.701	0.073	3.762	1.32	0.007149	0.641	0.09	21.11	0.061	0.226	9.611	0.013	3.663	21.607	2.806	1.857
2-1	42	AC1-06	6	25	w25-lm21	17.024	0.059	2.518	0.073	2.802	0.413	0.007149	1.176	0.09	20.876	0.015	0.101	6.205	0.013	3.066	23.318	2.284	2.058
2-1	43	AC1-30	30	14	w14-lm11	15.74	0.057	4.767	0.073	4.517	1.598	0.007149	0.654	0.09	21.228	0.082	0.209	10.964	0.013	4.365	21.607	2.087	1.869
2-1	44	AC1-28	28	32	w32-lm21	15.607	0.057	3.795	0.073	3.728	1.355	0.007149	0.609	0.09	19.586	0.064	0.101	9.483	0.013	3.605	20.195	2.725	1.821
2-1	45	AC1-30	30	14	w14-lm21	14.833	0.053	4.474	0.073	4.208	1.482	0.007149	0.641	0.09	20.524	0.07	0.101	10.614	0.013	4.178	19.853	2.029	1.715
2-1	46	AC1-25	25	17	w17-lm21	16.363	0.062	4.533	0.073	4.105	0.581	0.007149	1.395	0.09	19.703	0.079	0.101	11.477	0.013	4.002	20.794	2.76	1.928
2-1	47	AC1-02	2	29	w29-lm11	20.029	0.06	2.952	0.073	3.076	0.393	0.007149	0.726	0.09	23.691	0.015	0.101	4.934	0.013	2.867	27.383	1.484	2.211
2-1	48	EA	0	0	elm212	3.798	1.114	0.293	0.073	0.682	0.006	9.064298	0.029	0.09	0.443	2.626	16.041	0.058	0.013	0.059	45.353	0.058	0.02
2-1	49	AC1-29	29	21	w21-lm21	16.684	0.057	4.767	0.073	4.048	1.505	0.007149	0.605	0.09	20.876	0.079	0.237	11.302	0.013	4.529	22.249	2.18	2.07
2-1	50	AC1-29	29	21	w21-lm11	17.251	0.07	4.802	0.073	4.46	1.563	0.007149	0.662	0.09	22.518	0.085	0.204	11.092	0.013	4.482	22.677	2.261	1.999
2-1	51	AC1-24	24	18	w18-lm11	17.062	0.062	3.795	0.073	3.556	0.533	0.007149	1.164	0.09	21.697	0.076	0.101	9.926	0.013	3.78	22.891	2.319	1.987
2-1	52	AC1-25	25	17	w17-lm11	14.927	0.064	4.217	0.073	3.854	0.592	0.007149	1.395	0.09	19.82	0.07	0.252	10.533	0.029	3.815	20.195	2.621	1.809

Table A.1: Measured and Target Compositions (Lithium-metaborate Dissolution Method)

The oxide values were computed using the corrected cation concentations.

Block	Run Order	Glass ID	Glass #	Lab #	Lab ID	Al2O3	CaO	Ce2O3	Cr2O3	Er2O3	Eu2O3	Fe2O3	Gd2O3	K2O	La2O3	MnO	Na2O	Nd2O3	NiO	Pr2O3	SiO2	Sm2O3	SrO
2-1	53	AC1-24	24	18	w18-lm21	15.815	0.056	3.291	0.073	3.293	0.457	0.007149	1.092	0.09	18.178	0.067	0.101	8.538	0.056	3.277	21.329	2.087	1.798
2-1	54	AC1-01	1	26	w26-lm11	14.511	0.056	4.615	0.073	4.803	0.679	0.007149	1.671	0.09	19.703	0.015	0.264	12.364	0.013	4.669	20.216	3.606	1.644
2-1	55	AC1-02	2	29	w29-lm21	19.651	0.057	3.209	0.073	3.053	0.403	0.007149	0.733	0.09	24.042	0.015	0.101	5.109	0.013	2.937	25.886	1.496	2.318
2-1	56	AC1-01	1	26	w26-lm21	14.738	0.06	4.58	0.073	4.94	0.658	0.007149	1.683	0.09	20.172	0.015	0.243	12.364	0.085	4.751	19.767	3.711	1.703
2-1	57	EA	0	0	elm213	3.628	1.021	0.293	0.073	0.679	0.006	8.907031	0.029	0.09	0.442	2.641	15.637	0.058	0.538	0.059	44.925	0.058	0.019
2-2	58	EA	0	0	elm221	3.779	1.096	0.293	0.073	0.671	0.006	8.320854	0.029	0.09	0.436	2.892	16.58	0.058	0.641	0.059	47.065	0.058	0.006
2-2	59	AC1-30	30	14	w14-lm22	15.343	0.007	4.498	0.073	4.002	1.471	0.058618	0.606	0.09	21.462	0.05	0.204	11.139	0.038	4.014	20.965	1.832	1.798
2-2	60	AC1-01	1	26	w26-lm22	14.379	0.007	4.463	0.073	4.585	0.655	0.054329	1.625	0.09	20.172	0.015	0.217	12.83	0.118	4.307	19.553	3.514	1.597
2-2	61	AC1-29	29	21	w21-lm12	15.74	0.029	4.568	0.073	4.185	1.459	0.072915	0.647	0.09	20.993	0.055	0.101	11.116	0.025	4.014	22.463	2.052	1.869
2-2	62	AC1-01	1	26	w26-lm12	14.492	0.007	4.697	0.073	4.665	0.691	0.052899	1.671	0.09	20.524	0.015	0.263	12.714	0.036	4.681	20.687	3.595	1.667
2-2	63	AC1-02	2	29	w29-lm22	18.838	0.014	3.057	0.073	2.722	0.365	0.060047	0.716	0.09	23.221	0.015	0.101	5.214	0.038	2.668	27.597	1.368	2.342
2-2	64	AC1-30	30	14	w14-lm12	15.569	0.007	4.463	0.073	4.3	1.482	0.070055	0.634	0.09	21.345	0.061	0.101	11.396	0.032	4.084	22.463	1.983	1.786
2-2	65	AC1-29	29	21	w21-lm22	15.626	0.007	4.404	0.073	4.174	1.459	0.068626	0.605	0.09	21.345	0.061	0.233	10.789	0.028	4.143	22.891	2.064	1.809
2-2	66	AC1-24	24	18	w18-lm22	16.552	0.007	3.678	0.073	3.488	0.493	0.067196	1.138	0.09	20.759	0.055	0.101	10.008	0.107	3.277	22.891	2.203	1.916
2-2	67	EA	0	0	elm222	3.666	1.084	0.293	0.073	0.675	0.006	8.792655	0.029	0.09	0.429	3.005	16.715	0.058	0.655	0.059	45.781	0.058	0.006
2-2	68	AC1-28	28	32	w32-lm12	16.552	0.007	3.865	0.073	3.591	1.332	0.064336	0.624	0.09	20.759	0.041	0.252	10.381	0.033	3.64	21.821	2.795	1.845
2-2	69	AC1-02	2	29	w29-lm12	17.988	0.007	2.811	0.073	2.653	0.345	0.055758	0.658	0.09	21.11	0.015	0.101	4.981	0.037	2.481	26.741	1.252	2.152
2-2	70	AC1-24	24	18	w18-lm12	15.966	0.007	3.49	0.073	3.293	0.477	0.067196	1.09	0.09	20.172	0.05	0.101	9.075	0.046	3.136	22.891	2.064	1.774
2-2	71	AC1-06	6	25	w25-lm12	17.402	0.014	2.425	0.073	2.767	0.418	0.058618	1.089	0.09	21.931	0.015	0.101	6.427	0.067	3.09	23.746	2.168	1.963
2-2	72	AC1-28	28	32	w32-lm22	15.815	0.007	3.842	0.073	3.476	1.239	0.061477	0.607	0.09	19.234	0.038	0.101	9.833	0.036	3.417	21.093	2.713	1.774
2-2	73	AC1-06	6	25	w25-lm22	18.479	0.017	2.624	0.073	2.973	0.42	0.057188	1.187	0.09	22.283	0.015	0.101	6.544	0.031	3.054	24.602	2.284	2.081
2-2	74	AC1-25	25	17	w17-lm12	15.74	0.027	4.322	0.073	4.231	0.616	0.077204	1.475	0.09	21.11	0.061	0.224	11.116	0.081	4.119	22.035	2.853	1.892
2-2	75	AC1-25	25	17	w17-lm22	16.25	0.015	4.381	0.073	4.105	0.621	0.075774	1.498	0.09	21.58	0.064	0.101	12.364	0.013	4.166	22.891	2.899	1.845
2-2	76	EA	0	0	elm223	3.779	1.117	0.293	0.073	0.736	0.006	9.807742	0.029	0.09	0.474	3.297	15.906	0.058	0.739	0.059	52.627	0.058	0.006
3-1	77	EA	0	0	elm311	3.609	1.038	0.293	0.073	0.656	0.006	8.378042	0.029	0.09	0.491	2.824	16.446	0.058	0.54	0.059	43	0.058	0.006
3-1	78	AC1-13	13	12	w12-lm21	14.833	0.015	3.912	0.073	3.842	0.599	0.038602	1.487	0.09	19.703	0.029	0.101	9.798	0.032	3.71	19.895	3.827	1.762
3-1	79	AC1-12	12	15	w15-lm11	15.381	0.007	4.451	0.073	4.185	0.594	0.025735	1.429	0.09	21.58	0.015	0.101	7.803	0.037	4.33	19.468	1.531	1.667
3-1	80	AC1-15	15	19	w19-lm21	14.247	0.007	5.657	0.073	4.288	0.577	0.040032	1.406	0.09	20.407	0.015	0.101	11.302	0.043	3.757	18.89	1.67	1.585
3-1	81	AC1-22	22	7	w07-lm11	18.706	0.015	2.495	0.073	2.207	0.328	0.042891	0.76	0.09	21.462	0.117	0.101	6.159	0.043	2.352	23.96	1.147	2.093
3-1	82	AC1-12	12	15	w15-lm21	15.21	0.015	4.802	0.073	4.448	0.623	0.042891	1.441	0.09	20.993	0.015	0.101	8.281	0.127	4.552	19.639	1.647	1.727
3-1	83	AC1-22	22	7	w07-lm21	18.423	0.029	2.553	0.073	2.378	0.335	0.051469	0.772	0.09	21.814	0.12	0.101	6.555	0.038	2.352	24.388	1.194	2.117
3-1	84	AC1-21	21	2	w02-lm11	16.42	0.007	3.818	0.073	3.465	0.486	0.030024	1.233	0.09	19.586	0.015	0.216	8.585	0.043	3.487	21.158	2.018	1.821
3-1	85	AC1-23	23	9	w09-lm11	17.667	0.018	2.823	0.073	2.985	0.404	0.041461	0.973	0.09	20.876	0.128	0.101	7.488	0.033	2.715	22.891	1.763	1.939
3-1	86	EA	0	0	elm 312	3.685	1.077	0.293	0.073	0.639	0.006	8.678279	0.029	0.09	0.446	3.035	18.468	0.058	0.584	0.059	44.711	0.058	0.006
3-1	87	AC1-14	14	16	w16-lm11	15.154	0.007	3.924	0.073	3.648	0.515	0.034313	1.66	0.09	18.882	0.015	0.101	12.597	0.075	3.628	20.045	3.05	1.667
3-1	88	AC1-15	15	19	w19-lm11	14.738	0.007	5.669	0.073	4.345	0.586	0.028594	1.464	0.09	21.228	0.015	0.101	11.781	0.041	3.757	18.377	1.693	1.537
3-1	89	AC1-11	11	3	w03-lm21	14.946	0.014	3.807	0.073	3.865	0.571	0.035743	1.763	0.09	18.648	0.015	0.101	13.88	0.076	4.564	19.125	2.853	1.514
3-1	90	AC1-21	21	2	w02-lm21	16.325	0.007	3.772	0.073	3.659	0.509	0.032883	1.21	0.09	20.641	0.015	0.101	8.55	0.053	3.382	21.821	2.087	1.786
3-1	91	AC1-23	23	9	w09-lm21	18.253	0.017	3.209	0.073	2.779	0.408	0.038602	0.997	0.09	20.876	0.131	0.101	7.593	0.036	2.715	24.388	1.705	2.034
3-1	92	AC1-13	13	12	w12-lm11	14.53	0.007	4.053	0.073	3.751	0.549	0.037172	1.429	0.09	19.468	0.015	0.101	9.856	0.092	3.593	19.96	3.63	1.62
3-1	93	AC1-11	11	3	w03-lm11	13.472	0.014	3.76	0.073	3.854	0.529	0.025735	1.763	0.09	18.765	0.015	0.101	13.53	0.032	4.365	18.869	2.702	1.514
3-1	94	AC1-14	14	16	w16-lm21	15.286	0.014	3.924	0.073	3.591	0.516	0.030024	1.614	0.09	19.117	0.015	0.101	12.364	0.032	3.394	20.452	3.003	1.561
3-1	95	EA	0	0	elm313	3.552	1.044	0.293	0.073	0.66	0.006	8.992813	0.029	0.09	0.427	2.976	16.715	0.058	0.592	0.059	44.284	0.058	0.006
3-2	96	EA	0	0	elm321	3.817	1.161	0.293	0.073	0.708	0.006	9.092892	0.029	0.09	0.444	3.064	17.389	0.058	0.554	0.059	48.348	0.058	0.02
3-2	97	AC1-13	13	12	w12-lm22	16.325	0.035	4.123	0.073	4.345	0.668	0.014297	1.602	0.09	21.228	0.015	0.101	11.454	0.013	4.166	22.035	4.627	1.845
3-2	98	AC1-12	12	15	w15-lm12	15.891	0.028	4.931	0.073	4.677	0.669	0.007149	1.625	0.09	22.166	0.015	0.101	8.725	0.013	4.775	21.393	1.797	1.857
3-2	99	AC1-11	11	3	w03-lm12	14.625	0.031	4.076	0.073	4.357	0.622	0.007149	2.132	0.09	20.172	0.015	0.101	15.746	0.013	5.22	20.366	3.224	1.809
3-2	100	AC1-14	14	16	w16-lm22	15.664	0.035	4.182	0.073	3.979	0.595	0.007149	1.902	0.09	20.876	0.015	0.101	14.93	0.013	3.967	22.035	3.618	1.939
3-2	101	AC1-14	14	16	w16-lm12	15.022	0.028	3.9	0.073	3.751	0.514	0.007149	1.729	0.09	18.882	0.015	0.101	13.764	0.042	3.675	20.131	3.374	1.869
3-2	102	AC1-23	23	9	w09-lm12	19.084	0.041	3.315	0.073	3.133	0.478	0.021445	1.108	0.09	22.987	0.088	0.101	8.876	0.013	3.101	25.886	1.995	2.235
3-2	103	AC1-15	15	19	w19-lm12	14.568	0.029	5.564	0.073	5.031	0.648	0.007149	1.671	0.09	21.814	0.015	0.101	13.064	0.013	4.166	20.751	1.937	1.762
3-2	104	AC1-21	21	2	w02-lm22	16.42	0.028	3.971	0.073	3.648	0.53	0.007149	1.302	0.09	20.407	0.015	0.204	9.355	0.013	3.523	22.035	2.226	1.951

Table A.1: Measured and Target Compositions (Lithium-metaborate Dissolution Method)

The oxide values were computed using the corrected cation concentations.

Block	Run Order	Glass ID	Glass #	Lab #	Lab ID	Al2O3	CaO	Ce2O3	Cr2O3	Er2O3	Eu2O3	Fe2O3	Gd2O3	K2O	La2O3	MnO	Na2O	Nd2O3	NiO	Pr2O3	SiO2	Sm2O3	SrO
3-2	105	EA	0	0	elm322	3.685	1.073	0.293	0.073	0.668	0.006	9.407426	0.029	0.09	0.429	3.005	18.198	0.058	0.548	0.059	47.706	0.058	0.02
3-2	106	AC1-13	13	12	w12-lm12	14.833	0.027	4.1	0.073	3.922	0.609	0.007149	1.602	0.09	19.938	0.015	0.101	10.696	0.048	3.768	20.837	4.128	1.75
3-2	107	AC1-11	11	3	w03-lm22	14.077	0.029	3.783	0.073	4.151	0.621	0.007149	1.959	0.09	19.117	0.015	0.101	14.93	0.038	4.822	20.045	3.108	1.667
3-2	108	AC1-12	12	15	w15-lm22	15.551	0.031	4.931	0.073	4.677	0.653	0.007149	1.591	0.09	21.58	0.015	0.101	8.806	0.102	4.74	20.815	1.774	1.88
3-2	109	AC1-23	23	9	w09-lm22	18.026	0.035	3.104	0.073	3.03	0.437	0.007149	1.043	0.09	21.931	0.076	0.101	8.34	0.013	2.879	24.816	1.902	2.164
3-2	110	AC1-22	22	7	w07-lm22	19.462	0.049	2.635	0.073	2.527	0.355	0.015727	0.813	0.09	22.4	0.076	0.232	7.068	0.013	2.469	26.527	1.31	2.2
3-2	111	AC1-15	15	19	w19-lm22	15.097	0.032	5.517	0.073	4.86	0.657	0.007149	1.66	0.09	23.104	0.015	0.101	12.947	0.013	3.967	20.494	1.948	1.774
3-2	112	AC1-22	22	7	w07-lm12	18.385	0.032	2.401	0.073	2.39	0.355	0.007149	0.791	0.09	21.814	0.07	0.101	6.637	0.013	2.259	25.672	1.229	2.211
3-2	113	AC1-21	21	2	w02-lm12	15.947	0.031	3.783	0.073	3.579	0.535	0.007149	1.302	0.09	20.641	0.015	0.349	9.471	0.013	3.406	22.463	2.203	1.939
3-2	114	EA	0	0	elm323	.	.	.	.	.	.	.	.	0.09	.	.	16.985	.	.	.	.	.	.
4-1	115	EA	0	0	elm411	3.609	0.977	0.293	0.073	0.751	0.006	7.548816	0.029	0.09	0.796	2.679	15.906	0.058	0.49	0.059	41.502	0.058	0.013
4-1	116	ARM	100	10	w10-lm21	5.328	2.211	1.242	0.073	3.385	0.02	0.04575	0.199	0.09	0.123	0.015	9.476	5.295	0.034	0.213	42.572	0.058	0.434
4-1	117	AC1-07	7	8	w08-lm21	17.799	0.017	3.104	0.073	3.099	0.432	0.052899	1.153	0.09	21.462	0.015	0.101	8.106	0.028	2.832	23.96	1.635	2.247
4-1	118	AC1-26	26	5	w05-lm11	13.113	0.02	4.826	0.073	4.768	0.663	0.065766	1.625	0.09	20.172	0.058	0.101	12.131	0.013	4.049	18.762	2.366	1.727
4-1	119	AC1-31	31	1	w01-lm11	15.116	0.007	3.842	0.073	3.694	1.181	0.065766	0.701	0.09	19.703	0.015	0.303	8.211	0.064	3.054	20.559	0.969	1.892
4-1	120	AC1-27	27	11	w11-lm21	14.776	0.017	3.924	0.073	3.625	1.158	0.054329	0.659	0.09	19.234	0.029	0.101	8.608	0.013	3.148	20.473	1.937	1.833
4-1	121	AC1-03	3	13	w13-lm11	15.91	0.007	2.963	0.073	2.962	0.339	0.052899	0.779	0.09	19.586	0.015	0.209	5.529	0.013	2.341	21.821	1.11	2.176
4-1	122	AC1-05	5	6	w06-lm11	16.042	0.007	3.666	0.073	3.248	0.391	0.051469	1.072	0.09	19.117	0.015	0.101	8.515	0.013	2.188	22.463	1.1	2.164
4-1	123	AC1-04	4	4	w04-lm11	17.251	0.014	2.425	0.073	2.241	0.317	0.068626	0.937	0.09	21.11	0.015	0.101	6.369	0.28	2.071	24.174	1.357	2.223
4-1	124	EA	0	0	elm412	3.571	1.002	0.293	0.073	0.764	0.006	7.72038	0.029	0.09	0.867	2.804	15.098	0.058	0.531	0.059	41.716	0.058	0.012
4-1	125	ARM	100	10	w10-lm11	6.046	2.491	1.335	0.073	3.488	0.019	0.04861	0.234	0.09	0.103	0.015	9.234	5.785	0.013	0.247	48.562	0.058	0.499
4-1	126	AC1-07	7	8	w08-lm11	18.819	0.018	3.069	0.073	2.985	0.478	0.061477	1.256	0.09	22.635	0.015	0.101	8.946	0.039	2.949	25.886	1.809	2.483
4-1	127	AC1-04	4	4	w04-lm21	19.084	0.02	2.507	0.073	2.31	0.36	0.057188	1.006	0.09	22.4	0.015	0.253	6.823	0.013	2.305	25.458	1.6	2.413
4-1	128	AC1-03	3	13	w13-lm21	18.026	0.02	2.963	0.073	2.996	0.395	0.070055	0.879	0.09	22.635	0.015	0.101	6.275	0.057	2.739	26.955	0.961	2.389
4-1	129	AC1-05	5	6	w06-lm21	17.157	0.015	3.678	0.073	3.213	0.428	0.04861	1.104	0.09	20.524	0.015	0.101	8.585	0.013	2.352	22.677	1.082	2.164
4-1	130	AC1-31	31	1	w01-lm21	15.626	0.014	3.936	0.073	3.671	1.181	0.060047	0.74	0.09	20.641	0.032	0.101	9.191	0.013	3.289	21.821	0.904	1.975
4-1	131	AC1-27	27	11	w11-lm11	15.475	0.015	3.912	0.073	3.533	1.251	0.054329	0.717	0.09	20.876	0.038	0.101	9.133	0.013	3.3	21.607	1.855	1.999
4-1	132	AC1-26	26	5	w05-lm21	13.264	0.021	4.685	0.073	4.734	0.626	0.067196	1.671	0.09	18.999	0.055	0.101	12.247	0.031	4.026	18.484	2.458	1.703
4-1	133	EA	0	0	elm413	3.855	1.034	0.293	0.073	0.746	0.006	7.691786	0.029	0.09	0.878	2.813	15.367	0.287	0.523	0.059	43.642	0.058	0.017
4-2	134	EA	0	0	elm421	3.836	1.07	0.293	0.073	0.723	0.006	8.449527	0.029	0.09	0.863	2.798	16.58	0.24	0.515	0.059	44.925	0.029	0.043
4-2	135	AC1-26	26	5	w05-lm22	14.058	0.007	5.048	0.073	4.608	0.638	0.057188	1.51	0.09	20.524	0.053	0.206	11.781	0.013	4.506	18.869	2.192	1.679
4-2	136	AC1-05	5	6	w06-lm22	18.045	0.007	3.69	0.073	3.156	0.412	0.034313	0.954	0.09	20.993	0.015	0.101	8.561	0.013	2.493	22.891	1.104	2.294
4-2	137	AC1-31	31	1	w01-lm22	16.439	0.007	3.889	0.073	3.511	1.239	0.020016	0.577	0.09	21.228	0.032	0.101	8.771	0.013	3.417	21.372	1.565	2.034
4-2	138	ARM	100	10	w10-lm12	5.706	2.323	1.394	0.073	3.476	0.006	0.028594	0.029	0.09	0.089	0.015	9.975	5.062	0.013	0.145	43.642	0.029	0.471
4-2	139	AC1-04	4	4	w04-lm12	18.593	0.007	2.436	0.073	2.344	0.311	0.05004	0.77	0.09	22.518	0.015	0.216	6.089	0.288	2.06	24.388	0.702	2.353
4-2	140	AC1-03	3	13	w13-lm22	19.084	0.007	3.069	0.073	2.95	0.371	0.05004	0.675	0.09	22.635	0.015	0.43	6.077	0.013	2.633	25.672	1.16	2.353
4-2	141	AC1-04	4	4	w04-lm22	19.084	0.007	2.46	0.073	2.447	0.331	0.032883	0.771	0.09	21.814	0.015	0.226	6.159	0.013	2.153	25.244	0.758	2.353
4-2	142	AC1-27	27	11	w11-lm22	16.552	0.007	4.053	0.073	3.591	1.285	0.007149	0.556	0.09	21.228	0.035	0.101	9.168	0.013	3.183	23.96	1.037	1.916
4-2	143	EA	0	0	elm422	4.025	1.059	0.293	0.073	0.757	0.006	7.563113	0.029	0.09	0.88	2.897	16.715	0.257	0.557	0.059	45.995	0.029	0.046
4-2	144	AC1-31	31	1	w01-lm12	16.136	0.007	3.713	0.073	3.476	1.169	0.04718	0.523	0.09	21.462	0.029	0.101	8.573	0.059	3.195	22.035	1.461	1.951
4-2	145	AC1-03	3	13	w13-lm12	17.478	0.007	2.776	0.073	2.744	0.345	0.044321	0.628	0.09	21.11	0.015	0.101	5.855	0.013	2.575	23.532	1.095	2.271
4-2	146	AC1-07	7	8	w08-lm12	17.875	0.007	2.928	0.073	2.882	0.411	0.041461	0.858	0.09	21.58	0.015	0.101	8.165	0.013	2.575	25.03	1.658	2.164
4-2	147	AC1-27	27	11	w11-lm12	15.947	0.007	3.643	0.073	3.694	1.181	0.040032	0.498	0.09	20.524	0.035	0.101	8.655	0.013	3.113	22.463	1.844	1.833
4-2	148	ARM	100	10	w10-lm22	5.423	2.099	1.183	0.073	3.339	0.006	0.030024	0.029	0.09	0.122	0.015	9.746	4.817	0.013	0.138	43	0.094	0.439
4-2	149	AC1-05	5	6	w06-lm12	17.667	0.007	3.444	0.073	2.996	0.394	0.030024	0.886	0.09	20.876	0.015	0.101	8.036	0.013	2.2	22.891	1.069	2.141
4-2	150	AC1-26	26	5	w05-lm12	14.02	0.007	4.556	0.073	4.345	0.604	0.041461	1.372	0.09	19.117	0.053	0.101	11.337	0.013	4.272	18.441	2.099	1.608
4-2	151	AC1-07	7	8	w08-lm22	17.572	0.007	2.999	0.073	2.813	0.395	0.035743	0.907	0.09	21.11	0.015	0.101	7.43	0.013	2.61	22.891	1.438	2.117
4-2	152	EA	0	0	elm 423	3.836	1.026	0.293	0.073	0.68	0.006	7.43444	0.029	0.09	0.862	2.792	15.098	0.202	0.513	0.059	43	0.029	0.041

Orig - original values; Cor - Corrected (shaded) Values; < implies less than the indicated detection limit Concentrations are expressed as weight percents.

Table A.1: Measured and Target Compositions (Lithium-metaborate Dissolution Method)

Block	Run Order	Glass ID	Glass #	Lab #	Lab ID	Target Compositions Al2O3	CaO	Ce2O3	Cr2O3	Er2O3	Eu2O3	Fe2O3	Gd2O3	K2O	La2O3	MnO	Na2O	Nd2O3	NiO	Pr2O3	SiO2	Sm2O3	SrO
1-1	1	EA	0	0	elm111	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
1-1	2	AC1-10	10	28	w28-lm21	17.41	0	3.93	0	3.61	0.52	0	1.25	0	22.06	0	0	10.42	0	3.43	23.58	2.28	2.04
1-1	3	AC1-19	19	30	w30-lm11	17.41	0	3.93	0	3.61	0.52	0	1.25	0	22.06	0	0	10.42	0	3.43	23.58	2.28	2.04
1-1	4	AC1-17	17	22	w22-lm21	19.9	0	2.62	0	2.41	0.35	0	0.83	0	23.04	0	0	6.95	0	2.29	26.94	1.52	2.33
1-1	5	AC1-09	9	23	w23-lm11	17.41	0	3.2	0	2.92	0.49	0	1.07	0	21.2	0	0	11.83	0	4.08	23.58	2.72	2.04
1-1	6	AC1-20	20	20	w20-lm21	16.17	0	4.58	0	4.21	0.61	0	1.46	0	21.57	0	0	12.16	0	4.01	21.89	2.66	1.89
1-1	7	AC1-18	18	31	w31-lm11	18.65	0	3.27	0	3.01	0.44	0	1.04	0	22.55	0	0	8.68	0	2.86	25.26	1.9	2.18
1-1	8	AC1-09	9	23	w23-lm21	17.41	0	3.2	0	2.92	0.49	0	1.07	0	21.2	0	0	11.83	0	4.08	23.58	2.72	2.04
1-1	9	AC1-08	8	24	w24-lm11	17.41	0	3.94	0	4.35	0.47	0	1.45	0	22.94	0	0	8.84	0	2.79	23.58	2.72	2.04
1-1	10	EA	0	0	elm112	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
1-1	11	AC1-20	20	20	w20-lm11	16.17	0	4.58	0	4.21	0.61	0	1.46	0	21.57	0	0	12.16	0	4.01	21.89	2.66	1.89
1-1	12	AC1-18	18	31	w31-lm21	18.65	0	3.27	0	3.01	0.44	0	1.04	0	22.55	0	0	8.68	0	2.86	25.26	1.9	2.18
1-1	13	AC1-17	17	22	w22-lm11	19.9	0	2.62	0	2.41	0.35	0	0.83	0	23.04	0	0	6.95	0	2.29	26.94	1.52	2.33
1-1	14	AC1-16	16	27	w27-lm21	14.92	0	5.24	0	4.81	0.7	0	1.67	0	21.08	0	0	13.89	0	4.58	20.21	3.04	1.75
1-1	15	AC1-16	16	27	w27-lm11	14.92	0	5.24	0	4.81	0.7	0	1.67	0	21.08	0	0	13.89	0	4.58	20.21	3.04	1.75
1-1	16	AC1-19	19	30	w30-lm21	17.41	0	3.93	0	3.61	0.52	0	1.25	0	22.06	0	0	10.42	0	3.43	23.58	2.28	2.04
1-1	17	AC1-08	8	24	w24-lm21	17.41	0	3.94	0	4.35	0.47	0	1.45	0	22.94	0	0	8.84	0	2.79	23.58	2.72	2.04
1-1	18	AC1-10	10	28	w28-lm11	17.41	0	3.93	0	3.61	0.52	0	1.25	0	22.06	0	0	10.42	0	3.43	23.58	2.28	2.04
1-1	19	EA	0	0	elm113	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
1-2	20	EA	0	0	elm121	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
1-2	21	AC1-19	19	30	w30-lm22	17.41	0	3.93	0	3.61	0.52	0	1.25	0	22.06	0	0	10.42	0	3.43	23.58	2.28	2.04
1-2	22	AC1-17	17	22	w22-lm12	19.9	0	2.62	0	2.41	0.35	0	0.83	0	23.04	0	0	6.95	0	2.29	26.94	1.52	2.33
1-2	23	AC1-10	10	28	w28-lm12	17.41	0	3.93	0	3.61	0.52	0	1.25	0	22.06	0	0	10.42	0	3.43	23.58	2.28	2.04
1-2	24	AC1-17	17	22	w22-lm22	19.9	0	2.62	0	2.41	0.35	0	0.83	0	23.04	0	0	6.95	0	2.29	26.94	1.52	2.33
1-2	25	AC1-20	20	20	w20-lm12	16.17	0	4.58	0	4.21	0.61	0	1.46	0	21.57	0	0	12.16	0	4.01	21.89	2.66	1.89
1-2	26	AC1-08	8	24	w24-lm22	17.41	0	3.94	0	4.35	0.47	0	1.45	0	22.94	0	0	8.84	0	2.79	23.58	2.72	2.04
1-2	27	AC1-09	9	23	w23-lm12	17.41	0	3.2	0	2.92	0.49	0	1.07	0	21.2	0	0	11.83	0	4.08	23.58	2.72	2.04
1-2	28	AC1-10	10	28	w28-lm22	17.41	0	3.93	0	3.61	0.52	0	1.25	0	22.06	0	0	10.42	0	3.43	23.58	2.28	2.04
1-2	29	EA	0	0	elm122	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
1-2	30	AC1-08	8	24	w24-lm12	17.41	0	3.94	0	4.35	0.47	0	1.45	0	22.94	0	0	8.84	0	2.79	23.58	2.72	2.04
1-2	31	AC1-20	20	20	w20-lm22	16.17	0	4.58	0	4.21	0.61	0	1.46	0	21.57	0	0	12.16	0	4.01	21.89	2.66	1.89
1-2	32	AC1-18	18	31	w31-lm12	18.65	0	3.27	0	3.01	0.44	0	1.04	0	22.55	0	0	8.68	0	2.86	25.26	1.9	2.18
1-2	33	AC1-16	16	27	w27-lm12	14.92	0	5.24	0	4.81	0.7	0	1.67	0	21.08	0	0	13.89	0	4.58	20.21	3.04	1.75
1-2	34	AC1-09	9	23	w23-lm22	17.41	0	3.2	0	2.92	0.49	0	1.07	0	21.2	0	0	11.83	0	4.08	23.58	2.72	2.04
1-2	35	AC1-18	18	31	w31-lm22	18.65	0	3.27	0	3.01	0.44	0	1.04	0	22.55	0	0	8.68	0	2.86	25.26	1.9	2.18
1-2	36	AC1-16	16	27	w27-lm22	14.92	0	5.24	0	4.81	0.7	0	1.67	0	21.08	0	0	13.89	0	4.58	20.21	3.04	1.75
1-2	37	AC1-19	19	30	w30-lm12	17.41	0	3.93	0	3.61	0.52	0	1.25	0	22.06	0	0	10.42	0	3.43	23.58	2.28	2.04
1-2	38	EA	0	0	elm123	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
2-1	39	EA	0	0	elm211	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
2-1	40	AC1-06	6	25	w25-lm11	18.65	0	2.66	0	3.02	0.44	0	1.21	0	23.28	0	0	7.82	0	3.4	25.26	1.92	2.18
2-1	41	AC1-28	28	32	w32-lm11	16.82	0	4.31	0	3.91	1.41	0.01	0.63	0	21.9	0.045	0	10.74	0	3.77	22.78	2.55	1.97
2-1	42	AC1-06	6	25	w25-lm21	18.65	0	2.66	0	3.02	0.44	0	1.21	0	23.28	0	0	7.82	0	3.4	25.26	1.92	2.18
2-1	43	AC1-30	30	14	w14-lm11	15.91	0	4.8	0	4.35	1.57	0.011	0.7	0	21.55	0.05	0	11.96	0	4.2	21.54	2.84	1.86
2-1	44	AC1-28	28	32	w32-lm21	16.82	0	4.31	0	3.91	1.41	0.01	0.63	0	21.9	0.045	0	10.74	0	3.77	22.78	2.55	1.97
2-1	45	AC1-30	30	14	w14-lm21	15.91	0	4.8	0	4.35	1.57	0.011	0.7	0	21.55	0.05	0	11.96	0	4.2	21.54	2.84	1.86
2-1	46	AC1-25	25	17	w17-lm21	16.15	0.005	4.58	0.005	4.21	0.61	0.01	1.46	0.005	21.55	0.05	0.005	12.15	0.005	4.01	21.87	2.66	1.89
2-1	47	AC1-02	2	29	w29-lm11	19.9	0	3.12	0	2.88	0.39	0	0.7	0	23.63	0	0	5.31	0	2.72	26.94	1.26	2.33
2-1	48	EA	0	0	elm212	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
2-1	49	AC1-29	29	21	w21-lm21	16.17	0	4.66	0	4.23	1.53	0.011	0.68	0	21.65	0.049	0	11.61	0	4.07	21.89	2.76	1.89
2-1	50	AC1-29	29	21	w21-lm11	16.17	0	4.66	0	4.23	1.53	0.011	0.68	0	21.65	0.049	0	11.61	0	4.07	21.89	2.76	1.89
2-1	51	AC1-24	24	18	w18-lm11	17.39	0.005	3.93	0.005	3.61	0.52	0.01	1.25	0.005	22.04	0.05	0.005	10.41	0.005	3.43	23.56	2.28	2.04
2-1	52	AC1-25	25	17	w17-lm11	16.15	0.005	4.58	0.005	4.21	0.61	0.01	1.46	0.005	21.55	0.05	0.005	12.15	0.005	4.01	21.87	2.66	1.89

Table A.1: Measured and Target Compositions (Lithium-metaborate Dissolution Method)

						Target Compositions																	
Block	Run Order	Glass ID	Glass #	Lab #	Lab ID	Al2O3	CaO	Ce2O3	Cr2O3	Er2O3	Eu2O3	Fe2O3	Gd2O3	K2O	La2O3	MnO	Na2O	Nd2O3	NiO	Pr2O3	SiO2	Sm2O3	SrO
2-1	53	AC1-24	24	18	w18-lm21	17.39	0.005	3.93	0.005	3.61	0.52	0.01	1.25	0.005	22.04	0.05	0.005	10.41	0.005	3.43	23.56	2.28	2.04
2-1	54	AC1-01	1	26	w26-lm11	17.31	0	4.15	0	3.78	0.55	0	1.34	0	21.77	0	0	10.01	0	3.61	23.5	2.45	2.05
2-1	55	AC1-02	2	29	w29-lm21	19.9	0	3.12	0	2.88	0.39	0	0.7	0	23.63	0	0	5.31	0	2.72	26.94	1.26	2.33
2-1	56	AC1-01	1	26	w26-lm21	17.31	0	4.15	0	3.78	0.55	0	1.34	0	21.77	0	0	10.01	0	3.61	23.5	2.45	2.05
2-1	57	EA	0	0	elm213	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
2-2	58	EA	0	0	elm221	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
2-2	59	AC1-30	30	14	w14-lm22	15.91	0	4.8	0	4.35	1.57	0.011	0.7	0	21.55	0.05	0	11.96	0	4.2	21.54	2.84	1.86
2-2	60	AC1-01	1	26	w26-lm22	17.31	0	4.15	0	3.78	0.55	0	1.34	0	21.77	0	0	10.01	0	3.61	23.5	2.45	2.05
2-2	61	AC1-29	29	21	w21-lm12	16.17	0	4.66	0	4.23	1.53	0.011	0.68	0	21.65	0.049	0	11.61	0	4.07	21.89	2.76	1.89
2-2	62	AC1-01	1	26	w26-lm12	17.31	0	4.15	0	3.78	0.55	0	1.34	0	21.77	0	0	10.01	0	3.61	23.5	2.45	2.05
2-2	63	AC1-02	2	29	w29-lm22	19.9	0	3.12	0	2.88	0.39	0	0.7	0	23.63	0	0	5.31	0	2.72	26.94	1.26	2.33
2-2	64	AC1-30	30	14	w14-lm12	15.91	0	4.8	0	4.35	1.57	0.011	0.7	0	21.55	0.05	0	11.96	0	4.2	21.54	2.84	1.86
2-2	65	AC1-29	29	21	w21-lm22	16.17	0	4.66	0	4.23	1.53	0.011	0.68	0	21.65	0.049	0	11.61	0	4.07	21.89	2.76	1.89
2-2	66	AC1-24	24	18	w18-lm22	17.39	0.005	3.93	0.005	3.61	0.52	0.01	1.25	0.005	22.04	0.05	0.005	10.41	0.005	3.43	23.56	2.28	2.04
2-2	67	EA	0	0	elm222	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
2-2	68	AC1-28	28	32	w32-lm12	16.82	0	4.31	0	3.91	1.41	0.01	0.63	0	21.9	0.045	0	10.74	0	3.77	22.78	2.55	1.97
2-2	69	AC1-02	2	29	w29-lm12	19.9	0	3.12	0	2.88	0.39	0	0.7	0	23.63	0	0	5.31	0	2.72	26.94	1.26	2.33
2-2	70	AC1-24	24	18	w18-lm12	17.39	0.005	3.93	0.005	3.61	0.52	0.01	1.25	0.005	22.04	0.05	0.005	10.41	0.005	3.43	23.56	2.28	2.04
2-2	71	AC1-06	6	25	w25-lm12	18.65	0	2.66	0	3.02	0.44	0	1.21	0	23.28	0	0	7.82	0	3.4	25.26	1.92	2.18
2-2	72	AC1-28	28	32	w32-lm22	16.82	0	4.31	0	3.91	1.41	0.01	0.63	0	21.9	0.045	0	10.74	0	3.77	22.78	2.55	1.97
2-2	73	AC1-06	6	25	w25-lm22	18.65	0	2.66	0	3.02	0.44	0	1.21	0	23.28	0	0	7.82	0	3.4	25.26	1.92	2.18
2-2	74	AC1-25	25	17	w17-lm12	16.15	0.005	4.58	0.005	4.21	0.61	0.01	1.46	0.005	21.55	0.05	0.005	12.15	0.005	4.01	21.87	2.66	1.89
2-2	75	AC1-25	25	17	w17-lm22	16.15	0.005	4.58	0.005	4.21	0.61	0.01	1.46	0.005	21.55	0.05	0.005	12.15	0.005	4.01	21.87	2.66	1.89
2-2	76	EA	0	0	elm223	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
3-1	77	EA	0	0	elm311	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
3-1	78	AC1-13	13	12	w12-lm21	16.17	0	4.58	0	4.21	0.61	0	1.46	0	21.57	0	0	12.16	0	4.01	21.89	2.66	1.89
3-1	79	AC1-12	12	15	w15-lm11	16.17	0	5.21	0	4.82	0.68	0	1.7	0	22.6	0	0	9.29	0	4.76	21.89	2.2	1.89
3-1	80	AC1-15	15	19	w19-lm21	14.92	0	6.24	0	4.83	0.62	0	1.67	0	22.25	0	0	13.14	0	3.72	20.21	2.52	1.75
3-1	81	AC1-22	22	7	w07-lm11	19.88	0.005	2.62	0.005	2.41	0.35	0.01	0.83	0.005	23.02	0.05	0.005	6.94	0.005	2.29	26.91	1.52	2.33
3-1	82	AC1-12	12	15	w15-lm21	16.17	0	5.21	0	4.82	0.68	0	1.7	0	22.6	0	0	9.29	0	4.76	21.89	2.2	1.89
3-1	83	AC1-22	22	7	w07-lm21	19.88	0.005	2.62	0.005	2.41	0.35	0.01	0.83	0.005	23.02	0.05	0.005	6.94	0.005	2.29	26.91	1.52	2.33
3-1	84	AC1-21	21	2	w02-lm11	14.92	0	5.24	0	4.81	0.7	0	1.67	0	21.08	0	0	13.89	0	4.58	20.21	3.04	1.75
3-1	85	AC1-23	23	9	w09-lm11	18.63	0.005	3.27	0.005	3.01	0.44	0.01	1.04	0.005	22.53	0.05	0.005	8.67	0.005	2.86	25.24	1.9	2.18
3-1	86	EA	0	0	elm 312	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
3-1	87	AC1-14	14	16	w16-lm11	14.92	0	4.26	0	4.19	0.62	0	1.94	0	19.94	0	0	15.77	0	5.43	20.21	2.84	1.75
3-1	88	AC1-15	15	19	w19-lm11	14.92	0	6.24	0	4.83	0.62	0	1.67	0	22.25	0	0	13.14	0	3.72	20.21	2.52	1.75
3-1	89	AC1-11	11	3	w03-lm21	16.17	0	4.28	0	3.93	0.54	0	1.7	0	20.57	0	0	13.8	0	3.26	21.89	3.17	1.89
3-1	90	AC1-21	21	2	w02-lm21	14.92	0	5.24	0	4.81	0.7	0	1.67	0	21.08	0	0	13.89	0	4.58	20.21	3.04	1.75
3-1	91	AC1-23	23	9	w09-lm21	18.63	0.005	3.27	0.005	3.01	0.44	0.01	1.04	0.005	22.53	0.05	0.005	8.67	0.005	2.86	25.24	1.9	2.18
3-1	92	AC1-13	13	12	w12-lm11	16.17	0	4.58	0	4.21	0.61	0	1.46	0	21.57	0	0	12.16	0	4.01	21.89	2.66	1.89
3-1	93	AC1-11	11	3	w03-lm11	16.17	0	4.28	0	3.93	0.54	0	1.7	0	20.57	0	0	13.8	0	3.26	21.89	3.17	1.89
3-1	94	AC1-14	14	16	w16-lm21	14.92	0	4.26	0	4.19	0.62	0	1.94	0	19.94	0	0	15.77	0	5.43	20.21	2.84	1.75
3-1	95	EA	0	0	elm313	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
3-2	96	EA	0	0	elm321	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
3-2	97	AC1-13	13	12	w12-lm22	16.17	0	4.58	0	4.21	0.61	0	1.46	0	21.57	0	0	12.16	0	4.01	21.89	2.66	1.89
3-2	98	AC1-12	12	15	w15-lm12	16.17	0	5.21	0	4.82	0.68	0	1.7	0	22.6	0	0	9.29	0	4.76	21.89	2.2	1.89
3-2	99	AC1-11	11	3	w03-lm12	16.17	0	4.28	0	3.93	0.54	0	1.7	0	20.57	0	0	13.8	0	3.26	21.89	3.17	1.89
3-2	100	AC1-14	14	16	w16-lm22	14.92	0	4.26	0	4.19	0.62	0	1.94	0	19.94	0	0	15.77	0	5.43	20.21	2.84	1.75
3-2	101	AC1-14	14	16	w16-lm12	14.92	0	4.26	0	4.19	0.62	0	1.94	0	19.94	0	0	15.77	0	5.43	20.21	2.84	1.75
3-2	102	AC1-23	23	9	w09-lm12	18.63	0.005	3.27	0.005	3.01	0.44	0.01	1.04	0.005	22.53	0.05	0.005	8.67	0.005	2.86	25.24	1.9	2.18
3-2	103	AC1-15	15	19	w19-lm12	14.92	0	6.24	0	4.83	0.62	0	1.67	0	22.25	0	0	13.14	0	3.72	20.21	2.52	1.75
3-2	104	AC1-21	21	2	w02-lm22	14.92	0	5.24	0	4.81	0.7	0	1.67	0	21.08	0	0	13.89	0	4.58	20.21	3.04	1.75

Orig - original values; Cor - Corrected (shaded) Values; < implies less than the indicated detection limit Concentrations are expressed as weight percents.

Table A.1: Measured and Target Compositions (Lithium-metaborate Dissolution Method)

Block	Run Order	Glass ID	Glass #	Lab #	Lab ID	Target Compositions Al2O3	CaO	Ce2O3	Cr2O3	Er2O3	Eu2O3	Fe2O3	Gd2O3	K2O	La2O3	MnO	Na2O	Nd2O3	NiO	Pr2O3	SiO2	Sm2O3	SrO
3-2	105	EA	0	0	elm322	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
3-2	106	AC1-13	13	12	w12-lm12	16.17	0	4.58	0	4.21	0.61	0	1.46	0	21.57	0	0	12.16	0	4.01	21.89	2.66	1.89
3-2	107	AC1-11	11	3	w03-lm22	16.17	0	4.28	0	3.93	0.54	0	1.7	0	20.57	0	0	13.8	0	3.26	21.89	3.17	1.89
3-2	108	AC1-12	12	15	w15-lm22	16.17	0	5.21	0	4.82	0.68	0	1.7	0	22.6	0	0	9.29	0	4.76	21.89	2.2	1.89
3-2	109	AC1-23	23	9	w09-lm22	18.63	0.005	3.27	0.005	3.01	0.44	0.01	1.04	0.005	22.53	0.05	0.005	8.67	0.005	2.86	25.24	1.9	2.18
3-2	110	AC1-22	22	7	w07-lm22	19.88	0.005	2.62	0.005	2.41	0.35	0.01	0.83	0.005	23.02	0.05	0.005	6.94	0.005	2.29	26.91	1.52	2.33
3-2	111	AC1-15	15	19	w19-lm22	14.92	0	6.24	0	4.83	0.62	0	1.67	0	22.25	0	0	13.14	0	3.72	20.21	2.52	1.75
3-2	112	AC1-22	22	7	w07-lm12	19.88	0.005	2.62	0.005	2.41	0.35	0.01	0.83	0.005	23.02	0.05	0.005	6.94	0.005	2.29	26.91	1.52	2.33
3-2	113	AC1-21	21	2	w02-lm12	14.92	0	5.24	0	4.81	0.7	0	1.67	0	21.08	0	0	13.89	0	4.58	20.21	3.04	1.75
3-2	114	EA	0	0	elm323	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
4-1	115	EA	0	0	elm411	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
4-1	116	ARM	100	10	w10-lm21	5.59	2.23	1.44	0	0	0	0	0	0	0	0	9.67	5.96	0	0	46.5	0	0.45
4-1	117	AC1-07	7	8	w08-lm21	18.65	0	3.27	0	3.01	0.44	0	1.04	0	22.55	0	0	8.68	0	2.86	25.26	1.9	2.18
4-1	118	AC1-26	26	5	w05-lm11	14.91	0.005	5.24	0.005	4.81	0.7	0.01	1.67	0.005	21.06	0.05	0.005	13.88	0.005	4.58	20.19	3.04	1.75
4-1	119	AC1-31	31	1	w01-lm11	17.41	0	4	0	3.62	1.31	0.009	0.58	0	22.13	0.042	0	9.95	0	3.49	23.58	2.36	2.04
4-1	120	AC1-27	27	11	w11-lm21	17.27	0	4.07	0	3.7	1.33	0.009	0.59	0	22.07	0.043	0	10.15	0	3.56	23.38	2.41	2.02
4-1	121	AC1-03	3	13	w13-lm11	19.9	0	3.12	0	2.9	0.39	0	0.7	0	22.47	0	0	6.45	0	2.72	26.94	1.26	2.33
4-1	122	AC1-05	5	6	w06-lm11	18.65	0	3.9	0	3.2	0.44	0	1.04	0	21.84	0	0	9.43	0	2.33	25.26	1.58	2.18
4-1	123	AC1-04	4	4	w04-lm11	19.9	0	2.62	0	2.41	0.35	0	0.83	0	23.04	0	0	6.95	0	2.29	26.94	1.52	2.33
4-1	124	EA	0	0	elm412	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
4-1	125	ARM	100	10	w10-lm11	5.59	2.23	1.44	0	0	0	0	0	0	0	0	9.67	5.96	0	0	46.5	0	0.45
4-1	126	AC1-07	7	8	w08-lm11	18.65	0	3.27	0	3.01	0.44	0	1.04	0	22.55	0	0	8.68	0	2.86	25.26	1.9	2.18
4-1	127	AC1-04	4	4	w04-lm21	19.9	0	2.62	0	2.41	0.35	0	0.83	0	23.04	0	0	6.95	0	2.29	26.94	1.52	2.33
4-1	128	AC1-03	3	13	w13-lm21	19.9	0	3.12	0	2.9	0.39	0	0.7	0	22.47	0	0	6.45	0	2.72	26.94	1.26	2.33
4-1	129	AC1-05	5	6	w06-lm21	18.65	0	3.9	0	3.2	0.44	0	1.04	0	21.84	0	0	9.43	0	2.33	25.26	1.58	2.18
4-1	130	AC1-31	31	1	w01-lm21	17.41	0	4	0	3.62	1.31	0.009	0.58	0	22.13	0.042	0	9.95	0	3.49	23.58	2.36	2.04
4-1	131	AC1-27	27	11	w11-lm11	17.27	0	4.07	0	3.7	1.33	0.009	0.59	0	22.07	0.043	0	10.15	0	3.56	23.38	2.41	2.02
4-1	132	AC1-26	26	5	w05-lm21	14.91	0.005	5.24	0.005	4.81	0.7	0.01	1.67	0.005	21.06	0.05	0.005	13.88	0.005	4.58	20.19	3.04	1.75
4-1	133	EA	0	0	elm413	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
4-2	134	EA	0	0	elm421	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
4-2	135	AC1-26	26	5	w05-lm22	14.91	0.005	5.24	0.005	4.81	0.7	0.01	1.67	0.005	21.06	0.05	0.005	13.88	0.005	4.58	20.19	3.04	1.75
4-2	136	AC1-05	5	6	w06-lm22	18.65	0	3.9	0	3.2	0.44	0	1.04	0	21.84	0	0	9.43	0	2.33	25.26	1.58	2.18
4-2	137	AC1-31	31	1	w01-lm22	17.41	0	4	0	3.62	1.31	0.009	0.58	0	22.13	0.042	0	9.95	0	3.49	23.58	2.36	2.04
4-2	138	ARM	100	10	w10-lm12	5.59	2.23	1.44	0	0	0	0	0	0	0	0	9.67	5.96	0	0	46.5	0	0.45
4-2	139	AC1-04	4	4	w04-lm12	19.9	0	2.62	0	2.41	0.35	0	0.83	0	23.04	0	0	6.95	0	2.29	26.94	1.52	2.33
4-2	140	AC1-03	3	13	w13-lm22	19.9	0	3.12	0	2.9	0.39	0	0.7	0	22.47	0	0	6.45	0	2.72	26.94	1.26	2.33
4-2	141	AC1-04	4	4	w04-lm22	19.9	0	2.62	0	2.41	0.35	0	0.83	0	23.04	0	0	6.95	0	2.29	26.94	1.52	2.33
4-2	142	AC1-27	27	11	w11-lm22	17.27	0	4.07	0	3.7	1.33	0.009	0.59	0	22.07	0.043	0	10.15	0	3.56	23.38	2.41	2.02
4-2	143	EA	0	0	elm422	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0
4-2	144	AC1-31	31	1	w01-lm12	17.41	0	4	0	3.62	1.31	0.009	0.58	0	22.13	0.042	0	9.95	0	3.49	23.58	2.36	2.04
4-2	145	AC1-03	3	13	w13-lm12	19.9	0	3.12	0	2.9	0.39	0	0.7	0	22.47	0	0	6.45	0	2.72	26.94	1.26	2.33
4-2	146	AC1-07	7	8	w08-lm12	18.65	0	3.27	0	3.01	0.44	0	1.04	0	22.55	0	0	8.68	0	2.86	25.26	1.9	2.18
4-2	147	AC1-27	27	11	w11-lm12	17.27	0	4.07	0	3.7	1.33	0.009	0.59	0	22.07	0.043	0	10.15	0	3.56	23.38	2.41	2.02
4-2	148	ARM	100	10	w10-lm22	5.59	2.23	1.44	0	0	0	0	0	0	0	0	9.67	5.96	0	0	46.5	0	0.45
4-2	149	AC1-05	5	6	w06-lm12	18.65	0	3.9	0	3.2	0.44	0	1.04	0	21.84	0	0	9.43	0	2.33	25.26	1.58	2.18
4-2	150	AC1-26	26	5	w05-lm12	14.91	0.005	5.24	0.005	4.81	0.7	0.01	1.67	0.005	21.06	0.05	0.005	13.88	0.005	4.58	20.19	3.04	1.75
4-2	151	AC1-07	7	8	w08-lm22	18.65	0	3.27	0	3.01	0.44	0	1.04	0	22.55	0	0	8.68	0	2.86	25.26	1.9	2.18
4-2	152	EA	0	0	elm 423	3.7	1.12	0	0	0	0	8.99	0	0.04	0.42	1.34	16.8	0	0.57	0	48.73	0	0

Table A.1: Measured and Target Compositions (Lithium-metaborate Dissolution Method)

Block	Run Order	Glass ID	Glass #	Lab #	Lab ID	Al2O3	CaO	Ce2O3	Cr2O3	Er2O3	Eu2O3	Fe2O3	Target Compositions Gd2O3	K2O	La2O3	MnO	Na2O	Nd2O3	NiO	Pr2O3	SiO2	Sm2O3	SrO

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Orig - original values; Cor - Corrected (shaded) Values;   < implies less than the indicated detection limit   Concentrations are expressed as weight percents.

Table A.2: Measured and Target Compositions (Peroxide Fusion Dissolution Method)

Block	Run Order	Glass ID	Glass #	Lab #	Lab ID	B	Li	B2O3	Li2O	B2O3 (Bias Corrected)	Target Compositions B2O3	Target Compositions Li2O
1-1	1	EA	0	0	epf111	3.4	2.2	10.948	4.736	11.344	11.3	4.26
1-1	2	AC1-07	7	8	w08-pf21	3.04	<0.050	9.788	0.054	10.143	10.16	0
1-1	3	AC1-11	11	3	w03-pf11	2.52	<0.050	8.114	0.054	8.408	8.8	0
1-1	4	AC1-14	14	16	w16-pf21	2.6	<0.050	8.372	0.054	8.675	8.12	0
1-1	5	AC1-05	5	6	w06-pf21	3.05	<0.050	9.821	0.054	10.177	10.16	0
1-1	6	AC1-04	4	4	w04-pf21	3.34	<0.050	10.754	0.054	11.144	10.83	0
1-1	7	AC1-11	11	3	w03-pf21	2.55	<0.050	8.211	0.054	8.508	8.8	0
1-1	8	AC1-03	3	13	w13-pf21	3.19	<0.050	10.271	0.054	10.644	10.83	0
1-1	9	AC1-26	26	5	w05-pf21	2.49	<0.050	8.018	0.054	8.308	8.11	0
1-1	10	AC1-21	21	2	w02-pf21	2.75	<0.050	8.855	0.054	9.176	8.12	0
1-1	11	AC1-21	21	2	w02-pf11	2.72	<0.050	8.758	0.054	9.076	8.12	0
1-1	12	AC1-03	3	13	w13-pf11	3.08	<0.050	9.917	0.054	10.277	10.83	0
1-1	13	EA	0	0	epf112	3.41	1.98	10.98	4.263	11.378	11.3	4.26
1-1	14	AC1-14	14	16	w16-pf11	2.64	<0.050	8.501	0.054	8.809	8.12	0
1-1	15	AC1-05	5	6	w06-pf11	3.06	<0.050	9.853	0.054	10.21	10.16	0
1-1	16	AC1-23	23	9	w09-pf11	3.05	<0.050	9.821	0.054	10.177	10.15	0
1-1	17	AC1-07	7	8	w08-pf11	3.02	<0.050	9.724	0.054	10.077	10.16	0
1-1	18	AC1-04	4	4	w04-pf11	3.29	<0.050	10.593	0.054	10.977	10.83	0
1-1	19	AC1-22	22	7	w07-pf21	3.21	<0.050	10.336	0.054	10.711	10.82	0
1-1	20	AC1-31	31	1	w01-pf21	2.92	<0.050	9.402	0.054	9.743	9.48	0
1-1	21	AC1-22	22	7	w07-pf11	3.16	<0.050	10.175	0.054	10.544	10.82	0
1-1	22	AC1-31	31	1	w01-pf11	2.91	<0.050	9.37	0.054	9.71	9.48	0
1-1	23	AC1-23	23	9	w09-pf21	3.01	<0.050	9.692	0.054	10.043	10.15	0
1-1	24	AC1-26	26	5	w05-pf11	2.38	<0.050	7.663	0.054	7.941	8.11	0
1-1	25	EA	0	0	epf113	3.35	1.96	10.787	4.22	11.178	11.3	4.26
1-2	26	EA	0	0	epf121	3.65	1.94	11.753	4.177	11.597	11.3	4.26
1-2	27	AC1-26	26	5	w05-pf22	2.6	<0.050	8.372	0.054	8.261	8.11	0
1-2	28	AC1-21	21	2	w02-pf12	3.04	<0.050	9.788	0.054	9.658	8.12	0
1-2	29	AC1-26	26	5	w05-pf12	2.42	<0.050	7.792	0.054	7.689	8.11	0
1-2	30	AC1-07	7	8	w08-pf12	3.1	<0.050	9.982	0.054	9.849	10.16	0
1-2	31	AC1-31	31	1	w01-pf12	2.93	<0.050	9.434	0.054	9.309	9.48	0
1-2	32	AC1-04	4	4	w04-pf12	3.3	<0.050	10.626	0.054	10.485	10.83	0
1-2	33	AC1-05	5	6	w06-pf22	3.2	<0.050	10.304	0.054	10.167	10.16	0
1-2	34	AC1-22	22	7	w07-pf12	3.49	<0.050	11.237	0.054	11.088	10.82	0
1-2	35	AC1-23	23	9	w09-pf22	3.05	<0.050	9.821	0.054	9.69	10.15	0
1-2	36	AC1-07	7	8	w08-pf22	3.2	<0.050	10.304	0.054	10.167	10.16	0
1-2	37	AC1-21	21	2	w02-pf22	2.86	<0.050	9.209	0.054	9.087	8.12	0
1-2	38	EA	0	0	epf122	3.47	1.9	11.173	4.091	11.025	11.3	4.26
1-2	39	AC1-14	14	16	w16-pf22	2.78	<0.050	8.951	0.054	8.832	8.12	0
1-2	40	AC1-22	22	7	w07-pf22	3.29	<0.050	10.593	0.054	10.453	10.82	0
1-2	41	AC1-03	3	13	w13-pf22	3.32	<0.050	10.69	0.054	10.548	10.83	0
1-2	42	AC1-11	11	3	w03-pf12	2.74	<0.050	8.823	0.054	8.705	8.8	0
1-2	43	AC1-03	3	13	w13-pf12	3.26	<0.050	10.497	0.054	10.357	10.83	0
1-2	44	AC1-11	11	3	w03-pf22	2.48	<0.050	7.985	0.054	7.879	8.8	0
1-2	45	AC1-14	14	16	w16-pf12	2.61	<0.050	8.404	0.054	8.292	8.12	0
1-2	46	AC1-23	23	9	w09-pf12	3.07	<0.050	9.885	0.054	9.754	10.15	0
1-2	47	AC1-05	5	6	w06-pf12	3.03	<0.050	9.756	0.054	9.627	10.16	0
1-2	48	AC1-04	4	4	w04-pf22	3.38	<0.050	10.883	0.054	10.739	10.83	0
1-2	49	AC1-31	31	1	w01-pf22	2.91	<0.050	9.37	0.054	9.245	9.48	0
1-2	50	EA	0	0	epf123	3.55	1.9	11.431	4.091	11.279	11.3	4.26
2-1	51	EA	0	0	epf211	3.29	1.95	10.593	4.198	11.57	11.3	4.26
2-1	52	AC1-25	25	17	w17-pf21	2.57	<0.050	8.275	0.054	9.038	8.79	0
2-1	53	AC1-30	30	14	w14-pf11	2.48	<0.050	7.985	0.054	8.721	8.66	0
2-1	54	AC1-20	20	20	w20-pf11	2.47	<0.050	7.953	0.054	8.686	8.8	0
2-1	55	AC1-06	6	25	w25-pf11	3.04	<0.050	9.788	0.054	10.69	10.16	0
2-1	56	AC1-25	25	17	w17-pf11	2.55	<0.050	8.211	0.054	8.967	8.79	0
2-1	57	AC1-09	9	23	w23-pf11	2.73	<0.050	8.79	0.054	9.6	9.48	0
2-1	58	AC1-08	8	24	w24-pf21	2.57	<0.050	8.275	0.054	9.038	9.48	0
2-1	59	AC1-08	8	24	w24-pf11	2.57	<0.050	8.275	0.054	9.038	9.48	0
2-1	60	AC1-12	12	15	w15-pf21	2.41	<0.050	7.76	0.054	8.475	8.8	0
2-1	61	AC1-09	9	23	w23-pf21	3.04	<0.050	9.788	0.054	10.69	9.48	0
2-1	62	AC1-13	13	12	w12-pf21	2.45	<0.050	7.889	0.054	8.616	8.8	0
2-1	63	EA	0	0	epf212	3.24	1.8	10.432	3.875	11.394	11.3	4.26
2-1	64	AC1-01	1	26	w26-pf21	2.26	<0.050	7.277	0.054	7.948	9.49	0
2-1	65	AC1-06	6	25	w25-pf21	2.87	<0.050	9.241	0.054	10.093	10.16	0
2-1	66	AC1-02	2	29	w29-pf11	2.92	<0.050	9.402	0.054	10.268	10.83	0
2-1	67	AC1-02	2	29	w29-pf21	3.02	<0.050	9.724	0.054	10.62	10.83	0
2-1	68	AC1-10	10	28	w28-pf21	2.68	<0.050	8.629	0.054	9.424	9.48	0
2-1	69	AC1-01	1	26	w26-pf11	2.22	<0.050	7.148	0.054	7.807	9.49	0
2-1	70	AC1-12	12	15	w15-pf11	2.57	<0.050	8.275	0.054	9.038	8.8	0
2-1	71	AC1-30	30	14	w14-pf21	2.42	<0.050	7.792	0.054	8.51	8.66	0
2-1	72	AC1-20	20	20	w20-pf21	2.41	<0.050	7.76	0.054	8.475	8.8	0
2-1	73	AC1-13	13	12	w12-pf11	2.37	<0.050	7.631	0.054	8.334	8.8	0
2-1	74	AC1-10	10	28	w28-pf11	2.62	<0.050	8.436	0.054	9.213	9.48	0

< implies less than the indicated detection limit

Concentrations are expressed as weight percents.

Table A.2: Measured and Target Compositions (Peroxide Fusion Dissolution Method)

Block	Run Order	Glass ID	Glass #	Lab #	Lab ID	B	Li	B2O3	Li2O	B2O3 (Bias Corrected)	Target Compositions B2O3	Li2O
2-1	75	EA	0	0	epf213	3.11	1.76	10.014	3.789	10.937	11.3	4.26
2-2	76	EA	0	0	epf221	3.57	2.05	11.495	4.413	11.923	11.3	4.26
2-2	77	AC1-30	30	14	w14-pf22	2.58	<0.050	8.307	0.054	8.617	8.66	0
2-2	78	AC1-02	2	29	w29-pf12	3.34	<0.050	10.754	0.054	11.155	10.83	0
2-2	79	AC1-30	30	14	w14-pf12	2.59	<0.050	8.34	0.054	8.65	8.66	0
2-2	80	AC1-10	10	28	w28-pf12	2.7	<0.050	8.694	0.054	9.018	9.48	0
2-2	81	AC1-09	9	23	w23-pf12	2.78	<0.050	8.951	0.054	9.285	9.48	0
2-2	82	AC1-01	1	26	w26-pf22	2.37	<0.050	7.631	0.054	7.916	9.49	0
2-2	83	AC1-20	20	20	w20-pf12	2.56	<0.050	8.243	0.054	8.55	8.8	0
2-2	84	AC1-25	25	17	w17-pf12	2.44	<0.050	7.857	0.054	8.149	8.79	0
2-2	85	AC1-10	10	28	w28-pf22	2.74	<0.050	8.823	0.054	9.151	9.48	0
2-2	86	AC1-13	13	12	w12-pf12	2.57	<0.050	8.275	0.054	8.584	8.8	0
2-2	87	AC1-08	8	24	w24-pf12	2.83	<0.050	9.112	0.054	9.452	9.48	0
2-2	88	EA	0	0	epf222	3.28	2	10.561	4.306	10.955	11.3	4.26
2-2	89	AC1-08	8	24	w24-pf22	2.76	<0.050	8.887	0.054	9.218	9.48	0
2-2	90	AC1-01	1	26	w26-pf12	2.28	<0.050	7.341	0.054	7.615	9.49	0
2-2	91	AC1-12	12	15	w15-pf22	2.54	<0.050	8.179	0.054	8.483	8.8	0
2-2	92	AC1-25	25	17	w17-pf22	2.54	<0.050	8.179	0.054	8.483	8.79	0
2-2	93	AC1-02	2	29	w29-pf22	3.14	<0.050	10.11	0.054	10.487	10.83	0
2-2	94	AC1-06	6	25	w25-pf22	2.95	<0.050	9.499	0.054	9.853	10.16	0
2-2	95	AC1-12	12	15	w15-pf12	2.58	<0.050	8.307	0.054	8.617	8.8	0
2-2	96	AC1-20	20	20	w20-pf22	2.45	<0.050	7.889	0.054	8.183	8.8	0
2-2	97	AC1-13	13	12	w12-pf22	2.34	<0.050	7.535	0.054	7.815	8.8	0
2-2	98	AC1-09	9	23	w23-pf22	2.58	<0.050	8.307	0.054	8.617	9.48	0
2-2	99	AC1-06	6	25	w25-pf12	2.84	<0.050	9.145	0.054	9.485	10.16	0
2-2	100	EA	0	0	epf223	3.3	1.92	10.626	4.134	11.022	11.3	4.26
3-1	101	EA	0	0	epf311	3.4	2.12	10.948	4.564	11.278	11.3	4.26
3-1	102	AC1-18	18	31	w31-pf11	3.09	0.164	9.949	0.353	10.25	10.16	0
3-1	103	AC1-16	16	27	w27-pf11	2.72	<0.050	8.758	0.054	9.022	8.12	0
3-1	104	AC1-24	24	18	w18-pf11	2.84	<0.050	9.145	0.054	9.42	9.47	0
3-1	105	AC1-27	27	11	w11-pf21	2.74	<0.050	8.823	0.054	9.089	9.4	0
3-1	106	AC1-24	24	18	w18-pf21	2.8	<0.050	9.016	0.054	9.288	9.47	0
3-1	107	ARM	100	10	w10-pf11	3.62	2.27	11.656	4.887	12.008	11.3	5.08
3-1	108	AC1-29	29	21	w21-pf21	2.56	<0.050	8.243	0.054	8.492	8.8	0
3-1	109	ARM	100	10	w10-pf21	3.62	2.06	11.656	4.435	12.008	11.3	5.08
3-1	110	AC1-27	27	11	w11-pf11	2.79	<0.050	8.984	0.054	9.254	9.4	0
3-1	111	EA	0	0	epf312	3.49	2.19	11.237	4.715	11.576	11.3	4.26
3-1	112	AC1-15	15	19	w19-pf11	2.34	<0.050	7.535	0.054	7.762	8.12	0
3-1	113	AC1-15	15	19	w19-pf21	2.49	<0.050	8.018	0.054	8.259	8.12	0
3-1	114	AC1-29	29	21	w21-pf11	2.59	<0.050	8.34	0.054	8.591	8.8	0
3-1	115	AC1-19	19	30	w30-pf21	2.43	<0.050	7.824	0.054	8.06	9.48	0
3-1	116	AC1-17	17	22	w22-pf11	3.11	<0.050	10.014	0.054	10.316	10.83	0
3-1	117	AC1-28	28	32	w32-pf11	2.58	<0.050	8.307	0.054	8.558	9.16	0
3-1	118	AC1-17	17	22	w22-pf21	3.17	<0.050	10.207	0.054	10.515	10.83	0
3-1	119	AC1-28	28	32	w32-pf21	2.74	<0.050	8.823	0.054	9.089	9.16	0
3-1	120	AC1-16	16	27	w27-pf21	2.72	<0.050	8.758	0.054	9.022	8.12	0
3-1	121	AC1-18	18	31	w31-pf21	2.78	<0.050	8.951	0.054	9.221	10.16	0
3-1	122	AC1-19	19	30	w30-pf11	2.35	<0.050	7.567	0.054	7.795	9.48	0
3-1	123	EA	0	0	epf313	3.33	1.95	10.722	4.198	11.046	11.3	4.26
3-2	124	EA	0	0	epf321	3.55	2.2	11.431	4.736	12.168	11.3	4.26
3-2	125	AC1-16	16	27	w27-pf12	2.78	<0.050	8.951	0.054	9.529	8.12	0
3-2	126	AC1-17	17	22	w22-pf22	3.13	<0.050	10.078	0.054	10.729	10.83	0
3-2	127	ARM	100	10	w10-pf12	3.63	2.11	11.688	4.543	12.443	11.3	5.08
3-2	128	AC1-15	15	19	w19-pf12	2.43	<0.050	7.824	0.054	8.329	8.12	0
3-2	129	AC1-19	19	30	w30-pf12	2.41	<0.050	7.76	0.054	8.261	9.48	0
3-2	130	AC1-17	17	22	w22-pf12	3.12	<0.050	10.046	0.054	10.694	10.83	0
3-2	131	AC1-19	19	30	w30-pf22	2.34	<0.050	7.535	0.054	8.021	9.48	0
3-2	132	AC1-27	27	11	w11-pf12	2.83	<0.050	9.112	0.054	9.7	9.4	0
3-2	133	AC1-18	18	31	w31-pf22	2.83	<0.050	9.112	0.054	9.7	10.16	0
3-2	134	EA	0	0	epf322	3.09	1.9	9.949	4.091	10.592	11.3	4.26
3-2	135	AC1-29	29	21	w21-pf12	2.59	<0.050	8.34	0.054	8.878	8.8	0
3-2	136	ARM	100	10	w10-pf22	3.5	2.29	11.27	4.93	11.997	11.3	5.08
3-2	137	AC1-15	15	19	w19-pf22	2.26	<0.050	7.277	0.054	7.747	8.12	0
3-2	138	AC1-24	24	18	w18-pf22	2.71	<0.050	8.726	0.054	9.289	9.47	0
3-2	139	AC1-18	18	31	w31-pf12	2.85	0.267	9.177	0.575	9.769	10.16	0
3-2	140	AC1-28	28	32	w32-pf12	2.63	<0.050	8.468	0.054	9.015	9.16	0
3-2	141	AC1-29	29	21	w21-pf22	2.54	<0.050	8.179	0.054	8.706	8.8	0
3-2	142	AC1-28	28	32	w32-pf22	2.58	<0.050	8.307	0.054	8.843	9.16	0
3-2	143	AC1-24	24	18	w18-pf12	2.74	<0.050	8.823	0.054	9.392	9.47	0
3-2	144	AC1-27	27	11	w11-pf22	2.63	<0.050	8.468	0.054	9.015	9.4	0
3-2	145	AC1-16	16	27	w27-pf22	2.6	<0.050	8.372	0.054	8.912	8.12	0
3-2	146	EA	0	0	epf323	3.25	1.91	10.465	4.112	11.14	11.3	4.26

< implies less than the indicated detection limit

Concentrations are expressed as weight percents.

Table A.3: Comparisons of Target Versus Measured Oxide Concentrations

Short Glass ID	Al2O3 Target	Al2O3 Meas	Al2O3 % Rel Diff	B2O3 Target	B2O3 Meas	B2O3 Bias Cor. Block	B2O3 % Rel Diff Meas	B2O3 % Rel Diff BC	CaO Target	CaO Meas	CaO % Rel Diff
0 (EA)	3.700	3.726	0.7%	11.300	10.864	11.300	-3.9%	0.0%	1.120	1.070	-4.5%
1	17.310	14.530	-16.1%	9.490	7.349	7.821	-22.6%	-17.6%	0.000	0.033	
2	19.900	19.126	-3.9%	10.830	9.998	10.633	-7.7%	-1.8%	0.000	0.035	
3	19.900	17.624	-11.4%	10.830	10.344	10.457	-4.5%	-3.4%	0.000	0.010	
4	19.900	18.503	-7.0%	10.830	10.714	10.836	-1.1%	0.1%	0.000	0.012	
5	18.650	17.228	-7.6%	10.160	9.933	10.045	-2.2%	-1.1%	0.000	0.009	
6	18.650	18.045	-3.2%	10.160	9.418	10.030	-7.3%	-1.3%	0.000	0.037	
7	18.650	18.016	-3.4%	10.160	9.949	10.059	-2.1%	-1.0%	0.000	0.012	
8	17.410	16.812	-3.4%	9.480	8.637	9.186	-8.9%	-3.1%	0.000	0.021	
9	17.410	17.322	-0.5%	9.480	8.959	9.548	-5.5%	0.7%	0.000	0.015	
10	17.410	17.006	-2.3%	9.480	8.645	9.202	-8.8%	-2.9%	0.000	0.015	
11	16.170	14.280	-11.7%	8.800	8.283	8.375	-5.9%	-4.8%	0.000	0.022	
12	16.170	15.508	-4.1%	8.800	8.130	8.653	-7.6%	-1.7%	0.000	0.020	
13	16.170	15.130	-6.4%	8.800	7.832	8.337	-11.0%	-5.3%	0.000	0.021	
14	14.920	15.281	2.4%	8.120	8.557	8.652	5.4%	6.6%	0.000	0.021	
15	14.920	14.663	-1.7%	8.120	7.663	8.024	-5.6%	-1.2%	0.000	0.019	
16	14.920	16.339	9.5%	8.120	8.710	9.121	7.3%	12.3%	0.000	0.015	
17	19.900	20.170	1.4%	10.830	10.086	10.564	-6.9%	-2.5%	0.000	0.017	
18	18.650	18.106	-2.9%	10.160	9.297	9.735	-8.5%	-4.2%	0.000	0.017	
19	17.410	15.073	-13.4%	9.480	7.671	8.034	-19.1%	-15.3%	0.000	0.014	
20	16.170	15.990	-1.1%	8.800	7.961	8.473	-9.5%	-3.7%	0.000	0.014	
21	14.920	16.278	9.1%	8.120	9.153	9.249	12.7%	13.9%	0.000	0.018	
22	19.880	18.744	-5.7%	9.910	10.585	10.699	6.8%	8.0%	0.005	0.031	529.6%
23	18.630	18.257	-2.0%	9.300	9.805	9.916	5.4%	6.6%	0.005	0.028	452.7%
24	17.390	16.349	-6.0%	8.670	8.927	9.347	3.0%	7.8%	0.005	0.033	557.6%
25	16.150	15.820	-2.0%	8.050	8.130	8.659	1.0%	7.6%	0.005	0.042	739.5%
26	14.910	13.614	-8.7%	7.430	7.961	8.050	7.1%	8.3%	0.005	0.014	172.8%
27	17.270	15.688	-9.2%	9.400	8.847	9.265	-5.9%	-1.4%	0.000	0.012	
28	16.820	15.843	-5.8%	9.070	8.476	8.876	-6.5%	-2.1%	0.000	0.032	
29	16.170	16.325	1.0%	8.800	8.275	8.667	-6.0%	-1.5%	0.000	0.041	
30	15.910	15.371	-3.4%	8.660	8.106	8.625	-6.4%	-0.4%	0.000	0.031	
31	17.410	15.829	-9.1%	9.480	9.394	9.502	-0.9%	0.2%	0.000	0.009	
100 (ARM)	5.590	5.626	0.6%	11.300	11.567	12.114	2.4%	7.2%	2.230	2.281	2.3%
Min			-16.1%				-22.6%	-17.6%			-4.5%
Avg			-3.9%				-3.7%	0.1%			350.0%
Max			9.5%				12.7%	13.9%			739.5%

Table A.3: Comparisons of Target Versus Measured Oxide Concentrations

	Ce2O3			Cr2O3			Er2O3			Eu2O3		
Short Glass ID	Target	Meas	% Rel Diff	Target	Meas	% Rel Diff	Target	Meas	% Rel Diff	Target	Meas	% Rel Diff
0 (EA)	0.000	0.293		0.000	0.073		0.000	0.692		0.000	0.006	
1	4.150	4.589	10.6%	0.000	0.073		3.780	4.748	25.6%	0.550	0.671	21.9%
2	3.120	3.007	-3.6%	0.000	0.073		2.880	2.876	-0.1%	0.390	0.376	-3.5%
3	3.120	2.943	-5.7%	0.000	0.073		2.900	2.913	0.5%	0.390	0.362	-7.1%
4	2.620	2.457	-6.2%	0.000	0.073		2.410	2.336	-3.1%	0.350	0.330	-5.7%
5	3.900	3.619	-7.2%	0.000	0.073		3.200	3.153	-1.5%	0.440	0.406	-7.6%
6	2.660	2.556	-3.9%	0.000	0.073		3.020	2.913	-3.5%	0.440	0.425	-3.5%
7	3.270	3.025	-7.5%	0.000	0.073		3.010	2.945	-2.2%	0.440	0.429	-2.5%
8	3.940	3.725	-5.5%	0.000	0.073		4.350	4.211	-3.2%	0.470	0.457	-2.8%
9	3.200	2.975	-7.0%	0.000	0.073		2.920	2.756	-5.6%	0.490	0.465	-5.0%
10	3.930	3.728	-5.1%	0.000	0.073		3.610	3.568	-1.2%	0.520	0.516	-0.7%
11	4.280	3.857	-9.9%	0.000	0.073		3.930	4.057	3.2%	0.540	0.586	8.4%
12	5.210	4.779	-8.3%	0.000	0.073		4.820	4.497	-6.7%	0.680	0.635	-6.6%
13	4.580	4.047	-11.6%	0.000	0.073		4.210	3.965	-5.8%	0.610	0.606	-0.6%
14	4.260	3.982	-6.5%	0.000	0.073		4.190	3.742	-10.7%	0.620	0.535	-13.7%
15	6.240	5.602	-10.2%	0.000	0.073		4.830	4.631	-4.1%	0.620	0.617	-0.5%
16	5.240	3.903	-25.5%	0.000	0.073		4.810	3.622	-24.7%	0.700	0.535	-23.6%
17	2.620	2.483	-5.2%	0.000	0.073		2.410	2.404	-0.2%	0.350	0.359	2.6%
18	3.270	3.136	-4.1%	0.000	0.073		3.010	2.813	-6.5%	0.440	0.426	-3.2%
19	3.930	4.823	22.7%	0.000	0.073		3.610	4.488	24.3%	0.520	0.660	26.9%
20	4.580	4.205	-8.2%	0.000	0.073		4.210	4.159	-1.2%	0.610	0.608	-0.2%
21	5.240	3.836	-26.8%	0.000	0.073		4.810	3.588	-25.4%	0.700	0.515	-26.4%
22	2.620	2.521	-3.8%	0.005	0.073	1361.6%	2.410	2.376	-1.4%	0.350	0.343	-1.9%
23	3.270	3.113	-4.8%	0.005	0.073	1361.6%	3.010	2.982	-0.9%	0.440	0.432	-1.9%
24	3.930	3.564	-9.3%	0.005	0.073	1361.6%	3.610	3.408	-5.6%	0.520	0.490	-5.8%
25	4.580	4.363	-4.7%	0.005	0.073	1361.6%	4.210	4.074	-3.2%	0.610	0.602	-1.2%
26	5.240	4.779	-8.8%	0.005	0.073	1361.6%	4.810	4.614	-4.1%	0.700	0.633	-9.6%
27	4.070	3.883	-4.6%	0.000	0.073		3.700	3.611	-2.4%	1.330	1.219	-8.4%
28	4.310	3.801	-11.8%	0.000	0.073		3.910	3.639	-6.9%	1.410	1.311	-7.0%
29	4.660	4.635	-0.5%	0.000	0.073		4.230	4.217	-0.3%	1.530	1.497	-2.2%
30	4.800	4.551	-5.2%	0.000	0.073		4.350	4.257	-2.1%	1.570	1.508	-3.9%
31	4.000	3.845	-3.9%	0.000	0.073		3.620	3.588	-0.9%	1.310	1.193	-9.0%
100 (ARM)	1.440	1.288	-10.5%	0.000	0.073		0.000	3.422		0.000	0.012	
Min			-26.8%			1361.6%			-25.4%			-26.4%
Avg			-6.3%			1361.6%			-2.6%			-3.4%
Max			22.7%			1361.6%			25.6%			26.9%

Short Glass ID	Fe2O3 Target	Fe2O3 Meas	Fe2O3 % Rel Diff	Gd2O3 Target	Gd2O3 Meas	Gd2O3 % Rel Diff	K2O Target	K2O Meas	K2O % Rel Diff	La2O3 Target	La2O3 Meas	La2O3 % Rel Diff
0 (EA)	8.990	8.473	-5.7%	0.000	0.029		0.040	0.090	125.9%	0.420	0.547	30.3%
1	0.000	0.030		1.340	1.663	24.1%	0.000	0.090		21.770	20.143	-7.5%
2	0.000	0.033		0.700	0.708	1.2%	0.000	0.090		23.630	23.016	-2.6%
3	0.000	0.054		0.700	0.741	5.8%	0.000	0.090		22.470	21.492	-4.4%
4	0.000	0.052		0.830	0.871	4.9%	0.000	0.090		23.040	21.961	-4.7%
5	0.000	0.041		1.040	1.004	-3.4%	0.000	0.090		21.840	20.377	-6.7%
6	0.000	0.033		1.210	1.166	-3.7%	0.000	0.090		23.280	21.580	-7.3%
7	0.000	0.048		1.040	1.043	0.3%	0.000	0.090		22.550	21.697	-3.8%
8	0.000	0.068		1.450	1.432	-1.2%	0.000	0.090		22.940	22.225	-3.1%
9	0.000	0.067		1.070	0.902	-15.7%	0.000	0.090		21.200	20.671	-2.5%
10	0.000	0.063		1.250	1.187	-5.0%	0.000	0.090		22.060	21.785	-1.2%
11	0.000	0.019		1.700	1.905	12.0%	0.000	0.090		20.570	19.175	-6.8%
12	0.000	0.021		1.700	1.521	-10.5%	0.000	0.090		22.600	21.580	-4.5%
13	0.000	0.024		1.460	1.530	4.8%	0.000	0.090		21.570	20.084	-6.9%
14	0.000	0.020		1.940	1.726	-11.0%	0.000	0.090		19.940	19.439	-2.5%
15	0.000	0.021		1.670	1.550	-7.2%	0.000	0.090		22.250	21.638	-2.7%
16	0.000	0.061		1.670	1.374	-17.7%	0.000	0.090		21.080	20.436	-3.1%
17	0.000	0.074		0.830	0.830	0.0%	0.000	0.090		23.040	22.782	-1.1%
18	0.000	0.068		1.040	0.947	-9.0%	0.000	0.090		22.550	21.550	-4.4%
19	0.000	0.059		1.250	1.493	19.4%	0.000	0.090		22.060	21.110	-4.3%
20	0.000	0.071		1.460	1.357	-7.0%	0.000	0.090		21.570	21.081	-2.3%
21	0.000	0.019		1.670	1.262	-24.4%	0.000	0.090		21.080	20.319	-3.6%
22	0.010	0.029	193.1%	0.830	0.784	-5.6%	0.005	0.090	1706.9%	23.020	21.873	-5.0%
23	0.010	0.027	171.6%	1.040	1.030	-0.9%	0.005	0.090	1706.9%	22.530	21.667	-3.8%
24	0.010	0.037	271.7%	1.250	1.121	-10.3%	0.005	0.090	1706.9%	22.040	20.201	-8.3%
25	0.010	0.042	318.2%	1.460	1.441	-1.3%	0.005	0.090	1706.9%	21.550	20.553	-4.6%
26	0.010	0.058	479.0%	1.670	1.544	-7.5%	0.005	0.090	1706.9%	21.060	19.703	-6.4%
27	0.009	0.039	332.9%	0.590	0.607	3.0%	0.000	0.090		22.070	20.465	-7.3%
28	0.010	0.035	250.3%	0.630	0.620	-1.6%	0.000	0.090		21.900	20.172	-7.9%
29	0.011	0.039	254.2%	0.680	0.630	-7.4%	0.000	0.090		21.650	21.433	-1.0%
30	0.011	0.036	224.9%	0.700	0.634	-9.5%	0.000	0.090		21.550	21.140	-1.9%
31	0.009	0.048	436.1%	0.580	0.635	9.5%	0.000	0.090		22.130	20.759	-6.2%
100 (ARM)	0.000	0.038		0.000	0.123		0.000	0.090		0.000	0.109	
Min			-5.7%			-24.4%			125.9%			-8.3%
Avg			266.0%			-2.4%			1443.4%			-3.4%
Max			479.0%			24.1%			1706.9%			30.3%

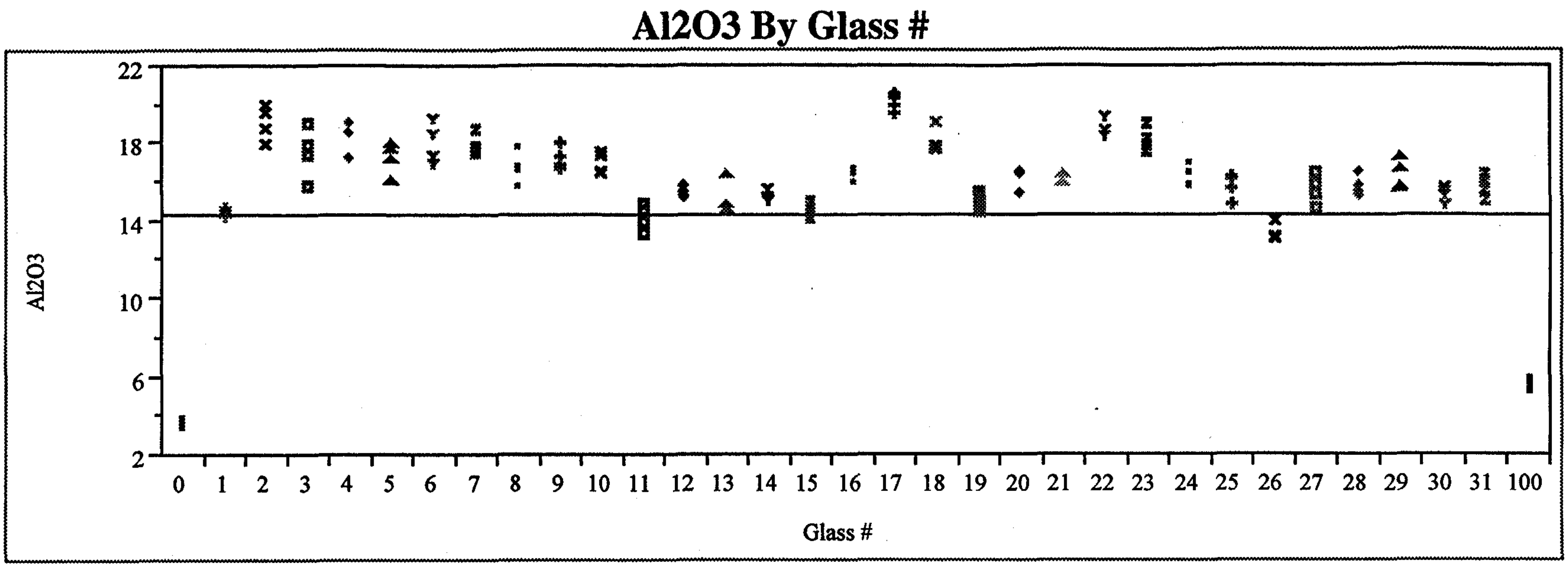
Short Glass ID	Li2O Target	Li2O Meas	Li2O % Rel Diff	MnO Target	MnO Meas	MnO % Rel Diff	Na2O Target	Na2O Meas	Na2O % Rel Diff	Nd2O3 Target	Nd2O3 Meas	Nd2O3 % Rel Diff
0 (EA)	4.260	4.262	0.0%	1.340	2.849	112.6%	16.800	16.440	-2.1%	0.000	0.091	
1	0.000	0.054		0.000	0.015		0.000	0.247		10.010	12.568	25.6%
2	0.000	0.054		0.000	0.015		0.000	0.101		5.310	5.059	-4.7%
3	0.000	0.054		0.000	0.015		0.000	0.210		6.450	5.934	-8.0%
4	0.000	0.054		0.000	0.015		0.000	0.199		6.950	6.360	-8.5%
5	0.000	0.054		0.000	0.015		0.000	0.101		9.430	8.424	-10.7%
6	0.000	0.054		0.000	0.015		0.000	0.101		7.820	6.503	-16.8%
7	0.000	0.054		0.000	0.015		0.000	0.101		8.680	8.162	-6.0%
8	0.000	0.054		0.000	0.031		0.000	0.228		8.840	7.806	-11.7%
9	0.000	0.054		0.000	0.031		0.000	0.101		11.830	10.288	-13.0%
10	0.000	0.054		0.000	0.030		0.000	0.101		10.420	9.250	-11.2%
11	0.000	0.054		0.000	0.015		0.000	0.101		13.800	14.522	5.2%
12	0.000	0.054		0.000	0.015		0.000	0.101		9.290	8.404	-9.5%
13	0.000	0.054		0.000	0.018		0.000	0.101		12.160	10.451	-14.1%
14	0.000	0.054		0.000	0.015		0.000	0.101		15.770	13.414	-14.9%
15	0.000	0.054		0.000	0.015		0.000	0.101		13.140	12.273	-6.6%
16	0.000	0.054		0.000	0.031		0.000	0.101		13.890	9.856	-29.0%
17	0.000	0.054		0.000	0.031		0.000	0.196		6.950	6.404	-7.9%
18	0.000	0.259		0.000	0.032		0.000	0.101		8.680	7.759	-10.6%
19	0.000	0.054		0.000	0.031		0.000	0.101		10.420	12.168	16.8%
20	0.000	0.054		0.000	0.031		0.000	0.101		12.160	10.757	-11.5%
21	0.000	0.054		0.000	0.015		0.000	0.217		13.890	8.990	-35.3%
22	0.000	0.054		0.050	0.096	91.1%	0.005	0.134	2575.8%	6.940	6.605	-4.8%
23	0.000	0.054		0.050	0.106	111.5%	0.005	0.101	1922.0%	8.670	8.074	-6.9%
24	0.000	0.054		0.050	0.062	24.0%	0.005	0.101	1922.0%	10.410	9.387	-9.8%
25	0.000	0.054		0.050	0.069	37.1%	0.005	0.170	3290.2%	12.150	11.372	-6.4%
26	0.000	0.054		0.050	0.055	9.4%	0.005	0.127	2447.7%	13.880	11.874	-14.5%
27	0.000	0.054		0.043	0.034	-20.3%	0.000	0.101		10.150	8.891	-12.4%
28	0.000	0.054		0.045	0.051	13.5%	0.000	0.170		10.740	9.827	-8.5%
29	0.000	0.054		0.049	0.070	42.9%	0.000	0.194		11.610	11.075	-4.6%
30	0.000	0.054		0.050	0.066	31.3%	0.000	0.154		11.960	11.028	-7.8%
31	0.000	0.054		0.042	0.027	-35.7%	0.000	0.152		9.950	8.687	-12.7%
100 (ARM)	5.080	4.699	-7.5%	0.000	0.015		9.670	9.608	-0.6%	5.960	5.240	-12.1%
Min			-7.5%			-35.7%			-2.1%			-35.3%
Avg			-3.7%			38.0%			1736.4%			-8.8%
Max			0.0%			112.6%			3290.2%			25.6%

Table A.3: Comparisons of Target Versus Measured Oxide Concentrations

	NiO			Pr2O3			SiO2			Sm2O3		
Short Glass ID	Target	Meas	% Rel Diff	Target	Meas	% Rel Diff	Target	Meas	% Rel Diff	Target	Meas	% Rel Diff
0 (EA)	0.570	0.546	-4.3%	0.000	0.059		48.730	45.232	-7.2%	0.000	0.054	
1	0.000	0.063		3.610	4.602	27.5%	23.500	20.056	-14.7%	2.450	3.606	47.2%
2	0.000	0.025		2.720	2.739	0.7%	26.940	26.902	-0.1%	1.260	1.400	11.1%
3	0.000	0.024		2.720	2.572	-5.5%	26.940	24.495	-9.1%	1.260	1.081	-14.2%
4	0.000	0.148		2.290	2.148	-6.2%	26.940	24.816	-7.9%	1.520	1.104	-27.4%
5	0.000	0.013		2.330	2.308	-0.9%	25.260	22.730	-10.0%	1.580	1.089	-31.1%
6	0.000	0.031		3.400	3.154	-7.2%	25.260	23.960	-5.1%	1.920	2.270	18.2%
7	0.000	0.023		2.860	2.741	-4.1%	25.260	24.442	-3.2%	1.900	1.635	-13.9%
8	0.000	0.155		2.790	2.853	2.2%	23.580	22.415	-4.9%	2.720	2.621	-3.7%
9	0.000	0.041		4.080	3.780	-7.4%	23.580	23.158	-1.8%	2.720	1.760	-35.3%
10	0.000	0.085		3.430	3.379	-1.5%	23.580	22.575	-4.3%	2.280	2.026	-11.1%
11	0.000	0.040		3.260	4.743	45.5%	21.890	19.601	-10.5%	3.170	2.971	-6.3%
12	0.000	0.070		4.760	4.599	-3.4%	21.890	20.329	-7.1%	2.200	1.687	-23.3%
13	0.000	0.046		4.010	3.809	-5.0%	21.890	20.682	-5.5%	2.660	4.053	52.4%
14	0.000	0.040		5.430	3.666	-32.5%	20.210	20.666	2.3%	2.840	3.261	14.8%
15	0.000	0.027		3.720	3.912	5.2%	20.210	19.628	-2.9%	2.520	1.812	-28.1%
16	0.000	0.059		4.580	3.490	-23.8%	20.210	21.297	5.4%	3.040	2.931	-3.6%
17	0.000	0.058		2.290	2.326	1.6%	26.940	25.672	-4.7%	1.520	1.403	-7.7%
18	0.000	0.139		2.860	2.841	-0.7%	25.260	24.495	-3.0%	1.900	1.589	-16.4%
19	0.000	0.025		3.430	4.389	27.9%	23.580	20.061	-14.9%	2.280	2.261	-0.8%
20	0.000	0.048		4.010	4.023	0.3%	21.890	20.773	-5.1%	2.660	1.838	-30.9%
21	0.000	0.031		4.580	3.449	-24.7%	20.210	21.869	8.2%	3.040	2.134	-29.8%
22	0.005	0.027	434.5%	2.290	2.358	3.0%	26.910	25.137	-6.6%	1.520	1.220	-19.7%
23	0.005	0.024	370.8%	2.860	2.853	-0.3%	25.240	24.495	-3.0%	1.900	1.841	-3.1%
24	0.005	0.055	1007.1%	3.430	3.368	-1.8%	23.560	22.500	-4.5%	2.280	2.168	-4.9%
25	0.005	0.034	580.8%	4.010	4.026	0.4%	21.870	21.479	-1.8%	2.660	2.783	4.6%
26	0.005	0.017	243.6%	4.580	4.213	-8.0%	20.190	18.639	-7.7%	3.040	2.279	-25.0%
27	0.000	0.013		3.560	3.186	-10.5%	23.380	22.126	-5.4%	2.410	1.668	-30.8%
28	0.000	0.024		3.770	3.581	-5.0%	22.780	21.179	-7.0%	2.550	2.760	8.2%
29	0.000	0.020		4.070	4.292	5.5%	21.890	22.570	3.1%	2.760	2.139	-22.5%
30	0.000	0.024		4.200	4.160	-0.9%	21.540	21.222	-1.5%	2.840	1.983	-30.2%
31	0.000	0.037		3.490	3.239	-7.2%	23.580	21.446	-9.0%	2.360	1.225	-48.1%
100 (ARM)	0.000	0.018		0.000	0.186		46.500	44.444	-4.4%	0.000	0.060	
Min			-4.3%			-32.5%			-14.9%			-48.1%
Avg			438.7%			-1.2%			-4.7%			-10.0%
Max			1007.1%			45.5%			8.2%			52.4%

Table A.3: Comparisons of Target Versus Measured Oxide Concentrations

	SrO			Sum of Oxides			Total Lanthanides		
Short Glass ID	Target	Meas	% Rel Diff	Target	Meas	Meas (bc)	Target	Meas	% Rel. Diff.
0 (EA)	0.000	0.017		97.27	95.41	95.85	0.420	1.770	321.5%
1	2.050	1.653	-19.4%	100.01	96.78	97.25	47.660	52.590	10.3%
2	2.330	2.256	-3.2%	100.01	97.89	98.52	40.010	39.182	-2.1%
3	2.330	2.297	-1.4%	100.01	93.33	93.44	40.010	38.038	-4.9%
4	2.330	2.336	0.2%	100.01	94.58	94.70	40.010	37.566	-6.1%
5	2.180	2.191	0.5%	100.01	92.86	92.97	43.760	40.382	-7.7%
6	2.180	2.070	-5.1%	100.00	94.49	95.10	43.750	40.566	-7.3%
7	2.180	2.253	3.3%	100.00	96.75	96.86	43.750	41.677	-4.7%
8	2.040	1.960	-3.9%	100.01	95.87	96.42	47.500	45.329	-4.6%
9	2.040	1.960	-3.9%	100.02	95.47	96.06	47.510	43.596	-8.2%
10	2.040	1.954	-4.2%	100.01	96.13	96.69	47.500	45.438	-4.3%
11	1.890	1.626	-14.0%	100.00	96.02	96.11	51.250	51.814	1.1%
12	1.890	1.783	-5.7%	100.01	93.90	94.42	51.260	47.702	-6.9%
13	1.890	1.744	-7.7%	100.01	94.36	94.87	51.260	48.545	-5.3%
14	1.750	1.759	0.5%	99.99	96.44	96.54	54.990	49.766	-9.5%
15	1.750	1.665	-4.9%	99.99	96.05	96.41	54.990	52.035	-5.4%
16	1.750	1.910	9.1%	100.01	94.89	95.30	55.010	46.148	-16.1%
17	2.330	2.315	-0.6%	100.01	97.83	98.30	40.010	38.990	-2.5%
18	2.180	2.031	-6.8%	100.00	95.77	96.21	43.750	41.061	-6.1%
19	2.040	1.750	-14.2%	100.01	96.40	96.76	47.500	51.392	8.2%
20	1.890	1.848	-2.2%	100.01	95.08	95.60	51.260	48.029	-6.3%
21	1.750	1.874	7.1%	100.01	93.78	93.88	55.010	44.093	-19.8%
22	2.330	2.155	-7.5%	99.10	95.24	95.35	39.980	38.080	-4.8%
23	2.180	2.093	-4.0%	99.16	97.14	97.26	43.720	41.992	-4.0%
24	2.040	1.869	-8.4%	99.22	93.86	94.28	47.470	43.706	-7.9%
25	1.890	1.869	-1.1%	99.28	97.08	97.61	51.230	49.215	-3.9%
26	1.750	1.679	-4.0%	99.35	92.02	92.11	54.980	49.639	-9.7%
27	2.020	1.895	-6.2%	100.00	92.50	92.92	47.880	43.530	-9.1%
28	1.970	1.824	-7.4%	99.92	93.56	93.96	49.220	45.712	-7.1%
29	1.890	1.937	2.5%	100.00	99.60	100.00	51.190	49.918	-2.5%
30	1.860	1.792	-3.7%	100.00	96.28	96.80	51.970	49.260	-5.2%
31	2.040	1.963	-3.8%	100.00	92.29	92.40	47.440	43.170	-9.0%
100 (ARM)	0.450	0.461	2.4%	88.22	89.36	89.91	7.400	10.440	41.1%
Min			-19.4%						-19.8%
Avg			-3.7%						5.8%
Max			9.1%						321.5%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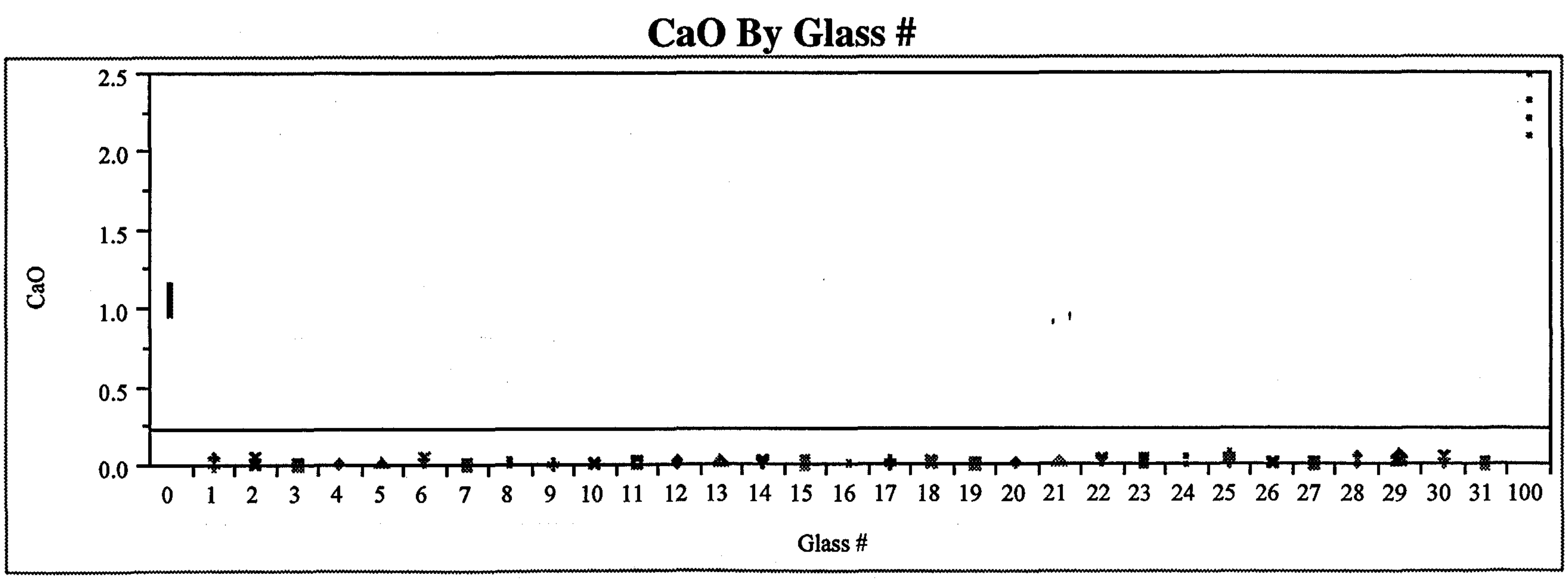
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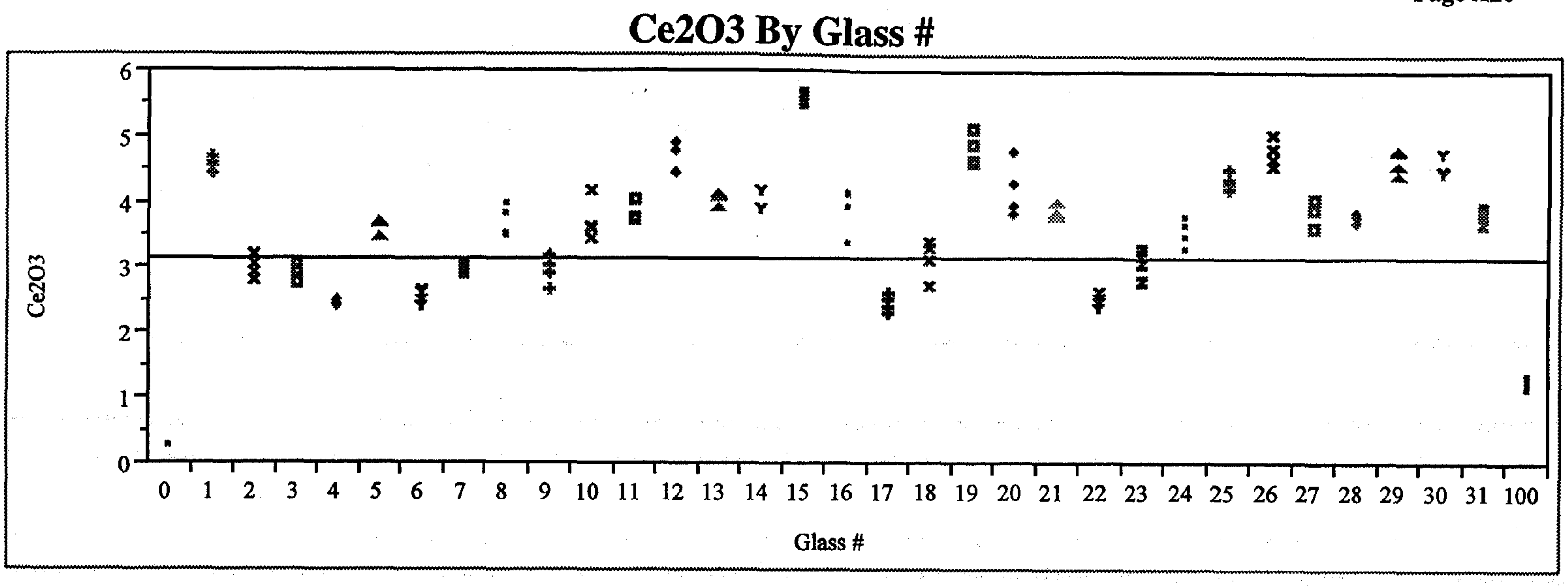
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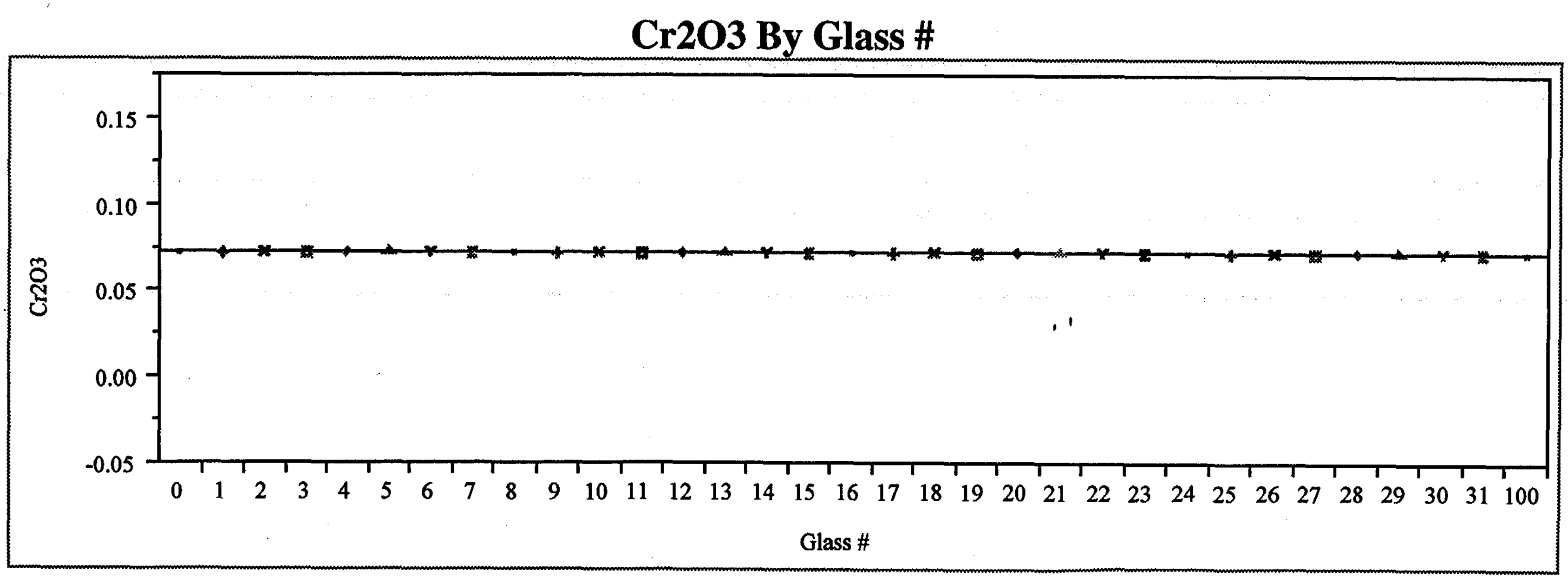
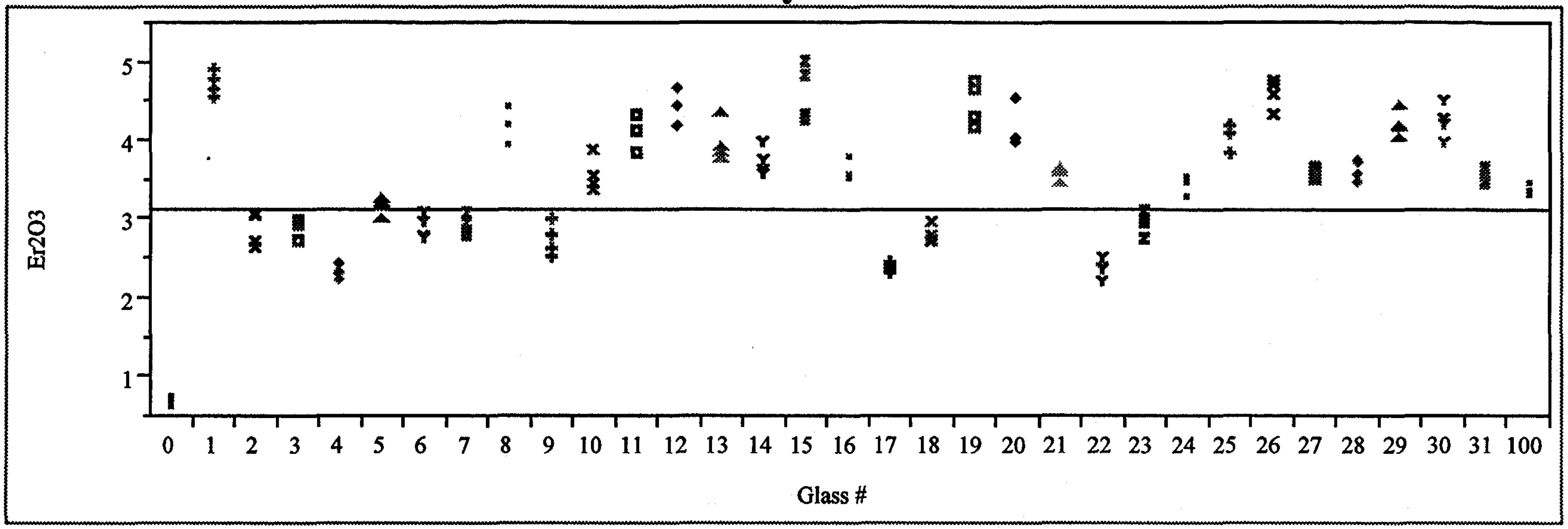
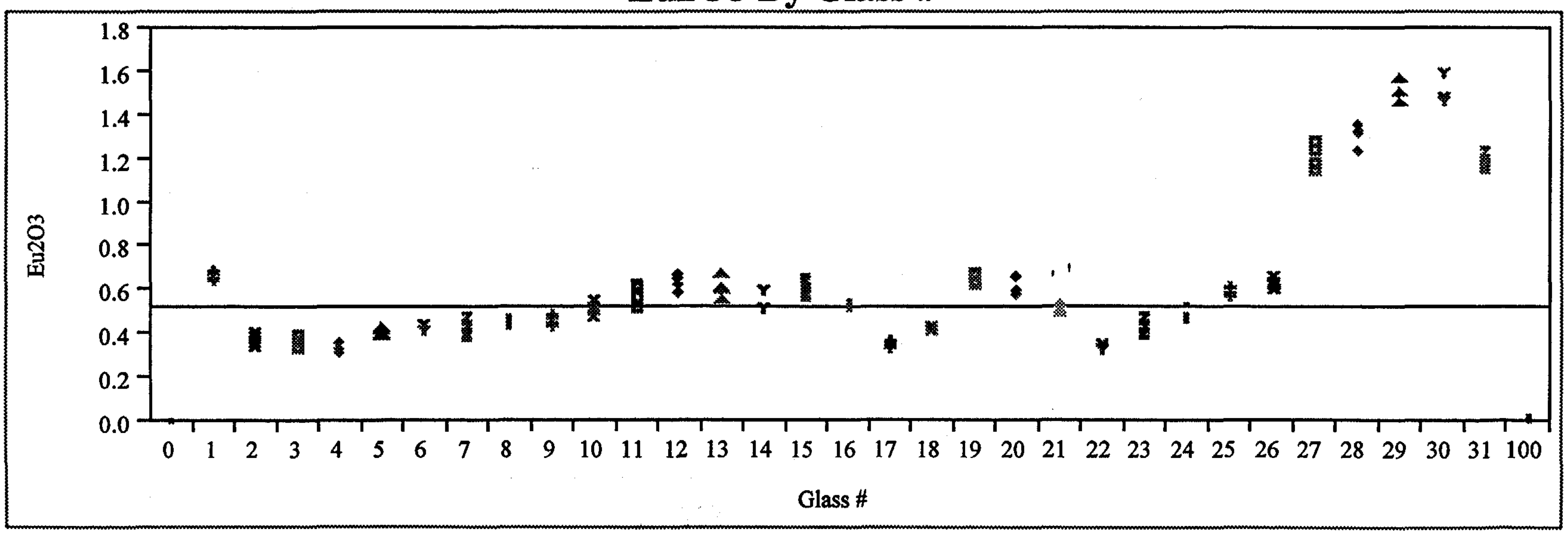

Cr2O3 By Glass #
Cr2O3
-0.05
0.00
0.05
0.10
0.15
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 100
Glass #

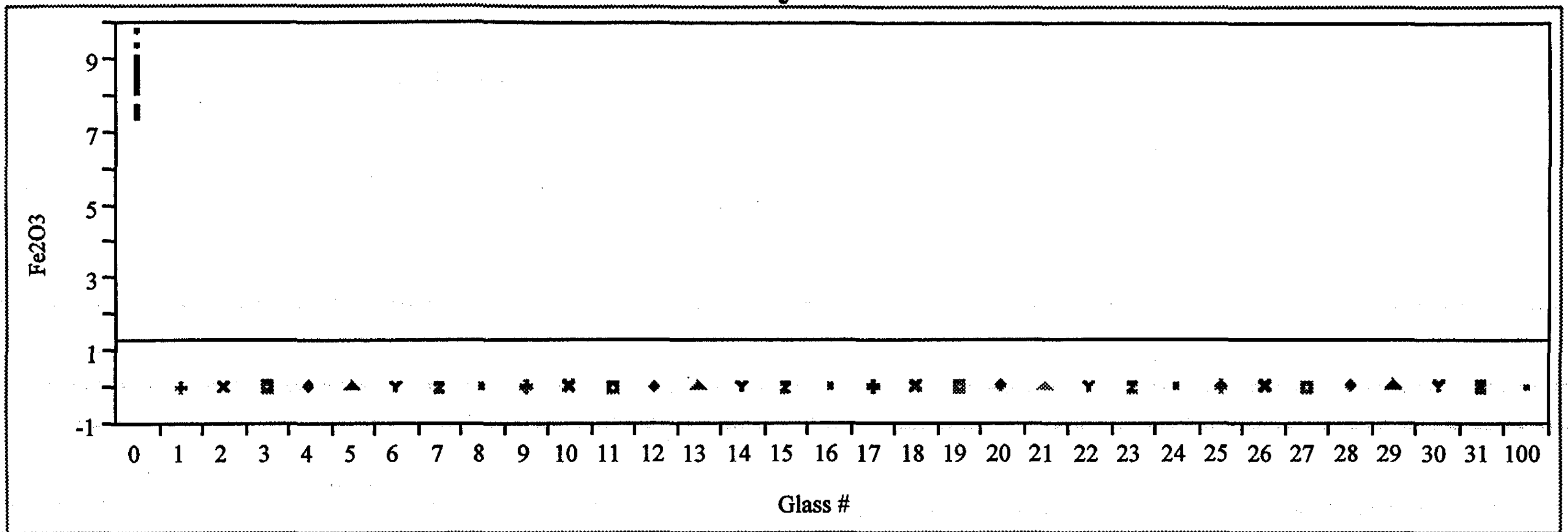
Er2O3 By Glass



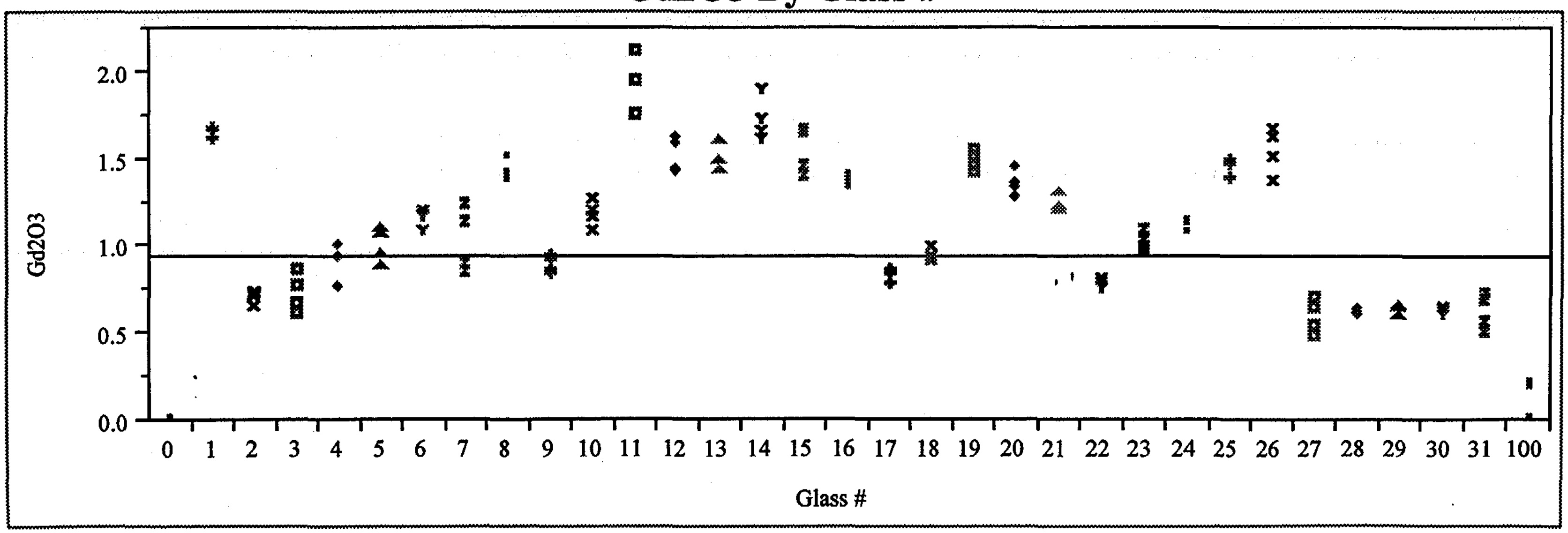
Eu2O3 By Glass

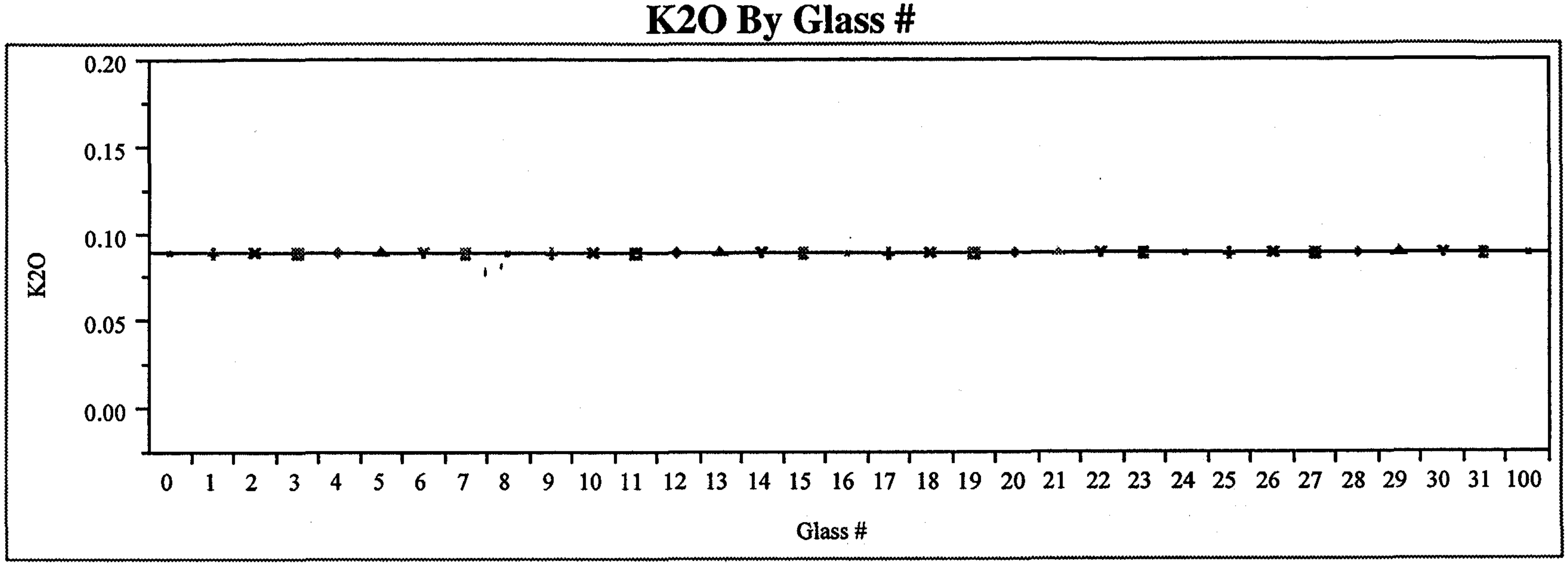


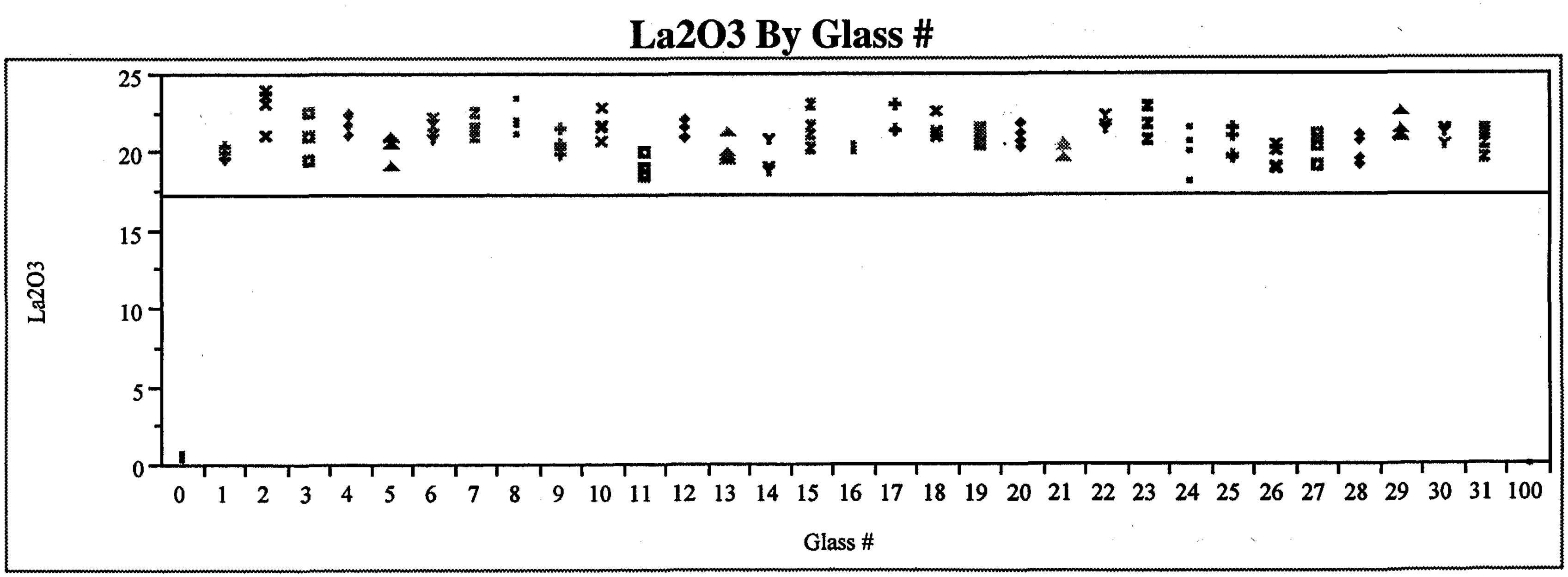
Fe2O3 By Glass



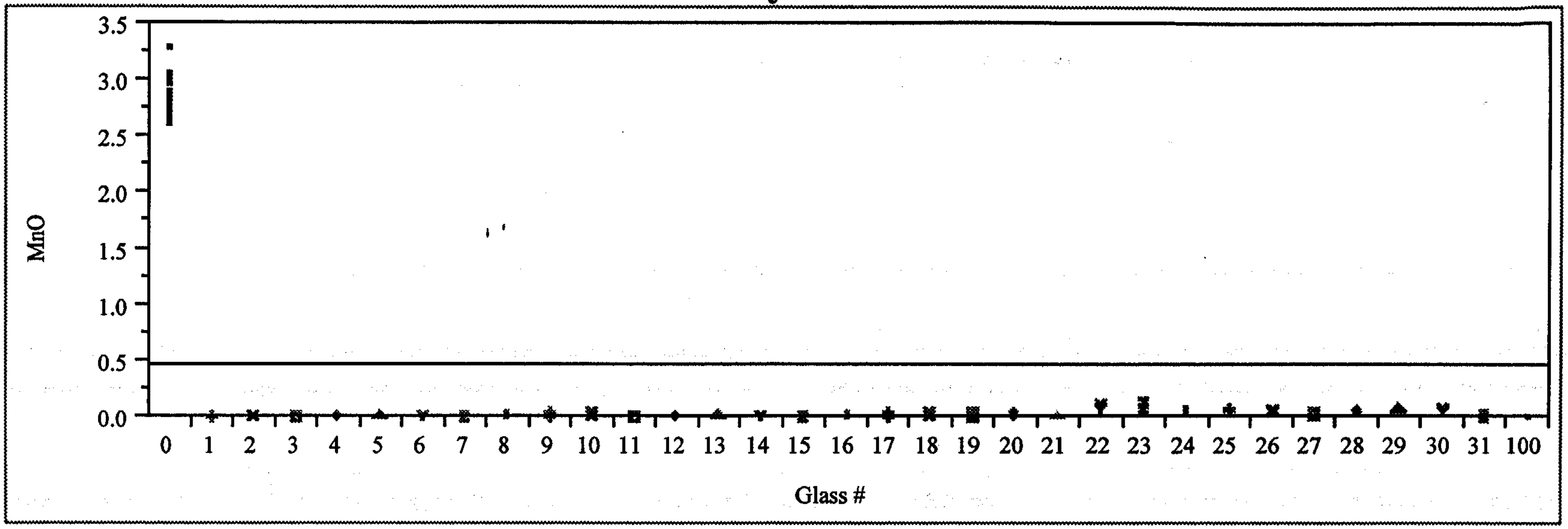
Gd2O3 By Glass




K2O By Glass #
0.20
0.15
0.10
0.05
0.00
K2O
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 100
Glass #


La2O3 By Glass #
25
20
15
10
5
0
La2O3
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 100
Glass #

MnO By Glass



Na2O By Glass

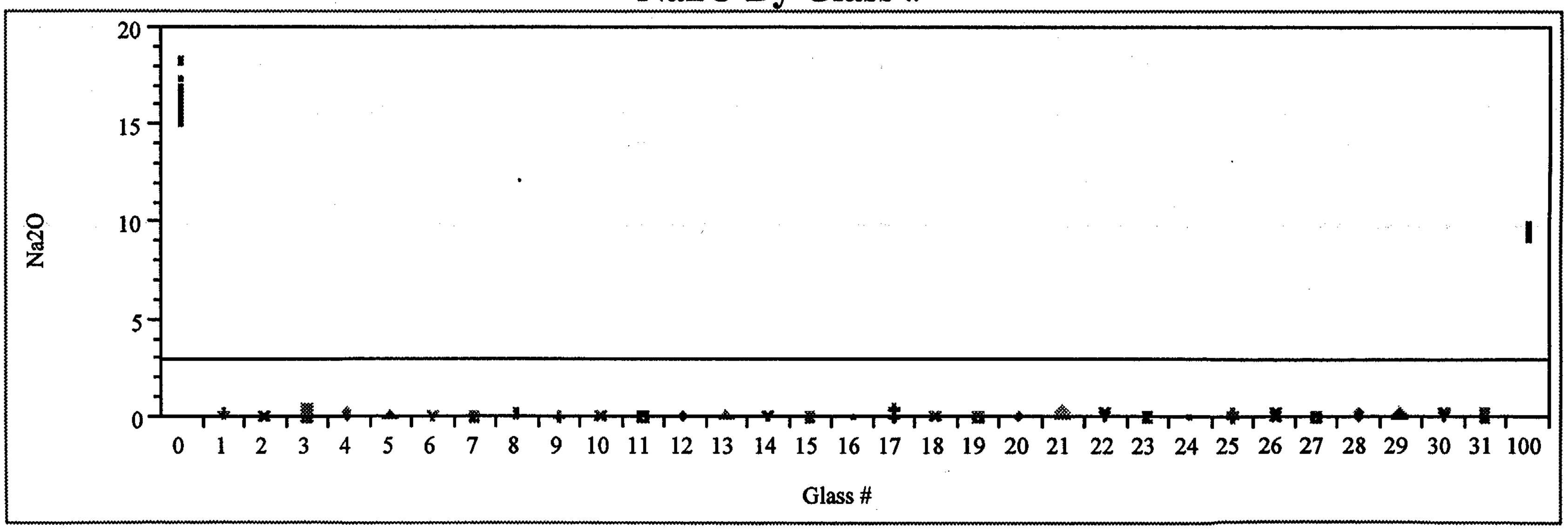
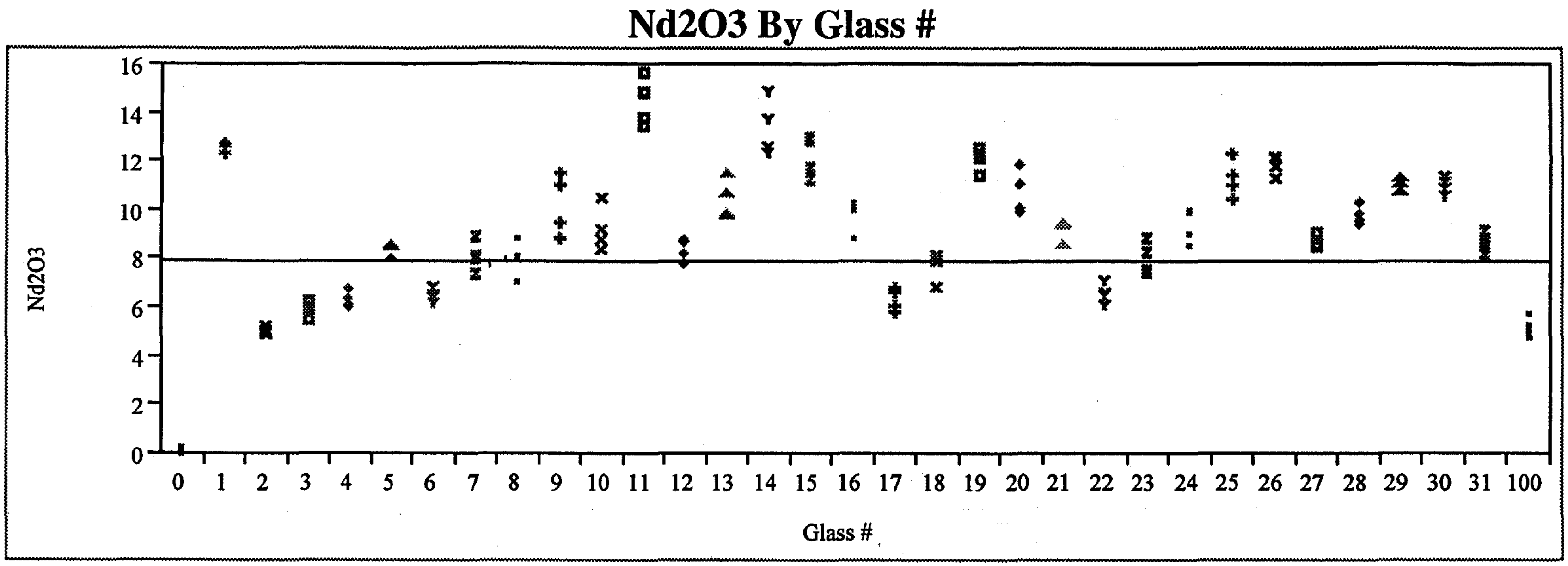
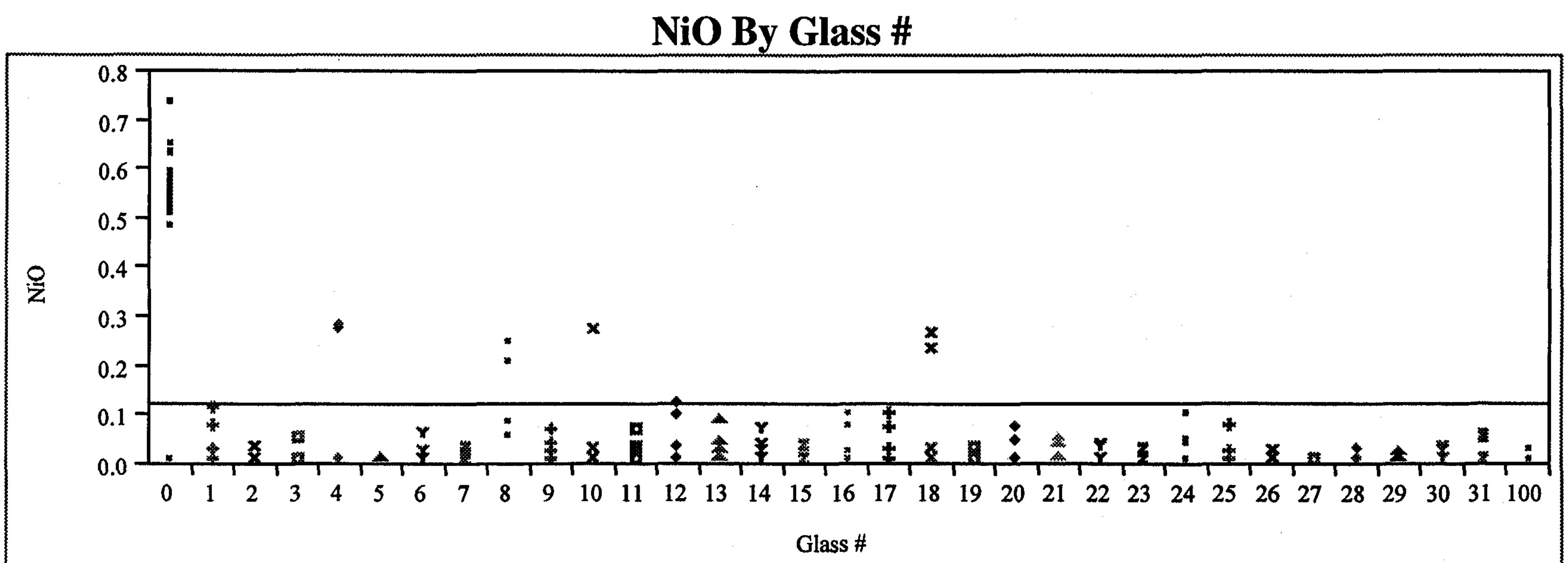
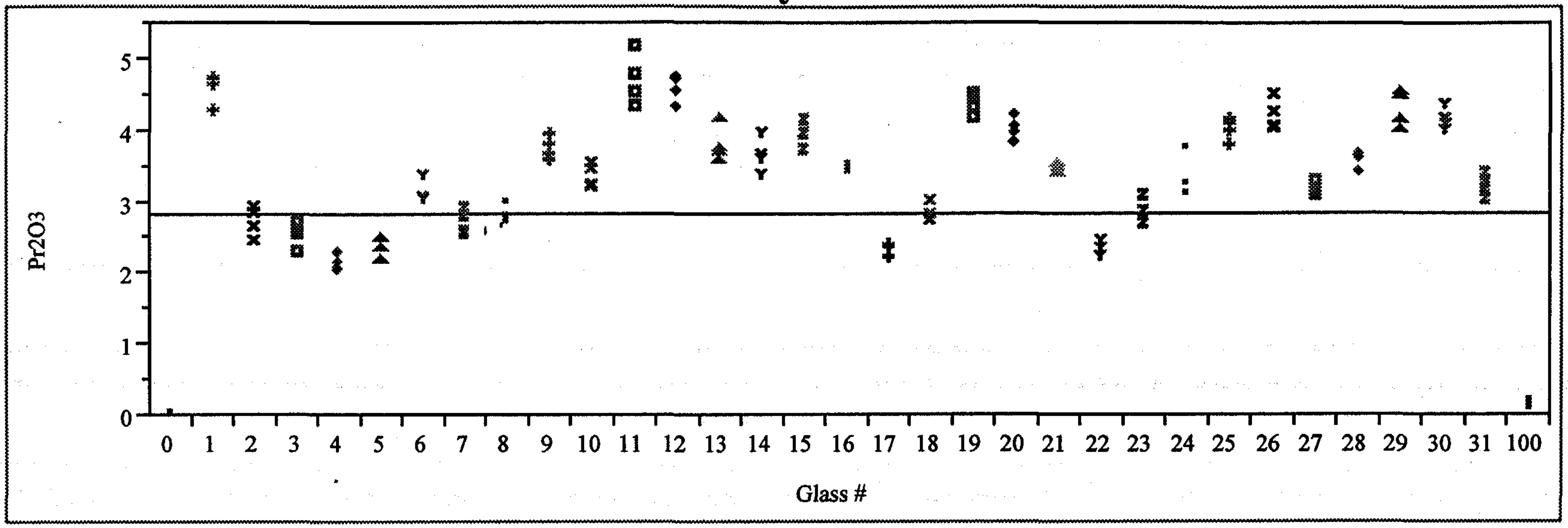


Exhibit A.1: Oxide Concentrations Measured Using Lithium-metaborate Dissolution by Glass Number (0-EA and 100-ARM)

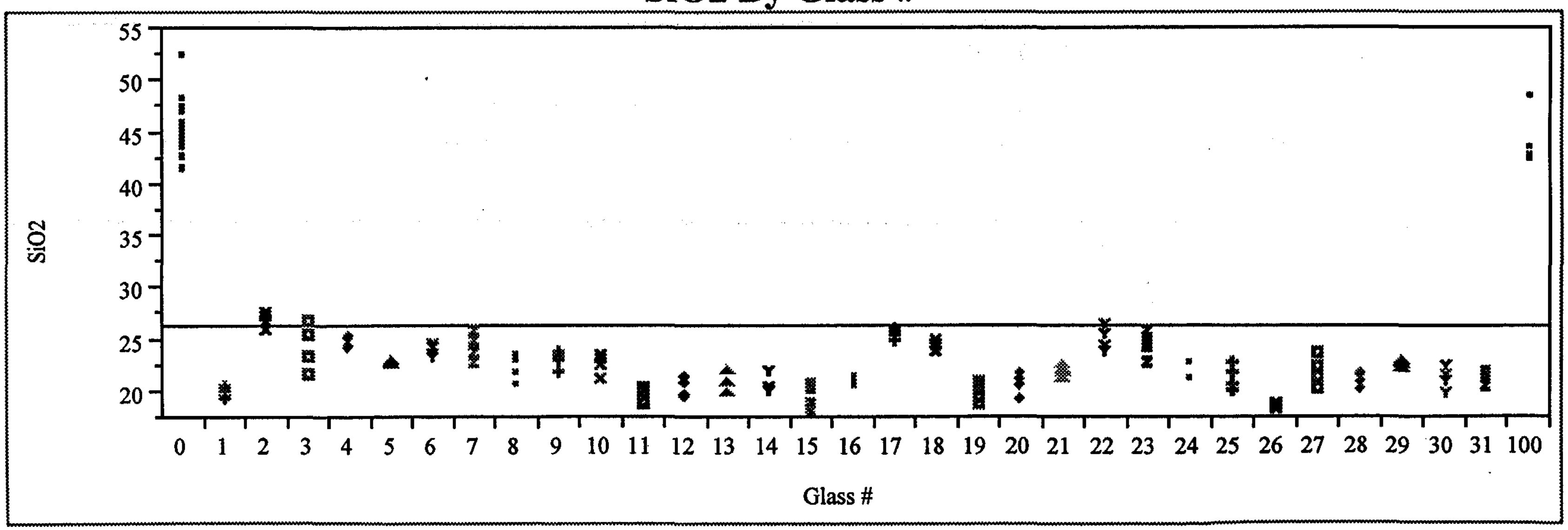




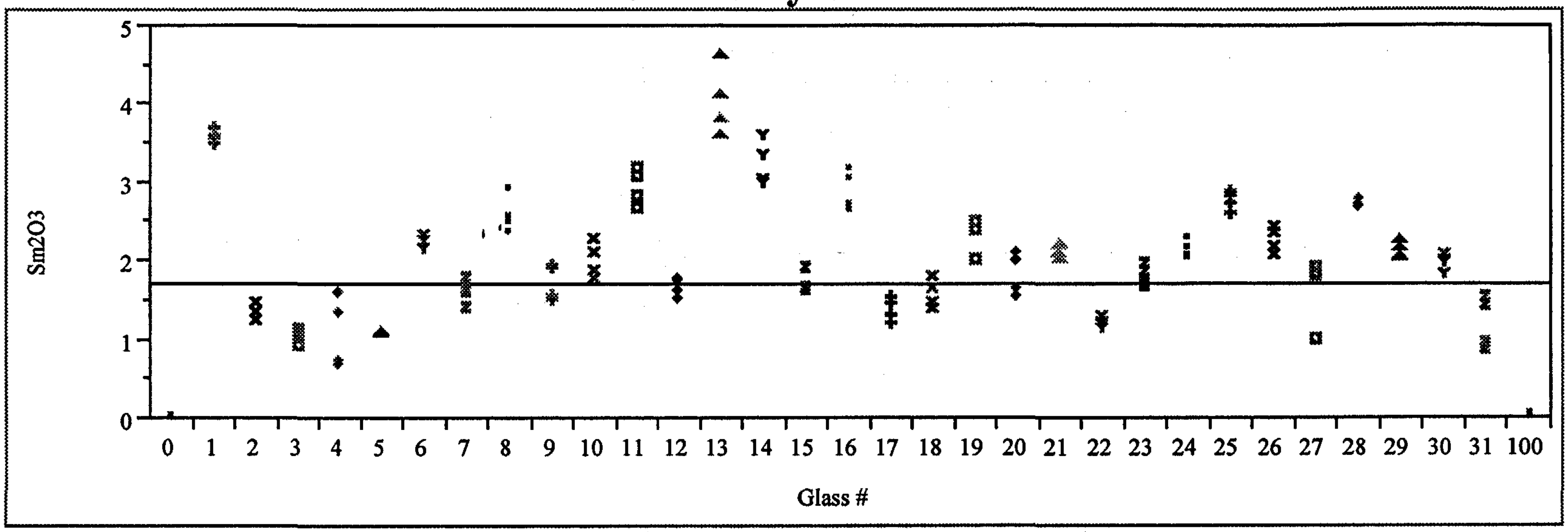
Pr2O3 By Glass



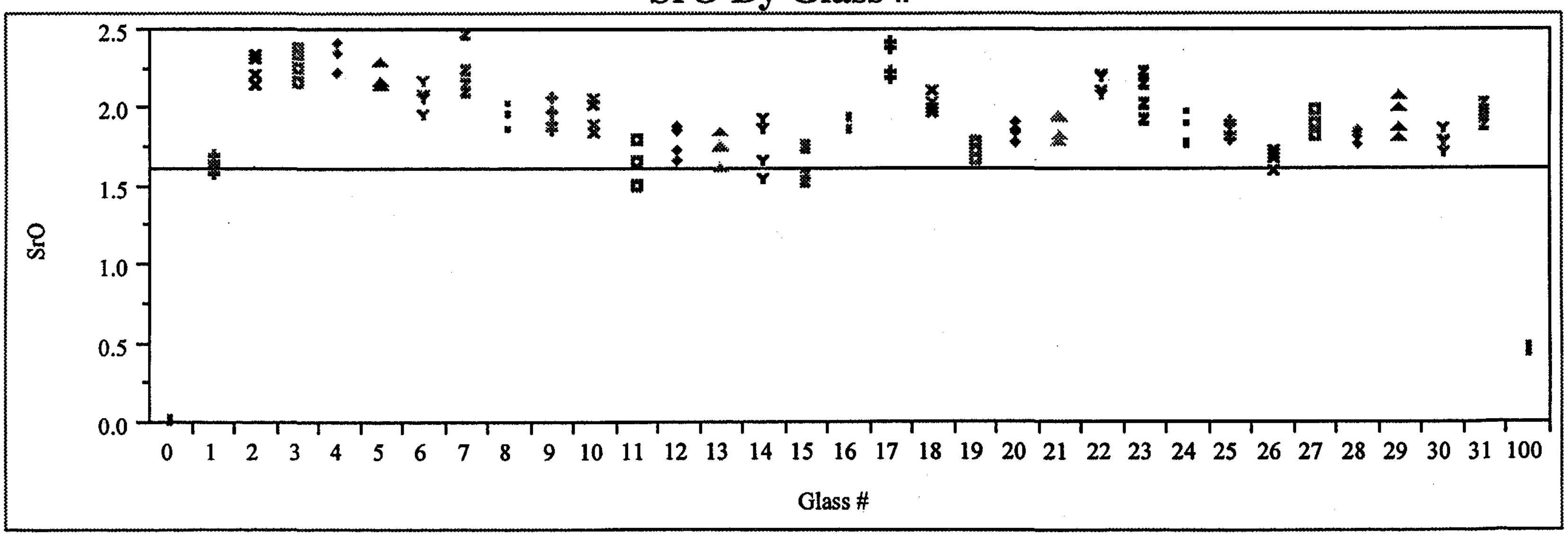
SiO2 By Glass



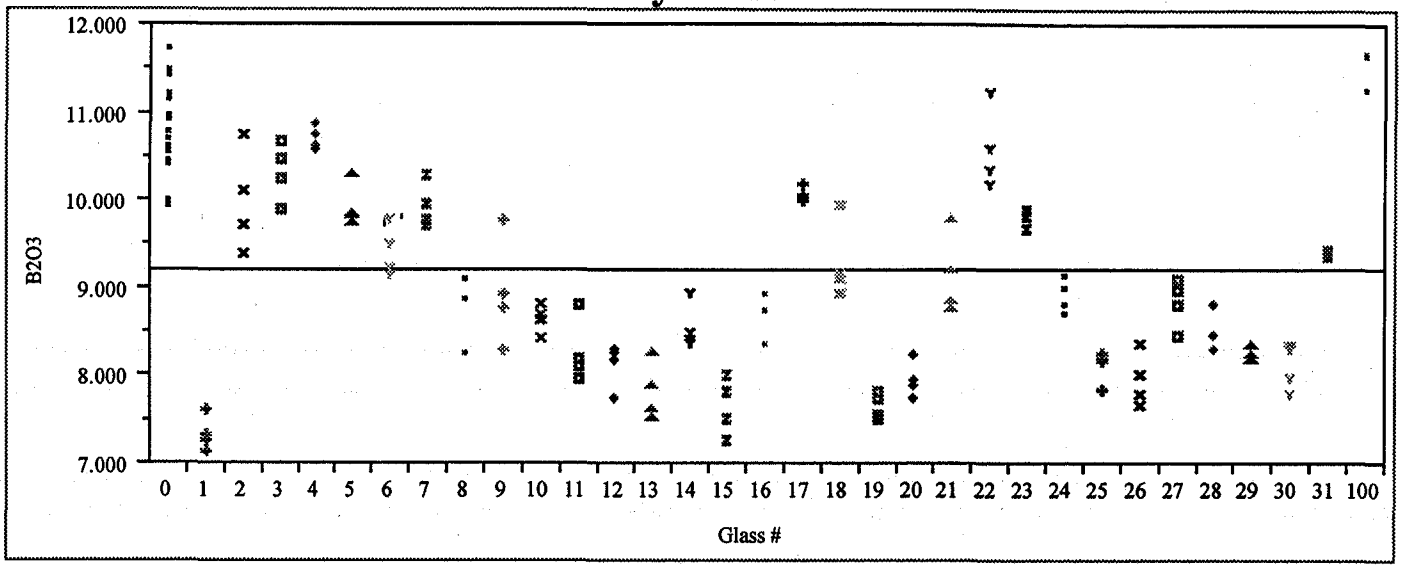
Sm2O3 By Glass



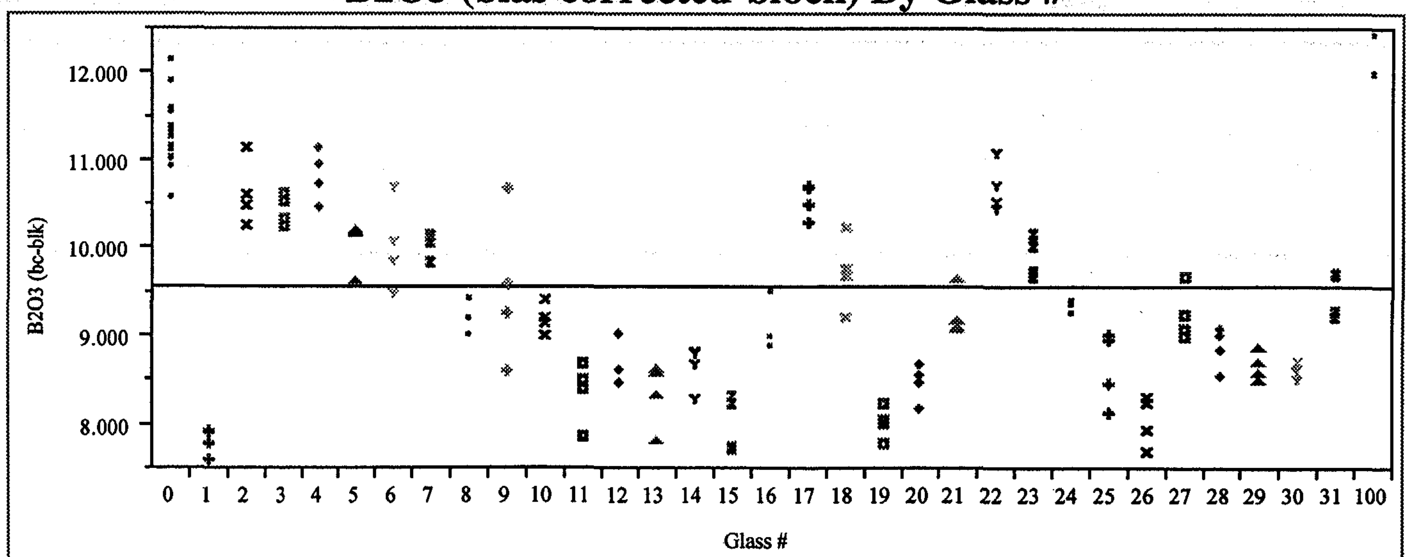
SrO By Glass

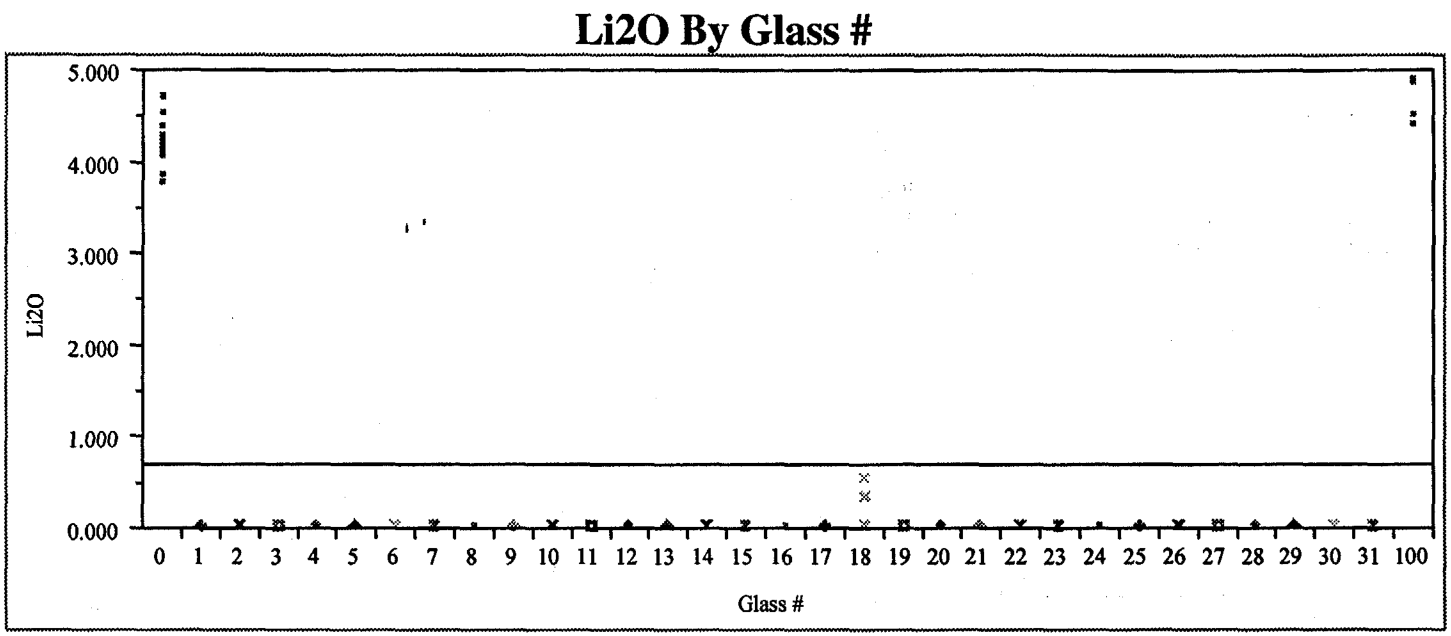


B2O3 By Glass

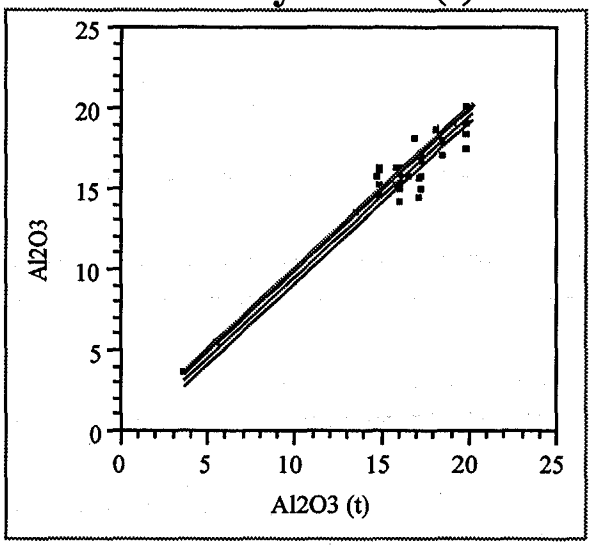


B2O3 (bias corrected-block) By Glass




Li2O By Glass #
5.000
4.000
3.000
2.000
1.000
0.000
Li2O
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 100
Glass #

Al2O3 By Al2O3 (t)



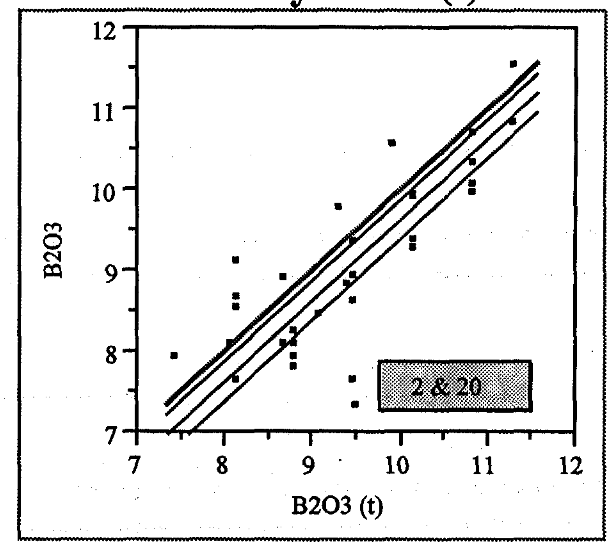
Paired t-Test

Paired t-Test

Al2O3 (t) - Al2O3

Mean Difference	0.47384	Prob > |t|0.0142
Std Error	0.182783	Prob > t 0.0071
t-Ratio	2.592357	Prob < t 0.9929
DF 32		

B2O3 By B2O3 (t)



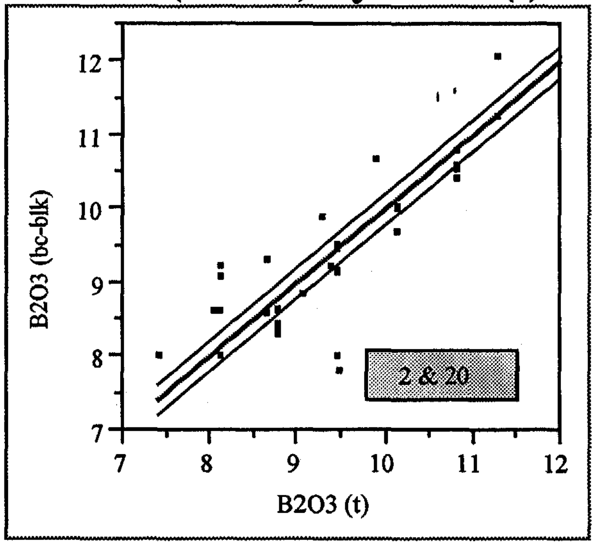
Paired t-Test

Paired t-Test

B2O3 (t) - B2O3

Mean Difference	0.369345	Prob > |t|0.0037
Std Error	0.11782	Prob > t 0.0018
t-Ratio	3.134836	Prob < t 0.9982
DF 32		

B2O3 (bc-blk) By B2O3 (t)



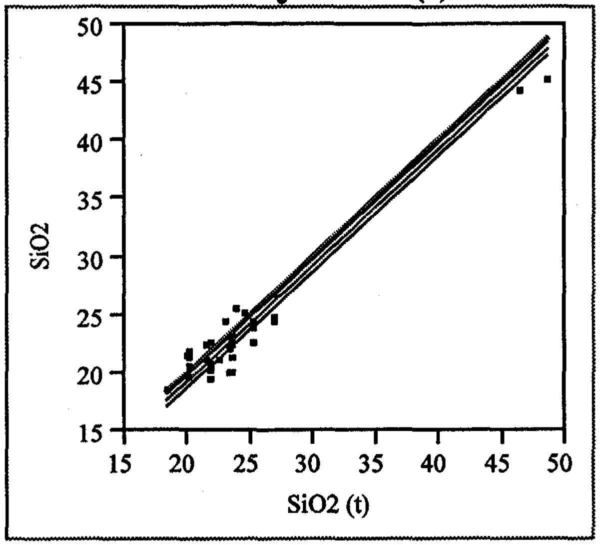
Paired t-Test

Paired t-Test

B2O3 (t) - B2O3 (bc-blk)

Mean Difference	0.011056	Prob > |t|0.9165
Std Error	0.104607	Prob > t 0.4582
t-Ratio	0.105692	Prob < t 0.5418
DF 32		

SiO2 By SiO2 (t)



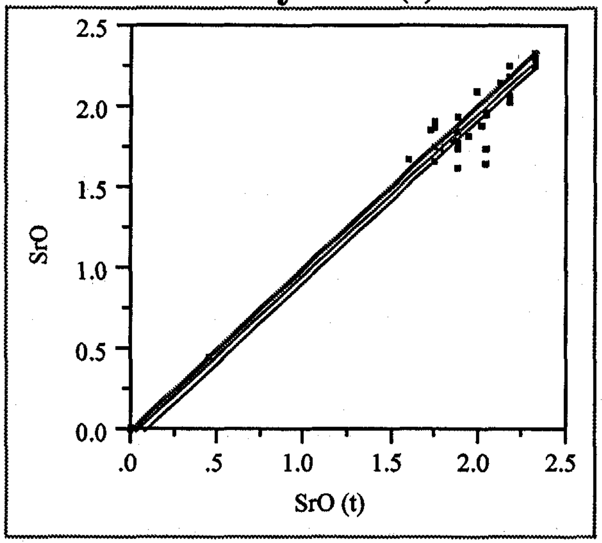
Paired t-Test

Paired t-Test

SiO2 (t) - SiO2

Mean Difference	0.817053	Prob > |t|0.0039
Std Error	0.26222	Prob > t 0.0019
t-Ratio	3.115902	Prob < t 0.9981
DF 32		

SrO By SrO (t)



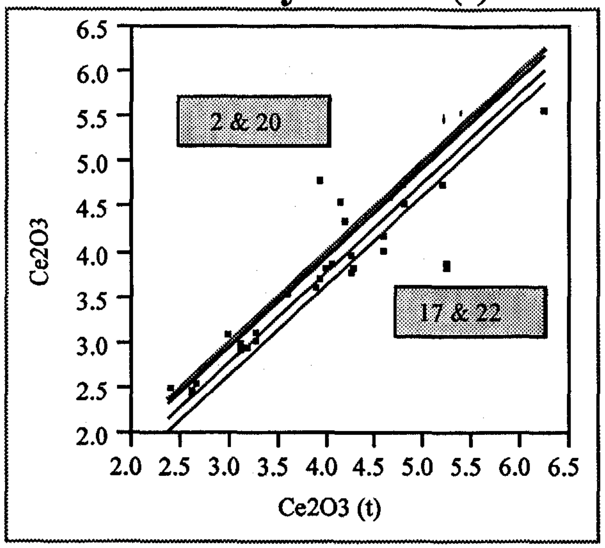
Paired t-Test

Paired t-Test

SrO (t) - SrO

Mean Difference	0.047064	Prob > |t|0.0327
Std Error	0.021083	Prob > t 0.0164
t-Ratio	2.232363	Prob < t 0.9836
DF 32		

Ce2O3 By Ce2O3 (t)



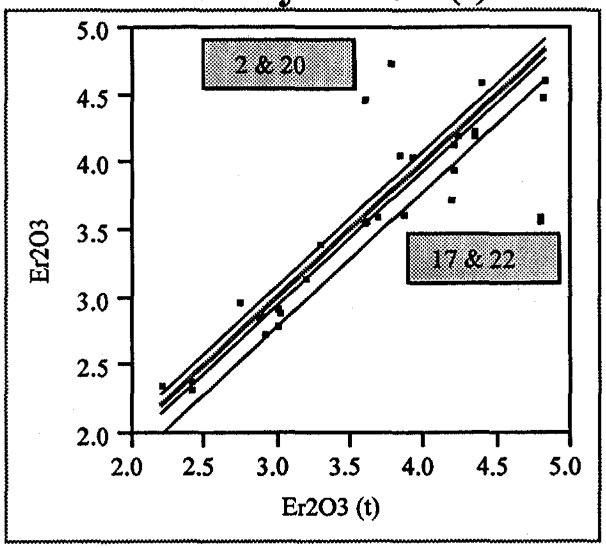
Paired t-Test

Paired t-Test

Ce2O3 (t) - Ce2O3

Mean Difference	0.219336	Prob > |t| 0.0070
Std Error	0.075694	Prob > t 0.0035
t-Ratio	2.897675	Prob < t 0.9965
DF 30		

Er2O3 By Er2O3 (t)



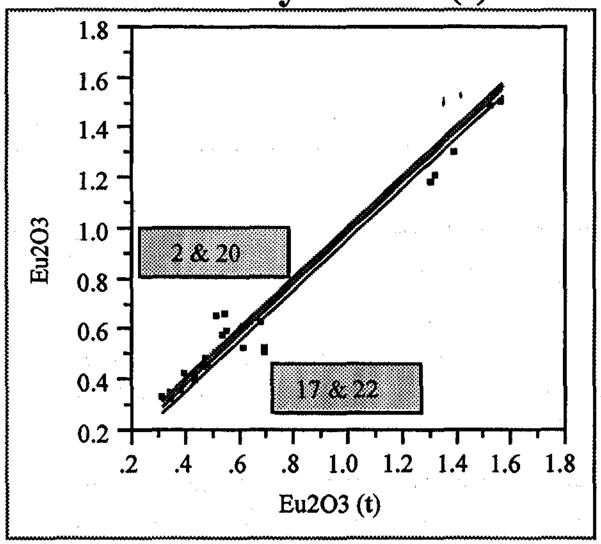
Paired t-Test

Paired t-Test

Er2O3 (t) - Er2O3

Mean Difference	0.066187	Prob > |t| 0.3863
Std Error	0.075291	Prob > t 0.1932
t-Ratio	0.879086	Prob < t 0.8068
DF 30		

Eu2O3 By Eu2O3 (t)



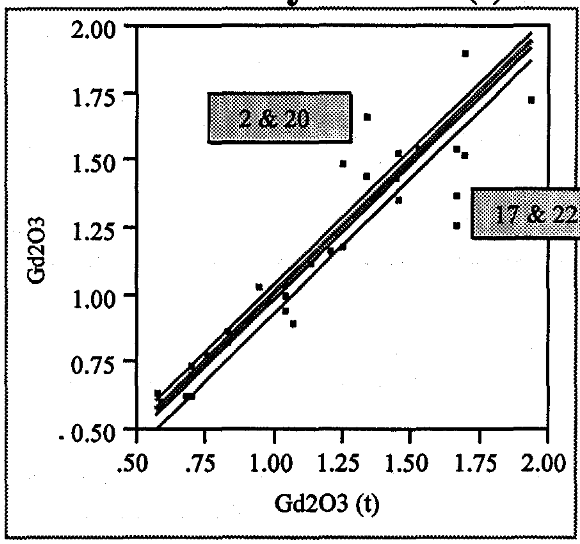
Paired t-Test

Paired t-Test

Eu2O3 (t) - Eu2O3

Mean Difference	0.021365	Prob > |t|0.0910
Std Error	0.012233	Prob > t 0.0455
t-Ratio	1.746419	Prob < t 0.9545
DF 30		

Gd2O3 By Gd2O3 (t)



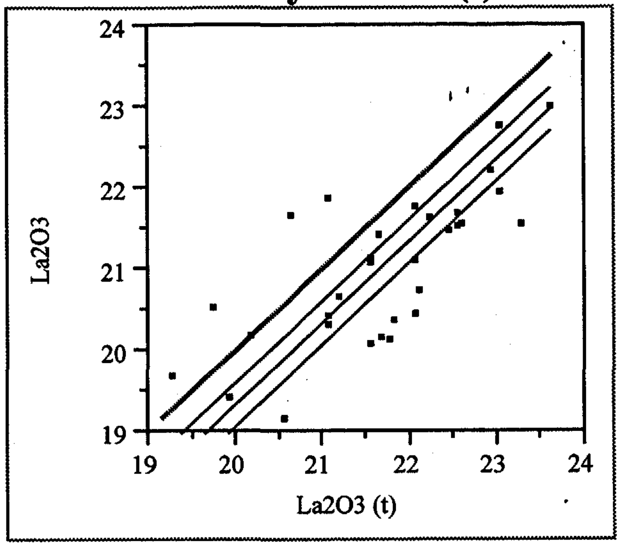
Paired t-Test

Paired t-Test

Gd2O3 (t) - Gd2O3

Mean Difference	0.021031	Prob > |t|0.4248
Std Error	0.025993	Prob > t 0.2124
t-Ratio	0.809121	Prob < t 0.7876
DF 30		

La2O3 By La2O3 (t)



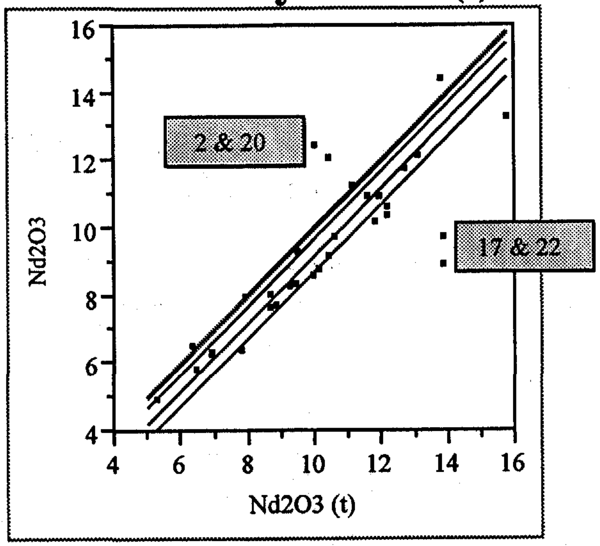
Paired t-Test

Paired t-Test

La2O3 (t) - La2O3

Mean Difference	0.676899	Prob > |t|<.0001
Std Error	0.131461	Prob > t <.0001
t-Ratio	5.149067	Prob < t 1.0000
DF 30		

Nd2O3 By Nd2O3 (t)



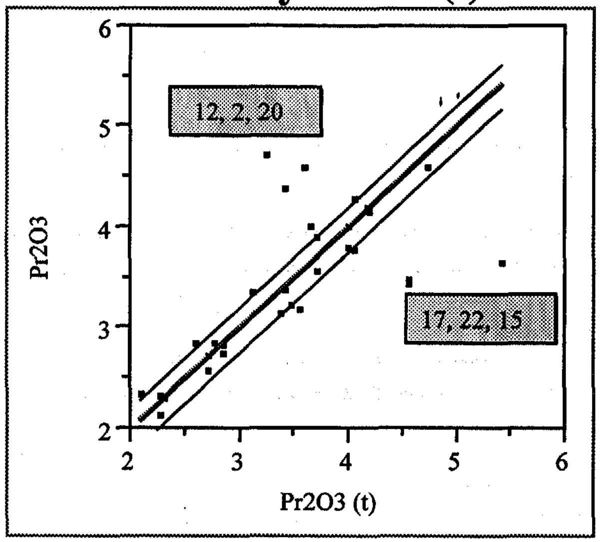
Paired t-Test

Paired t-Test

Nd2O3 (t) - Nd2O3

Mean Difference	0.82866	Prob > |t|0.0021
Std Error	0.24667	Prob > t 0.0011
t-Ratio	3.359388	Prob < t 0.9989
DF 30		

Pr2O3 By Pr2O3 (t)



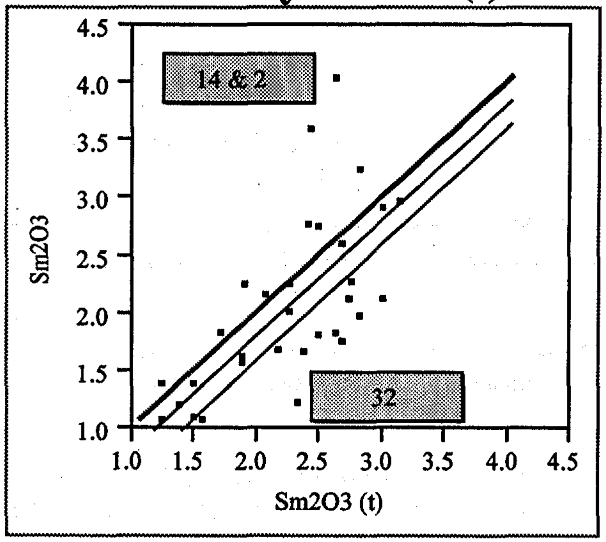
Paired t-Test

Paired t-Test

Pr2O3 (t) - Pr2O3

Mean Difference	0.036495	Prob > |t| 0.7340
Std Error	0.106417	Prob > t 0.3670
t-Ratio	0.342943	Prob < t 0.6330
DF 30		

Sm2O3 By Sm2O3 (t)

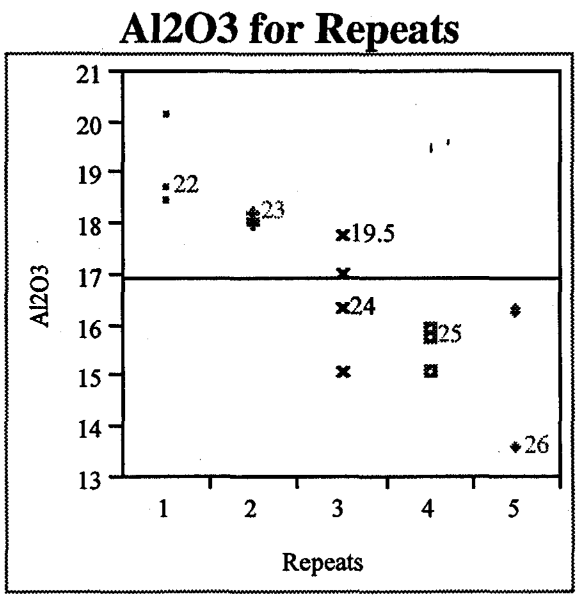


Paired t-Test

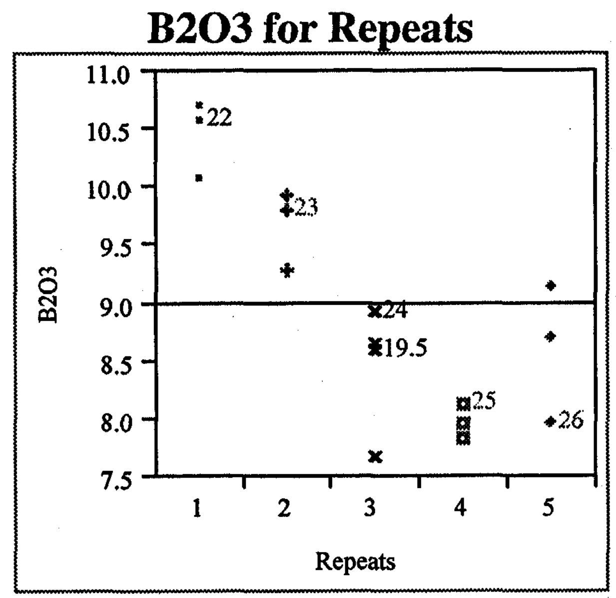
Paired t-Test

Sm2O3 (t) - Sm2O3

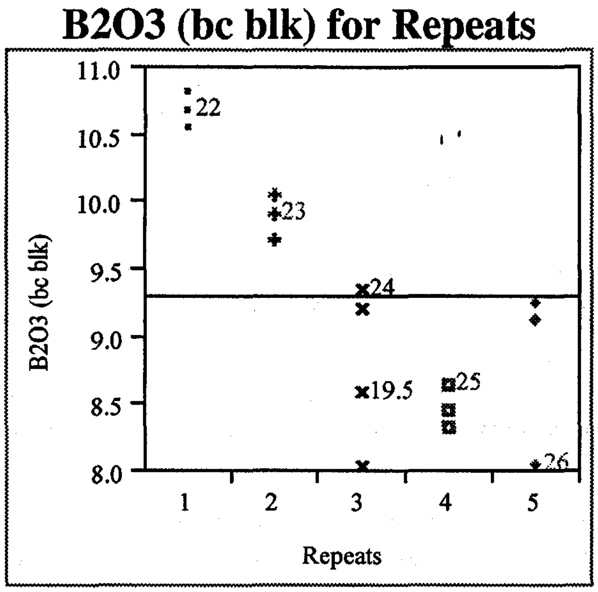
Mean Difference	0.198723	Prob > |t| 0.0617
Std Error	0.102368	Prob > t 0.0308
t-Ratio	1.941262	Prob < t 0.9692
DF 30		



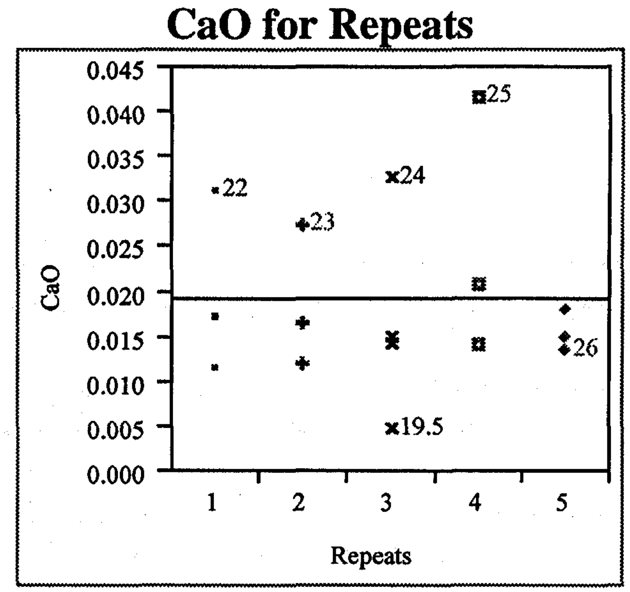
Repeatability Standard Deviation	0.995564
Overall Mean of Response	16.94976
Repeatability % Relative Std Dev	5.9%



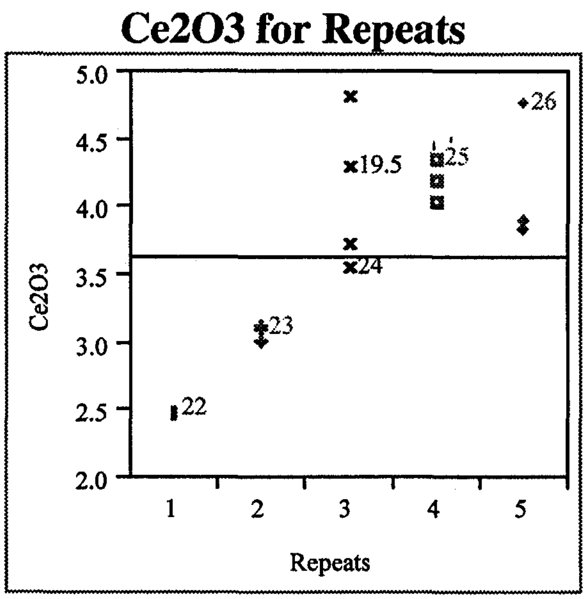
Repeatability Standard Deviation	0.438842
Overall Mean of Response	9.001812
Repeatability % Relative Std Dev	4.9%



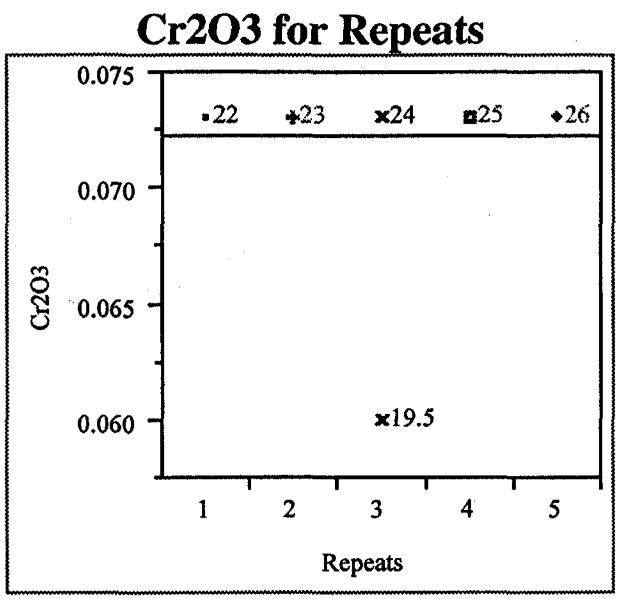
Repeatability Standard Deviation	0.436652
Overall Mean of Response	9.305133
Repeatability % Relative Std Dev	4.7%



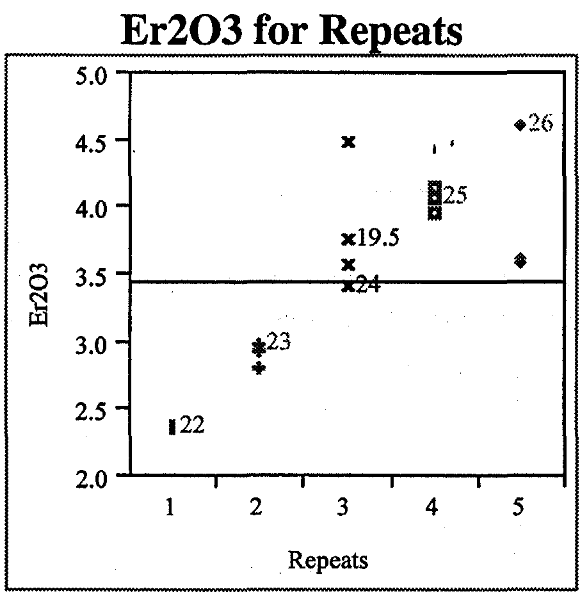
Repeatability Standard Deviation	0.010281
Overall Mean of Response	0.019311
Repeatability % Relative Std Dev	53.3%



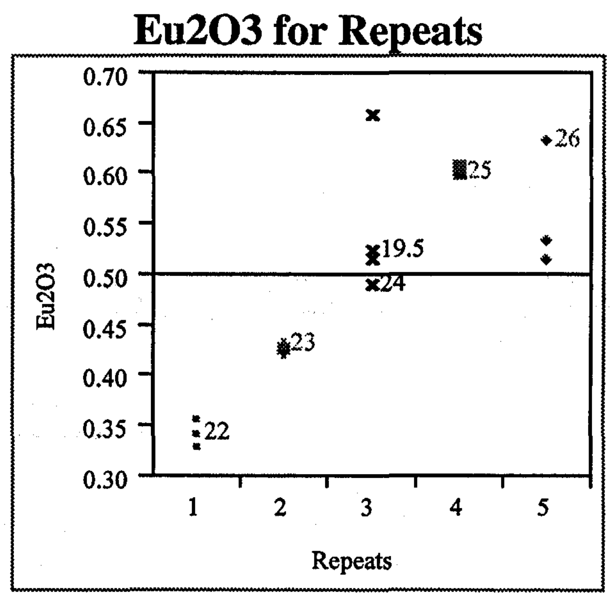
Repeatability Standard Deviation	0.381514
Overall Mean of Response	3.642643
Repeatability % Relative Std Dev	10.5%



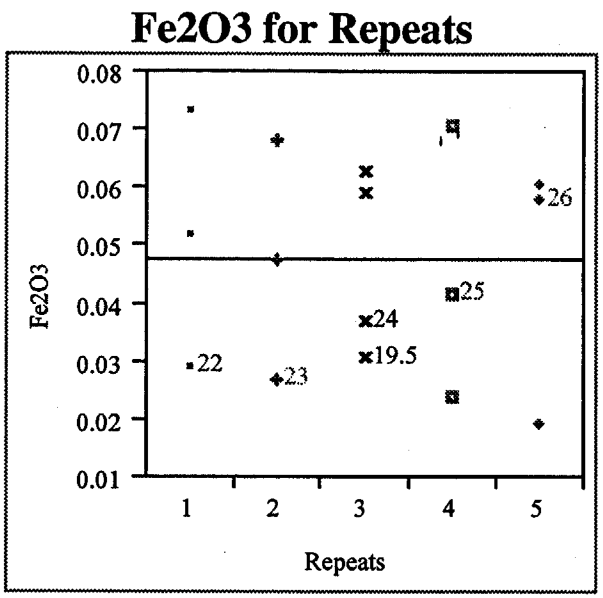
Repeatability Standard Deviation	0.003415
Overall Mean of Response	0.072263
Repeatability % Relative Std Dev	4.7%



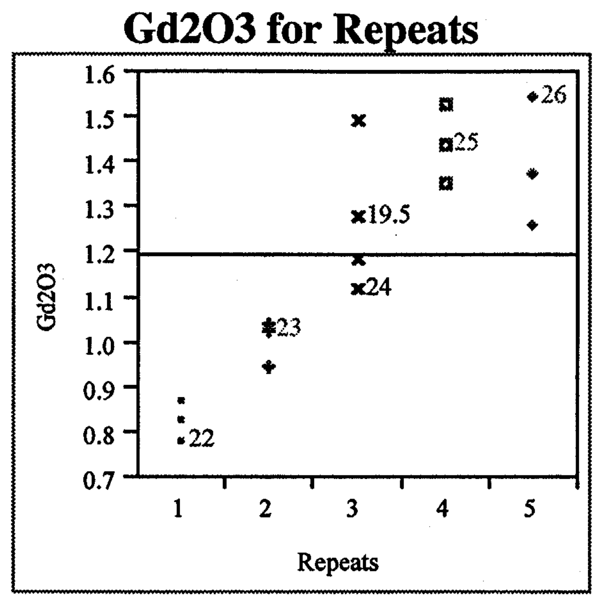
Repeatability Standard Deviation	0.356702
Overall Mean of Response	3.443768
Repeatability % Relative Std Dev	10.4%



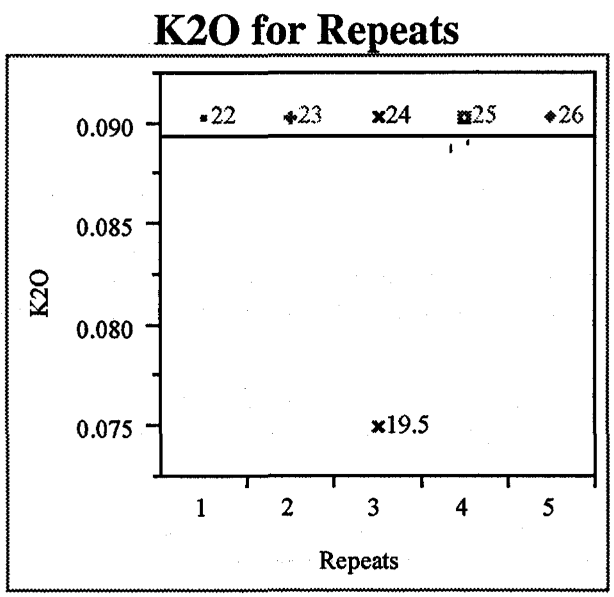
Repeatability Standard Deviation	0.048549
Overall Mean of Response	0.50056
Repeatability % Relative Std Dev	9.7%



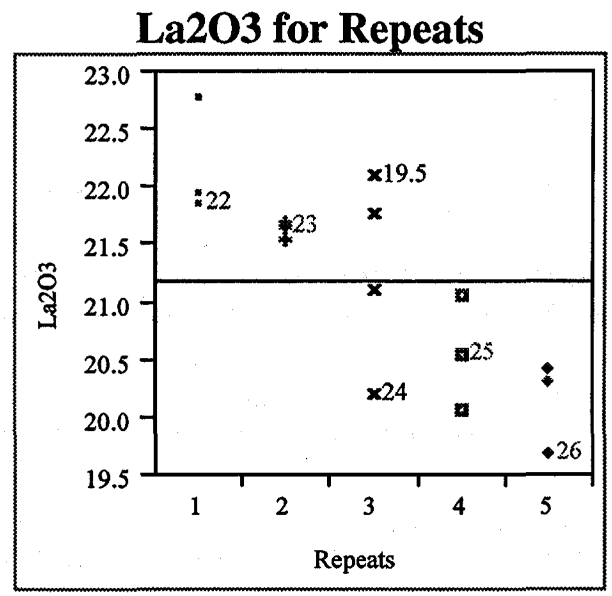
Repeatability Standard Deviation	0.020836
Overall Mean of Response	0.047755
Repeatability % Relative Std Dev	43.6%



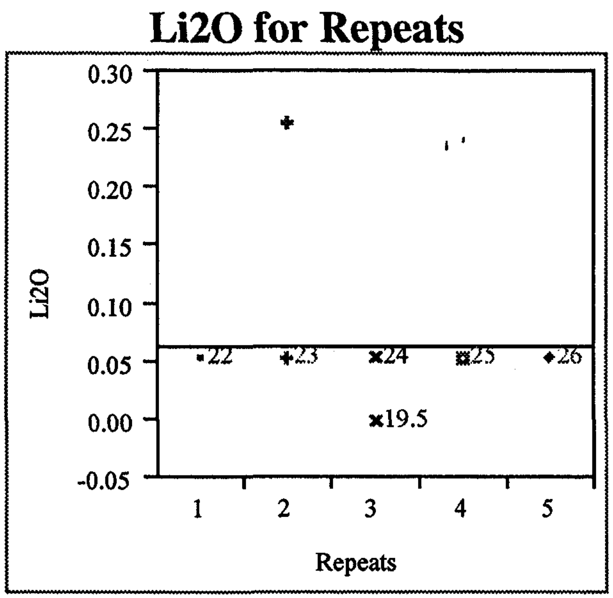
Repeatability Standard Deviation	0.114216
Overall Mean of Response	1.193394
Repeatability % Relative Std Dev	9.6%



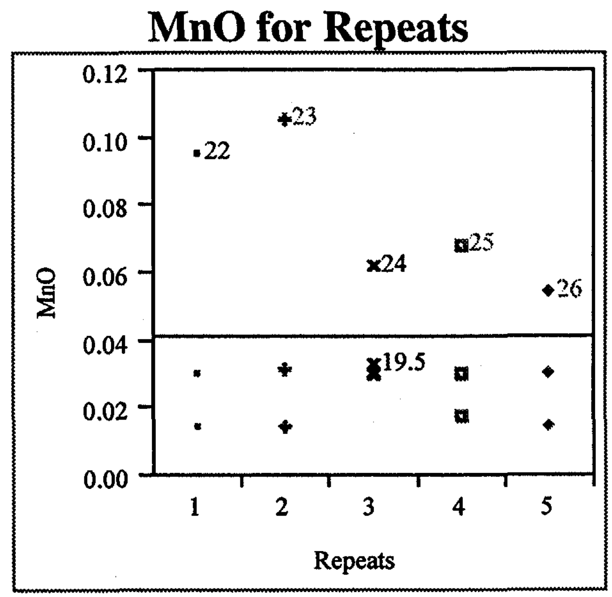
Repeatability Standard Deviation	0.004007
Overall Mean of Response	0.089386
Repeatability % Relative Std Dev	4.5%



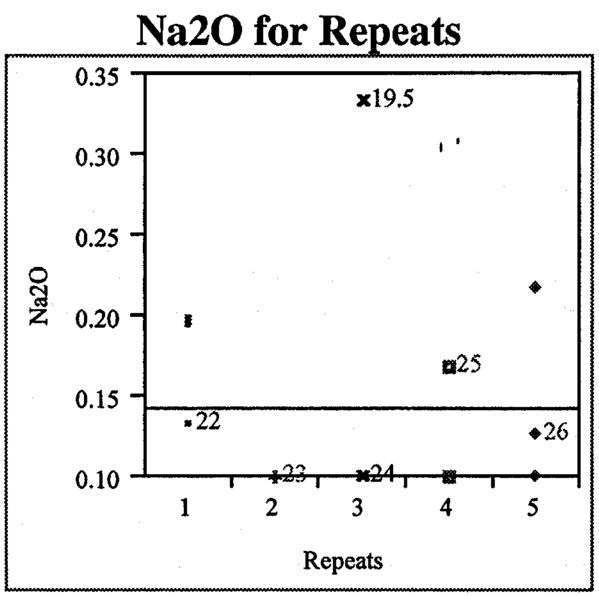
Repeatability Standard Deviation	0.559208
Overall Mean of Response	21.18141
Repeatability % Relative Std Dev	2.6%



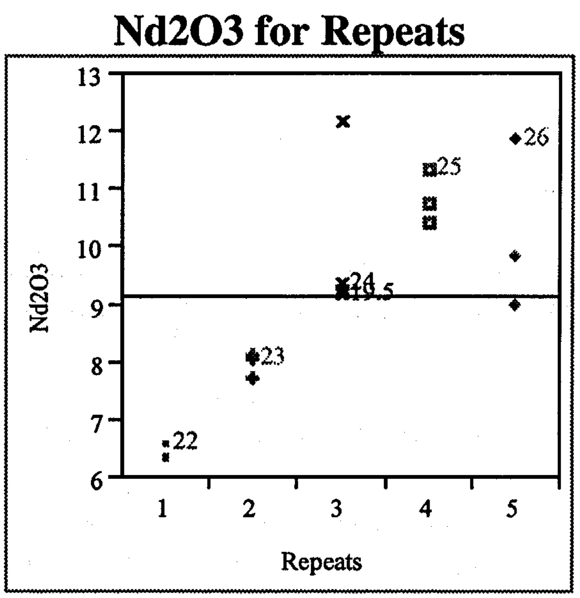
Repeatability Standard Deviation	0.052403
Overall Mean of Response	0.063275
Repeatability % Relative Std Dev	82.8%



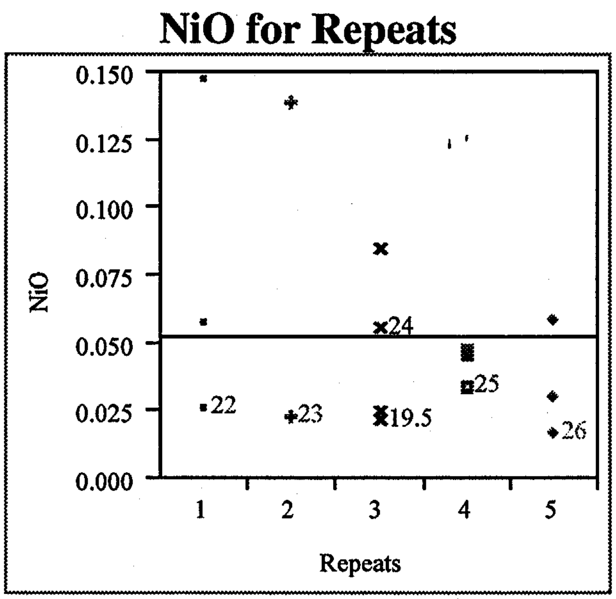
Repeatability Standard Deviation	0.032005
Overall Mean of Response	0.041635
Repeatability % Relative Std Dev	76.2%



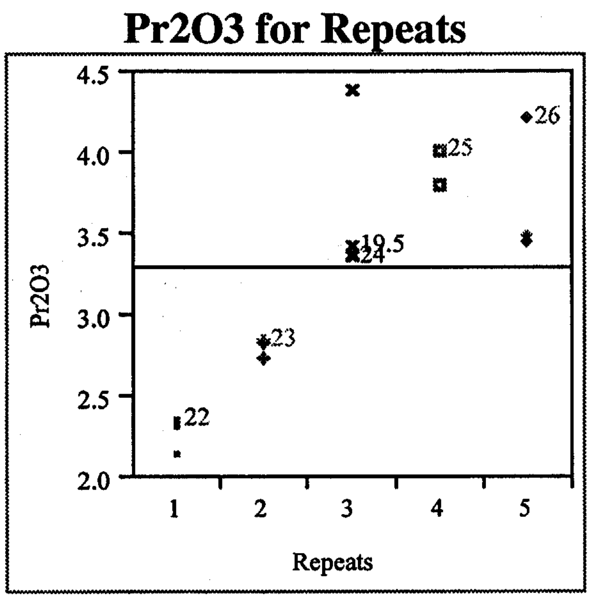
Repeatability Standard Deviation	0.07003
Overall Mean of Response	0.142932
Repeatability % Relative Std Dev	49.1%



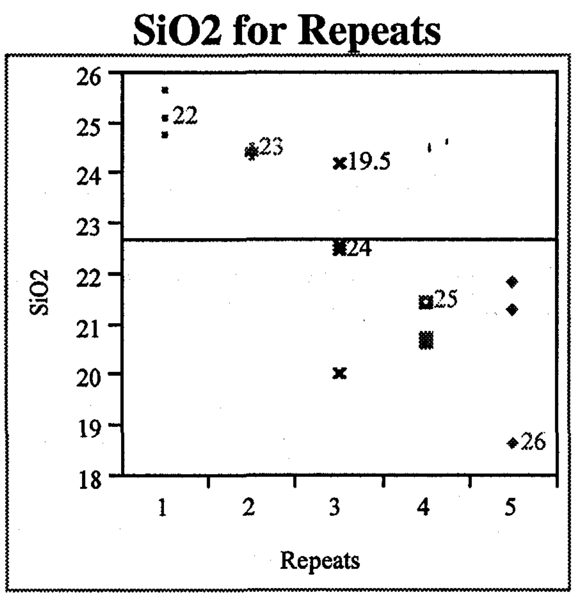
Repeatability Standard Deviation	1.012388
Overall Mean of Response	9.164937
Repeatability % Relative Std Dev	11.0%



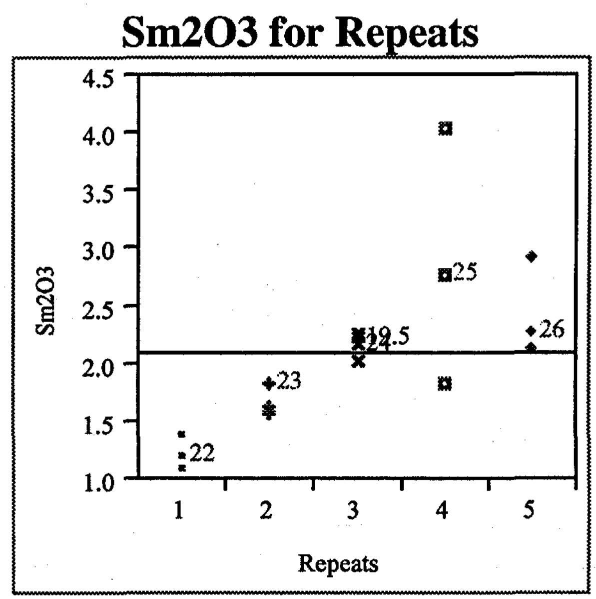
Repeatability Standard Deviation	0.043212
Overall Mean of Response	0.052573
Repeatability % Relative Std Dev	82.1%



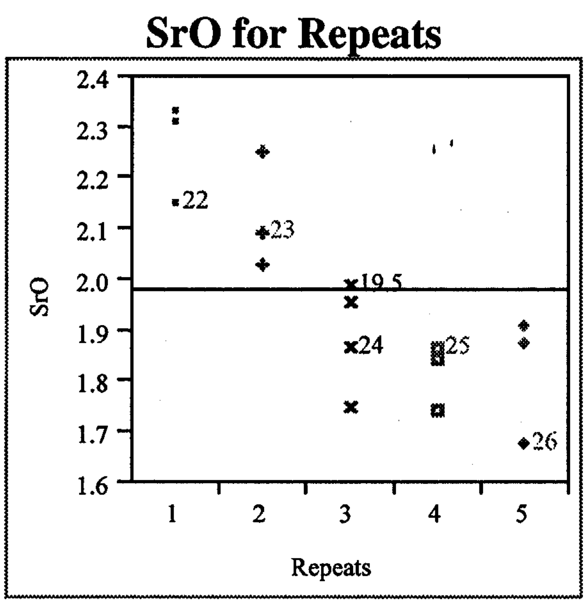
Repeatability Standard Deviation	0.327501
Overall Mean of Response	3.302687
Repeatability % Relative Std Dev	9.9%



Repeatability Standard Deviation	1.184434
Overall Mean of Response	22.69558
Repeatability % Relative Std Dev	5.2%



Repeatability Standard Deviation	0.517327
Overall Mean of Response	2.092821
Repeatability % Relative Std Dev	25.1%



Repeatability Standard Deviation	0.104211
Overall Mean of Response	1.979394
Repeatability % Relative Std Dev	5.3%

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Appendix B – Summary Table of Viscosity-Temperature Data, T in °C, η in Pa·s

Table B.1 – Summary Table of Viscosity-Temperature Data, T in °C, η in Pa·s

Run	1st point	2nd point	3rd point	4th point	5th point	6th point	7th point	8th point	9th point	10th point
AC1-01 T	1285	1236	~~**1187**~~	1236	1285	1334	1384	1286	**1138**	
AC1-01 η	2.593	5.678	~~**16.436**~~	9.896	2.569	1.622	1.087	2.572	**42.897**	
AC1-02 T	1284	1235	**1186**	1235	1284	1333	**1383**	1432	1284	1137
AC1-02 η	9.585	20.153	**51.731**	20.253	9.256	4.648	**2.482**	1.530	9.100	153.734
AC1-03 T	1284	1235	**1186**	1235	1284	1333	1383	1433	1284	**1137**
AC1-03 η	9.758	20.552	**52.557**	20.386	9.187	4.648	2.482	1.674	9.083	**157.66**
AC1-04 T	1284	1235	1186	1235	1284	1333	1383	1432	1284	1137
AC1-04 η	9.671	20.752	53.51	20.951	9.481	4.795	2.527	1.691	9.239	160.68
AC1-05 T	1284	1235	1186	1235	1284	1334	1383	1433	1285	1137
AC1-05 η	7.253	15.363	36.669	15.312	7.019	3.445	1.804	1.393	6.907	110.11
AC1-06 T	1284	1236	1186	1235	1284	1334	1383	1433	1285	1137
AC1-06 η	8.231	16.462	41.118	16.329	7.867	3.921	2.081	1.445	7.772	122.51
AC1-07 T	1284	1236	1186	1235	1284	1334	1383	1433	1285	**1137**
AC1-07 η	7.261	15.277	36.033	15.225	7.054	3.471	1.852	1.373	6.924	**108.73**
AC1-08 T	1285	1236	1187	1235	1284	1334	1384	1285	**1137**	
AC1-08 η	5.279	11.073	27.104	11.09	5.202	2.548	1.644	5.124	**81.166**	
AC1-09 T	1285	1236	1187	1236	1285	1334	1384	**1434**	1286	1138
AC1-09 η	5.271	11.073	26.838	11.073	5.236	2.61	1.676	**1.091**	5.158	77.95
AC1-10 T	1284	1235	1186	1235	1284	1334	1384	1285	**1137**	**1087**
AC1-10 η	5.228	10.865	26.605	10.969	5.132	2.541	1.66	5.002	**77.643**	**293.58**
AC1-11 T	1285	1236	~~**1187**~~	~~**1236**~~	1285	1334	**1384**	**1286**	~~**1138**~~	
AC1-11 η	2.88	6.145	~~**17.007**~~	~~**8.421**~~	2.832	1.506	**1.075**	**2.766**	~~**45.058**~~	
AC1-12 T	1285	1236	1187	1236	1285	1335	**1385**	1286	**1138**	**1088**
AC1-12 η	3.713	8.032	18.524	8.058	3.765	1.904	**1.255**	3.73	**54.972**	**210.82**
AC1-13 T	1285	1236	**1187**	1235	**1285**	**1334**	1384	1286	1137	1087
AC1-13 η	3.895	8.577	**19.588**	8.577	**3.869**	**1.928**	1.402	3.817	58.658	214.75
AC1-14 T	1284	**1236**	**1186**	1235	1284	1334	1384	1285	**1137**	**1087**
AC1-14 η	3.739	**8.205**	**18.923**	8.257	3.713	1.856	1.288	3.696	**57.514**	**221.99**
AC1-15 T	1285	1236	**1186**	~~**1236**~~	1285	1334	1384	1285	**1138**	**1088**
AC1-15 η	2.631	5.678	**15.433**	~~**7.893**~~	2.624	1.617	1.016	2.59	**45.312**	**233.77**
AC1-16 T	1284	1235	1186	1235	1284	1333	1383	1285	1137	**1087**
AC1-16 η	4.985	10.415	25.541	10.45	4.916	2.434	1.61	4.847	74.121	**279.98**
AC1-17 T	1283	1234	1185	1234	1283	**1333**	**1383**	1432	1284	**1137**
AC1-17 η	10.104	21.417	55.162	21.75	9.896	**4.977**	**2.621**	1.682	9.671	**165.82**
AC1-18 T	1285	1236	1187	1236	1285	1335	1384	1434	1286	**1138**
AC1-18 η	6.898	14.498	34.508	14.395	6.69	3.351	1.748	1.347	6.569	**102.15**
AC1-19 T	1285	1236	**1187**	**1236**	1285	1335	1384	**1286**	**1138**	**1088**
AC1-19 η	2.950	6.292	**15.865**	**6.829**	2.866	1.523	1.092	**2.835**	**47.727**	**223.806**

Table B.1 – Summary Table of Viscosity-Temperature Data, T in °C, η in Pa·s

Run	1st point	2nd point	3rd point	4th point	5th point	6th point	7th point	8th point	9th point	10th point
AC1-19b T	1283	1234	1185	1234	1283	1333	1383	1432	1284	1136
AC1-19b η	5.219	11.038	27.037	11.107	5.193	2.624	1.681	1.070	5.150	80.553
AC1-20 T	1285	1236	1186	**1235**	1284	1334	**1384**	~~**1285**~~	1137	**1087**
AC1-20 η	4.111	8.11	18.823	**8.196**	3.696	1.852	**1.317**	~~**3.618**~~	55.48	**208.4**
AC1-21 T	1284	1236	1186	1235	1284	**1334**	1384	1285	1138	1088
AC1-21 η	4.916	10.156	24.709	10.225	4.803	**2.416**	1.605	4.734	70.446	265.18
AC1-22 T	1285	1236	1187	1235	1285	1334	1384	1433	1286	1138
AC1-22 η	8.789	18.79	48.172	18.956	8.754	4.501	2.409	1.61	8.443	143.16
AC1-23 T	1284	1236	1186	1235	1285	1334	1383	**1433**	**1285**	1138
AC1-23 η	6.69	14.273	33.809	14.273	6.63	3.299	1.741	**1.322**	**6.569**	101.69
AC1-24 T	1284	1235	1186	**1235**	1284	1334	1383	1284	**1137**	**1087**
AC1-24 η	4.916	10.363	25.009	**10.45**	4.916	2.441	1.594	4.855	**72.283**	**277.27**
AC1-25 T	1285	1236	1187	1236	1285	**1334**	**1384**	1285	1138	**1088**
AC1-25 η	3.583	7.841	18.025	7.867	3.583	**1.838**	**1.291**	3.505	53.701	**204.78**
AC1-26 T	1285	1237	**1187**	~~**1236**~~	1285	1335	1384	1286	**1138**	
AC1-26 η	2.804	6.119	**16.99**	~~**8.196**~~	2.797	1.658	1.023	2.763	**47.409**	
AC1-27 T	1285	1236	1187	1236	1285	1335	1384	1286	1138	1088
AC1-27 η	4.76	9.931	24.277	10	4.751	2.396	1.587	4.7	71.211	267.3
AC1-28 T	1284	1236	1187	1236	1285	1335	1384	1285	1138	1088
AC1-28 η	4.362	8.997	22.049	9.031	4.25	2.139	1.47	4.232	63.554	235.89
AC1-29 T	1285	1236	1187	1236	1285	**1334**	**1384**	1285	1136	**1088**
AC1-29 η	3.730	7.876	18.058	7.815	3.583	**1.824**	**1.284**	3.505	51.603	**192.998**
AC1-30 T	1285	**1236**	1187	**1236**	1285	1335	**1385**	**1286**	**1138**	**1088**
AC1-30 η	3.296	**7.209**	16.229	**7.218**	3.275	1.641	**1.238**	**3.289**	**49.443**	**189.37**
AC1-31 T	1285	1235	**1186**	**1235**	1284	1334	1384	1285	1137	**1088**
AC1-31 η	5.072	10.64	**25.973**	**10.675**	4.994	2.465	1.62	4.933	75.959	**286.33**

Appendix C – PCT Raw Data

Table C.1: Measured Concentrations in PCT Leachate Solutions

Block	Glass #	Lab ID	Al	B	Er	La	Li	Na	Nd	Si	Sr	Al (ppm)	B (ppm)	Er (ppm)	La (ppm)	Li (ppm)	Na (ppm)	Nd (ppm)	Si (ppm)	Sr (ppm)
			Values are in Parts Per Million (ppm).									Values have been adjusted for blanks (Reduced Al ppm's by 0.083) and dilution factor of 1.6667.								
1	0	stdb1-1	4.05	22.9	<0.100	<0.100	9.88	87.1	<0.500	53.3	0.011	4.050	22.900	0.050	0.050	9.880	87.100	0.250	53.300	0.011
1	1	y50	<0.200	0.338	<0.100	0.183	<0.050	<0.530	<0.500	0.632	0.157	0.028	0.563	0.083	0.305	0.042	0.442	0.417	1.053	0.262
1	1	y36	0.201	0.279	<0.100	0.171	0.05	<0.530	<0.500	0.695	0.162	0.196	0.465	0.083	0.285	0.083	0.442	0.417	1.158	0.270
1	1	y32	<0.200	<0.180	<0.100	0.147	<0.050	<0.530	<0.500	0.756	0.153	0.028	0.150	0.083	0.245	0.042	0.442	0.417	1.260	0.255
1	13	y1	<0.200	<0.180	<0.100	0.258	<0.050	<0.530	<0.500	0.759	0.183	0.028	0.150	0.083	0.430	0.042	0.442	0.417	1.265	0.305
1	13	y90	0.214	0.199	<0.100	0.173	<0.050	<0.530	<0.500	0.832	0.185	0.218	0.332	0.083	0.288	0.042	0.442	0.417	1.387	0.308
1	13	y42	0.409	0.248	0.133	0.76	<0.050	<0.530	<0.500	1.18	0.238	0.543	0.413	0.222	1.267	0.042	0.442	0.417	1.967	0.397
1	5	y86	0.577	0.394	<0.100	<0.100	<0.050	<0.530	<0.500	1.18	0.27	0.823	0.657	0.083	0.083	0.042	0.442	0.417	1.967	0.450
1	5	y78	0.44	0.49	<0.100	0.159	<0.050	0.777	<0.500	1.57	0.226	0.594	0.817	0.083	0.265	0.042	1.295	0.417	2.617	0.377
1	5	y81	<0.200	0.225	<0.100	0.235	<0.050	<0.530	<0.500	0.978	0.246	0.028	0.375	0.083	0.392	0.042	0.442	0.417	1.630	0.410
1	11	y29	0.276	<0.180	<0.100	0.161	<0.050	<0.530	<0.500	0.714	0.167	0.321	0.150	0.083	0.268	0.042	0.442	0.417	1.190	0.278
1	11	y54	<0.200	<0.180	<0.100	0.199	<0.050	<0.530	<0.500	0.619	0.16	0.028	0.150	0.083	0.332	0.042	0.442	0.417	1.032	0.267
1	0	stdb1-2	4	20.8	<0.100	<0.100	9.69	86.4	<0.500	49.5	<0.010	4.000	20.800	0.050	0.050	9.690	86.400	0.250	49.500	0.005
1	11	y100	<0.200	0.36	<0.100	0.148	<0.050	<0.530	<0.500	0.718	0.18	0.028	0.600	0.083	0.247	0.042	0.442	0.417	1.197	0.300
1	19	y8	0.241	0.202	<0.100	0.12	0.066	<0.530	<0.500	0.705	0.16	0.263	0.337	0.083	0.200	0.110	0.442	0.417	1.175	0.267
1	19	y57	0.217	<0.180	<0.100	0.121	0.065	<0.530	<0.500	0.707	0.176	0.223	0.150	0.083	0.202	0.108	0.442	0.417	1.178	0.293
1	19	y92	0.204	<0.180	<0.100	0.104	0.055	<0.530	<0.500	0.726	0.177	0.201	0.150	0.083	0.173	0.092	0.442	0.417	1.210	0.295
1	29	y58	0.234	<0.180	<0.100	0.285	<0.050	<0.530	<0.500	0.771	0.193	0.251	0.150	0.083	0.475	0.042	0.442	0.417	1.285	0.322
1	29	y22	0.21	<0.180	<0.100	0.285	<0.050	<0.530	<0.500	0.805	0.189	0.211	0.150	0.083	0.475	0.042	0.442	0.417	1.342	0.315
1	29	y18	0.274	<0.180	<0.100	0.244	<0.050	<0.530	<0.500	0.784	0.212	0.318	0.150	0.083	0.407	0.042	0.442	0.417	1.307	0.353
1	33	y26	3.13	11.7	<0.100	<0.100	8.92	24.4	<0.500	40	0.015	5.078	19.500	0.083	0.083	14.867	40.667	0.417	66.668	0.025
1	33	y31	3.3	10.8	<0.100	<0.100	8.58	24.2	<0.500	38.7	0.02	5.361	18.000	0.083	0.083	14.300	40.334	0.417	64.501	0.033
1	33	y98	3.56	12.8	<0.100	<0.100	9.69	28	<0.500	43.8	0.017	5.795	21.334	0.083	0.083	16.150	46.668	0.417	73.001	0.028
1	0	stdb1-3	4	22.7	<0.100	<0.100	9.78	81.9	<0.500	52.4	<0.010	4.000	22.700	0.050	0.050	9.780	81.900	0.250	52.400	0.005
2	0	stdb2-1	4.11	19.8	<0.100	0.106	10.4	88.6	<0.500	51	0.084	4.110	19.800	0.050	0.106	10.400	88.600	0.250	51.000	0.084
2	2	y84	<0.200	0.576	<0.100	0.197	<0.050	<0.530	<0.500	1.21	0.358	0.028	0.960	0.083	0.328	0.042	0.442	0.417	2.017	0.597
2	2	y24	0.202	0.437	<0.100	0.25	<0.050	<0.530	<0.500	1.27	0.361	0.198	0.728	0.083	0.417	0.042	0.442	0.417	2.117	0.602
2	2	y87	0.202	0.332	<0.100	0.221	<0.050	<0.530	<0.500	1.22	0.353	0.198	0.553	0.083	0.368	0.042	0.442	0.417	2.033	0.588
2	3	y3	1.07	0.605	<0.100	<0.100	<0.050	0.759	<0.500	2.05	0.388	1.644	1.008	0.083	0.083	0.042	1.265	0.417	3.417	0.647
2	3	y27	0.365	0.294	<0.100	<0.100	<0.050	<0.530	<0.500	1.19	0.325	0.469	0.490	0.083	0.083	0.042	0.442	0.417	1.983	0.542
2	3	y94	0.213	0.287	0.133	0.146	<0.050	<0.530	<0.500	1.18	0.347	0.216	0.478	0.222	0.243	0.042	0.442	0.417	1.967	0.578
2	7	y30	<0.200	0.235	<0.100	0.156	<0.050	<0.530	<0.500	1.91	0.325	0.028	0.392	0.083	0.260	0.042	0.442	0.417	3.183	0.542
2	7	y76	<0.200	<0.180	<0.100	0.185	<0.050	<0.530	<0.500	2.04	0.3	0.028	0.150	0.083	0.308	0.042	0.442	0.417	3.400	0.500
2	7	y75	0.204	0.213	<0.100	0.245	<0.050	<0.530	<0.500	1.11	0.317	0.201	0.355	0.083	0.408	0.042	0.442	0.417	1.850	0.528
2	17	y14	0.203	0.199	<0.100	0.263	<0.050	<0.530	<0.500	1.09	0.333	0.199	0.332	0.083	0.438	0.042	0.442	0.417	1.817	0.555
2	17	y2	0.222	0.218	<0.100	0.291	<0.050	<0.530	<0.500	1.21	0.336	0.231	0.363	0.083	0.485	0.042	0.442	0.417	2.017	0.560
2	0	stdb2-2	3.97	20.5	<0.100	<0.100	9.6	80.9	<0.500	49.6	0.082	3.970	20.500	0.050	0.050	9.600	80.900	0.250	49.600	0.082

< implies less than the given detection limit

Below detection values were set to half their detection limits.

Table C.1: Measured Concentrations in PCT Leachate Solutions

			Values are in Parts Per Million (ppm).									Values have been adjusted for blanks (Reduced Al ppm's by 0.083) and dilution factor of 1.6667.								
Block	Glass #	Lab ID	Al	B	Er	La	Li	Na	Nd	Si	Sr	Al (ppm)	B (ppm)	Er (ppm)	La (ppm)	Li (ppm)	Na (ppm)	Nd (ppm)	Si (ppm)	Sr (ppm)
2	17	y43	0.211	0.463	<0.100	0.37	<0.050	<0.530	<0.500	1.24	0.351	0.213	0.772	0.083	0.617	0.042	0.442	0.417	2.067	0.585
2	23	y49	<0.200	0.246	<0.100	0.111	<0.050	<0.530	<0.500	1.04	0.298	0.028	0.410	0.083	0.185	0.042	0.442	0.417	1.733	0.497
2	23	y7	<0.200	0.24	<0.100	0.217	<0.050	<0.530	<0.500	1.05	0.318	0.028	0.400	0.083	0.362	0.042	0.442	0.417	1.750	0.530
2	23	y67	<0.200	0.217	<0.100	0.259	<0.050	<0.530	<0.500	1.02	0.307	0.028	0.362	0.083	0.432	0.042	0.442	0.417	1.700	0.512
2	31	y6	<0.200	<0.180	<0.100	0.243	<0.050	<0.530	<0.500	0.945	0.285	0.028	0.150	0.083	0.405	0.042	0.442	0.417	1.575	0.475
2	31	y68	<0.200	<0.180	<0.100	0.32	<0.050	<0.530	<0.500	0.931	0.3	0.028	0.150	0.083	0.533	0.042	0.442	0.417	1.552	0.500
2	31	y9	<0.200	0.218	<0.100	0.288	<0.050	<0.530	<0.500	1.07	0.325	0.028	0.363	0.083	0.480	0.042	0.442	0.417	1.783	0.542
2	34	y73	0.25	<0.180	<0.100	<0.100	<0.050	<0.530	<0.500	<0.180	0.083	0.250	0.090	0.050	0.050	0.025	0.265	0.250	0.090	0.083
2	34	y85	<0.200	<0.180	<0.100	<0.100	<0.050	<0.530	<0.500	<0.180	0.083	0.000	0.090	0.050	0.050	0.025	0.265	0.250	0.090	0.083
2	34	y56	<0.200	<0.180	<0.100	<0.100	<0.050	<0.530	<0.500	<0.180	0.083	0.000	0.090	0.050	0.050	0.025	0.265	0.250	0.090	0.083
2	0	stdb2-3	4.21	20.4	<0.100	<0.100	10.3	83.1	<0.500	49.6	0.082	4.210	20.400	0.050	0.050	10.300	83.100	0.250	49.600	0.082
3	0	stdb3-1	4.21	20.4	<0.100	<0.100	10.4	85.9	<0.500	54.4	0.099	4.210	20.400	0.050	0.050	10.400	85.900	0.250	54.400	0.099
3	4	y11	0.296	0.653	<0.100	0.214	<0.050	0.544	<0.500	1.25	0.367	0.354	1.088	0.083	0.357	0.042	0.907	0.417	2.083	0.612
3	6	y80	0.574	0.453	<0.100	<0.100	<0.050	0.69	<0.500	1.19	0.35	0.818	0.755	0.083	0.083	0.042	1.150	0.417	1.983	0.583
3	8	y77	0.426	0.269	<0.100	<0.100	<0.050	<0.530	<0.500	0.932	0.27	0.571	0.448	0.083	0.083	0.042	0.442	0.417	1.553	0.450
3	9	y19	0.264	0.208	<0.100	0.128	<0.050	<0.530	<0.500	0.817	0.282	0.301	0.347	0.083	0.213	0.042	0.442	0.417	1.362	0.470
3	10	y25	0.626	0.296	<0.100	<0.100	<0.050	0.702	<0.500	0.988	0.295	0.904	0.493	0.083	0.083	0.042	1.170	0.417	1.647	0.492
3	12	y70	0.289	<0.180	<0.100	0.132	<0.050	<0.530	<0.500	0.789	0.273	0.343	0.150	0.083	0.220	0.042	0.442	0.417	1.315	0.455
3	14	y10	0.531	0.194	<0.100	<0.100	<0.050	0.655	<0.500	0.714	0.268	0.746	0.323	0.083	0.083	0.042	1.092	0.417	1.190	0.447
3	15	y21	0.237	<0.180	<0.100	0.133	<0.050	<0.530	<0.500	0.622	0.26	0.256	0.150	0.083	0.222	0.042	0.442	0.417	1.037	0.433
3	16	y40	0.504	<0.180	<0.100	<0.100	<0.050	0.796	<0.500	0.608	0.241	0.701	0.150	0.083	0.083	0.042	1.327	0.417	1.013	0.402
3	18	y55	0.262	0.213	<0.100	0.171	<0.050	<0.530	<0.500	0.874	0.313	0.298	0.355	0.083	0.285	0.042	0.442	0.417	1.457	0.522
3	0	stdb3-2	4	19.1	<0.100	<0.100	9.53	83.2	<0.500	51.2	0.096	4.000	19.100	0.050	0.050	9.530	83.200	0.250	51.200	0.096
3	20	y101	0.307	0.404	<0.100	<0.100	<0.050	0.691	<0.500	0.758	0.257	0.373	0.673	0.083	0.083	0.042	1.152	0.417	1.263	0.428
3	21	y65	0.221	0.247	<0.100	0.186	<0.050	0.583	<0.500	0.837	0.287	0.229	0.412	0.083	0.310	0.042	0.972	0.417	1.395	0.478
3	22	y46	0.377	0.286	<0.100	0.115	<0.050	0.657	<0.500	1.05	0.329	0.489	0.477	0.083	0.192	0.042	1.095	0.417	1.750	0.548
3	24	y96	0.283	0.276	<0.100	0.151	<0.050	0.559	<0.500	0.991	0.299	0.333	0.460	0.083	0.252	0.042	0.932	0.417	1.652	0.498
3	25	y82	0.266	<0.180	<0.100	0.12	<0.050	0.58	<0.500	0.682	0.258	0.304	0.150	0.083	0.200	0.042	0.967	0.417	1.137	0.430
3	26	y61	0.313	<0.180	<0.100	0.123	<0.050	0.612	<0.500	0.645	0.246	0.383	0.150	0.083	0.205	0.042	1.020	0.417	1.075	0.410
3	27	y53	0.258	<0.180	<0.100	0.142	<0.050	0.603	<0.500	0.687	0.277	0.291	0.150	0.083	0.237	0.042	1.005	0.417	1.145	0.462
3	28	y12	0.758	0.296	0.195	1.19	<0.050	0.679	0.614	1.29	0.401	1.124	0.493	0.325	1.983	0.042	1.132	1.023	2.150	0.668
3	30	y95	0.315	<0.180	<0.100	0.141	<0.050	0.608	<0.500	0.781	0.262	0.386	0.150	0.083	0.235	0.042	1.013	0.417	1.302	0.437
3	32	y66	20.9	328	<10.0	<10.0	113	1123	<50.0	588	<10.0	34.695	546.678	8.334	8.334	188.337	1871.704	41.668	980.020	8.334
3	0	stdb3-3	3.94	19.5	<0.100	<0.100	9.6	85.2	<0.500	52.5	0.096	3.940	19.500	0.050	0.050	9.600	85.200	0.250	52.500	0.096
4	0	stdb4-1	4.2	20.6	<0.100	<0.100	10.1	86.8	<0.500	52.6	<0.010	4.200	20.600	0.050	0.050	10.100	86.800	0.250	52.600	0.005
4	4	y62	0.209	0.582	<0.100	0.171	<0.050	<0.530	<0.500	1.01	0.27	0.209	0.970	0.083	0.285	0.042	0.442	0.417	1.683	0.450
4	6	y20	0.357	0.461	<0.100	0.142	<0.050	<0.530	<0.500	0.904	0.242	0.456	0.768	0.083	0.237	0.042	0.442	0.417	1.507	0.403

< implies less than the given detection limit

Below detection values were set to half their detection limits.

Table C.1: Measured Concentrations in PCT Leachate Solutions

			Values are in Parts Per Million (ppm).									Values have been adjusted for blanks (Reduced Al ppm's by 0.083) and dilution factor of 1.6667.								
Block	Glass #	Lab ID	Al	B	Er	La	Li	Na	Nd	Si	Sr	Al (ppm)	B (ppm)	Er (ppm)	La (ppm)	Li (ppm)	Na (ppm)	Nd (ppm)	Si (ppm)	Sr (ppm)
4	8	y34	0.254	0.362	<0.100	<0.100	<0.050	<0.530	<0.500	0.821	0.211	0.284	0.603	0.083	0.083	0.042	0.442	0.417	1.368	0.352
4	9	y35	0.2	0.345	<0.100	0.197	<0.050	<0.530	<0.500	0.853	0.219	0.194	0.575	0.083	0.328	0.042	0.442	0.417	1.422	0.365
4	10	y83	0.254	0.331	<0.100	<0.100	<0.050	<0.530	<0.500	0.832	0.212	0.284	0.552	0.083	0.083	0.042	0.442	0.417	1.387	0.353
4	12	y28	<0.200	0.29	<0.100	0.206	<0.050	<0.530	<0.500	0.711	0.202	0.028	0.483	0.083	0.343	0.042	0.442	0.417	1.185	0.337
4	14	y16	<0.200	0.199	<0.100	<0.100	<0.050	<0.530	<0.500	0.436	0.155	0.028	0.332	0.083	0.083	0.042	0.442	0.417	0.727	0.258
4	15	y4	0.222	0.284	<0.100	0.114	<0.050	<0.530	<0.500	0.686	0.189	0.231	0.473	0.083	0.190	0.042	0.442	0.417	1.143	0.315
4	16	y69	0.447	0.257	<0.100	<0.100	<0.050	0.713	<0.500	0.57	0.168	0.606	0.428	0.083	0.083	0.042	1.188	0.417	0.950	0.280
4	18	y13	0.19	0.363	<0.100	<0.100	<0.050	<0.530	<0.500	0.878	0.235	0.178	0.605	0.083	0.083	0.042	0.442	0.417	1.463	0.392
4	0	stdb4-2	4.12	20.6	<0.100	<0.100	9.4	83.6	<0.500	50.8	<0.010	4.120	20.600	0.050	0.050	9.400	83.600	0.250	50.800	0.005
4	20	y93	<0.200	0.417	<0.100	0.171	<0.050	<0.530	<0.500	0.677	0.211	0.028	0.695	0.083	0.285	0.042	0.442	0.417	1.128	0.352
4	21	y89	<0.200	0.349	<0.100	0.198	<0.050	<0.530	<0.500	0.725	0.214	0.028	0.582	0.083	0.330	0.042	0.442	0.417	1.208	0.357
4	22	y48	0.26	0.424	<0.100	0.135	<0.050	<0.530	<0.500	0.986	0.258	0.294	0.707	0.083	0.225	0.042	0.442	0.417	1.643	0.430
4	24	y33	<0.200	0.299	<0.100	0.162	<0.050	<0.530	<0.500	0.779	0.197	0.028	0.498	0.083	0.270	0.042	0.442	0.417	1.298	0.328
4	25	y41	<0.200	0.258	<0.100	0.158	<0.050	<0.530	<0.500	0.841	0.172	0.028	0.430	0.083	0.263	0.042	0.442	0.417	1.402	0.287
4	26	y88	<0.200	0.237	<0.100	0.137	<0.050	<0.530	<0.500	0.554	0.163	0.028	0.395	0.083	0.228	0.042	0.442	0.417	0.923	0.272
4	27	y37	<0.200	0.304	<0.100	0.174	<0.050	<0.530	<0.500	0.753	0.217	0.028	0.507	0.083	0.290	0.042	0.442	0.417	1.255	0.362
4	28	y52	0.208	0.276	<0.100	0.181	<0.050	<0.530	0.614	0.765	0.209	0.208	0.460	0.083	0.302	0.042	0.442	1.023	1.275	0.348
4	30	y99	0.226	0.245	<0.100	0.181	<0.050	<0.530	<0.500	0.623	0.19	0.238	0.408	0.083	0.302	0.042	0.442	0.417	1.038	0.317
4	32	y51	<20.0	362	<10.0	<10.0	114	1150	<50.0	612	<10.0	16.529	603.345	8.334	8.334	190.004	1916.705	41.668	1020.020	8.334
4	0	stdb4-3	3.81	19.9	<0.100	<0.100	9.3	83.7	<0.500	51.8	<0.010	3.810	19.900	0.050	0.050	9.300	83.700	0.250	51.800	0.005
5	0	stdb5-1	4.28	20.8	<0.100	<0.100	10.9	87.8	<0.500	53.2	<0.010	4.280	20.800	0.050	0.050	10.900	87.800	0.250	53.200	0.005
5	4	y102	<0.200	0.692	<0.100	0.234	<0.050	<0.530	<0.500	1.1	0.256	0.028	1.153	0.083	0.390	0.042	0.442	0.417	1.833	0.427
5	6	y45	<0.200	0.472	<0.100	0.106	<0.050	<0.530	<0.500	0.848	0.211	0.028	0.787	0.083	0.177	0.042	0.442	0.417	1.413	0.352
5	8	y97	0.208	0.362	<0.100	<0.100	<0.050	<0.530	<0.500	0.875	0.14	0.208	0.603	0.083	0.083	0.042	0.442	0.417	1.458	0.233
5	9	y63	<0.200	0.337	<0.100	0.22	<0.050	<0.530	<0.500	0.755	0.155	0.028	0.562	0.083	0.367	0.042	0.442	0.417	1.258	0.258
5	10	y72	<0.200	0.312	<0.100	0.256	<0.050	<0.530	<0.500	0.787	0.157	0.028	0.520	0.083	0.427	0.042	0.442	0.417	1.312	0.262
5	12	y59	<0.200	0.276	<0.100	0.274	<0.050	<0.530	<0.500	0.702	0.138	0.028	0.460	0.083	0.457	0.042	0.442	0.417	1.170	0.230
5	14	y71	<0.200	0.234	<0.100	0.101	<0.050	<0.530	<0.500	0.551	0.135	0.028	0.390	0.083	0.168	0.042	0.442	0.417	0.918	0.225
5	15	y5	<0.200	0.333	<0.100	<0.100	<0.050	<0.530	<0.500	0.698	0.122	0.028	0.555	0.083	0.083	0.042	0.442	0.417	1.163	0.203
5	16	y23	0.377	0.229	<0.100	<0.100	<0.050	<0.530	<0.500	0.564	0.128	0.489	0.382	0.083	0.083	0.042	0.442	0.417	0.940	0.213
5	18	y60	<0.200	0.367	<0.100	0.232	<0.050	<0.530	<0.500	0.991	0.19	0.028	0.612	0.083	0.387	0.042	0.442	0.417	1.652	0.317
5	0	stdb5-2	4	20.8	<0.100	<0.100	10.4	86.2	<0.500	55.4	<0.010	4.000	20.800	0.050	0.050	10.400	86.200	0.250	55.400	0.005
5	20	y64	<0.200	0.443	<0.100	0.237	<0.050	<0.530	<0.500	0.601	0.13	0.028	0.738	0.083	0.395	0.042	0.442	0.417	1.002	0.217
5	21	y44	<0.200	0.384	<0.100	0.183	<0.050	<0.530	<0.500	0.753	0.17	0.028	0.640	0.083	0.305	0.042	0.442	0.417	1.255	0.283
5	22	y47	<0.200	0.4	<0.100	0.146	<0.050	<0.530	<0.500	1.02	0.215	0.028	0.667	0.083	0.243	0.042	0.442	0.417	1.700	0.358
5	24	y74	<0.200	0.334	<0.100	0.304	<0.050	<0.530	<0.500	0.881	0.168	0.028	0.557	0.083	0.507	0.042	0.442	0.417	1.468	0.280

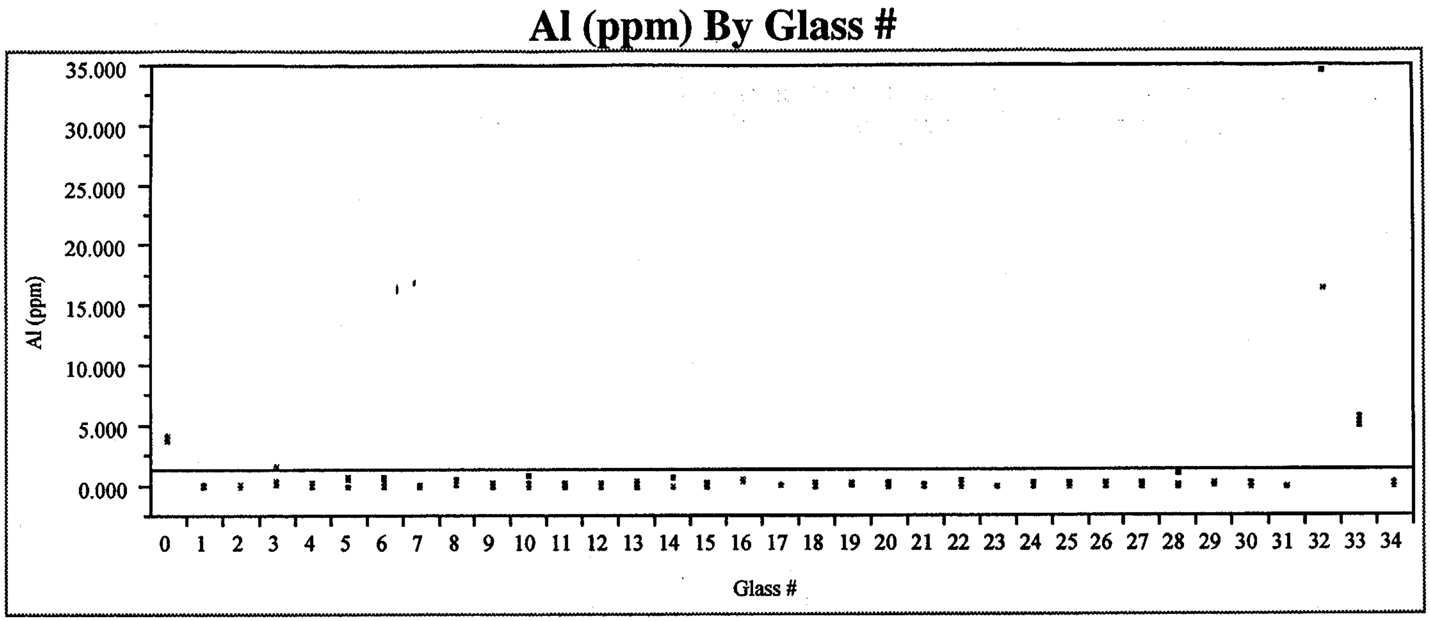
< implies less than the given detection limit

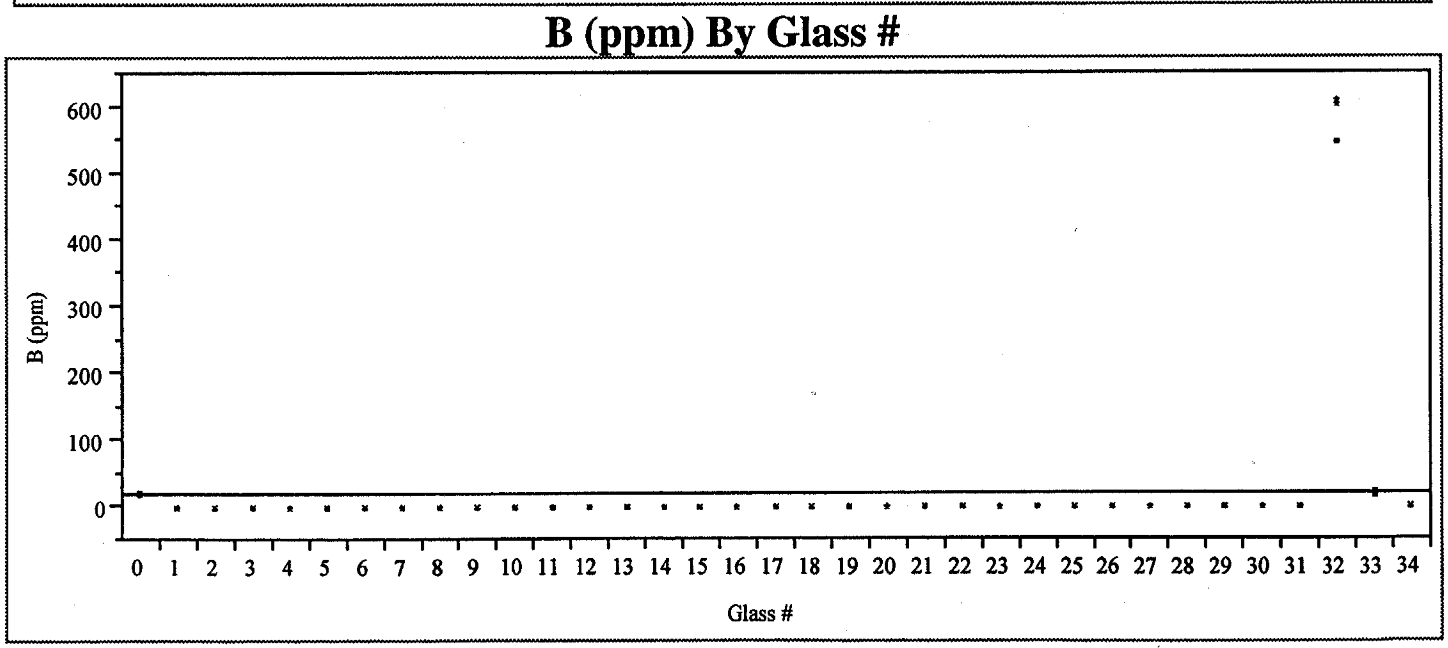
Below detection values were set to half their detection limits.

			Values are in Parts Per Million (ppm).									Values have been adjusted for blanks (Reduced Al ppm's by 0.083) and dilution factor of 1.6667.								
Block	Glass #	Lab ID	Al	B	Er	La	Li	Na	Nd	Si	Sr	Al (ppm)	B (ppm)	Er (ppm)	La (ppm)	Li (ppm)	Na (ppm)	Nd (ppm)	Si (ppm)	Sr (ppm)
5	25	y91	<0.200	0.251	<0.100	0.181	<0.050	<0.530	<0.500	0.76	0.119	0.028	0.418	0.083	0.302	0.042	0.442	0.417	1.267	0.198
5	26	y17	<0.200	0.274	<0.100	0.103	<0.050	<0.530	<0.500	0.679	0.145	0.028	0.457	0.083	0.172	0.042	0.442	0.417	1.132	0.242
5	27	y15	<0.200	0.298	<0.100	0.182	<0.050	<0.530	<0.500	0.709	0.171	0.028	0.497	0.083	0.303	0.042	0.442	0.417	1.182	0.285
5	28	y39	<0.200	0.246	<0.100	0.287	<0.050	<0.530	0.614	0.632	0.152	0.028	0.410	0.083	0.478	0.042	0.442	1.023	1.053	0.253
5	30	y79	<0.200	0.241	<0.100	0.188	<0.050	<0.530	<0.500	0.767	0.13	0.028	0.402	0.083	0.313	0.042	0.442	0.417	1.278	0.217
5	32	y38	<20.0	365	<10.0	<10.0	126	1140	<50.0	632	<10.0	16.529	608.346	8.334	8.334	210.004	1900.038	41.668	1053.354	8.334
5	0	stdb5-3	3.88	20.8	<0.100	<0.100	9.91	85.2	<0.500	53.8	<0.500	3.880	20.800	0.050	0.050	9.910	85.200	0.250	53.800	0.250

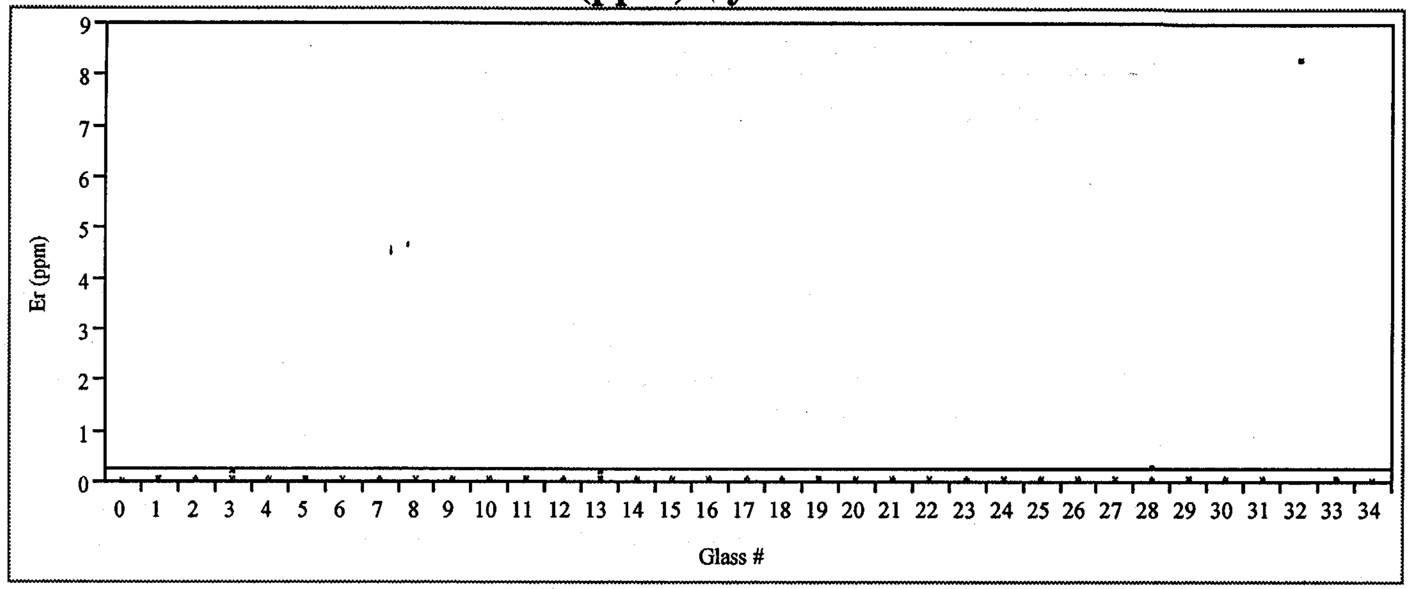
< implies less than the given detection limit

Below detection values were set to half their detection limits.


Al (ppm) By Glass #
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Al (ppm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Glass #


B (ppm) By Glass #
600
500
400
300
200
100
0
B (ppm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Glass #

Er (ppm) By Glass



La (ppm) By Glass

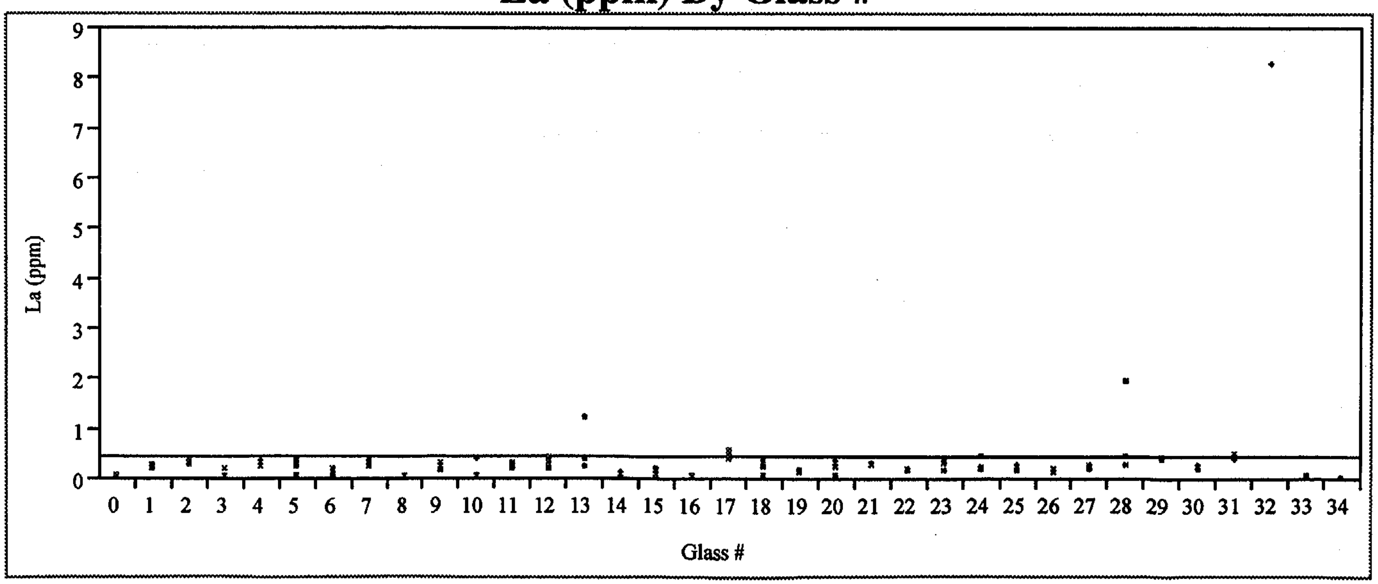
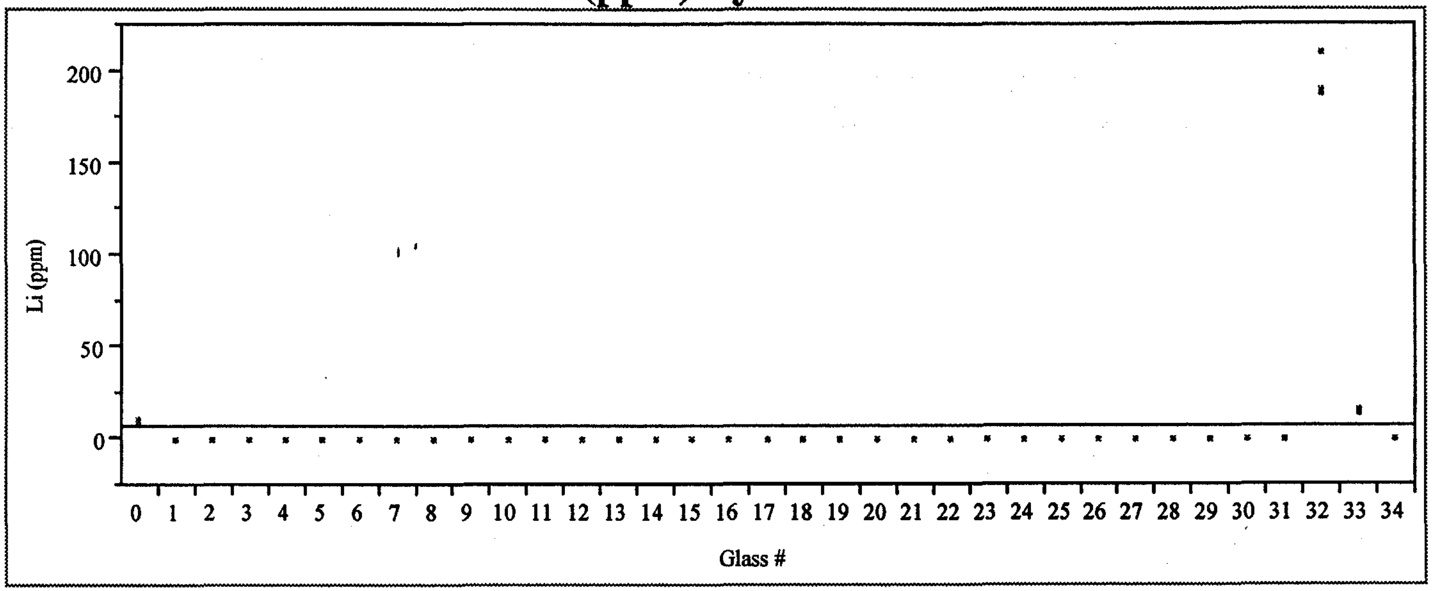
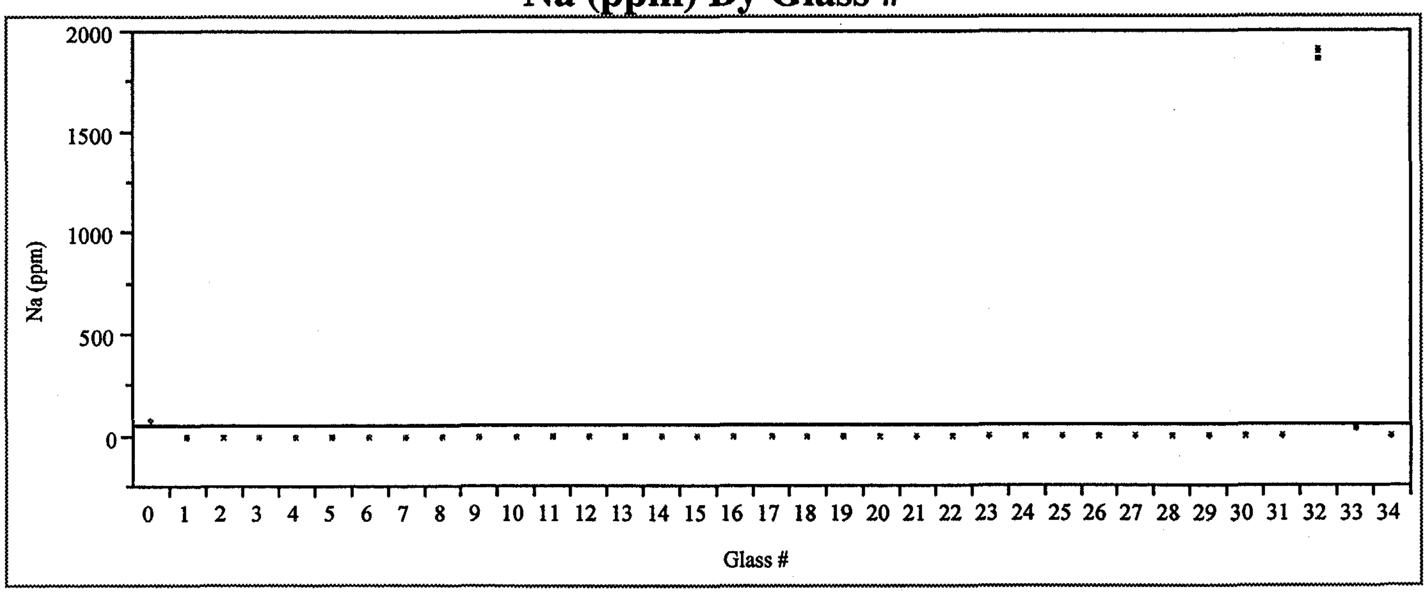


Exhibit C.1: PCT Leachate Concentrations by Glass Number
(0-Standard Solution; 1:31-AmCm Glasses; 32-EA; 33-ARM; 34-blank

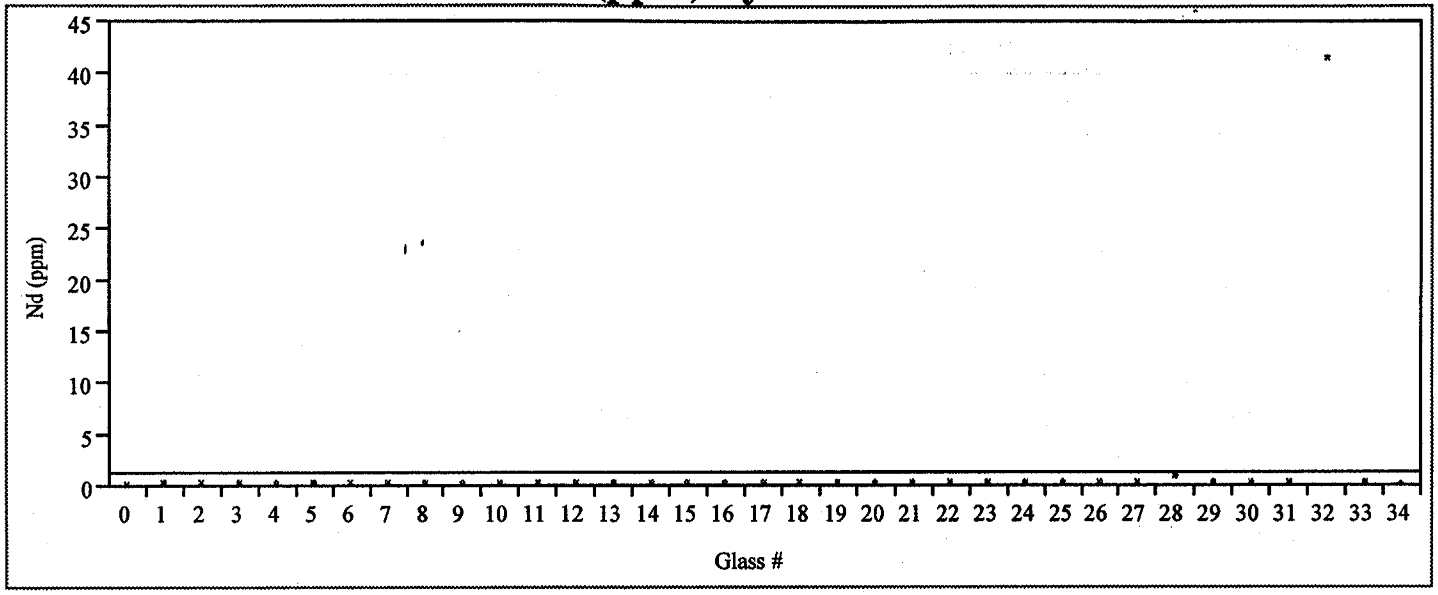
Li (ppm) By Glass



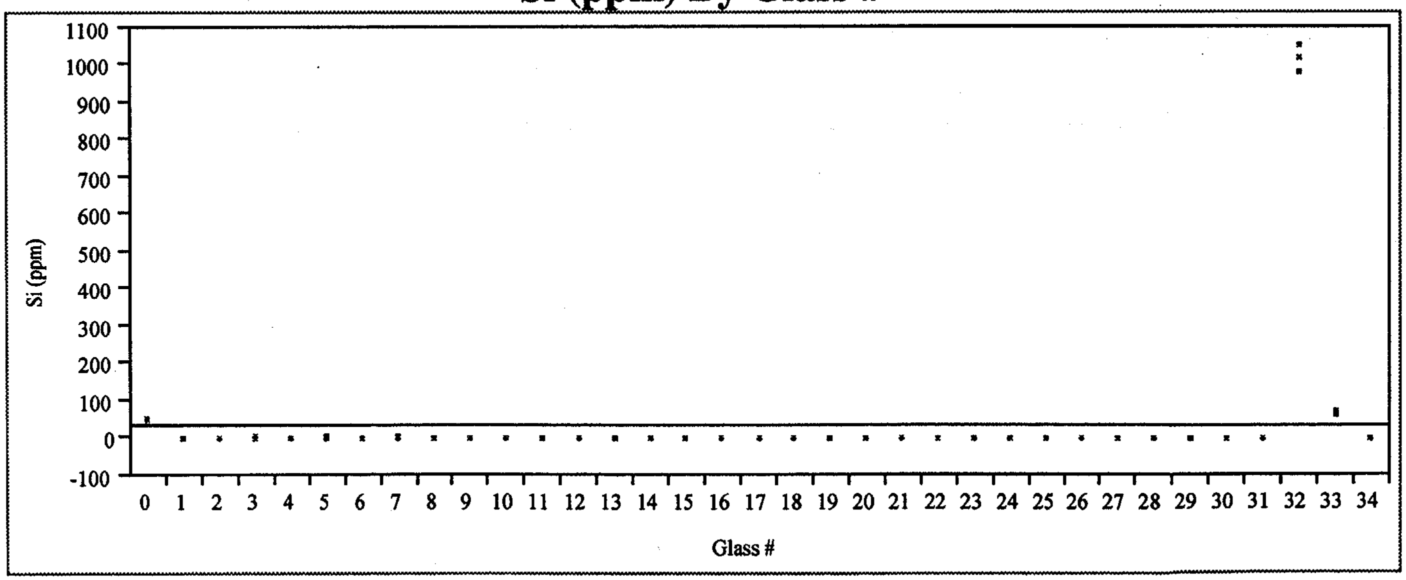
Na (ppm) By Glass



Nd (ppm) By Glass



Si (ppm) By Glass



Sr (ppm) By Glass

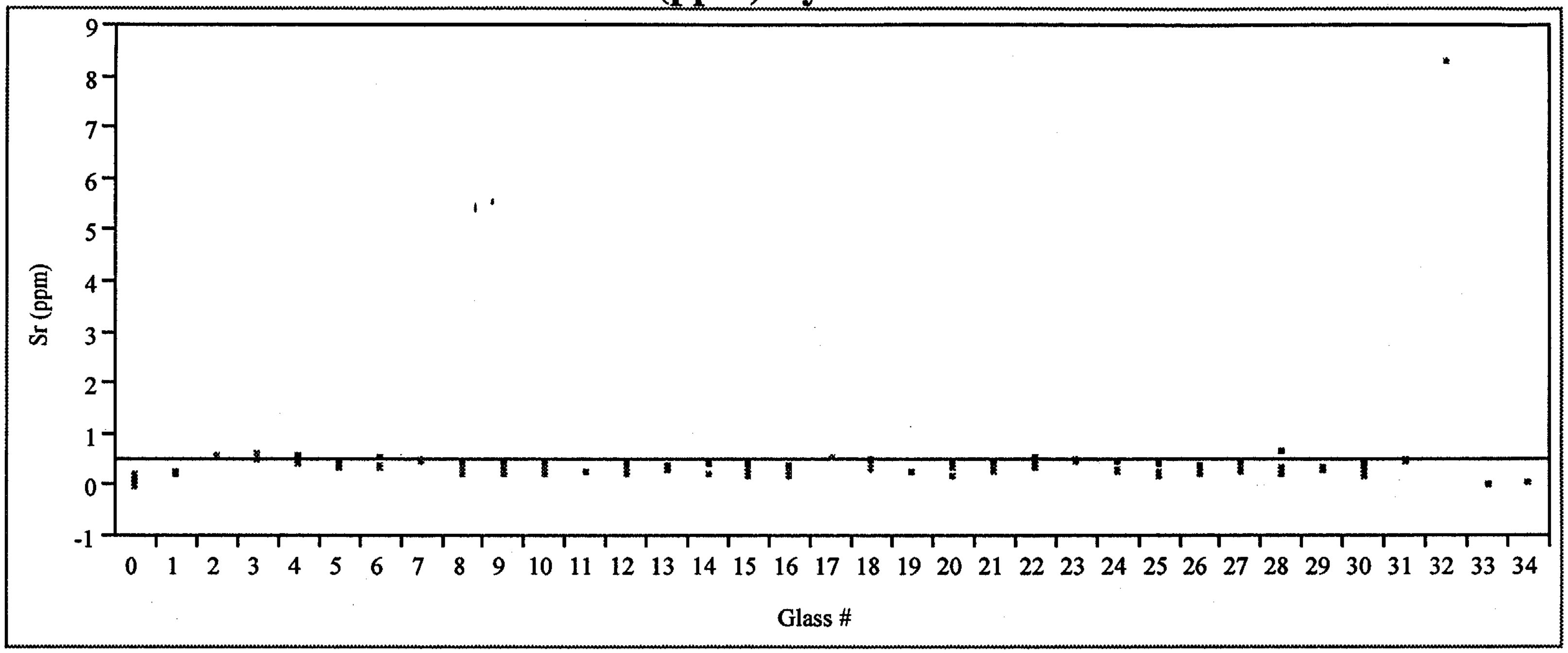
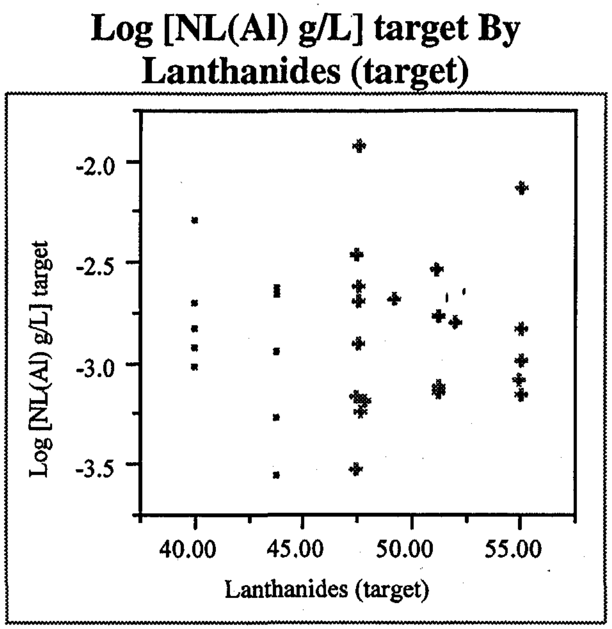
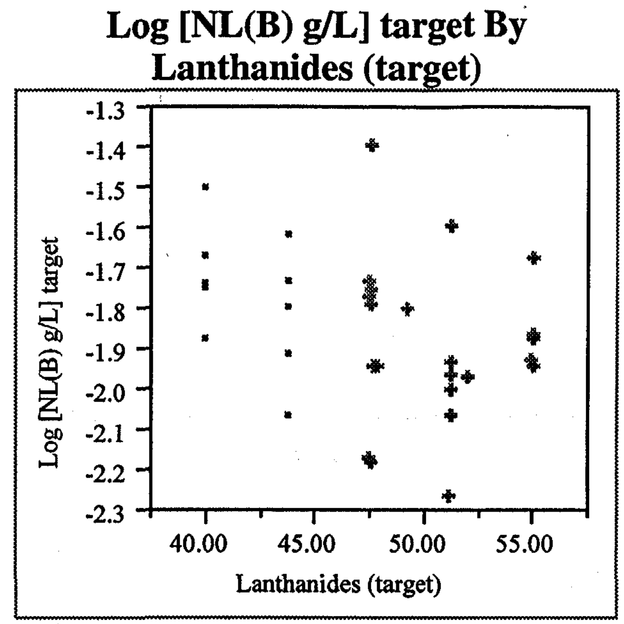
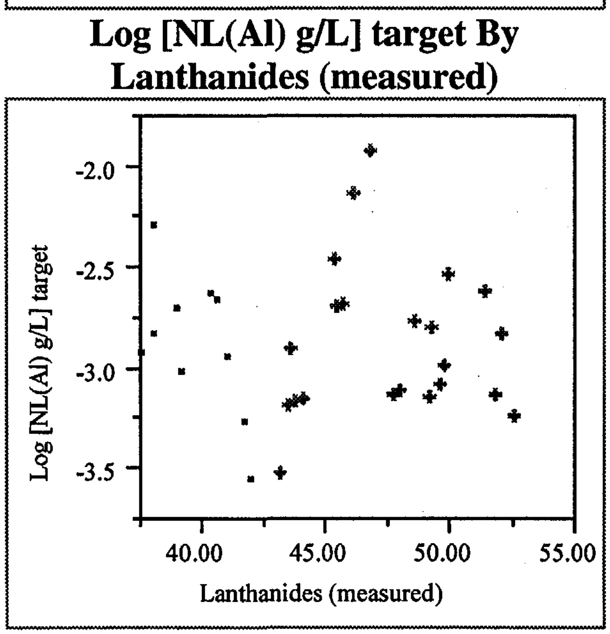
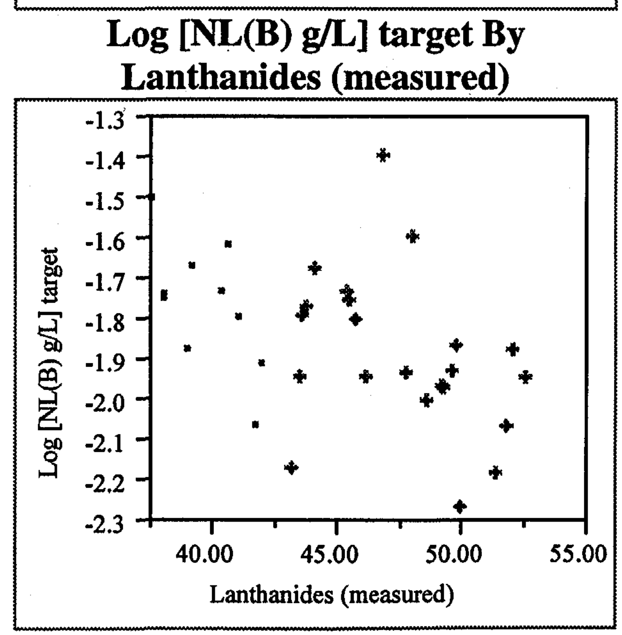


Exhibit C.2: Log Normalized PCTs by Lanthanides

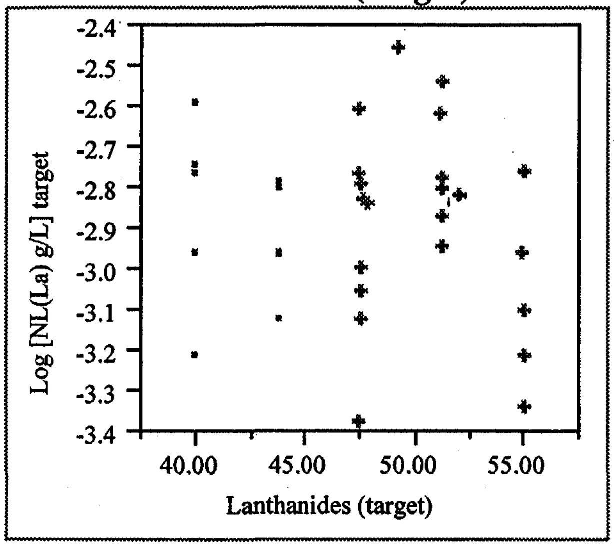




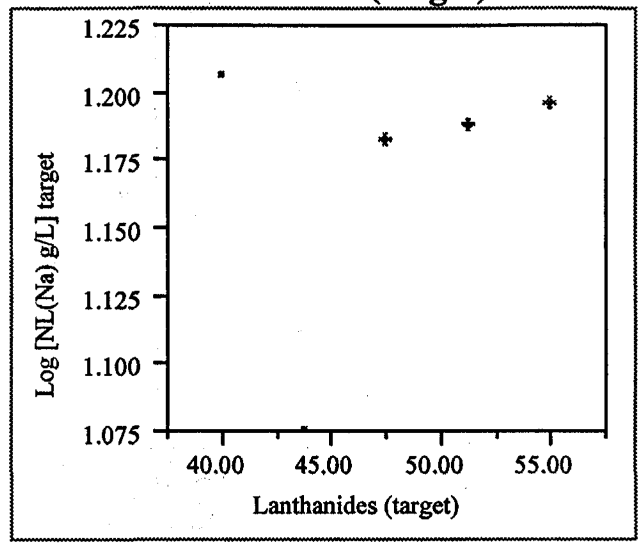




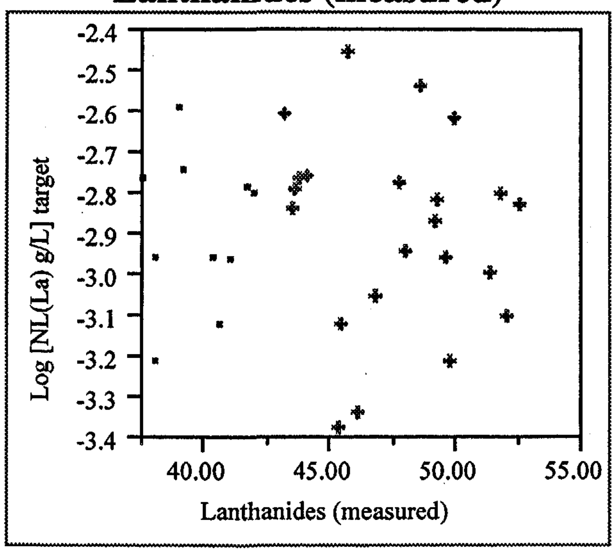
Log [NL(La) g/L] target By Lanthanides (target)



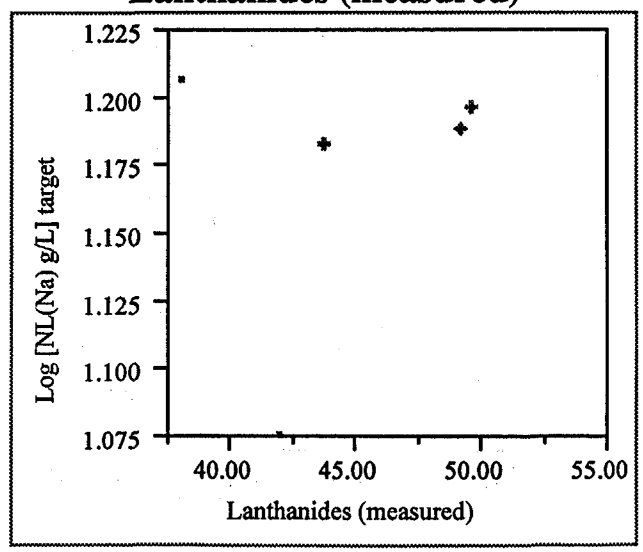
Log [NL(Na) g/L] target By Lanthanides (target)



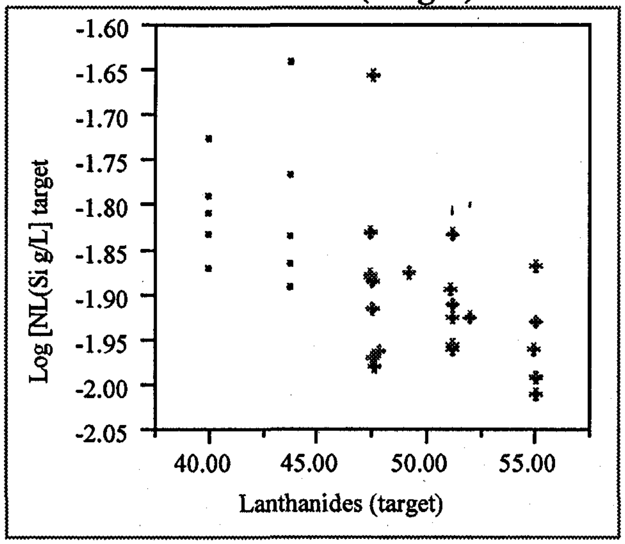
Log [NL(La) g/L] target By Lanthanides (measured)



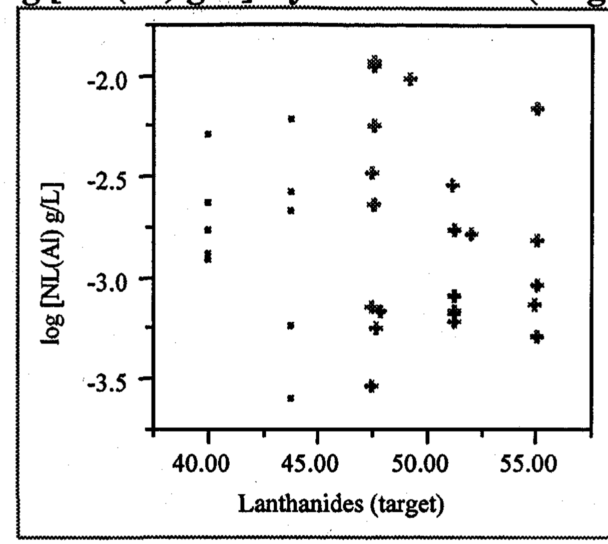
Log [NL(Na) g/L] target By Lanthanides (measured)



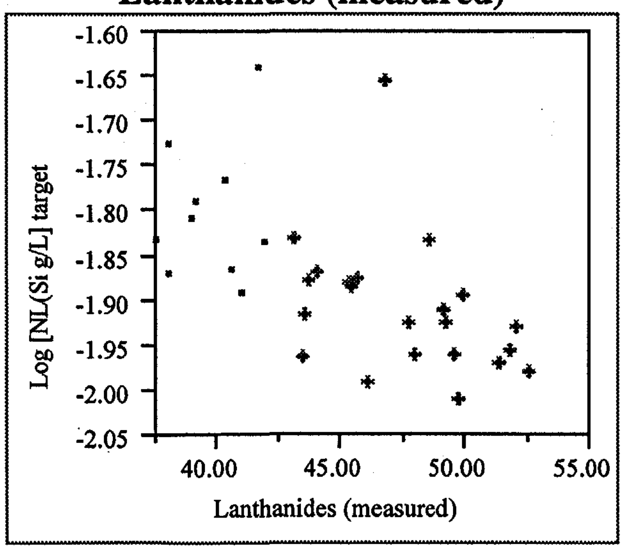
Log [NL(Si g/L] target By Lanthanides (target)



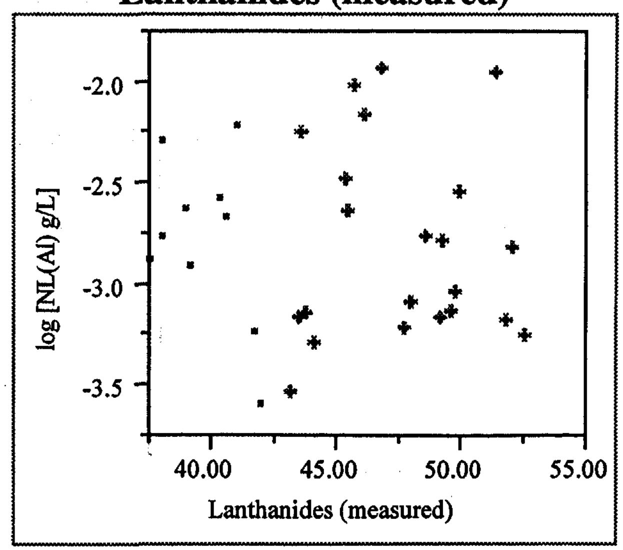
log [NL(Al) g/L] By Lanthanides (target)

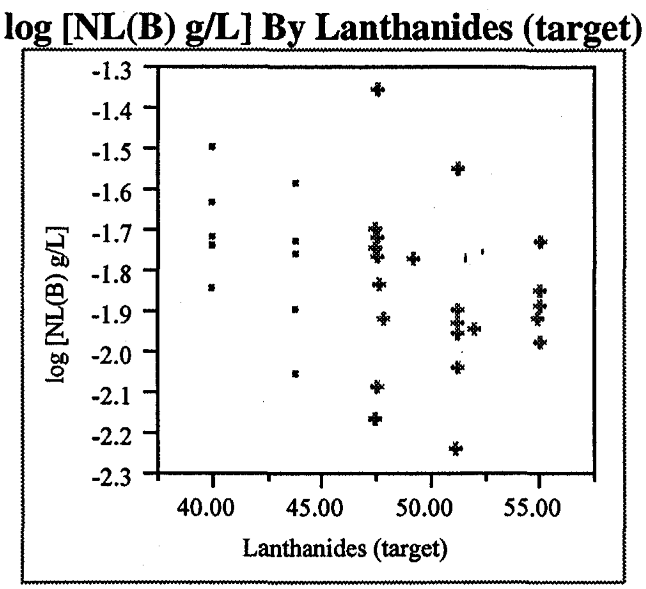


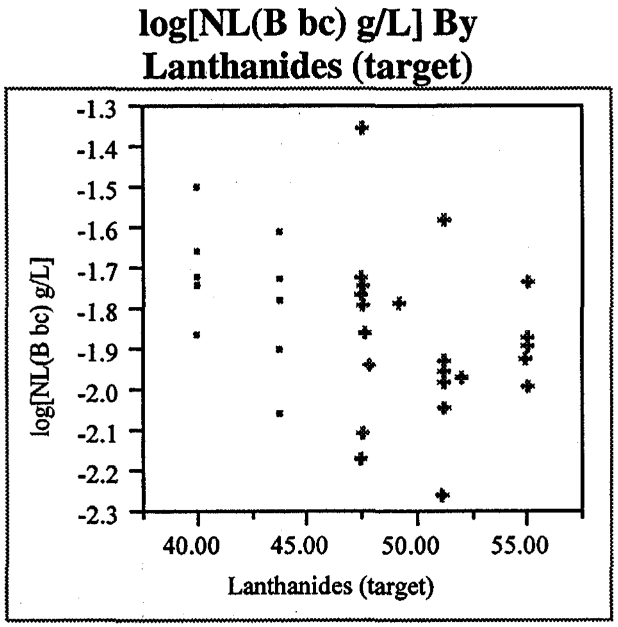
Log [NL(Si g/L] target By Lanthanides (measured)

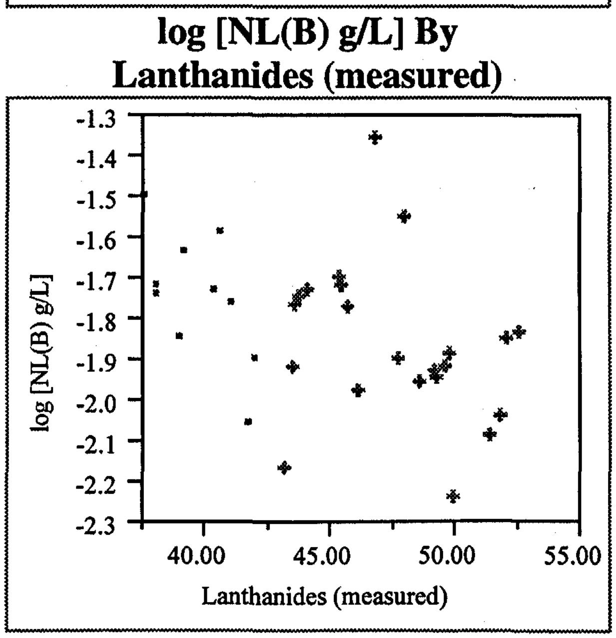


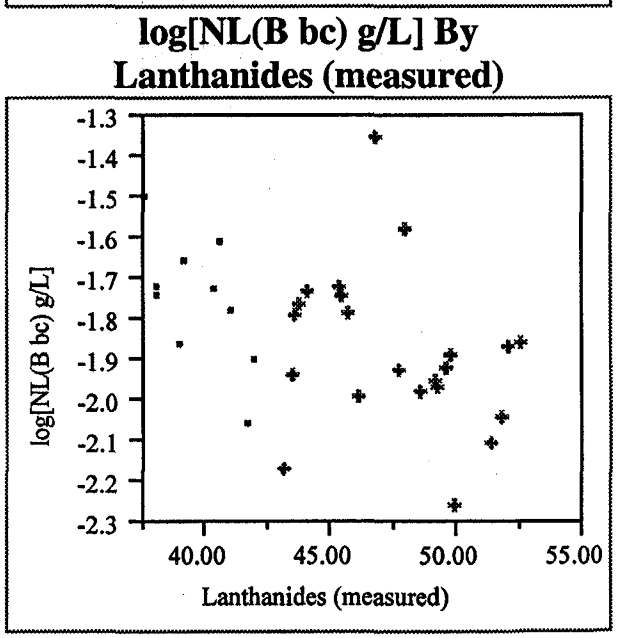
log [NL(Al) g/L] By Lanthanides (measured)



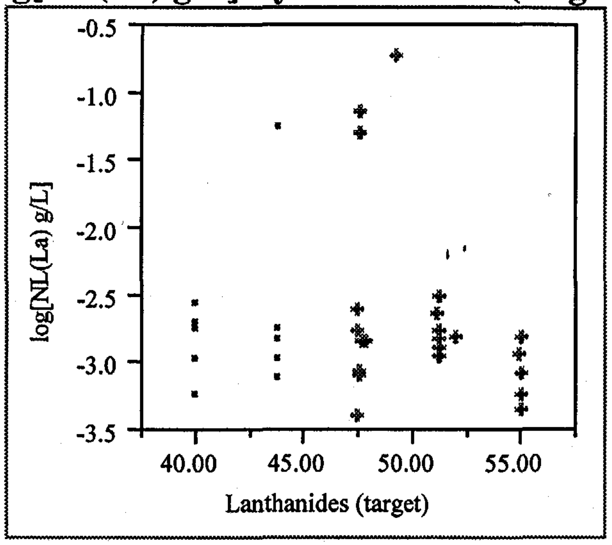

log [NL(B) g/L] By Lanthanides (target)
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
log [NL(B) g/L]
40.00
45.00
50.00
55.00
Lanthanides (target)


log[NL(B bc) g/L] By
Lanthanides (target)
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
log[NL(B bc) g/L]
40.00
45.00
50.00
55.00
Lanthanides (target)

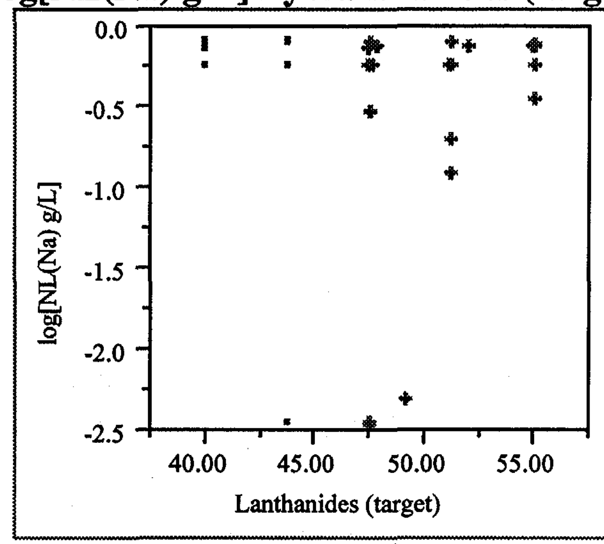

log [NL(B) g/L] By
Lanthanides (measured)
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
log [NL(B) g/L]
40.00
45.00
50.00
55.00
Lanthanides (measured)


log[NL(B bc) g/L] By
Lanthanides (measured)
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
log[NL(B bc) g/L]
40.00
45.00
50.00
55.00
Lanthanides (measured)

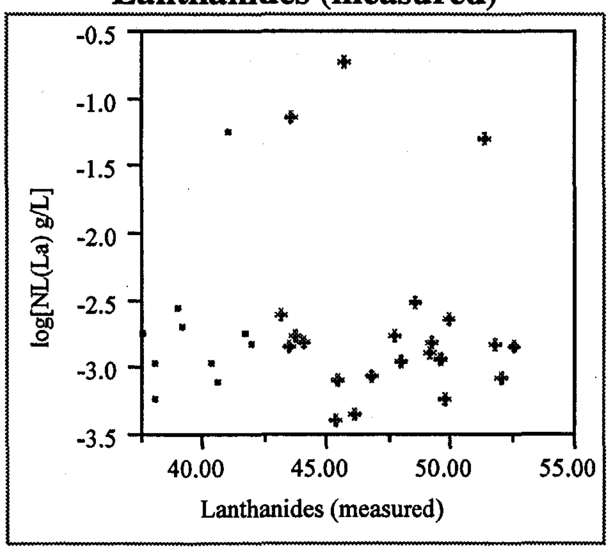
log[NL(La) g/L] By Lanthanides (target)



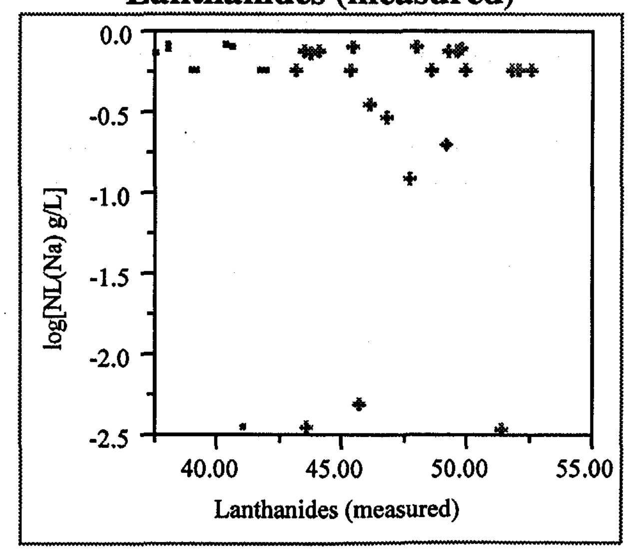
log[NL(Na) g/L] By Lanthanides (target)



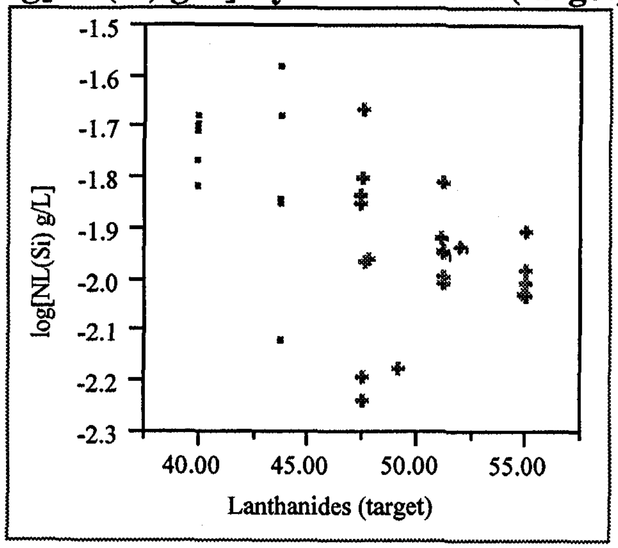
log[NL(La) g/L] By Lanthanides (measured)



log[NL(Na) g/L] By Lanthanides (measured)



log[NL(Si) g/L] By Lanthanides (target)



log[NL(Si) g/L] By Lanthanides (measured)

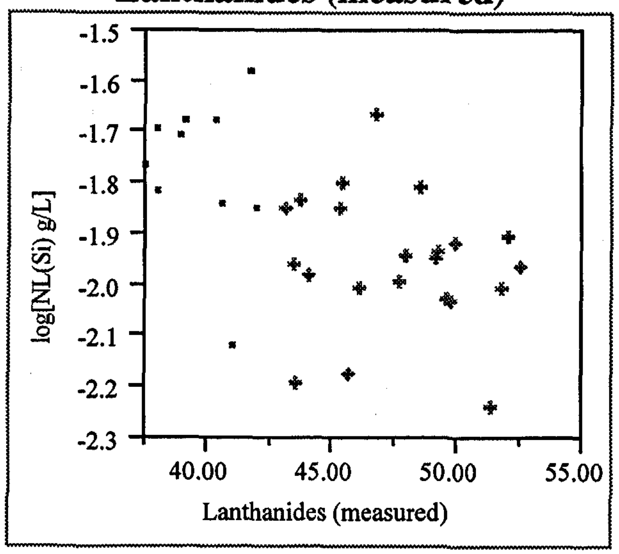
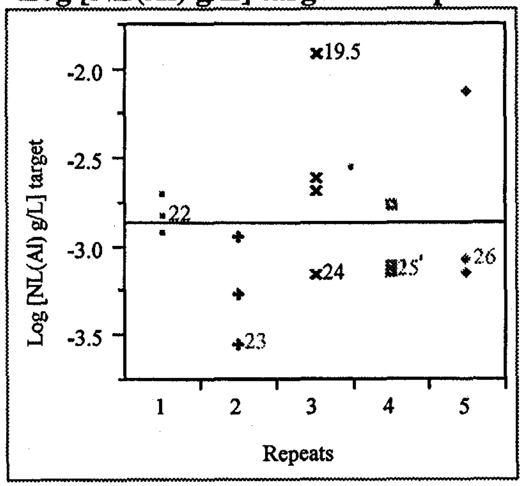


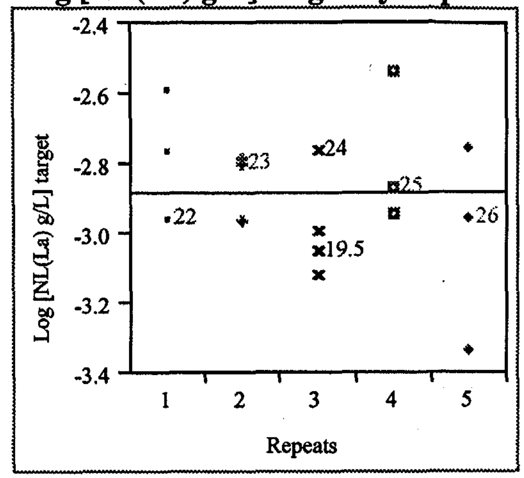
Exhibit C.3: Log Normalized PCT's for Duplicate Glasses

Log [NL(Al) g/L] target for Repeats



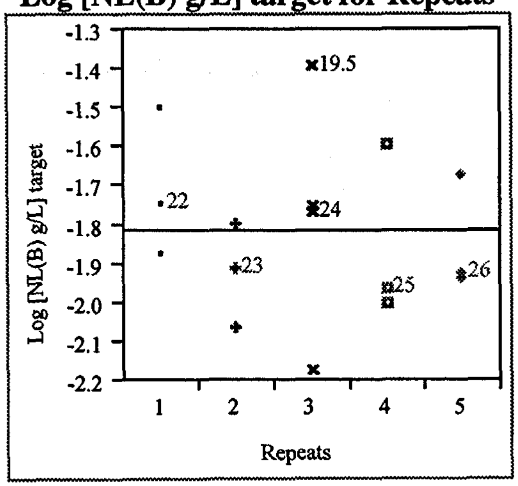
Repeatability Standard Deviation 0.396614
Overall Mean of Response -2.86534

Log [NL(La) g/L] target By Repeats



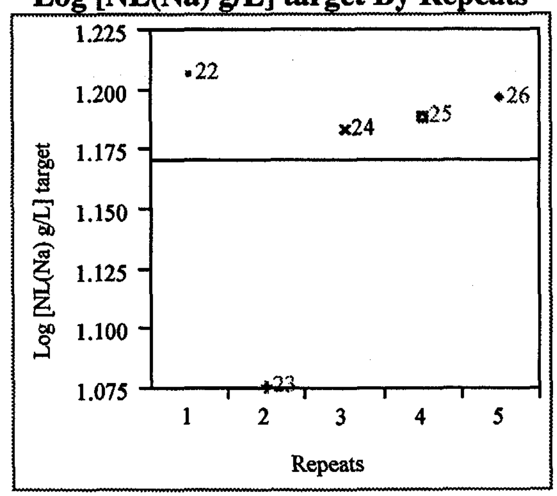
Repeatability Standard Deviation 0.196688
Overall Mean of Response -2.88394

Log [NL(B) g/L] target for Repeats

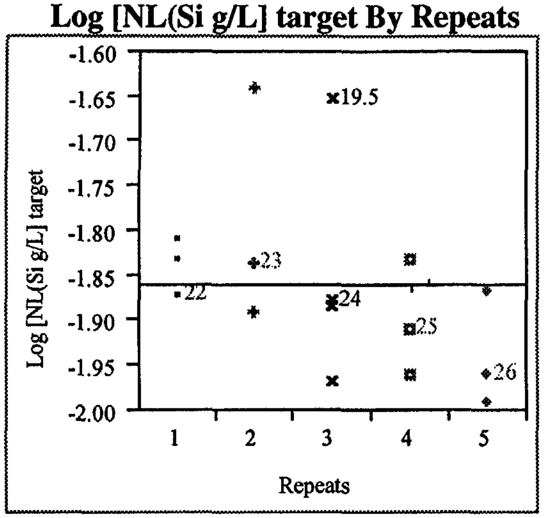


Repeatability Standard Deviation 0.22545
Overall Mean of Response -1.81527

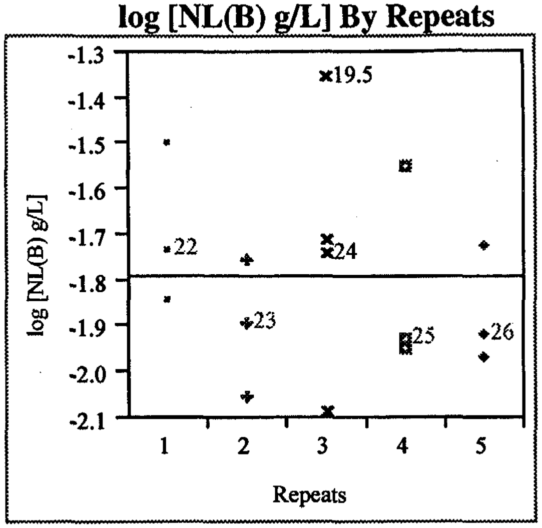
Log [NL(Na) g/L] target By Repeats



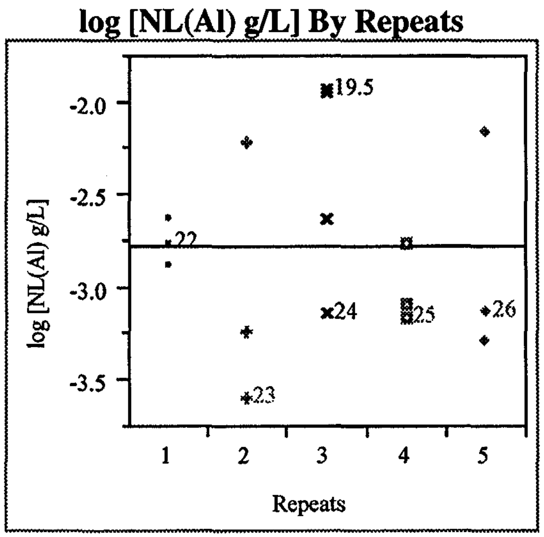
No Repeatability Standard Deviation; Na only in spiked glasses.
Overall Mean of Response 1.170635
(Large values due to low target Na concentrations in these glasses)



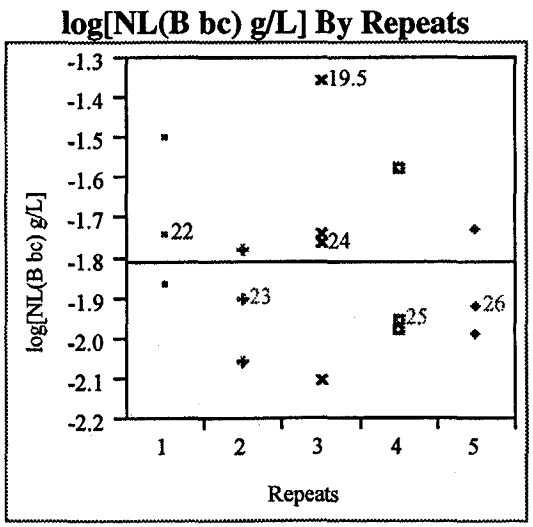
Repeatability Standard Deviation	0.099038
Overall Mean of Response	-1.86008



Repeatability Standard Deviation	0.215157
Overall Mean of Response	-1.79255

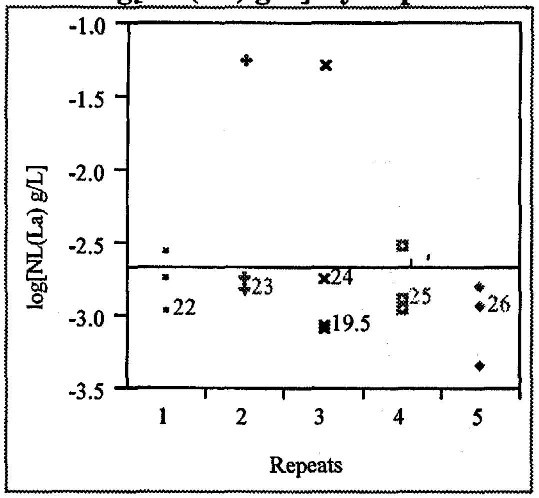


Repeatability Standard Deviation	0.51445
Overall Mean of Response	-2.77781



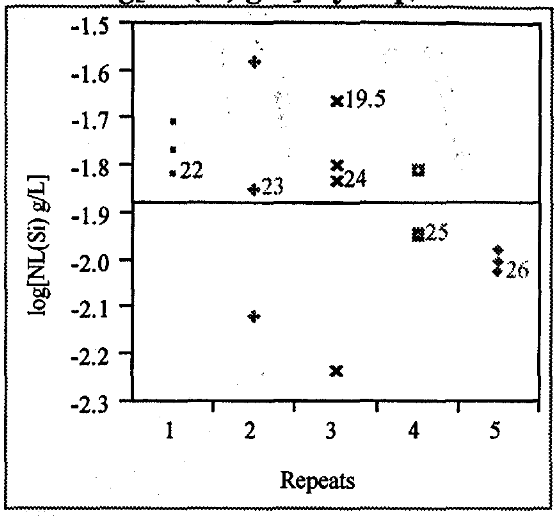
Repeatability Standard Deviation	0.219082
Overall Mean of Response	-1.80739

log[NL(La) g/L] By Repeats



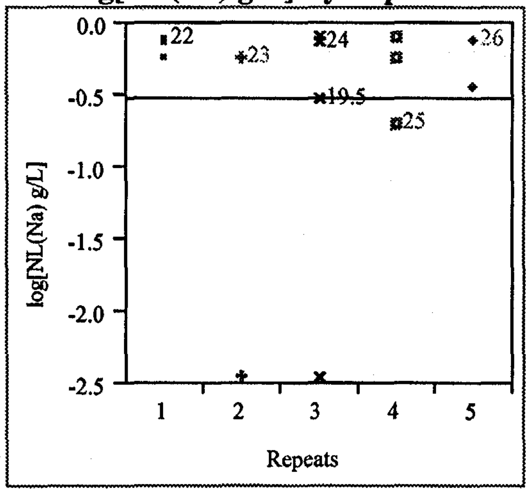
Root Mean Square Error 0.61191
Overall Mean of Response -2.65963

log[NL(Si) g/L] By Repeats



Root Mean Square Error 0.1775
Mean of Response -1.87793

log[NL(Na) g/L] By Repeats



Repeatability Standard Deviation 0.815294
Overall Mean of Response -0.51324