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Impacts of Small Column Ion Exchange Streams on DWPF Glass Formulation: KT05 and KT06-Series Glass Compositions

K. M. Fox
T. B. Edwards

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Savannah River National Laboratory
Savannah River Nuclear Solutions, LLC
Aiken, SC 29808

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REVIEWS AND APPROVALS

AUTHORS:

____
K. M. Fox, Process Technology Programs Date

____
T. B. Edwards, Applied Computational Engineering and Statistics Date

TECHNICAL REVIEW:

____
D. K. Peeler, Process Technology Programs Date

APPROVAL:

____
C. C. Herman, Manager Date
Process Technology Programs

____
F. M. Pennebaker, Manager Date
SRNL SCIX Program

____
S. L. Marra, Manager Date
Environmental & Chemical Process Technology Research Programs

____
J. E. Occhipinti, Manager Date
Waste Solidification Engineering

____
T. H. Huff, Manager Date
SCIX Engineering

EXECUTIVE SUMMARY

This report is the second in a series of studies of the impacts of the addition of Crystalline Silicotitanate (CST) and Monosodium Titanate (MST) from the Small Column Ion Exchange (SCIX) process on the Defense Waste Processing Facility (DWPF) glass waste form and the applicability of the DWPF process control models. The KT05-series glasses were selected, fabricated, and characterized to further study glass compositions where iron titanate crystals had been previously found to form. The intent was to better understand the mechanisms and compositions that favored the formation of crystals containing titanium. Formation of these crystalline phases was confirmed. Increased Na_2O concentrations had little if any impact on reducing the propensity for the formation of the iron titanate crystalline phases. Other physical properties of these glasses were not measured since the intent was to focus on crystallization. Additional studies are suggested to investigate the potential impacts of Al_2O_3 and K_2O on crystallization in glasses with high TiO_2 concentrations.

The KT06-series glasses were selected, fabricated, and characterized to further study glass compositions that, while broader than the current projections for DWPF feeds with SCIX material, are potential candidates for future processing (i.e., the compositions are acceptable for processing by the Product Composition Control System (PCCS) with the exception of the current TiO_2 concentration constraint). The chemical compositions of these glasses matched well with the target values. The chemical durabilities of all the glasses were acceptable relative to the Environmental Assessment (EA) benchmark. Minor crystallization was identified in some of the slowly cooled glasses, although this crystallization did not impact chemical durability.

Several of the KT06-series compositions had durability values that, while acceptable, were not accurately predicted by the current durability models. It was shown that for these high TiO_2 concentration glasses, relatively high Fe_2O_3 concentrations combined with relatively high Al_2O_3 concentrations led to durabilities that were unpredictable. Several of the KT06-series glasses also had measured viscosity values that were not well predicted by the current model. A statistical partitioning routine showed that the measured viscosities became unpredictable by the current model when the Fe_2O_3 concentration in the glasses was less than about 8.2 wt % at the elevated TiO_2 concentrations. The current durability and viscosity models will have to be further evaluated should compositions in these regions become necessary for DWPF processing.

Overall, the results presented for the KT06-series glasses show that TiO_2 from the SCIX streams can be incorporated into DWPF-type glasses at concentrations of 6 wt % (in glass) without any detrimental impacts on crystallization or chemical durability that are of practical importance. The measured values for chemical durability and viscosity were acceptable for processing; however, not all of the values were predictable by the current PCCS models. Since the compositions selected for the KT06-series glasses were outside the current projections for DWPF processing with the SCIX streams (in terms of waste components other than TiO_2), these results help identify compositional regions that, if necessary for processing, would require modifications to the current models. Additional experiments are currently underway. Once completed, all of the measured data will be reviewed and compared to model predictions to better determine whether the validation range of the DWPF process control models can be confidently extended, or whether refitting of the models will be necessary.

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LIST OF ABBREVIATIONS

AD	Analytical Development
ANOVA	ANalysis Of VAriance
ARM	Approved Reference Material
CCC	Canister Centerline Cooled
CST	Crystalline Silicotitanate
DWPF	Defense Waste Processing Facility
EA	Environmental Assessment
EDS	Energy Dispersive Spectroscopy
HLW	High Level Waste
ICP-AES	Inductively Coupled Plasma – Atomic Emission Spectroscopy
LM	Lithium-Metaborate Fusion
MAR	Measurement Acceptability Region
MST	Monosodium Titanate
PCCS	Product Composition Control System
PCT	Product Consistency Test
PF	Sodium Peroxide Fusion
PSAL	Process Science Analytical Laboratory
RMF	Rotary Micro Filtration
SCIX	Small Column Ion Exchange
SEM	Scanning Electron Microscopy
SRR	Savannah River Remediation
SRS	Savannah River Site
SWPF	Salt Waste Processing Facility
T_L	Liquidus Temperature
XRD	X-ray Diffraction

1.0 Introduction

1.1 Background

Savannah River Remediation (SRR) will begin a process referred to as Small Column Ion Exchange (SCIX) to disposition salt solution at the Savannah River Site (SRS) in fiscal year 2014. In the first step of the process, salt solution retrieved from various waste tanks will be struck with Monosodium Titanate (MST) to remove key actinides and strontium. The salt solution will then be processed using Rotary Micro Filtration (RMF) to remove the MST and any insoluble solids. The MST and insoluble solids will accumulate on the bottom of Tank 41. The filtrate from RMF will be fed to ion exchange columns, also in Tank 41, to remove the ^{137}Cs using Crystalline Silicotitanate (CST) resin. The decontaminated salt solution from SCIX will be sent to the Saltstone Production Facility for immobilization in grout. The ^{137}Cs-laden CST resin will be sluiced and ground for particle size reduction, then sent to the Defense Waste Processing Facility (DWPF) for immobilization in glass. These processes mirror the current disposition paths for streams associated with the Salt Waste Processing Facility (SWPF), which is under construction.

The MST and insoluble solids from Tank 41 will periodically be transferred to a sludge batch preparation tank (e.g., Tank 42 or Tank 51) as part of the High Level Waste (HLW) sludge batch preparation process for DWPF. The ground, ^{137}Cs-laden CST material (hereafter referred to simply as CST) from SCIX will be periodically transferred to Tank 40 prior to being processed at DWPF. Periodic additions of CST to Tank 40 would result in a changing composition of each sludge batch as it is processed since Tank 40 serves as the feed tank for the DWPF. Work is currently in progress to determine the feasibility of dropping the ground CST into Tank 41. If ground CST can be dropped into Tank 41 (depending on heat loading issues, among others), the CST would be sent to Tank 42 or Tank 51 using an existing transfer line. Therefore, the studies of SCIX impacts on DWPF glass formulation will encompass scenarios where the CST is sent to either Tank 40 or a sludge batch preparation tank.

This work was initiated by a DWPF Technical Task Request[1] and was performed following a Task Technical and Quality Assurance Plan.[2]

1.2 Potential Impacts of SCIX on DWPF Glass Formulation

The MST and CST from the SCIX process will significantly increase the concentrations of Nb_2O_5, TiO_2, and ZrO_2 in the DWPF feed. Other constituents of MST and CST – Na_2O and SiO_2 – are already present in high concentrations in DWPF glass; thus their influences are well understood. The increased concentrations of Nb_2O_5, TiO_2, and ZrO_2 will likely have some impact on the properties and performance of the DWPF glass product. Properties such as the liquidus temperature, viscosity, and rate of melting of the glass may be impacted. The performance of the glass, particularly its chemical durability as it pertains to repository acceptance requirements, may also be impacted. The DWPF uses a set of semi-empirical and first-principles models referred to as the Product Composition Control System (PCCS)[3] to predict the properties and performance of a glass based on its composition since it is not possible or practical to measure these attributes during processing. The objective of this study is to evaluate the impacts of the SCIX streams on the properties and performance of the DWPF glass product and on the applicability of the current process control models.

This report is part of a series of studies on the potential impacts of SCIX on DWPF glass. Fox and Edwards recently performed a paper study evaluation using updated projections for sludge batch compositions and SCIX CST and MST addition rates.[4] This study found that, as a result of the updated composition projections, several viable options were predicted to be available for incorporation of the SCIX streams into either Tank 40 or a sludge batch preparation tank. Transfer of the CST to a sludge batch preparation tank was the preferred option since it allowed more compositional flexibility for frit development while maintaining sufficient projected operating windows. The report again identified several assumptions and limitations associated with the current PCCS models, and recommended that these be further evaluated.

The first report on experimental results in this series covered glass compositions identified as the KT01, KT02, KT03, and KT04-series.[5] The results presented in that report showed a reasonable ability to incorporate the anticipated SCIX streams into the DWPF-type glass compositions studied, with TiO_2 concentrations of 4-5 wt % in glass. The durability and viscosity models satisfactorily predicted the measured values for the study glasses with the exception of a small number of extreme compositions. It was shown that, based on results for the KT01-series glasses, the liquidus temperature model may need to be adjusted to correctly predict the liquidus temperatures of glasses including the SCIX streams based on the data measured. Liquidus temperature measurements for the KT03 and KT04-series glasses will be documented in a future report.

This report follows with the KT05- and KT06-series glasses. As will be described below, these glasses were selected, fabricated, and characterized to study the potential formation of titanium-containing crystalline phases (KT05), and to study a broader range of potential DWPF glass compositions including the SCIX material (KT06).

2.0 Experimental Procedure

2.1 Selection of Glass Compositions

2.1.1 *KT05-series*

A recent study of high waste loading glasses for enhanced melter throughput identified glass compositions with relatively high TiO_2 concentrations (5.7-6.0 wt %) that formed iron titanate crystalline phases during liquidus temperature determinations.[6] These compositions are of interest since none of the previous glasses fabricated for the SCIX study have formed crystalline phases containing titanium.[5] For the current study, the KT05-series glasses, it was hypothesized that an increase in the concentration of Na_2O in the original compositions could avoid the formation of an iron titanate phase. This hypothesis was based on the results of earlier studies of the KT02-series compositions.[5] The three glasses that formed iron titanate crystals, labeled FY09EM21-05, -14, and -23 in the previous study, were fabricated again for the current study with the labels KT05-01, -02, and -03 (see Table 2-1). The target compositions of these three glasses were taken from the target values provided in the report, which did not differ significantly from the measured values.[6] The target Na_2O concentration for these three compositions was increased to 12 wt % (glasses KT05-04, -05, and -06) and 14 wt % (glasses KT05-07, -08, and -09), with the remaining components being normalized to 100 wt %. The resulting compositions are given in Table 2-1. These glasses were fabricated, heat treated, and characterized via X-ray diffraction (XRD) only, since the type of crystallization formed, if any, was the characteristic of interest for these compositions. Chemical composition, durability, viscosity, and liquidus temperature of these glasses were not determined.

Table 2-1. Target Compositions (wt %) of the KT05-Series Glasses.

Oxide	KT05-01	KT05-02	KT05-03	KT05-04	KT05-05	KT05-06	KT05-07	KT05-08	KT05-09
Al_2O_3	3.60	3.25	13.96	3.52	3.18	13.65	3.44	3.11	13.34
B_2O_3	4.50	13.65	5.78	4.40	13.34	5.65	4.30	13.04	5.52
BaO	0.00	0.08	0.08	0.00	0.08	0.08	0.00	0.08	0.08
CaO	4.00	0.00	0.00	3.91	0.00	0.00	3.82	0.00	0.00
CdO	0.00	0.30	0.30	0.00	0.29	0.29	0.00	0.28	0.28
Ce_2O_3	0.00	0.36	0.36	0.00	0.35	0.35	0.00	0.34	0.34
Cr_2O_3	0.00	0.20	0.00	0.00	0.20	0.00	0.00	0.19	0.00
CuO	0.00	0.13	0.13	0.00	0.13	0.13	0.00	0.12	0.12
Fe_2O_3	13.77	20.54	12.11	13.46	20.09	11.84	13.16	19.63	11.57
La_2O_3	0.00	0.10	0.10	0.00	0.10	0.10	0.00	0.09	0.09
Li_2O	4.00	4.00	4.00	3.91	3.91	3.91	3.82	3.82	3.82
MgO	0.00	0.00	1.50	0.00	0.00	1.47	0.00	0.00	1.43
MnO	0.30	0.30	0.30	0.29	0.29	0.29	0.29	0.29	0.29
Na_2O	10.00	10.00	10.00	12.00	12.00	12.00	14.00	14.00	14.00
NiO	2.50	0.00	0.00	2.44	0.00	0.00	2.39	0.00	0.00
PbO	0.00	0.22	0.22	0.00	0.21	0.21	0.00	0.21	0.21
SiO_2	51.50	40.35	44.35	50.35	39.46	43.37	49.21	38.56	42.38
SO_4^{2-}	0.00	0.48	0.48	0.00	0.47	0.47	0.00	0.46	0.46
TiO_2	5.83	5.71	6.00	5.70	5.58	5.87	5.57	5.45	5.73
ZnO	0.00	0.13	0.13	0.00	0.13	0.13	0.00	0.13	0.13
ZrO_2	0.00	0.21	0.21	0.00	0.20	0.20	0.00	0.20	0.20

2.1.2 *KT06-series*

Previous glass compositions studied for the SCIX program (the KT01-, KT02-, KT03-, and KT04-series) showed that, in general, the SCIX streams can be incorporated into simulated HLW glass (based on current composition projections) with most properties being predictable using the current DWPF models. Liquidus temperature predictions were the main exception. A different selection strategy was used for the KT06-series glasses with the intent of identifying compositional regions where it becomes difficult to incorporate the SCIX streams in glass, particularly higher TiO_2 concentrations. First, the minimum and maximum concentrations of the waste constituents used in the earlier paper study[4] were identified, as shown in Table 2-2.[a] Second, the minor components (i.e., those present in concentrations less than 1 wt %) were combined into a single group identified as Others based on their maximum concentrations, as shown in Table 2-3. Third, additional variation was added to expand these intervals as follows:

- Any minimum value that was more than 2 wt % was decreased by 2 wt %,
- Any maximum value that was greater than 4 wt % was increased by 2 wt %,
- Any maximum value that was greater than 1 wt % but less than 4 wt % was increased by 1 wt %, and
- Any maximum value that was less than 1 wt % was increased by 0.5 wt %.

The resulting intervals with variation applied are given on the right side of Table 2-2. Note that the Na_2O concentration was limited to three specific values representing potential washing endpoints for sludge preparation, rather than an interval of potential values. The TiO_2 concentration was fixed at 15 wt % to represent a high loading of CST and MST (relative to the projected values of about 12 wt % TiO_2). The SO_4^{2-} concentration was fixed at the current PCCS limit of 0.40 wt % since no projected value was given at the time of the paper study.[4]

[a] Note that the projected values used in this study have been revised slightly from those that appear in the paper study report, although they remain very similar.

Table 2-2. Individual Component Ranges Covering Projections of Sludge Batches 8 through 17, Including SCIX and SWPF Streams.

Oxide	Original Values		Values with Variation Applied	
	Minimum (wt %)	Maximum (wt %)	Minimum (wt %)	Maximum (wt %)
Al_2O_3	10.18	21.41	8.18	23.41
BaO	0.17	0.23	to others	
CaO	1.76	3.31	1.76	4.31
Ce_2O_3	0.17	0.96	to others	
Cr_2O_3	0.22	0.46		
CuO	0.09	0.13		
Fe_2O_3	19.97	41.18	17.97	43.18
K_2O	0.09	0.37	to others	
La_2O_3	0.09	0.36		
MgO	0.25	0.52		
MnO	0.90	6.43	0.90	8.43
Na_2O	20.75	28.55	fixed at 20, 25, and 30	
Nb_2O_5	0.02	3.27	0.02	4.27
NiO	0.29	1.95	0.29	2.95
PbO	0.16	0.55	to others	
SiO_2	0.95	9.42	0.95	11.42
SO_4^{2-}	n/a	n/a	fixed at 0.40	
ThO_2	0.00	2.91	0.00	3.91
TiO_2	0.97	11.03	fixed at 15.00	
U_3O_8	0.54	18.63	0.54	20.63
ZnO	0.00	0.26	to others	
ZrO_2	0.48	2.87	0.48	3.87
Others	n/a	n/a	1.00	3.00

Table 2-3. Composition of the Others Category.

Oxide	wt %
BaO	6.07
Ce_2O_3	25.05
Cr_2O_3	11.91
CuO	3.40
K_2O	9.72
La_2O_3	9.33
MgO	13.52
PbO	14.28
ZnO	6.73

The individual component intervals with variation applied (the right side of Table 2-2) were used to define the outer layer of the sludge composition region from which the KT06-series glass compositions would be developed. Note again that the concentrations of Na_2O, SO_4^{2-}, and TiO_2 were fixed at specific values, leaving 11 components with variable concentrations. An inner layer was also defined for the sludge composition region in order to provide more thorough coverage of the potential sludge compositions. The inner layer was created by adding 25% of each interval to the minimum value of that interval and subtracting 25% of each interval from the maximum value of that interval. The resulting component ranges for the inner layer composition region are also given in Table 2-4.

Table 2-4. Outer and Inner Layer Component Ranges for the KT06-Series Sludge Composition Region.

Oxide	Outer Layer		Inner Layer	
	Minimum (wt %)	Maximum (wt %)	Minimum (wt %)	Maximum (wt %)
Al_2O_3	8.18	23.41	11.98	19.60
CaO	1.76	4.31	2.40	3.68
Fe_2O_3	17.97	43.18	24.27	36.88
MnO	0.90	8.43	2.78	6.54
Nb_2O_5	0.02	4.27	0.95	2.28
NiO	0.29	2.95	3.56	8.80
SiO_2	0.95	11.42	0.98	2.94
ThO_2	0.00	3.91	5.56	15.61
U_3O_8	0.54	20.63	1.33	3.02
ZrO_2	0.48	3.87	1.08	3.20
Others	1.00	3.00	1.50	2.50

The information of Table 2-4 was used to define the sludge region from which the KT06-series glass compositions were to be selected. Initially, the Design of Experiment platform's Custom Design feature of JMP Version 7.0.2 (SAS Institute, Cary, NC) was used to select 11 sludge compositions satisfying the concentration intervals of Table 2-4, with a provision to incorporate Na_2O, SO_4^{2-}, and TiO_2 at the fixed concentrations defined earlier. This JMP feature allows the user to specify the form of a model such as a linear model consisting of a term for each of the 11 oxides of Table 2-4 (including Others). Then the coordinate exchange algorithm in JMP was used to optimally select a specified number of design points, n (where $n \geq 11$), for this model from the region defined by the intervals of Table 2-4, with the intervals being specified in JMP during the design activity. The optimality criterion used in this case was D-optimality, which has the goal of minimizing $|(X^TX)^{-1}|$, where X is the design matrix, X^T indicates the transpose of X, $(X^TX)^{-1}$ indicates the matrix inversion of the product of X^T and X, and $|(X^TX)^{-1}|$ represents the determinant of the matrix $(X^TX)^{-1}$. In the task, the number of design points, n, was taken to be its smallest possible value, 11. This procedure was performed several times: once for the outer layer region defined by Table 2-4 at each Na_2O concentration of 20, 25, and 30 wt %, and once for the inner layer region defined by Table 2-4 at Na_2O concentrations of 20 and 25 wt %. The centroids, or averages, of each set of optimal sludge compositions were also defined, for a total of 60 sludge compositions.

Each of the 60 sludge compositions was combined with an array of 1,144 potential frit compositions, as defined by the ranges of frit oxides given in Table 2-5 in 1 wt % increments, over a series of waste loadings from 30 to 60%. The resulting glass compositions (2,127,840 frit and sludge combinations) were evaluated using the PCCS Measurement Acceptability Region (MAR) to identify glasses that were predicted to be acceptable for processing at the DWPF. The PCCS constraint for TiO_2 concentration was ignored for the purposes of this study. The results were reviewed and only frit and sludge combinations that provided acceptable glasses over a range of waste loadings of at least 35-45% were allowed to continue in the selection process.

Table 2-5. Array of Candidate Frit Compositions Used in Selecting the KT06-Series Glasses.

Oxide	wt %
B_2O_3	8 – 20
Li_2O	5 – 12
Na_2O	0 – 10
SiO_2	58 – 87

In order to further reduce the number of glass compositions to a reasonable quantity for fabrication and characterization, the acceptable frit and sludge compositions were reviewed to identify those sludge compositions that provided broad coverage of Al_2O_3 and Fe_2O_3 concentrations, as these components are major constituents of the sludge. The sludges were grouped by their Na_2O concentrations (20, 25, and 30 wt %) and screened for those that provided the largest variation in Al_2O_3:Fe_2O_3 ratios. The results are shown in Figure 2-1, where the diagonal and corner points of the Al_2O_3:Fe_2O_3 ratios have been identified. This process resulted in the identification of four sludge compositions at 20 wt % Na_2O, three sludge compositions at 25 wt % Na_2O, and two sludge compositions at 30 wt % Na_2O. Note that two of the sludge compositions at 20 wt % Na_2O have the same Al_2O_3 and Fe_2O_3 concentrations but differ in their values for some of the other components; therefore, only three points are shown on the plot in Figure 2-1a.

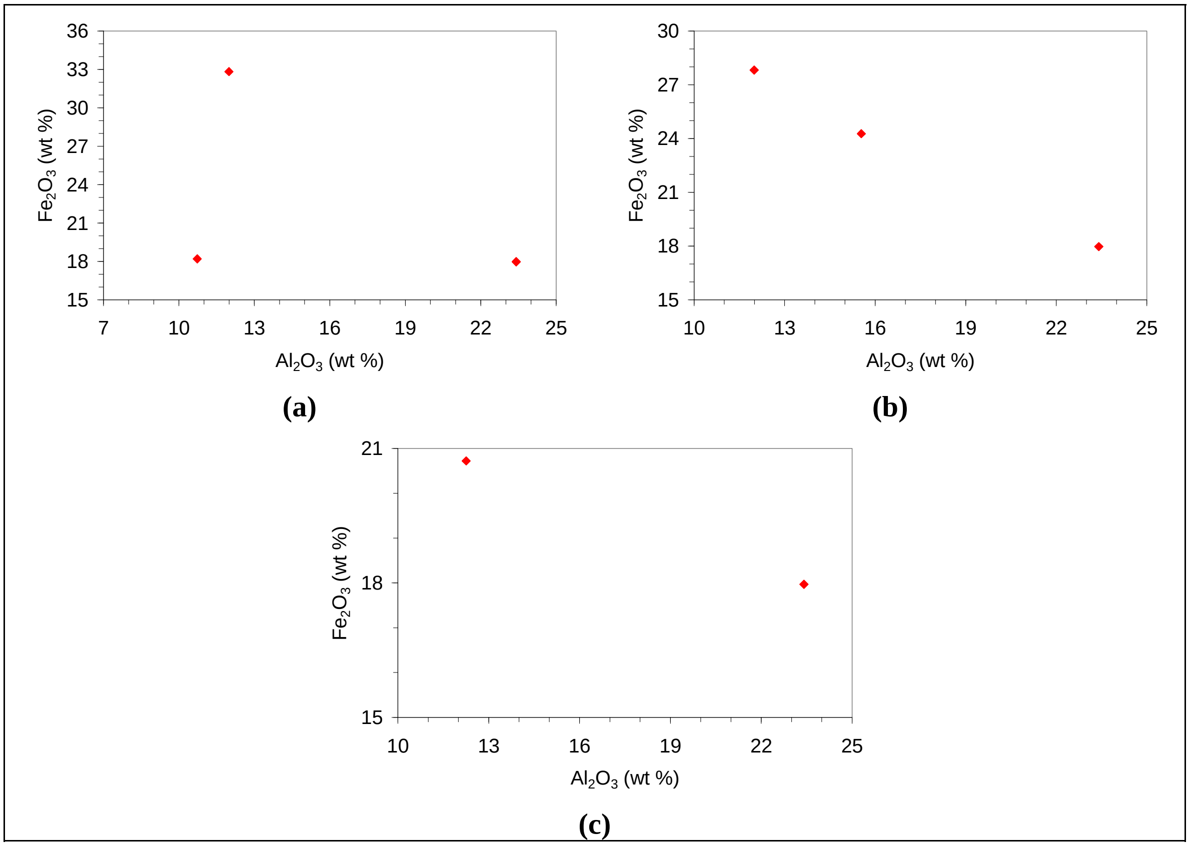


Figure 2-1. Graphical Representation of the Al_2O_3:Fe_2O_3 Ratios of the Sludge Compositions Selected for the KT06-Series Glasses. The Plots Correspond to Sludge Na_2O Concentrations of 20 wt % (a), 25 wt % (b), and 30 wt % (c).

Next, frit compositions producing PCCS MAR acceptable glasses with these sludges at 40% waste loading were down-selected. The Na_2O in the frits was fixed at 2 wt % since the sludges provide three different Na_2O concentrations. The B_2O_3 concentration in the frits was fixed at either 8 or 14 wt % to provide the opportunity to study any potential impact of this component on the properties and performance of the glasses. The Li_2O concentrations in the frits were kept as similar as possible, although some variation was necessary in order to maintain PCCS MAR acceptability while meeting the other conditions described above. Six frit compositions were needed to meet these criteria for the sludge compositions selected, and the compositions of these frits are given in Table 2-6.[a] The outcome of the selection process was 18 glass compositions for the KT06-series, as described in Table 2-7. The compositions of these glasses were normalized to 100 wt % without their U_3O_8 and ThO_2 components to facilitate fabrication and testing in a non-radiological laboratory. The normalized compositions were again evaluated using the PCCS MAR, which confirmed that the compositions were acceptable with the exception of the TiO_2 constraint. The target compositions of each of the KT06-series glasses are given in detail in Table 2-8.

[a] Note that these frit compositions and their identifiers were developed solely for this research and development work, and they do not represent candidate frits for actual processing at the DWPF.

Table 2-6. Frit Compositions Selected for the KT06-Series Glasses.

Frit ID	B_2O_3 (wt %)	Li_2O (wt %)	Na_2O (wt %)	SiO_2 (wt %)
KS-100	14	6	2	78
KS-101	14	7	2	77
KS-102	14	9	2	75
KS-103	8	11	2	79
KS-104	8	8	2	82
KS-105	8	9	2	81

Table 2-7. Description of Glasses Selected for the KT06-Series.

Glass ID	WL (%)	Sludge ID	Sludge Al_2O_3 (wt %)	Sludge Fe_2O_3 (wt %)	Sludge Na_2O (wt %)	Frit ID	Frit B_2O_3 (wt %)
KT06-01	40	Outer Layer Centroid	12.25	20.72	30	KS-100	14
KT06-02	40	Outer Layer 8	23.41	17.97	30	KS-100	14
KT06-03	40	Outer Layer Centroid	12.25	20.72	30	KS-104	8
KT06-04	40	Outer Layer 8	23.41	17.97	30	KS-104	8
KT06-05	40	Inner Layer 2	15.54	24.27	25	KS-101	14
KT06-06	40	Inner Layer 6	11.99	27.83	25	KS-101	14
KT06-07	40	Outer Layer 6	23.41	17.97	25	KS-101	14
KT06-08	40	Inner Layer 2	15.54	24.27	25	KS-105	8
KT06-09	40	Inner Layer 6	11.99	27.83	25	KS-105	8
KT06-10	40	Outer Layer 6	23.41	17.97	25	KS-105	8
KT06-11	40	Inner Layer 11	11.99	32.83	20	KS-101	14
KT06-12	40	Outer Layer 7	10.73	18.20	20	KS-102	14
KT06-13	40	Outer Layer 9	23.41	17.97	20	KS-102	14
KT06-14	40	Outer Layer 10	23.41	17.97	20	KS-102	14
KT06-15	40	Outer Layer 7	10.73	18.20	20	KS-103	8
KT06-16	40	Outer Layer 9	23.41	17.97	20	KS-103	8
KT06-17	40	Outer Layer 10	23.41	17.97	20	KS-103	8
KT06-18	40	Inner Layer 11	11.99	32.83	20	KS-104	8

Table 2-8. Target Compositions (wt %) of the KT06-Series Glasses.

Oxide	KT06-01	KT06-02	KT06-03	KT06-04	KT06-05	KT06-06	KT06-07	KT06-08	KT06-09
Al_2O_3	5.45	9.46	5.45	9.46	6.98	5.38	9.45	6.98	5.38
B_2O_3	8.40	8.40	4.80	4.80	8.40	8.40	8.40	4.80	4.80
BaO	0.05	0.02	0.05	0.02	0.03	0.03	0.05	0.03	0.03
CaO	1.20	1.74	1.20	1.74	1.08	1.08	0.71	1.08	1.08
Ce_2O_3	0.21	0.10	0.21	0.10	0.11	0.11	0.22	0.11	0.11
Cr_2O_3	0.10	0.05	0.10	0.05	0.05	0.05	0.10	0.05	0.05
CuO	0.03	0.01	0.03	0.01	0.02	0.02	0.03	0.02	0.02
Fe_2O_3	9.22	7.26	9.22	7.26	10.90	12.49	7.25	10.90	12.49
K_2O	0.08	0.04	0.08	0.04	0.04	0.04	0.09	0.04	0.04
La_2O_3	0.08	0.04	0.08	0.04	0.04	0.04	0.08	0.04	0.04
Li_2O	3.60	3.60	4.80	4.80	4.20	4.20	4.20	5.40	5.40
MgO	0.11	0.05	0.11	0.05	0.06	0.06	0.12	0.06	0.06
MnO	1.38	1.13	1.38	1.13	1.25	1.25	3.40	1.25	1.25
Na_2O	13.20	13.20	13.20	13.20	11.20	11.20	11.20	11.20	11.20
Nb_2O_5	0.63	0.08	0.63	0.08	0.55	0.55	0.08	0.55	0.55
NiO	0.63	1.19	0.63	1.19	0.43	0.43	0.12	0.43	0.43
PbO	0.12	0.06	0.12	0.06	0.06	0.06	0.13	0.06	0.06
SO_4^{2-}	0.18	0.16	0.18	0.16	0.18	0.18	0.16	0.18	0.18
SiO_2	48.49	47.18	50.89	49.58	47.80	47.80	46.58	50.20	50.20
TiO_2	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
ZnO	0.06	0.03	0.06	0.03	0.03	0.03	0.06	0.03	0.03
ZrO_2	0.76	0.19	0.76	0.19	0.60	0.60	1.56	0.60	0.60

Table 2-8. Target Compositions (wt %) of the KT06-Series Glasses. (continued)

Oxide	KT06-10	KT06-11	KT06-12	KT06-13	KT06-14	KT06-15	KT06-16	KT06-17	KT06-18
Al_2O_3	9.45	5.33	6.29	9.44	11.42	6.29	9.44	11.42	5.33
B_2O_3	4.80	8.40	8.40	8.40	8.40	4.80	4.80	4.80	4.80
BaO	0.05	0.03	0.11	0.07	0.03	0.11	0.07	0.03	0.03
CaO	0.71	1.07	1.03	0.71	2.10	1.03	0.71	2.10	1.07
Ce_2O_3	0.22	0.11	0.44	0.30	0.12	0.44	0.30	0.12	0.11
Cr_2O_3	0.10	0.05	0.21	0.14	0.06	0.21	0.14	0.06	0.05
CuO	0.03	0.02	0.06	0.04	0.02	0.06	0.04	0.02	0.02
Fe_2O_3	7.25	14.60	10.66	7.25	8.77	10.66	7.25	8.77	14.60
K_2O	0.09	0.04	0.17	0.12	0.05	0.17	0.12	0.05	0.04
La_2O_3	0.08	0.04	0.16	0.11	0.05	0.16	0.11	0.05	0.04
Li_2O	5.40	4.20	5.40	5.40	5.40	6.60	6.60	6.60	4.80
MgO	0.12	0.06	0.24	0.16	0.07	0.24	0.16	0.07	0.06
MnO	3.40	1.24	0.53	3.40	0.44	0.53	3.40	0.44	1.24
Na_2O	11.20	9.20	9.20	9.20	9.20	9.20	9.20	9.20	9.20
Nb_2O_5	0.08	0.54	2.50	0.08	0.10	2.50	0.08	0.10	0.54
NiO	0.12	0.42	0.17	0.12	0.14	0.17	0.12	0.14	0.42
PbO	0.13	0.06	0.25	0.17	0.07	0.25	0.17	0.07	0.06
SO_4^{2-}	0.16	0.18	0.23	0.16	0.20	0.23	0.16	0.20	0.18
SiO_2	48.98	47.79	45.56	48.44	45.46	47.96	50.84	47.86	50.79
TiO_2	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
ZnO	0.06	0.03	0.12	0.08	0.03	0.12	0.08	0.03	0.03
ZrO_2	1.56	0.59	2.27	0.19	1.89	2.27	0.19	1.89	0.59

2.2 Glass Fabrication

Each of the study glasses was prepared from the proper proportions of reagent-grade metal oxides, carbonates, and boric acid in 200 g batches. The raw materials were thoroughly mixed and placed into platinum/gold, 250 ml crucibles. The batch was placed into a high-temperature furnace at the melt temperature of 1150 °C. The crucible was removed from the furnace after an isothermal hold for 1 hour. The glass was poured onto a clean, stainless steel plate and allowed to air cool (quench). The glass pour patty was used as a sampling stock for the various property measurements described below.

Glasses KT05-02, -03, and -04 were ground and melted a second time due to unincorporated batch material remaining in the crucibles after the first melt.

Approximately 25 g of each glass was heat-treated to simulate cooling along the centerline of a DWPF-type canister[7] to gauge the effects of thermal history on the product performance. This cooling schedule is referred to as the CCC heat treatment. Visual observations of both quenched and CCC glasses were documented.

2.3 Composition Analysis

To confirm that the as-fabricated glasses met the target compositions, a representative sample from each quenched glass in the KT06-series was submitted to the Process Science Analytical Laboratory (PSAL) for chemical analysis under the auspices of an analytical plan.[8] Once again, the KT05-series glasses were not measured. Two dissolution techniques, sodium peroxide fusion (PF) and lithium-metaborate (LM), were used to prepare the glass samples, in duplicate, for analysis. Each of the samples was analyzed, twice for each element of interest, by Inductively Coupled Plasma – Atomic Emission Spectroscopy (ICP-AES). Glass standards (Batch 1) were also intermittently measured to assess the performance of the ICP-AES instrument over the course of these analyses.

2.4 X-Ray Diffraction Analysis

Representative samples of each quenched and CCC glass were submitted to Analytical Development (AD) for XRD analysis. Samples were run under conditions providing a detection limit of approximately 0.5 vol %. That is, if crystals (or unincorporated batch material) were present at 0.5 vol % or greater, the diffractometer would not only be capable of detecting the crystals but would also allow a qualitative determination of the type of crystal(s) present. Otherwise, a characteristically high background signal (amorphous hump) devoid of crystalline peaks indicates that the glass is free of crystallization, suggesting either a completely amorphous product or that the degree of crystallization is below the detection limit.

2.5 Scanning Electron Microscopy and Energy Dispersive Spectroscopy

Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) were used to provide qualitative information on the types of crystallization present in select glasses in the KT05- and KT06-series. Samples of crushed glass were prepared by adhering particles to carbon tape on aluminum specimen holders. The samples were viewed both with and without a conductive carbon coating, depending on the instrument used.

2.6 Product Consistency Test

The Product Consistency Test (PCT) Method-A[9] was performed in triplicate on each KT06-series quenched and CCC glass to assess chemical durability. The PCT responses for the KT05-series glasses were not measured. Also included in the experimental test matrix was the Environmental

Assessment (EA) benchmark glass,[10] the Approved Reference Material (ARM) glass,[11] and blanks from the sample cleaning batch. Samples were ground, washed, and prepared according to the standard procedure.[9] Fifteen milliliters of Type-I ASTM water were added to 1.5 g of glass in stainless steel vessels. The vessels were closed, sealed, and placed in an oven at 90 ± 2 °C where the samples were maintained at temperature for 7 days. Once cooled, the resulting solutions were sampled (filtered and acidified), then labeled and analyzed by PSAL under the auspices of an analytical plan.[12] Samples of a multi-element, standard solution were also included in the analytical plan as a check on the accuracy of the ICP-AES instrument used for these measurements. Normalized release rates were calculated based on the target and measured compositions using the average of the common logarithms of the leachate concentrations.

2.7 Viscosity

The viscosities of the KT06-series glasses were measured following Procedure A of the ASTM C 965 standard.[13] The viscosities of the KT05-series glasses were not measured. An Orton high temperature rotating spindle viscometer was used with platinum crucibles and spindles. The crucible and spindle were specially designed to operate with small quantities of glass to support measurements of radioactive glasses when necessary.[14,15] A well characterized standard glass was used to determine the appropriate spindle constants.[15,16] Measurements were taken over a range of temperatures from 1050 to 1250 °C in 50 °C intervals. Measurements at 1150 °C were taken at three different times during the procedure to provide an opportunity to identify the effects of any crystallization or volatilization that may have occurred during the test. The data were fit to a Fulcher equation[17,18] to provide a measured viscosity value at the nominal DWPF melt temperature of 1150 °C.

2.8 Liquidus Temperature

Measurements of the liquidus temperatures (T_L) of the KT06-series glasses are underway at the time of this report. The data will be reported separately, along with T_L data for the KT03 and KT04-series glasses.[a]

3.0 Results and Discussion

3.1 Homogeneity

The homogeneity of each glass sample was assessed via XRD and visual observations. The results will be discussed below for each series of glasses. The potential impacts of any crystallization that was identified will be discussed during the later description of the measured properties of the glasses (i.e., durability, viscosity, etc.).

3.1.1 *KT05-Series*

Visual observations of the quenched versions of the KT05-series glasses identified no visible crystallization for most of the compositions.[b] Composition KT05-02 had some minor crystallization visible on the surface of the quenched glass. Compositions KT05-03 and -06 had visible crystallization throughout the quenched glass. The XRD results agreed with these observations in that most of the glasses were XRD amorphous. Composition KT05-02 was XRD amorphous, indicating that the volume of the visible surface crystallization was very small. Composition KT05-03 contained iron titanium oxide ($Fe_3Ti_3O_{10}$) and a second crystalline phase

[a] SRNL-STI-2010-00703, "Impacts of Small Column Ion Exchange Streams on DWPF Glass Formulation: KT03, KT04, and KT06-Series Liquidus Temperature Measurements," in draft.

[b] See laboratory notebook SRNL-NB-2010-00027 for a complete record of the visual observations and XRD data.

that could not be identified using the crystallographic database. Composition KT05-06 contained a different form of iron titanium oxide, best matched by the stoichiometry Fe_9TiO_{15}.

Visual observations of the CCC versions of the KT05-series glasses identified surface and bulk crystallization for all of the compositions. The XRD results for the CCC versions of these glasses are given in Table 3-1. Note that it was not possible to distinguish between the diffraction patterns for Hematite (Fe_2O_3) and a form of iron titanium oxide, Fe_9TiO_{15}, which was identified in some of the glasses. SEM and EDS were used to further characterize these phases.

Table 3-1. XRD Results for the KT05-Series Glasses.

Glass ID	Heat Treatment	XRD Results
KT05-01	Quenched	Amorphous
	CCC	Aegirine ($NaFe^{+3}(SiO_3)_2$), Trevorite ($NiFe_2O_4$), unidentified phase
KT05-02	Quenched	Amorphous
	CCC	Hematite (Fe_2O_3) -or- Fe_9TiO_{15}, and unidentified phase
KT05-03	Quenched	$Fe_2Ti_3O_{10}$ and unidentified phase
	CCC	$Fe_3Ti_3O_{10}$
KT05-04	Quenched	Amorphous
	CCC	Aegirine ($NaFe^{+3}(SiO_3)_2$)
KT05-05	Quenched	Amorphous
	CCC	Hematite (Fe_2O_3) -or- Fe_9TiO_{15}
KT05-06	Quenched	Hematite (Fe_2O_3) -or- Fe_9TiO_{15}
	CCC	Pseudobrookite (Fe_2TiO_5), Hematite (Fe_2O_3) -or- Fe_9TiO_{15}, Nepheline ($NaAlSiO_4$)
KT05-07	Quenched	Amorphous
	CCC	$LiFeO_2$
KT05-08	Quenched	Amorphous
	CCC	Hematite (Fe_2O_3) -or- Fe_9TiO_{15}
KT05-09	Quenched	Amorphous
	CCC	$LiFeTiO_4$, Nepheline ($NaAlSiO_4$) and Fe_9TiO_{15}

In general, the glasses based on composition FY09EM21-05 (KT05-01, -04, and -07; see Section 2.1.1) had no Ti-containing crystalline phases, regardless of heat treatment or Na_2O concentration. The glasses based on composition FY09EM21-14 (KT-02, -05, and -08) formed a Ti-containing crystalline phase after the CCC heat treatment (as will be confirmed via SEM and EDS), regardless of Na_2O concentration. For the glasses based on composition FY09EM21-23 (KT05-03, -06, and -09), increasing Na_2O concentrations did appear to reduce the propensity for the formation of a Ti-containing crystalline phase, for both the quenched and the CCC versions of the glasses. However, due to the higher Al_2O_3 concentration of composition FY09EM21-23, the addition of larger concentrations of Na_2O results in the formation of nepheline in the CCC versions of glasses KT05-06 and -09, which can adversely impact chemical durability.

SEM/EDS analysis of select KT05-series glasses confirmed the presence of multiple Ti-containing crystalline phases. Glass KT05-03 was found to contain $Fe_2Ti_3O_{10}$ and an unidentified phase by XRD (Table 3-1). SEM/EDS analysis showed that the unidentified phase was likely another iron titanium oxide with a different stoichiometry. Figure 3-1 shows the results of SEM/EDS analysis of one area of this glass. The amorphous region, Spot 1, contains mostly Si along with several other elements. The larger crystals at Spot 2 contain a high concentration of Ti relative to Fe, while the smaller crystals at Spot 3 contain a high concentration of Fe relative to Ti. This indicates that two different stoichiometries of iron titanium oxide are present in this glass.

SEM/EDS elemental mapping was used to determine whether the CCC version of glass KT05-05 contained an iron titanium oxide or simply hematite. The EDS map for Ti in Figure 3-2 indicates a higher concentration of Ti in the crystalline phases relative to the surrounding amorphous glass. In particular, the small crystal near the center of the micrograph appears to contain a higher concentration of Ti relative to the larger crystals at the bottom of the micrograph, which may indicate two different stoichiometries. Overall, these data confirm the presence of a Ti-containing crystalline phase in glass KT05-05. A similar result was found for the CCC version of glass KT05-08 (Figure 3-3), where the crystalline phase contains both Fe and Ti.

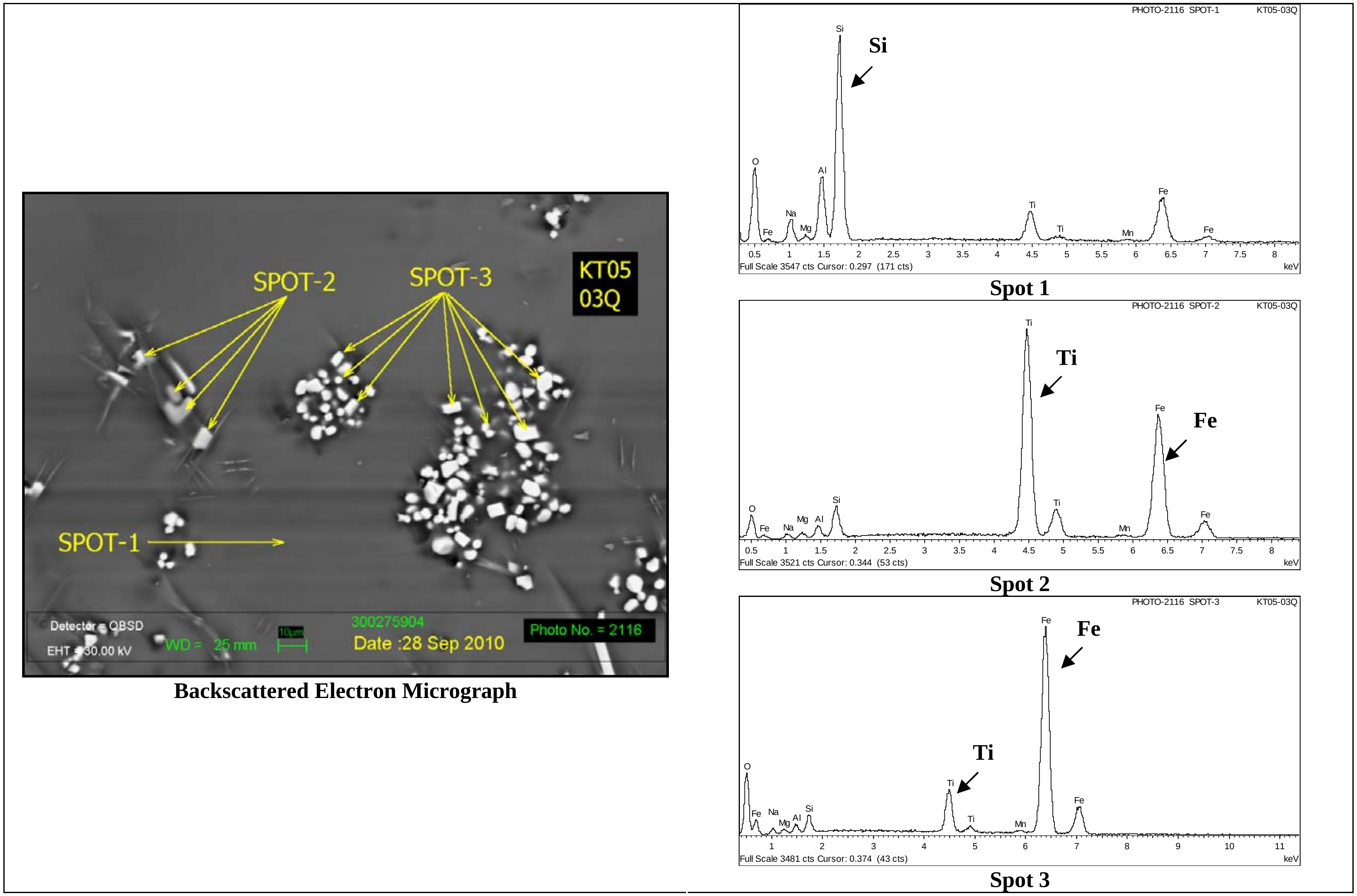
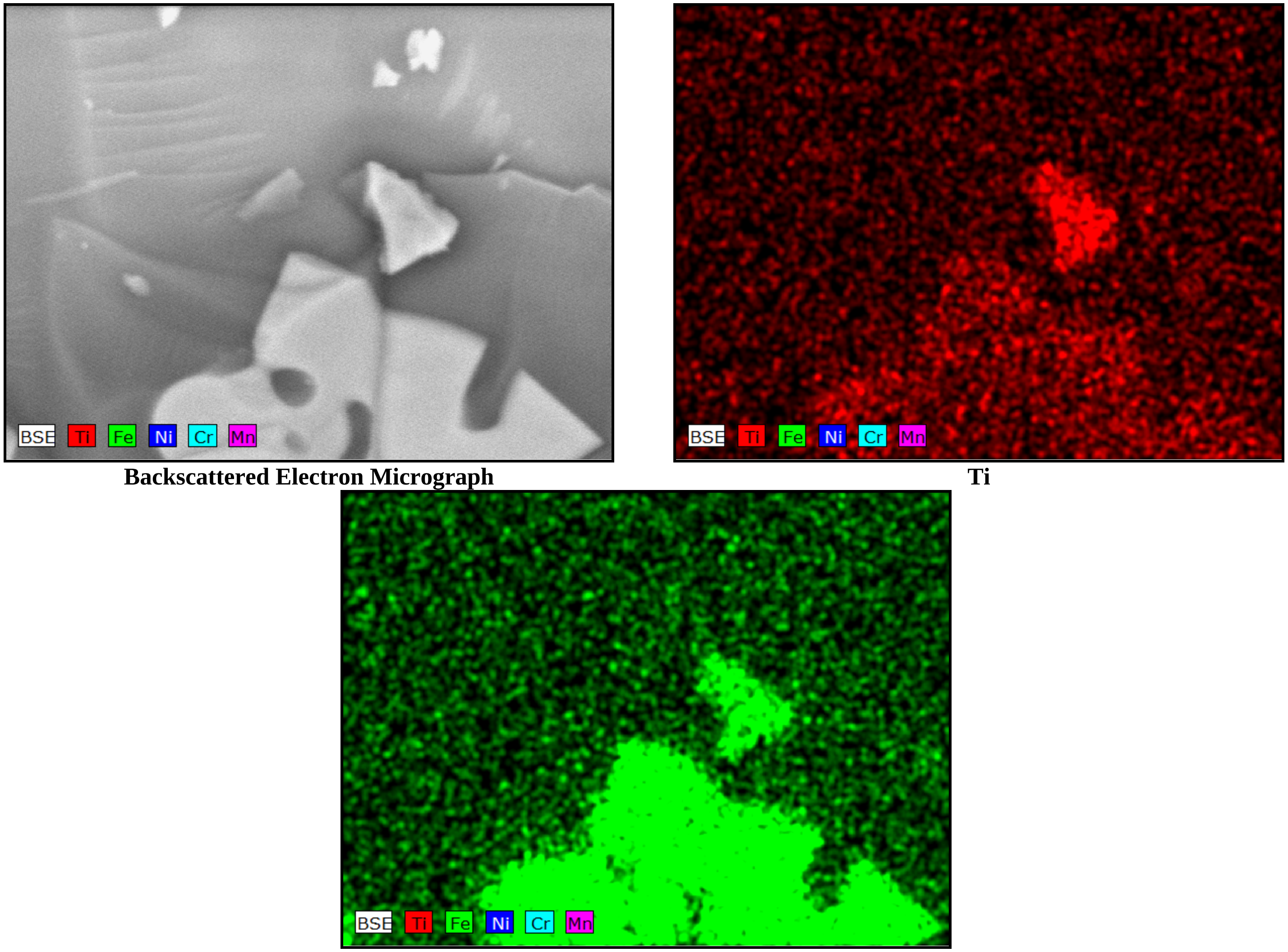


Figure 3-1. Electron Micrograph and Corresponding EDS Spectra of the Quenched Version of Glass KT05-03.



Backscattered Electron Micrograph

Ti

Fe

Figure 3-2. Electron Micrograph and Corresponding EDS Maps of the CCC Version of Glass KT05-05.

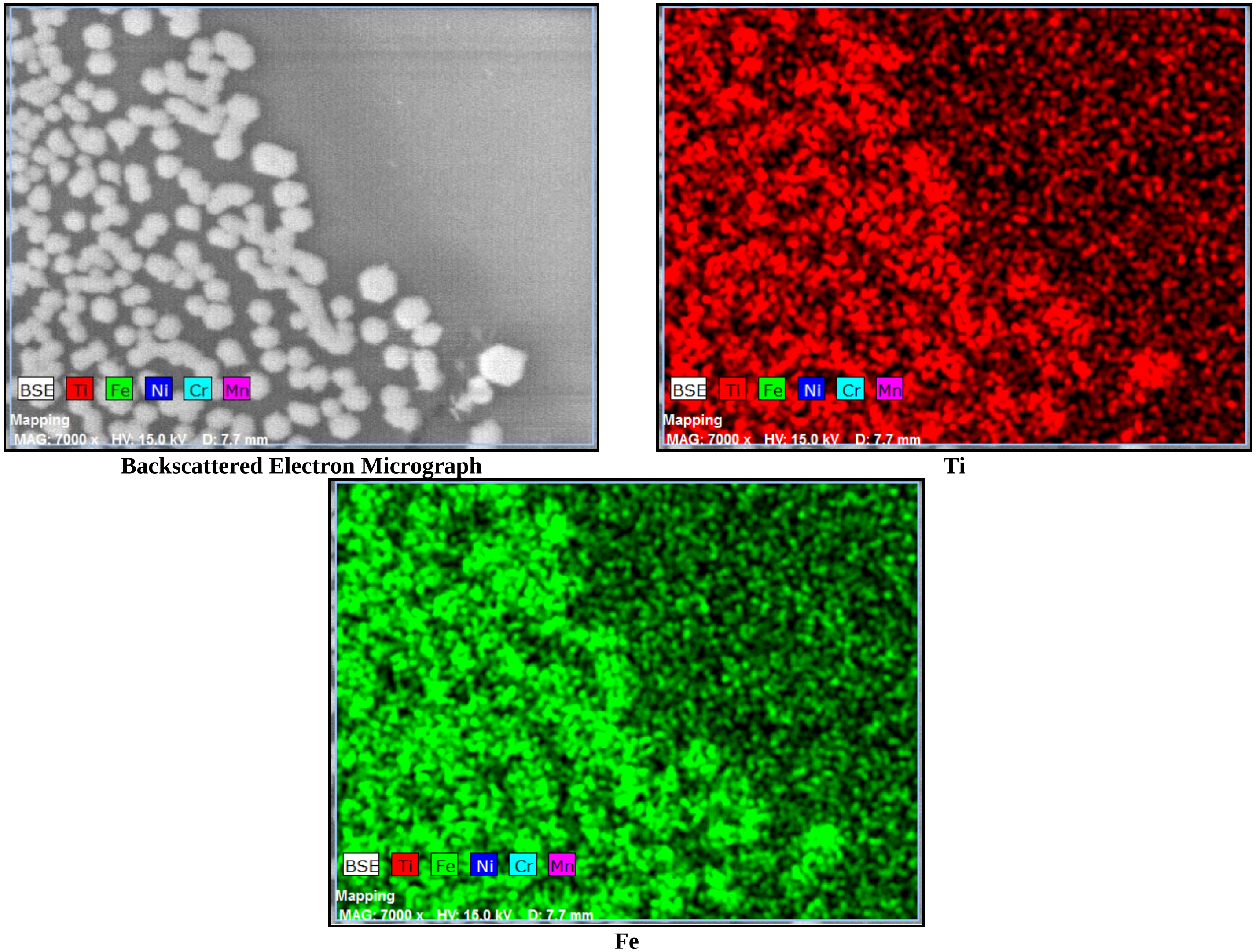


Figure 3-3. Electron Micrograph and Corresponding EDS Maps of the CCC Version of Glass KT05-08.

3.1.2 *KT06-Series*

Visual observations of the quenched versions of the KT06-series glasses identified no visible crystallization on any of the glasses. All of the quenched glasses were amorphous by XRD as well. Visual observations of the CCC versions of the KT06 glasses identified varying degrees of surface crystallization on all of the glasses. Several of the glasses were also crystallized in the bulk. The observations of crystallization within the bulk of the CCC glasses agreed well with the XRD results shown in Table 3-2. Those glasses where only surface crystallization was visible were amorphous by XRD, indicating that the volume fraction of the visible crystallization was very small.

Table 3-2. XRD Results for the CCC Versions of the KT06-Series Glasses.

Glass	XRD Results
KT06-01	Amorphous
KT06-02	Possible Trevorite ($NiFe_2O_4$)
KT06-03	Amorphous
KT06-04	Trevorite ($NiFe_2O_4$), Unidentified Phase
KT06-05	Hematite (Fe_2O_3)
KT06-06	Hematite (Fe_2O_3)
KT06-07	Trevorite ($NiFe_2O_4$), Unidentified Phase
KT06-08	Amorphous
KT06-09	Amorphous
KT06-10	Amorphous
KT06-11	Hematite (Fe_2O_3), Unidentified Phase
KT06-12	Hematite (Fe_2O_3)
KT06-13	Amorphous
KT06-14	Hematite (Fe_2O_3), Unidentified Phase
KT06-15	Amorphous
KT06-16	Amorphous
KT06-17	Amorphous
KT06-18	Hematite (Fe_2O_3), Unidentified Phase

No titanium-containing crystalline phases were identified in the CCC versions of the KT06-series glasses by XRD. As shown in Table 3-2, only Trevorite ($NiFe_2O_4$) and Hematite (Fe_2O_3) were found. However, diffraction peaks corresponding to a phase that could not be identified were also present for several of the glasses. These glasses were further examined by SEM/EDS. A micrograph of the CCC version of glass KT06-04 is shown in Figure 3-4. Crystals are visible as small, white, dendritic shapes distributed throughout the glass. The size of these crystals was too small to get good elemental information via EDS. Larger crystals were present in the CCC version of glass KT06-07, as shown in Figure 3-5. EDS mapping shows that some of the crystals contain higher concentrations of Ti, in addition to Fe and Ni. Narrow, elongated crystals were visible in the CCC versions of glasses KT06-11, -14, and -18. An image from the CCC version of glass KT06-14 is shown in Figure 3-6 as an example. EDS again shows that the crystals contain Ti in addition to Fe oxide. As will be discussed further in Section 3.3, the crystallization identified in these CCC glasses did not impact chemical durability.

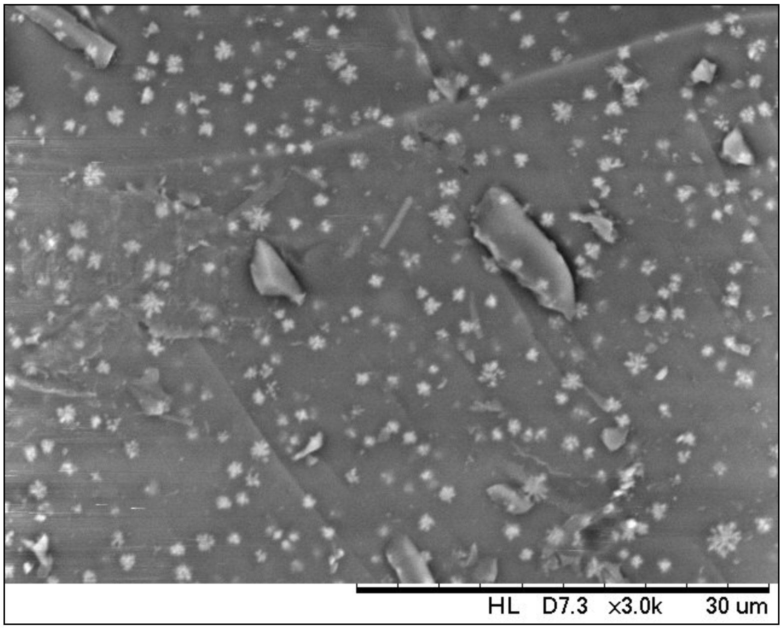


Figure 3-4. Backscattered Electron Micrograph of the CCC Version of Glass KT06-04.

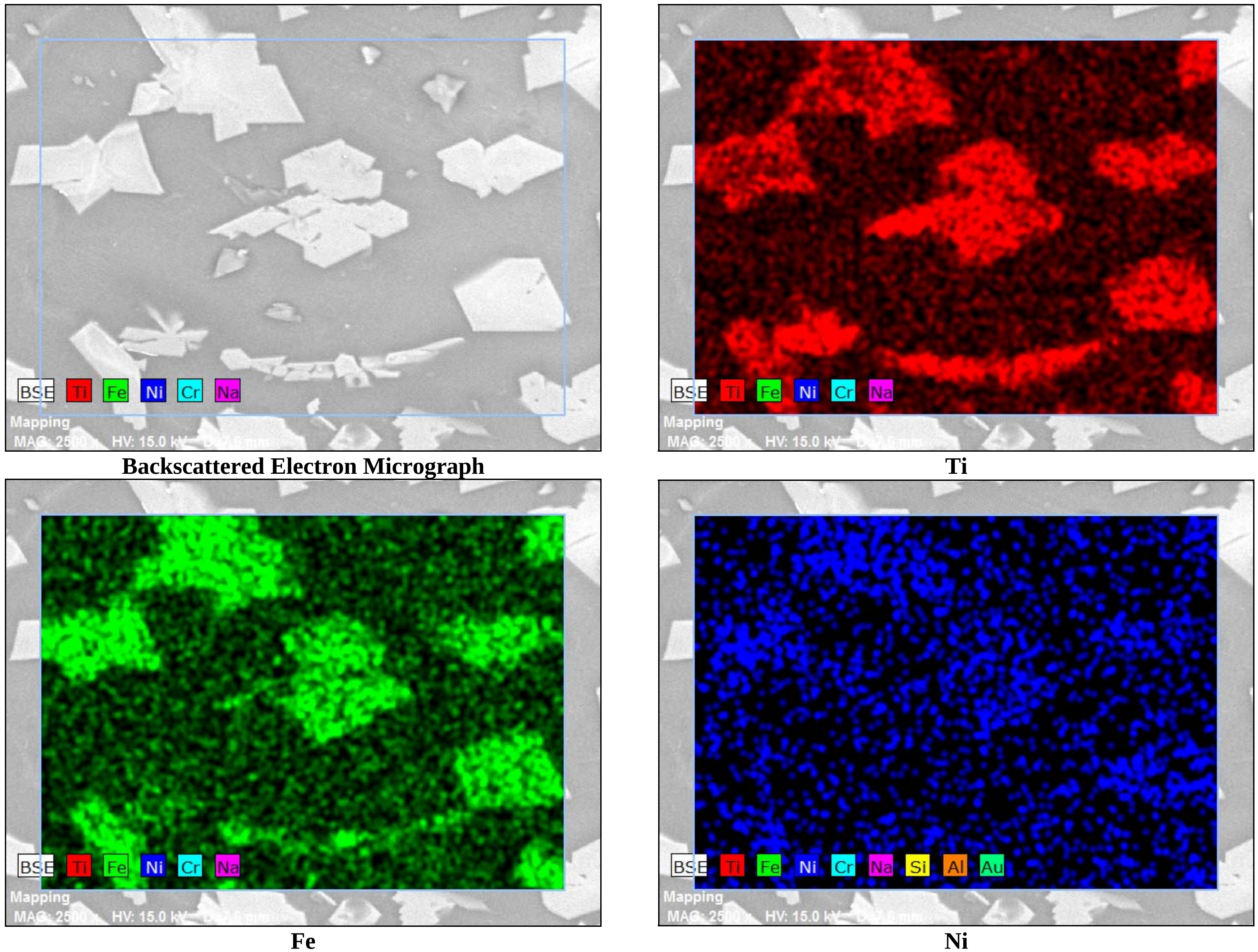
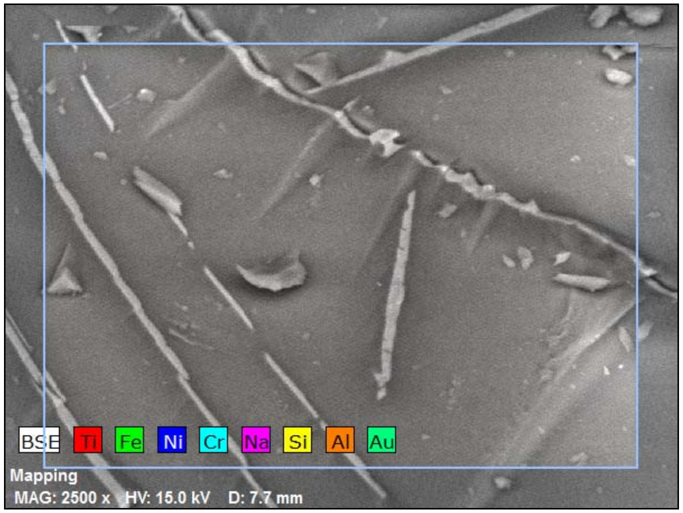
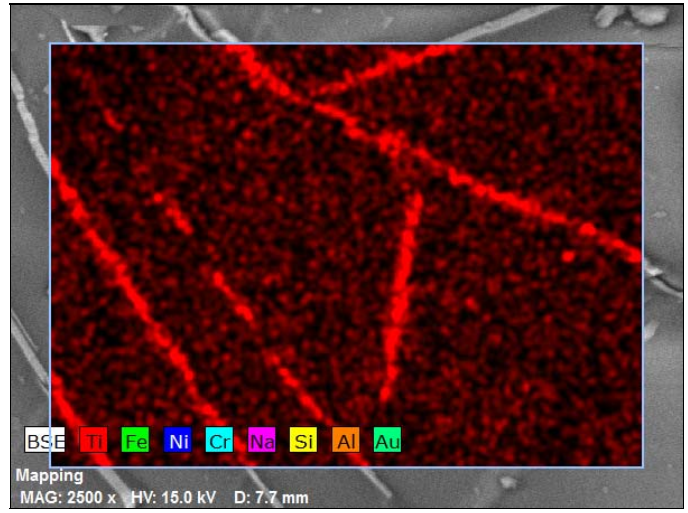


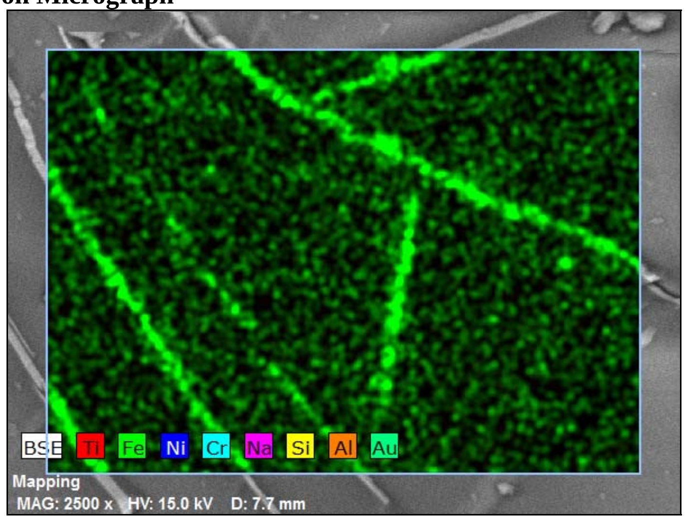
Figure 3-5. Electron Micrograph and Corresponding EDS Maps of the CCC Version of Glass KT06-07.



Backscattered Electron Micrograph



Ti



Fe

Figure 3-6. Electron Micrograph and Corresponding EDS Maps of the CCC Version of Glass KT06-14.

3.2 Chemical Composition

In this section, the measured versus targeted compositions of the study glasses are presented and compared. Measurements for samples of the Batch 1 standard glass that were included in the analytical plan along with the study glasses are also discussed. The elemental concentrations were converted to oxide concentrations by multiplying the values for each element by the gravimetric factor for the corresponding oxide. During this process, an elemental concentration that was determined to be below the detection limit of the analytical procedures used was reduced to half of that detection limit as the oxide concentration was determined. In the discussion that follows, the analytical sequences of the measurements are explored, the measurements of the standard are investigated, the measurements for each glass are reviewed, the average chemical compositions for each glass are determined, and comparisons are made between the measurements and the targeted compositions of the glasses.

Table A-1 and Table A-2 in Appendix A provide the elemental concentration measurements from the KT06 glasses that were prepared using LM, and Table A-3 in Appendix A provides the measurements from the samples of these glasses prepared using PF. Measurements for samples of the standard Batch 1 glass that were included in the analytical plan along with the study glasses are also provided in these tables. Exhibit A-1 in Appendix A provides plots of the sample measurements generated by PSAL for each oxide over both preparation methods. The plots are in analytical sequence with different symbols and colors being used to represent each of the study glasses and the standard glass. In general, there does not appear to be any gross patterns or trends due to the analytical sequence. Further opportunity for a review of the measurements for each glass is provided in the discussions that follow.

Exhibit A-2 in Appendix A provides plots of the oxide concentration measurements by Glass ID (including the Batch 1 standard) by analytical solution or Lab ID for both preparation methods for the KT06-series. The different symbols and colors being used to represent the glasses are discernable in this exhibit. These plots show the individual measurements across the duplicates of each preparation method and the two ICP-AES calibrations for each glass for each oxide. The results are grouped by analytical block and arranged by targeted concentration to facilitate the interpretation of the measurements. A review of the plots presented in this exhibit reveals the repeatability of the four individual values for each oxide for each glass. There appears to be good repeatability of these measurements for each of the oxides for each of the glasses. The measured TiO_2 values appear to be low for the first preparation of glass KT06-16. The measured ZrO_2 values appear to be low for the second preparation of glass KT06-01. Overall, the data suggest no significant issues with the batching of the KT06 glasses or with the analytical process used to provide representative measurements of their compositions.

Exhibit A-3 in Appendix A provides statistical analyses of the results for the Batch 1 standard that was included with the KT06 glasses by analytical block/sub-block for each oxide of interest over both preparation methods. The results include analysis of variance (ANOVA) investigations looking for statistically significant differences among the means of these groups for each of the oxides. The reference values for the oxide concentrations of the standard are given in the header for each set of measurements in the exhibit. The results from the statistical tests for the Batch 1 standard included with the KT06 glasses may be summarized as follows: BaO, Cr_2O_3, MnO, TiO_2, and ZrO_2 have measurements that indicate an ICP-AES calibration effect on the block averages at the 5% significance level. While statistically significant, the practical impact of these calibration effects is minimal.

All of the measurements for each oxide for each KT06 glass (i.e., all of the measurements in Appendix A Table A-1, Table A-2, and Table A-3) were averaged to determine a representative chemical composition for each glass. A sum of oxides was also computed for each glass based upon the measured values. Exhibit A-4 in Appendix A provides plots showing results for each glass for each oxide to help highlight the comparisons among the measured and targeted values. Some observations from the plots of Exhibit A-4 are offered: The Al_2O_3 and CuO concentrations are slightly high for some of the study glasses. The B_2O_3 and Fe_2O_3 concentrations show minor deviations from the target values. The Na_2O concentrations show more significant deviations from the target values. The BaO, La_2O_3, and Li_2O concentrations are slightly low for all of the study glasses. The SiO_2 concentrations are low for all of the study glasses. The CaO concentrations are slightly high for all of the study glasses. The Cr_2O_3, Nb_2O_5, NiO, PbO, and ZrO_2 concentrations are slightly low for some of the study glasses. The K_2O concentration is low for the Batch 1 standard. All of the SO_4^{2-} measurements are below the analytical detection limit. The sum of oxides is low for all of the study glasses, but remains greater than the PCCS minimum of 95% in all cases. In general, there appear to have been only minor difficulties in meeting the targeted concentrations for the KT06 glasses, none of which should impact the outcome of the study.

Table A-4 in Appendix A provides a summary of the average measured compositions as well as the targeted compositions and the associated differences and relative differences. Note that the targeted sum of oxides for the Batch 1 standard does not sum to 100% due to an incomplete coverage of the oxides in this glass. All of the sums of oxides for the KT06 glasses fall within the PCCS acceptable interval of 95 to 105 wt%. Entries in Table A-4 show the relative differences between the measured values and the targeted values. These differences are shaded when they are greater than or equal to 5%. Overall, these comparisons between the measured and targeted compositions again suggest only minor difficulties in meeting the targeted compositions for the KT06 glasses. A MAR assessment using the measured compositions of the KT06 glasses showed that each composition was PCCS acceptable except for the current TiO_2 constraint.

3.3 Durability

The measurements generated by the PCTs are presented and reviewed in the following sections. For each series of glasses below, the analytical sequence of the measurements is explored, the measurements of the standards are investigated and used to assess the overall accuracy of the ICP-AES measurement process, the measurements for each glass are reviewed, plots are provided that explore the effects of heat treatment on the PCTs for these glasses, the PCTs are normalized using the compositions (targeted and measured) discussed in Section 3.2, and the normalized PCTs are compared to durability predictions for these compositions generated from the current DWPF models.[3]

One of the quality control checkpoints for the PCT procedure is solution mass loss over the course of the seven day test. None of the vessels in the KT06 PCTs had any issues with mass loss. The ratio of leachant volume to the mass of ground glass was also confirmed to be correct for each vessel. All of the measurements of the ARM glass fell within the control ranges.[11]

Table B-1 in Appendix B provides the elemental leachate concentration measurements determined by the PSAL for the solution samples generated by the PCTs for the KT06 glasses. The values were adjusted for the dilution factors: the values for the study glasses, the blanks, and the ARM glass in Table B-1 were multiplied by 1.6667 to determine the values in parts per million and the values for EA were multiplied by 16.6667. Table B-1 also provides the resulting ppm measurements.

Exhibit B-1 in Appendix B provides plots of the leachate (ppm) concentrations in analytical sequence as generated by the PSAL for all of the data from the KT06 PCTs. Different colors and symbols are used for each of the study glasses and standards. No issues are seen in these plots.

Exhibit B-2 in Appendix B provides analyses of the PSAL measurements of the samples of the multi-element standard solution by analytical set and ICP-AES calibration block for the KT06-series. An ANOVA investigating for statistically significant differences among the block averages for these samples for each element of interest is included in the exhibit. A statistically significant (at a 5% level) difference among the averages of these measurements was indicated for B, Li, Na, and Si. However, no attempt was made to bias correct for these effects since averaging the measured concentrations for each set of triplicates in the PCT helps to minimize the impact of any potential ICP-AES bias effects.

Exhibit B-3 in Appendix B provides plots of the leachate concentrations for each type of submitted sample: the study glasses by heat treatment and the standards (EA, ARM, the multi-element solution standard, and blanks). The common logarithm plots allow for the assessment of the repeatability of the measurements, which suggest only minor scatter in the triplicate values for some analytes for some of the glasses.

The PCT leachate concentrations were normalized using the target and measured cation compositions of the glasses to obtain g/L leachate concentrations following the procedure.[9] Exhibit B-4 in Appendix B provides scatter plots for these results and offers an opportunity to investigate the consistency in the leaching across the elements for the KT06 glasses. All combinations of the normalizations of the PCTs (i.e., those generated using the targeted and measured compositional views) and both heat treatments are represented in the series of scatter plots. Consistency in the leaching across the elements is typically demonstrated by a high degree of linear correlation among the values for pairs of these elements. The smallest correlation in this plot is that for Li and Na with a value of ~87%, indicating relatively linear correlations for all of the element pairs.

Table B-2 in Appendix B summarizes the normalized PCTs for the KT06 glasses. The PCTs are listed by heat treatment and compositional view for each glass. The KT06 glasses all had normalized leachate for boron (NL [B]) values that were well below the 16.695 g/L value of the benchmark EA glass.[10] The highest NL [B] value was for glass KT06-16, with values of 0.595 g/L and 0.581 g/L for the quenched and CCC versions of this glass, respectively, normalized to the measured composition.

Exhibit B-5 in Appendix B provides plots showing comparisons of the normalized PCT responses for the two heat treatments for each glass. A review of these plots shows only minor differences in normalized release for the KT06 glasses as a function of heat treatment.

The predictability of the KT06 PCT responses was evaluated using the DWPF durability models. The predicted PCT values, determined using the targeted and measured compositions of the KT06 glasses, were compared with the normalized PCT responses. Exhibit B-6 in Appendix B provides plots of the DWPF models for B, Li, Na, and Si that relate the logarithm of the normalized PCT value (for each element of interest) to a linear function of a free energy of hydration term (ΔG_p, in kcal/100 g glass) derived from all of the compositional views and heat treatments of the KT06 glasses. Prediction limits at a 95% confidence for an individual PCT result are also plotted along with the linear fit. The EA and ARM results are indicated on these plots as well. The plots show that while all of the glasses have normalized PCT responses that are acceptable relative to the EA glass, several of the compositions have predicted values that fall above the upper 95% confidence prediction limit. A similar lack of fit for model predicted values in this region (values in the more positive direction of ΔG_p) has been seen in previous studies of DWPF-type glasses.[19-21]

As noted in Section 3.1.2, some of the CCC versions of the KT06-series glasses were found to be partially crystallized. The DWPF durability models are only expected to be applicable to amorphous glasses. Therefore, a second comparison of the measured versus predicted durabilities was made with the crystallized glasses omitted. The resulting plots are shown in Exhibit B-7 in Appendix B, and show that even with the partially crystallized glasses omitted, several of the remaining compositions (both quenched and CCC) have predicted values that fall above the upper 95% confidence prediction limit.

The data were further reviewed to identify any similarities among those KT06 compositions with durabilities that, while acceptable, were not predictable using the current models. Scatter plots of the major oxides using Fe_2O_3 as a reference were prepared to look for any trends in composition versus predictability. These plots are shown in Figure 3-7. The □ symbol indicates a composition with a normalized release for boron that was not predictable by the current PCCS durability model, and the Y symbol indicates a composition with a normalized release for boron that was predictable by the model. The plots of Figure 3-7 demonstrate that there is no single oxide that clearly partitions the unpredictable compositions from the predictable compositions.

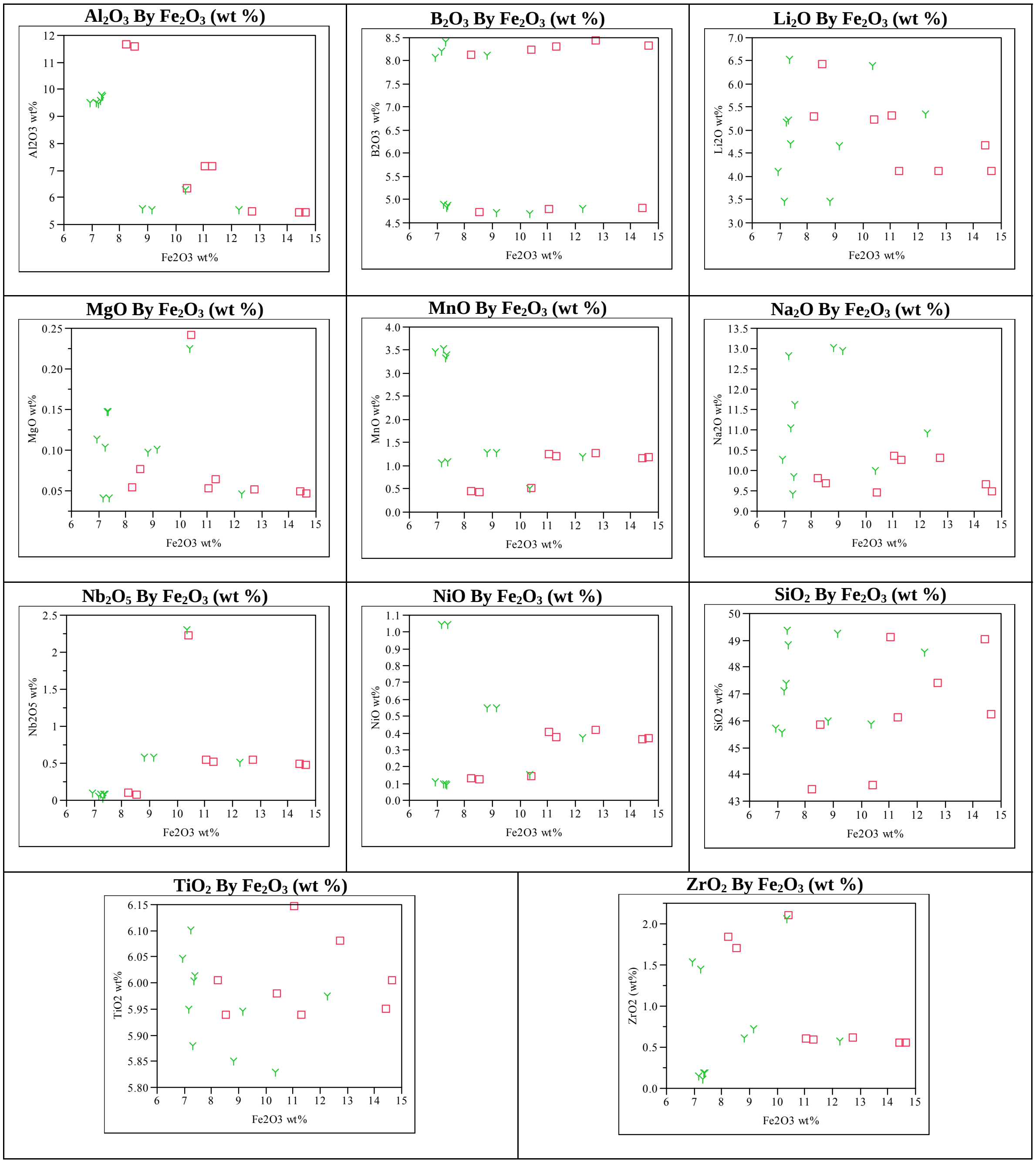
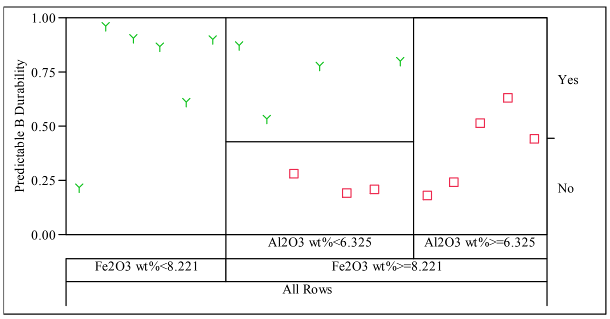


Figure 3-7. Scatter Plots of the Major Oxides of the KT06-Series Glasses Prepared to Identify Any Compositional Impacts on Predictability of Chemical Durability.

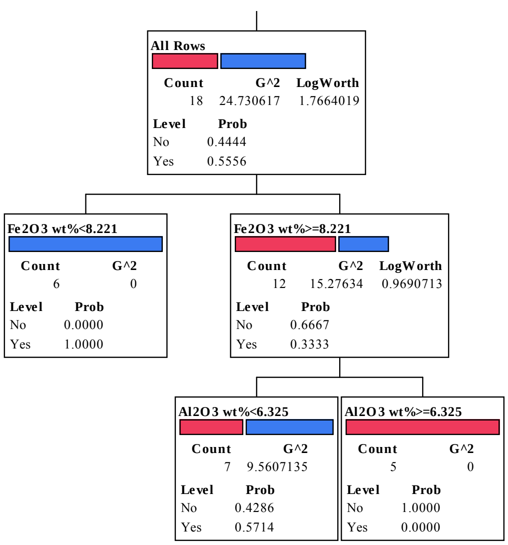
Partitioning of the data using a statistical analysis software package was completed as an additional effort to identify any similarities among the KT06-series glasses with durabilities that were not predictable by the current models. The oxides Al_2O_3, B_2O_3, CaO, Fe_2O_3, Li_2O, MgO, MnO, Na_2O, Nb_2O_5, NiO, SiO_2, TiO_2, and ZrO_2 were activated in this partitioning as these oxides were present in the most significant concentrations. The outcome from the execution of the partitioning routine is given in Figure 3-8. It shows that the KT06-series glasses that have relatively high Fe_2O_3 concentrations (greater than 8.2 wt %) and relatively high Al_2O_3

concentrations (greater than 6.3 wt %) have durabilities that are unpredictable. The glasses with lower Fe_2O_3 concentrations are all predictable by the current models. Those with relatively high Fe_2O_3 concentrations but Al_2O_3 concentrations less than 6.3 wt % had a mix of predictable and unpredictable durabilities, although all of the durability values were acceptable.

Repeating the scatter plot of Al_2O_3 versus Fe_2O_3 concentrations from Figure 3-7 in the right-side of Figure 3-8, the pattern in unpredictable versus predictable durabilities as a function of these two components is visible. This response can be explained in that Al_2O_3 and Fe_2O_3 both have positive ΔG_i values, which in turn give a more positive ΔG_p value for the glass composition. A glass with relatively high Al_2O_3 and Fe_2O_3 concentrations will tend to have a ΔG_p value that is shifted more to the right on the plots shown in Exhibit B-6 of Appendix B. With enough of an increase in Al_2O_3 and Fe_2O_3 concentrations, the ΔG_p value can be pushed outside of the 95% confidence bounds of the current models, resulting in a durability value that is not predictable but is acceptable relative to the EA glass.



RSquare	N	Number of Splits
0.613	18	2



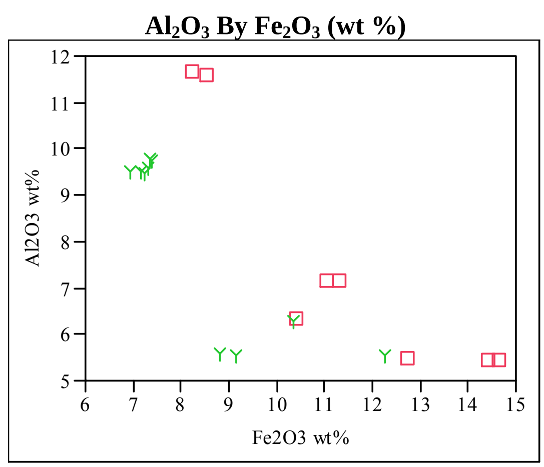


Figure 3-8. Outcome of the Partitioning Routine for Chemical Composition and Predictability of Chemical Durability for the KT06-Series Glasses.

3.4 Viscosity

Viscosity data were collected for all of the glasses in the KT06-series. The viscosity values showed no evidence of volatilization or crystallization during the measurements. The measured viscosity at 1150 °C was determined by fitting the data for each glass to the Fulcher equation.[17,18] Complete data from the fitting of Fulcher equations are given in Exhibit C-1 in Appendix C. The results of the Fulcher fits were used to calculate a measured viscosity value for each glass at 1150 °C. These values are given in Exhibit C-2 in Appendix C. The measured values are displayed graphically versus the model predictions in Exhibit C-3 in Appendix C. The table and plot show that there were mixed results for the KT06-series glasses in terms of the measured viscosities being predictable by the current model. The model generally over predicted the measured viscosity values. Several of the values fell below the lower 95% confidence bound of the model prediction.

The viscosity results were further evaluated to identify any compositional trends among the KT06-series glasses that led to unpredictable viscosity values. Scatter plots of the major oxides using Fe_2O_3 as a reference were prepared to look for any trends in composition versus predictability. These plots are shown in Figure 3-9. The □ symbol indicates a composition with a viscosity value that was not predictable by the current PCCS model, and the Y symbol indicates a composition with a viscosity value that was predictable by the model. A review of the plots shows a clear delineation between the glasses with predictable and unpredictable viscosities based on their Fe_2O_3 concentrations, regardless of the concentrations of the other oxides.

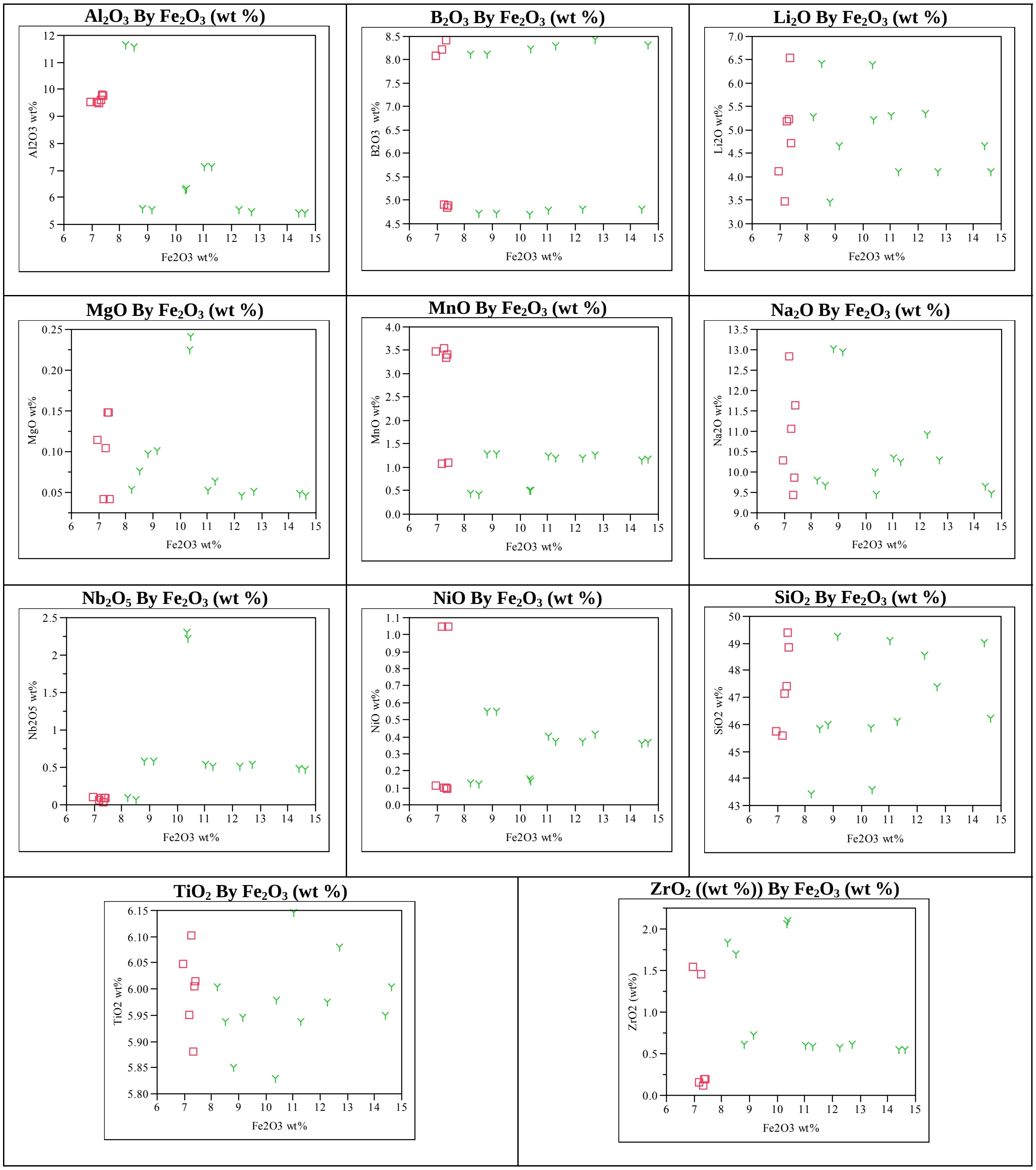
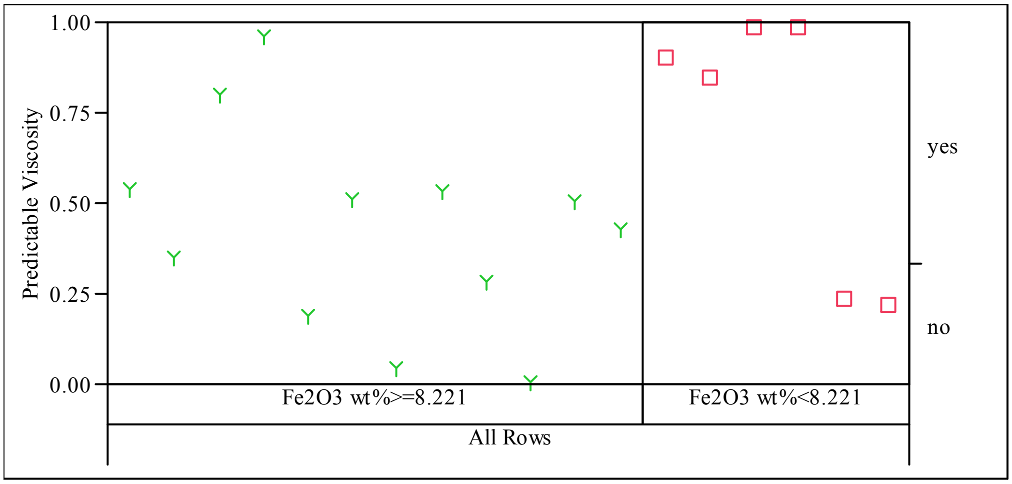


Figure 3-9. Scatter Plots of the Major Oxides of the KT06-Series Glasses Prepared to Identify Any Compositional Impacts on Predictability of Viscosity.

These observations were confirmed by partitioning of the data. The oxides Al_2O_3, B_2O_3, CaO, Fe_2O_3, Li_2O, MgO, MnO, Na_2O, Nb_2O_5, NiO, SiO_2, TiO_2, and ZrO_2 were activated in this partitioning as these oxides were present in the most significant concentrations. The outcome from the execution of the partitioning routine is given in Figure 3-10. The Fe_2O_3 concentrations of the KT06-series glasses allow for a complete partitioning of the predictable versus unpredictable viscosities. The measured viscosities become unpredictable by the current model when the Fe_2O_3 concentration in the glasses is less than about 8.2 wt %.



RSquare	N	Number of Splits
1.000	18	1

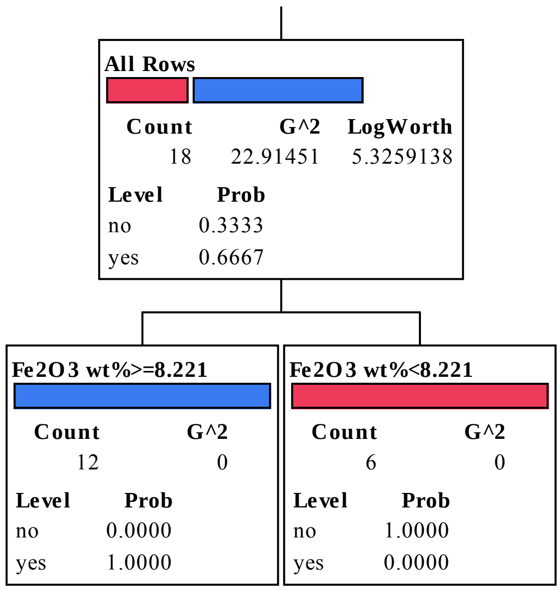


Figure 3-10. Outcome of the Partitioning Routine for Chemical Composition and Predictability of Viscosity for the KT06-Series Glasses.

4.0 Summary

The KT05-series glasses were selected, fabricated, and characterized to further study HLW glass compositions where iron titanate crystals had been found to form. The intent was to better understand the mechanisms and compositions that favored the formation of crystals containing titanium. Formation of these crystalline phases was confirmed. Increased Na_2O concentrations had little if any impact on reducing the propensity for the formation of the iron titanate crystalline phases. Other physical properties of these glasses were not measured since the intent was to focus on crystallization.

The KT06-series glasses were selected, fabricated, and characterized to further study HLW glass compositions that, while broader than the current projections for DWPF feeds with SCIX material, are potential candidates for future processing (i.e., the compositions are acceptable for processing by PCCS with the exception of the current TiO_2 concentration constraint). The chemical compositions of these glasses matched well with the target values. The chemical durabilities of all the glasses were acceptable relative to the EA benchmark. Minor crystallization was identified in some of the slowly cooled glasses, although this crystallization did not impact chemical durability. Measurements of the liquidus temperatures of the KT06-series glasses are underway at the time of this report. The data will be reported separately.

Several of the KT06-series compositions had durability values that, while acceptable, were not accurately predicted by the current PCCS models. A similar lack of fit for model predicted durabilities for glasses with more positive ΔG_p values has been seen in previous studies of DWPF-type glasses. It was shown that for the high TiO_2 concentration glasses (6 wt % TiO_2) in this study, relatively high Fe_2O_3 concentrations combined with relatively high Al_2O_3 concentrations led to durabilities that were unpredictable. The current durability models will have to be further evaluated should compositions in this region become necessary for DWPF processing.

Several of the KT06-series glasses also had measured viscosity values that were not well predicted by the current model. A statistical partitioning routine showed that the measured viscosities became unpredictable by the current model when the Fe_2O_3 concentration in the glasses was less than about 8.2 wt % at the elevated TiO_2 concentrations. The current viscosity model will have to be further evaluated should compositions in this region become necessary for DWPF processing.

5.0 Recommendations and Path Forward

The baseline compositions in the KT05-series should be further investigated to identify the potential influence of increased K_2O and Al_2O_3 concentrations on hindering the formation of titanium-containing crystalline phases. Liquidus temperature measurements will continue, and the results will be presented in a separate technical report. The potential impacts of noble metals on crystallization in glasses with increased TiO_2 concentrations will be investigated through the KT07-series glasses. The potential impacts of ThO_2 and U_3O_8 (as well as noble metals) on the properties and performance of glasses with increased TiO_2 concentrations will be investigated through the KT08-series glasses. Both the KT07 and KT08-series have been fabricated, and characterization is now underway.

At the completion of this series of studies, all of the data generated will be reviewed with regard to applicability of the DWPF PCCS model and recommendations will be made as to whether the validation ranges of the current models can be extended, or whether some or all of the models need to be refit to allow for the incorporation of the SCIX streams coupled with the current sludge batch projections. As changes are made to the projected sludge compositions and the volume of the SCIX material, additional evaluations should be performed.

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Appendix A. Data Supporting the Chemical Composition Measurements of the KT06-Series Glasses

Table A-1. PSAL Chemical Composition Measurements of the KT06-Series of Glasses Using LM Preparation Method (Part 1).

Glass ID	Block	Sub-Blk	Sequence	Lab ID	Ba (wt%)	Ca (wt%)	Ce (wt%)	Cr (wt%)	Cu (wt%)	K (wt%)	La (wt%)	Mg (wt%)
Batch 1	1	1	1	BCHLM111	0.124	0.855	<0.010	0.074	0.317	2.228	<0.010	0.851
KT06-16	1	1	2	C03LM21	0.055	0.534	0.247	0.086	0.038	0.116	0.074	0.092
KT06-16	1	1	3	C03LM11	0.054	0.536	0.242	0.084	0.037	0.121	0.073	0.089
KT06-11	1	1	4	C05LM21	0.018	0.770	0.090	0.036	0.035	0.045	0.024	0.029
KT06-13	1	1	5	C07LM11	0.054	0.536	0.241	0.093	0.037	0.124	0.072	0.088
KT06-01	1	1	6	C15LM21	0.035	0.893	0.165	0.064	0.031	0.093	0.048	0.057
KT06-13	1	1	7	C07LM21	0.055	0.530	0.252	0.092	0.037	0.115	0.075	0.090
KT06-14	1	1	8	C14LM21	0.021	1.56	0.100	0.038	0.016	0.047	0.028	0.033
KT06-06	1	1	9	C06LM21	0.019	0.795	0.098	0.039	0.035	0.043	0.026	0.032
KT06-11	1	1	10	C05LM11	0.018	0.807	0.089	0.035	0.032	0.049	0.023	0.028
Batch 1	1	1	11	BCHLM112	0.119	0.892	<0.010	0.072	0.327	2.318	<0.010	0.825
KT06-03	1	1	12	C10LM21	0.039	0.867	0.182	0.069	0.033	0.078	0.051	0.063
KT06-09	1	1	13	C18LM21	0.017	0.808	0.089	0.035	0.015	0.050	0.025	0.028
KT06-01	1	1	14	C15LM11	0.037	0.870	0.177	0.067	0.031	0.081	0.050	0.061
KT06-14	1	1	15	C14LM11	0.021	1.56	0.103	0.038	0.015	0.043	0.029	0.034
KT06-06	1	1	16	C06LM11	0.018	0.803	0.095	0.038	0.019	0.047	0.025	0.030
KT06-04	1	1	17	C01LM21	0.014	1.32	0.080	0.034	0.036	0.047	0.022	0.025
KT06-09	1	1	18	C18LM11	0.017	0.794	0.093	0.037	0.015	0.045	0.025	0.029
KT06-04	1	1	19	C01LM11	0.014	1.31	0.081	0.035	0.032	0.045	0.022	0.025
KT06-03	1	1	20	C10LM11	0.036	0.916	0.165	0.063	0.034	0.098	0.047	0.058
Batch 1	1	1	21	BCHLM113	0.120	0.895	<0.010	0.071	0.326	2.310	<0.010	0.822
Batch 1	1	2	1	BCHLM121	0.122	0.870	<0.010	0.073	0.317	2.189	<0.010	0.855
KT06-06	1	2	2	C06LM22	0.018	0.782	0.097	0.039	0.032	0.040	0.024	0.032
KT06-03	1	2	3	C10LM12	0.036	0.895	0.163	0.065	0.031	0.092	0.044	0.059
KT06-13	1	2	4	C07LM22	0.055	0.527	0.250	0.093	0.034	0.110	0.073	0.090
KT06-01	1	2	5	C15LM22	0.034	0.896	0.164	0.062	0.029	0.091	0.046	0.056
KT06-16	1	2	6	C03LM12	0.052	0.544	0.238	0.082	0.035	0.120	0.070	0.087
KT06-01	1	2	7	C15LM12	0.036	0.860	0.174	0.067	0.029	0.078	0.049	0.061
KT06-03	1	2	8	C10LM22	0.038	0.855	0.179	0.069	0.030	0.074	0.048	0.063
KT06-11	1	2	9	C05LM22	0.017	0.791	0.090	0.034	0.034	0.045	0.021	0.027
KT06-14	1	2	10	C14LM22	0.020	1.56	0.098	0.037	0.013	0.045	0.025	0.031
Batch 1	1	2	11	BCHLM122	0.120	0.874	<0.010	0.072	0.320	2.221	<0.010	0.839
KT06-14	1	2	12	C14LM12	0.020	1.56	0.101	0.038	0.012	0.040	0.026	0.033
KT06-06	1	2	13	C06LM12	0.017	0.787	0.093	0.039	0.016	0.043	0.023	0.029
KT06-16	1	2	14	C03LM22	0.053	0.541	0.244	0.084	0.036	0.114	0.071	0.089
KT06-04	1	2	15	C01LM12	0.013	1.29	0.078	0.035	0.029	0.041	0.019	0.024
KT06-11	1	2	16	C05LM12	0.017	0.781	0.088	0.035	0.029	0.045	0.021	0.027
KT06-13	1	2	17	C07LM12	0.053	0.536	0.239	0.091	0.034	0.120	0.070	0.087
KT06-04	1	2	18	C01LM22	0.014	1.36	0.078	0.034	0.033	0.043	0.019	0.025
KT06-09	1	2	19	C18LM12	0.017	0.785	0.091	0.036	0.013	0.042	0.022	0.028
KT06-09	1	2	20	C18LM22	0.016	0.801	0.087	0.035	0.013	0.047	0.022	0.026
Batch 1	1	2	21	BCHLM123	0.120	0.877	<0.010	0.073	0.319	2.200	<0.010	0.840
Batch 1	2	1	1	BCHLM211	0.121	0.850	<0.010	0.073	0.315	2.109	<0.010	0.848
KT06-05	2	1	2	C12LM21	0.013	0.755	0.090	0.038	0.012	0.041	0.024	0.028
KT06-18	2	1	3	C04LM21	0.014	0.790	0.088	0.036	0.041	0.048	0.023	0.028
KT06-17	2	1	4	C17LM21	0.016	1.71	0.094	0.036	0.022	0.055	0.026	0.058
KT06-15	2	1	5	C16LM11	0.084	0.759	0.363	0.115	0.065	0.149	0.112	0.137
KT06-05	2	1	6	C12LM11	0.013	0.907	0.091	0.040	0.011	0.053	0.025	0.048
KT06-02	2	1	7	C08LM21	0.012	1.23	0.078	0.031	0.035	0.041	0.020	0.023
KT06-07	2	1	8	C11LM21	0.038	0.530	0.192	0.068	0.026	0.075	0.055	0.067
KT06-15	2	1	9	C16LM21	0.081	0.768	0.367	0.116	0.072	0.157	0.108	0.132
KT06-12	2	1	10	C13LM21	0.075	0.975	0.338	0.113	0.056	0.197	0.098	0.149
Batch 1	2	1	11	BCHLM212	0.116	0.886	<0.010	0.071	0.324	2.189	<0.010	0.815
KT06-18	2	1	12	C04LM11	0.013	0.813	0.085	0.034	0.033	0.052	0.022	0.027
KT06-08	2	1	13	C09LM11	0.014	0.789	0.094	0.036	0.024	0.042	0.024	0.029
KT06-10	2	1	14	C02LM11	0.037	0.528	0.183	0.069	0.044	0.079	0.052	0.063
KT06-17	2	1	15	C17LM11	0.016	1.52	0.095	0.039	0.015	0.050	0.026	0.029
KT06-12	2	1	16	C13LM11	0.083	0.764	0.375	0.130	0.056	0.151	0.111	0.137
KT06-07	2	1	17	C11LM11	0.037	0.533	0.188	0.067	0.025	0.075	0.053	0.066
KT06-02	2	1	18	C08LM11	0.012	1.33	0.080	0.033	0.036	0.040	0.020	0.023
KT06-10	2	1	19	C02LM21	0.035	0.550	0.174	0.067	0.044	0.092	0.050	0.059
KT06-08	2	1	20	C09LM21	0.015	0.788	0.094	0.037	0.022	0.042	0.025	0.031
Batch 1	2	1	21	BCHLM213	0.119	0.871	<0.010	0.071	0.319	2.156	<0.010	0.831
Batch 1	2	2	1	BCHLM221	0.124	0.843	<0.010	0.076	0.311	2.138	<0.010	0.838
KT06-12	2	2	2	C13LM22	0.082	0.921	0.339	0.120	0.057	0.187	0.105	0.158
KT06-17	2	2	3	C17LM12	0.023	1.54	0.098	0.043	0.018	0.048	0.029	0.034
KT06-15	2	2	4	C16LM12	0.091	0.746	0.363	0.119	0.067	0.152	0.115	0.141
KT06-08	2	2	5	C09LM22	0.021	0.787	0.098	0.040	0.026	0.043	0.029	0.034
KT06-07	2	2	6	C11LM22	0.045	0.526	0.195	0.072	0.030	0.075	0.057	0.070

Table A-1. PSAL Chemical Composition Measurements of the KT06-Series of Glasses Using LM Preparation Method (Part 1). (continued)

Glass ID	Block	Sub-Blk	Sequence	Lab ID	Ba (wt%)	Ca (wt%)	Ce (wt%)	Cr (wt%)	Cu (wt%)	K (wt%)	La (wt%)	Mg (wt%)
KT06-05	2	2	7	C12LM22	0.019	0.773	0.094	0.041	0.017	0.043	0.028	0.030
KT06-18	2	2	8	C04LM12	0.020	0.811	0.090	0.039	0.037	0.052	0.025	0.031
KT06-07	2	2	9	C11LM12	0.044	0.536	0.194	0.071	0.029	0.077	0.058	0.070
KT06-18	2	2	10	C04LM22	0.021	0.804	0.093	0.039	0.045	0.050	0.026	0.032
Batch 1	2	2	11	BCHLM222	0.125	0.886	<0.010	0.076	0.323	2.248	<0.010	0.831
KT06-10	2	2	12	C02LM22	0.041	0.555	0.180	0.071	0.049	0.094	0.054	0.063
KT06-08	2	2	13	C09LM12	0.021	0.802	0.099	0.041	0.029	0.043	0.028	0.033
KT06-02	2	2	14	C08LM22	0.019	1.29	0.083	0.035	0.040	0.043	0.024	0.027
KT06-05	2	2	15	C12LM12	0.019	0.949	0.096	0.042	0.016	0.056	0.028	0.049
KT06-15	2	2	16	C16LM22	0.086	0.791	0.376	0.120	0.077	0.164	0.112	0.133
KT06-10	2	2	17	C02LM12	0.043	0.548	0.190	0.072	0.049	0.082	0.057	0.066
KT06-17	2	2	18	C17LM22	0.023	1.75	0.100	0.041	0.026	0.058	0.030	0.062
KT06-12	2	2	19	C13LM12	0.089	0.793	0.387	0.132	0.062	0.161	0.117	0.139
KT06-02	2	2	20	C08LM12	0.019	1.37	0.086	0.037	0.042	0.042	0.024	0.028
Batch 1	2	2	21	BCHLM223	0.124	0.905	<0.010	0.076	0.328	2.269	<0.010	0.833

Table A-2. PSAL Chemical Composition Measurements of the KT06-Series of Glasses Using LM Preparation Method (Part 2).

Glass ID	Block	Sub-Blk	Sequence	Lab ID	Mn (wt%)	Na (wt%)	Nb (wt%)	Ni (wt%)	Pb (wt%)	S (wt%)	Ti (wt%)	Zn (wt%)	Zr (wt%)
Batch 1	1	1	1	BCHLM111	1.29	6.87	<0.010	0.555	<0.010	<0.100	0.397	<0.010	0.063
KT06-16	1	1	2	C03LM21	2.65	7.30	0.054	0.075	0.133	<0.100	3.63	0.069	0.137
KT06-16	1	1	3	C03LM11	2.62	7.23	0.054	0.073	0.127	<0.100	3.58	0.060	0.136
KT06-11	1	1	4	C05LM21	0.937	6.98	0.345	0.290	0.053	<0.100	3.60	0.023	0.420
KT06-13	1	1	5	C07LM11	2.59	6.95	0.022	0.076	0.129	<0.100	3.52	0.060	0.089
KT06-01	1	1	6	C15LM21	0.955	9.54	0.410	0.412	0.085	<0.100	3.47	0.042	0.360
KT06-13	1	1	7	C07LM21	2.59	6.91	0.018	0.079	0.134	<0.100	3.54	0.059	0.076
KT06-14	1	1	8	C14LM21	0.340	7.39	0.071	0.099	0.053	<0.100	3.59	0.019	1.343
KT06-06	1	1	9	C06LM21	0.983	7.61	0.383	0.346	0.061	<0.100	3.66	0.021	0.460
KT06-11	1	1	10	C05LM11	0.895	7.04	0.321	0.283	0.049	<0.100	3.58	0.023	0.396
Batch 1	1	1	11	BCHLM112	1.30	6.91	<0.010	0.537	<0.010	<0.100	0.396	<0.010	0.064
KT06-03	1	1	12	C10LM21	1.04	9.47	0.429	0.457	0.098	<0.100	3.59	0.043	0.565
KT06-09	1	1	13	C18LM21	0.901	7.96	0.352	0.283	0.047	<0.100	3.57	0.018	0.421
KT06-01	1	1	14	C15LM11	1.03	9.68	0.411	0.448	0.094	<0.100	3.55	0.043	0.543
KT06-14	1	1	15	C14LM11	0.349	7.13	0.069	0.103	0.056	<0.100	3.61	0.019	1.368
KT06-06	1	1	16	C06LM11	0.957	7.58	0.367	0.304	0.052	<0.100	3.66	0.019	0.443
KT06-04	1	1	17	C01LM21	0.819	8.61	0.057	0.807	0.044	<0.100	3.62	0.032	0.140
KT06-09	1	1	18	C18LM11	0.950	8.27	0.359	0.304	0.049	<0.100	3.61	0.017	0.432
KT06-04	1	1	19	C01LM11	0.834	8.51	0.057	0.819	0.046	<0.100	3.61	0.031	0.143
KT06-03	1	1	20	C10LM11	0.939	9.66	0.380	0.399	0.081	<0.100	3.55	0.043	0.512
Batch 1	1	1	21	BCHLM113	1.27	6.96	<0.010	0.539	<0.010	<0.100	0.397	<0.010	0.065
Batch 1	1	2	1	BCHLM121	1.29	6.90	<0.010	0.555	<0.010	<0.100	0.390	<0.010	0.061
KT06-06	1	2	2	C06LM22	0.997	7.59	0.383	0.352	0.059	<0.100	3.64	0.020	0.460
KT06-03	1	2	3	C10LM12	0.961	9.67	0.380	0.408	0.082	<0.100	3.51	0.043	0.515
KT06-13	1	2	4	C07LM22	2.58	6.98	0.018	0.079	0.134	<0.100	3.50	0.059	0.074
KT06-01	1	2	5	C15LM22	0.948	9.70	0.409	0.411	0.084	<0.100	3.47	0.040	0.358
KT06-16	1	2	6	C03LM12	2.61	7.30	0.053	0.071	0.124	<0.100	3.57	0.058	0.134
KT06-01	1	2	7	C15LM12	1.03	9.73	0.408	0.456	0.092	<0.100	3.54	0.042	0.545
KT06-03	1	2	8	C10LM22	1.03	9.61	0.423	0.465	0.095	<0.100	3.61	0.042	0.566
KT06-11	1	2	9	C05LM22	0.932	7.05	0.343	0.287	0.050	<0.100	3.61	0.021	0.424
KT06-14	1	2	10	C14LM22	0.339	7.41	0.071	0.099	0.052	<0.100	3.61	0.018	1.343
Batch 1	1	2	11	BCHLM122	1.29	6.86	<0.010	0.544	<0.010	<0.100	0.389	<0.010	0.064
KT06-14	1	2	12	C14LM12	0.351	7.16	0.072	0.103	0.056	<0.100	3.59	0.018	1.382
KT06-06	1	2	13	C06LM12	0.957	7.78	0.367	0.311	0.049	<0.100	3.62	0.018	0.446
KT06-16	1	2	14	C03LM22	2.63	7.38	0.053	0.073	0.129	<0.100	3.62	0.066	0.136
KT06-04	1	2	15	C01LM12	0.851	8.49	0.057	0.829	0.043	<0.100	3.59	0.030	0.140
KT06-11	1	2	16	C05LM12	0.919	7.06	0.320	0.287	0.050	<0.100	3.61	0.022	0.395
KT06-13	1	2	17	C07LM12	2.58	7.11	0.022	0.075	0.125	<0.100	3.54	0.058	0.087
KT06-04	1	2	18	C01LM22	0.838	8.91	0.056	0.823	0.042	<0.100	3.60	0.031	0.139
KT06-09	1	2	19	C18LM12	0.939	8.23	0.356	0.306	0.048	<0.100	3.59	0.016	0.432
KT06-09	1	2	20	C18LM22	0.903	7.97	0.352	0.283	0.046	<0.100	3.56	0.016	0.420
Batch 1	1	2	21	BCHLM123	1.27	7.06	<0.010	0.545	<0.010	<0.100	0.388	<0.010	0.062
Batch 1	2	1	1	BCHLM211	1.28	6.83	<0.010	0.553	<0.010	<0.100	0.385	<0.010	0.061
KT06-05	2	1	2	C12LM21	0.937	7.37	0.352	0.295	0.048	<0.100	3.46	0.015	0.426
KT06-18	2	1	3	C04LM21	0.912	6.99	0.351	0.296	0.050	<0.100	3.55	0.024	0.418
KT06-17	2	1	4	C17LM21	0.324	7.12	0.022	0.095	0.050	<0.100	3.48	0.018	1.25
KT06-15	2	1	5	C16LM11	0.408	7.46	1.610	0.118	0.210	<0.100	3.35	0.095	1.52
KT06-05	2	1	6	C12LM11	0.942	7.60	0.361	0.293	0.049	<0.100	3.59	0.023	0.448
KT06-02	2	1	7	C08LM21	0.828	9.21	0.018	0.817	0.041	<0.100	3.52	0.029	0.075
KT06-07	2	1	8	C11LM21	2.71	7.52	0.059	0.085	0.102	<0.100	3.62	0.039	1.157
KT06-15	2	1	9	C16LM21	0.399	7.40	1.615	0.117	0.201	<0.100	3.57	0.093	1.532
KT06-12	2	1	10	C13LM21	0.368	7.03	1.442	0.096	0.176	<0.100	3.53	0.088	1.510
Batch 1	2	1	11	BCHLM212	1.30	6.70	<0.010	0.534	<0.010	<0.100	0.386	<0.010	0.065
KT06-18	2	1	12	C04LM11	0.870	6.95	0.337	0.268	0.045	<0.100	3.57	0.024	0.400
KT06-08	2	1	13	C09LM11	0.973	7.42	0.378	0.315	0.049	<0.100	3.68	0.021	0.444
KT06-10	2	1	14	C02LM11	2.73	7.85	0.056	0.078	0.101	<0.100	3.65	0.055	1.098
KT06-17	2	1	15	C17LM11	0.328	6.95	0.067	0.090	0.051	<0.100	3.62	0.018	1.277
KT06-12	2	1	16	C13LM11	0.415	6.80	1.649	0.116	0.205	<0.100	3.63	0.089	1.586
KT06-07	2	1	17	C11LM11	2.68	7.32	0.061	0.086	0.102	<0.100	3.62	0.038	1.132
KT06-02	2	1	18	C08LM11	0.845	9.36	0.057	0.824	0.041	<0.100	3.56	0.030	0.144
KT06-10	2	1	19	C02LM21	2.71	8.03	0.053	0.071	0.093	<0.100	3.63	0.046	1.047
KT06-08	2	1	20	C09LM21	0.979	7.32	0.374	0.319	0.050	<0.100	3.71	0.023	0.452
Batch 1	2	1	21	BCHLM213	1.32	6.65	<0.010	0.543	<0.010	<0.100	0.389	<0.010	0.063
Batch 1	2	2	1	BCHLM221	1.32	6.85	<0.010	0.548	<0.010	<0.100	0.407	<0.010	0.065
KT06-12	2	2	2	C13LM22	0.372	7.06	1.435	0.103	0.183	<0.100	3.53	0.091	1.520
KT06-17	2	2	3	C17LM12	0.331	7.20	0.072	0.096	0.057	<0.100	3.56	0.022	1.275
KT06-15	2	2	4	C16LM12	0.405	7.60	1.590	0.121	0.216	<0.100	3.39	0.099	1.520

Table A-2. PSAL Chemical Composition Measurements of the KT06-Series of Glasses Using LM Preparation Method (Part 2). (continued)

Glass ID	Block	Sub-Blk	Sequence	Lab ID	Mn (wt%)	Na (wt%)	Nb (wt%)	Ni (wt%)	Pb (wt%)	S (wt%)	Ti (wt%)	Zn (wt%)	Zr (wt%)
KT06-08	2	2	5	C09LM22	0.944	7.73	0.376	0.317	0.053	<0.100	3.64	0.027	0.448
KT06-07	2	2	6	C11LM22	2.68	7.90	0.065	0.088	0.106	<0.100	3.63	0.043	1.141
KT06-05	2	2	7	C12LM22	0.909	7.56	0.354	0.289	0.051	<0.100	3.50	0.019	0.426
KT06-18	2	2	8	C04LM12	0.866	7.35	0.337	0.275	0.049	<0.100	3.58	0.028	0.406
KT06-07	2	2	9	C11LM12	2.66	7.78	0.069	0.091	0.108	<0.100	3.63	0.043	1.130
KT06-18	2	2	10	C04LM22	0.899	7.32	0.353	0.298	0.054	<0.100	3.57	0.028	0.422
Batch 1	2	2	11	BCHLM222	1.32	6.98	<0.010	0.548	<0.010	<0.100	0.408	<0.010	0.067
KT06-10	2	2	12	C02LM22	2.71	8.57	0.061	0.076	0.099	<0.100	3.64	0.050	1.053
KT06-08	2	2	13	C09LM12	0.959	8.21	0.384	0.319	0.056	<0.100	3.71	0.026	0.450
KT06-02	2	2	14	C08LM22	0.813	9.72	0.026	0.812	0.047	<0.100	3.59	0.034	0.079
KT06-05	2	2	15	C12LM12	0.907	7.87	0.360	0.287	0.052	<0.100	3.69	0.026	0.447
KT06-15	2	2	16	C16LM22	0.395	7.25	1.618	0.120	0.204	<0.100	3.67	0.096	1.530
KT06-10	2	2	17	C02LM12	2.77	8.33	0.063	0.082	0.107	<0.100	3.71	0.059	1.107
KT06-17	2	2	18	C17LM22	0.328	7.43	0.029	0.099	0.055	<0.100	3.58	0.022	1.25
KT06-12	2	2	19	C13LM12	0.413	7.16	1.669	0.119	0.214	<0.100	3.65	0.093	1.587
KT06-02	2	2	20	C08LM12	0.844	9.78	0.065	0.835	0.046	<0.100	3.60	0.035	0.151
Batch 1	2	2	21	BCHLM223	1.34	7.10	<0.010	0.549	<0.010	<0.100	0.411	<0.010	0.068

Table A-3. PSAL Chemical Composition Measurements of the KT06 Series of Glasses Using PF Preparation Method.

Glass ID	Block	Sub-Blk	Sequence	Lab ID	Al (wt%)	B (wt%)	Fe (wt%)	Li (wt%)	Si (wt%)
Batch 1	1	1	1	BCHPF111	2.56	2.58	9.15	2.07	23.1
KT06-08	1	1	2	C09PF11	3.84	1.63	7.72	2.50	23.1
KT06-04	1	1	3	C01PF21	5.19	1.60	5.20	2.20	22.9
KT06-03	1	1	4	C10PF11	2.94	1.53	6.43	2.17	23.1
KT06-02	1	1	5	C08PF21	5.10	2.61	4.99	1.62	21.4
KT06-09	1	1	6	C18PF21	2.98	1.55	8.67	2.51	22.9
KT06-07	1	1	7	C11PF11	5.15	2.61	4.88	1.93	21.1
KT06-12	1	1	8	C13PF11	3.41	2.59	7.19	2.47	20.5
KT06-02	1	1	9	C08PF11	5.09	2.60	4.99	1.62	21.3
KT06-04	1	1	10	C01PF11	5.20	1.54	5.14	2.21	22.8
Batch 1	1	1	11	BCHPF112	2.56	2.41	9.02	2.06	22.9
KT06-16	1	1	12	C03PF21	5.15	1.53	5.09	3.03	22.8
KT06-09	1	1	13	C18PF11	2.96	1.52	8.40	2.50	22.5
KT06-03	1	1	14	C10PF21	2.96	1.49	6.31	2.19	22.9
KT06-07	1	1	15	C11PF21	4.94	2.47	4.76	1.89	21.4
KT06-12	1	1	16	C13PF21	3.35	2.55	7.29	2.42	20.3
KT06-08	1	1	17	C09PF21	3.78	1.49	7.67	2.46	22.8
KT06-11	1	1	18	C05PF21	2.91	2.61	10.19	1.93	21.7
KT06-16	1	1	19	C03PF11	5.18	1.49	5.12	3.03	23.0
KT06-11	1	1	20	C05PF11	2.86	2.60	10.14	1.90	21.3
Batch 1	1	1	21	BCHPF113	2.51	2.36	8.76	2.03	22.6
Batch 1	1	2	1	BCHPF121	2.46	2.47	9.03	2.00	22.8
KT06-12	1	2	2	C13PF12	3.32	2.62	7.32	2.42	20.4
KT06-16	1	2	3	C03PF22	5.15	1.51	5.17	3.03	23.1
KT06-11	1	2	4	C05PF12	2.85	2.59	10.23	1.91	21.7
KT06-09	1	2	5	C18PF12	2.91	1.48	8.56	2.47	22.6
KT06-03	1	2	6	C10PF12	2.90	1.45	6.54	2.15	23.1
KT06-16	1	2	7	C03PF12	5.19	1.47	5.15	3.04	23.4
KT06-04	1	2	8	C01PF22	5.12	1.46	5.17	2.18	22.8
KT06-09	1	2	9	C18PF22	2.92	1.44	8.71	2.47	22.8
KT06-03	1	2	10	C10PF22	2.94	1.40	6.32	2.18	23.0
Batch 1	1	2	11	BCHPF122	2.54	2.31	9.04	2.05	23.0
KT06-02	1	2	12	C08PF22	4.99	2.50	4.97	1.60	21.2
KT06-04	1	2	13	C01PF12	5.12	1.45	5.15	2.18	22.8
KT06-08	1	2	14	C09PF22	3.76	1.44	7.74	2.46	23.0
KT06-12	1	2	15	C13PF22	3.31	2.47	7.24	2.41	20.3
KT06-07	1	2	16	C11PF22	4.94	2.43	4.76	1.91	21.6
KT06-07	1	2	17	C11PF12	5.10	2.52	4.97	1.92	21.4
KT06-11	1	2	18	C05PF22	2.86	2.53	10.32	1.90	21.7
KT06-02	1	2	19	C08PF12	4.99	2.50	5.04	1.60	21.3
KT06-08	1	2	20	C09PF12	3.76	1.40	7.74	2.46	22.9
Batch 1	1	2	21	BCHPF123	2.44	2.24	8.86	1.98	22.5
Batch 1	2	1	1	BCHPF211	2.46	2.45	8.89	1.99	22.7
KT06-13	2	1	2	C07PF11	5.06	2.67	5.11	2.43	22.2
KT06-06	2	1	3	C06PF21	2.90	2.61	8.91	1.90	22.3
KT06-05	2	1	4	C12PF11	3.80	2.54	8.00	1.92	21.2
KT06-15	2	1	5	C16PF11	3.31	1.45	7.26	2.96	21.4
KT06-18	2	1	6	C04PF21	2.87	1.48	10.17	2.16	23.1
KT06-10	2	1	7	C02PF21	4.98	1.46	5.06	2.38	21.9
KT06-06	2	1	8	C06PF11	2.88	2.55	8.90	1.89	21.9
KT06-17	2	1	9	C17PF11	6.18	1.43	5.92	3.01	21.5
KT06-15	2	1	10	C16PF21	3.38	1.41	7.15	3.01	21.5
Batch 1	2	1	11	BCHPF212	2.50	2.27	8.75	2.01	22.7
KT06-10	2	1	12	C02PF11	5.01	1.47	5.03	2.40	21.9
KT06-17	2	1	13	C17PF21	6.15	1.44	5.89	3.00	21.3
KT06-01	2	1	14	C15PF11	2.99	2.45	5.97	1.62	21.3
KT06-14	2	1	15	C14PF21	6.15	2.47	5.67	2.47	20.1
KT06-13	2	1	16	C07PF21	5.14	2.54	5.05	2.45	22.0
KT06-05	2	1	17	C12PF21	3.82	2.57	7.63	1.92	21.8
KT06-01	2	1	18	C15PF21	2.97	2.53	6.23	1.62	21.6
KT06-18	2	1	19	C04PF11	2.92	1.43	9.95	2.20	22.8
KT06-14	2	1	20	C14PF11	6.28	2.50	5.66	2.49	20.4
Batch 1	2	1	21	BCHPF213	2.52	2.31	8.76	2.04	22.8
Batch 1	2	2	1	BCHPF221	2.43	2.50	8.97	1.97	22.6
KT06-10	2	2	2	C02PF12	5.01	1.61	5.15	2.40	22.1
KT06-18	2	2	3	C04PF12	2.83	1.55	10.17	2.14	22.8
KT06-13	2	2	4	C07PF22	5.02	2.64	5.23	2.40	22.2
KT06-15	2	2	5	C16PF22	3.28	1.50	7.35	2.93	21.4

Table A-3. PSAL Chemical Composition Measurements of the KT06 Series of Glasses Using PF Preparation Method. (continued)

Glass ID	Block	Sub-Blk	Sequence	Lab ID	Al (wt%)	B (wt%)	Fe (wt%)	Li (wt%)	Si (wt%)
KT06-01	2	2	6	C15PF12	2.89	2.56	6.25	1.58	21.5
KT06-14	2	2	7	C14PF22	6.00	2.52	5.84	2.41	20.2
KT06-05	2	2	8	C12PF12	3.80	2.60	8.19	1.92	21.5
KT06-17	2	2	9	C17PF12	6.09	1.49	5.98	2.97	21.5
KT06-05	2	2	10	C12PF22	3.72	2.60	7.72	1.88	21.7
Batch 1	2	2	11	BCHPF222	2.44	2.35	8.85	1.98	22.6
KT06-06	2	2	12	C06PF12	2.92	2.67	8.86	1.91	22.0
KT06-10	2	2	13	C02PF22	5.07	1.56	5.05	2.43	22.2
KT06-17	2	2	14	C17PF22	6.05	1.50	5.98	2.96	21.4
KT06-01	2	2	15	C15PF22	2.95	2.56	6.16	1.61	21.6
KT06-13	2	2	16	C07PF12	5.04	2.61	5.10	2.42	22.2
KT06-06	2	2	17	C06PF22	2.91	2.65	8.92	1.94	22.4
KT06-14	2	2	18	C14PF12	6.20	2.59	5.83	2.46	20.5
KT06-18	2	2	19	C04PF22	2.90	1.51	10.04	2.18	23.0
KT06-15	2	2	20	C16PF12	3.35	1.47	7.24	2.99	21.5
Batch 1	2	2	21	BCHPF223	2.50	2.37	8.79	2.03	22.8

Table A-4. Comparison of Measured versus Targeted Compositions for the KT06-Series Glasses.

Glass ID	Oxide	Measured (wt%)	Targeted (wt%)	Difference of Measured vs Targeted	% Difference of Measured vs Targeted
Batch 1	Al_2O_3	4.7112	4.8770	-0.1658	-3.4%
Batch 1	B_2O_3	7.6795	7.7770	-0.0975	-1.3%
Batch 1	BaO	0.1353	0.1510	-0.0157	-10.4%
Batch 1	CaO	1.2248	1.2200	0.0048	0.4%
Batch 1	Ce_2O_3	0.0059	0.0000	0.0059	
Batch 1	Cr_2O_3	0.1069	0.1070	-0.0001	-0.1%
Batch 1	CuO	0.4012	0.3990	0.0022	0.6%
Batch 1	Fe_2O_3	12.7327	12.8390	-0.1063	-0.8%
Batch 1	K_2O	2.6677	3.3270	-0.6593	-19.8%
Batch 1	La_2O_3	0.0059	0.0000	0.0059	
Batch 1	Li_2O	4.3435	4.4290	-0.0855	-1.9%
Batch 1	MgO	1.3858	1.4190	-0.0332	-2.3%
Batch 1	MnO	1.6775	1.7260	-0.0485	-2.8%
Batch 1	Na_2O	9.2866	9.0030	0.2836	3.2%
Batch 1	Nb_2O_5	0.0072	0.0000	0.0072	
Batch 1	NiO	0.6946	0.7510	-0.0564	-7.5%
Batch 1	PbO	0.0054	0.0000	0.0054	
Batch 1	SiO_2	48.6869	50.2200	-1.5331	-3.1%
Batch 1	SO_4	0.1498	0.0000	0.1498	
Batch 1	TiO_2	0.6593	0.6770	-0.0177	-2.6%
Batch 1	ZnO	0.0062	0.0000	0.0062	
Batch 1	ZrO_2	0.0865	0.0980	-0.0115	-11.8%
Batch 1	Sum	96.6600	99.0200	-2.3600	-2.4%
KT06-01	Al_2O_3	5.5740	5.4539	0.1201	2.2%
KT06-01	B_2O_3	8.1302	8.4000	-0.2698	-3.2%
KT06-01	BaO	0.0396	0.0516	-0.0120	-23.2%
KT06-01	CaO	1.2309	1.1959	0.0350	2.9%
KT06-01	Ce_2O_3	0.1991	0.2127	-0.0136	-6.4%
KT06-01	Cr_2O_3	0.0950	0.1010	-0.0060	-6.0%
KT06-01	CuO	0.0376	0.0289	0.0086	29.8%
KT06-01	Fe_2O_3	8.7962	9.2233	-0.4270	-4.6%
KT06-01	K_2O	0.1033	0.0828	0.0205	24.8%
KT06-01	La_2O_3	0.0566	0.0792	-0.0226	-28.6%
KT06-01	Li_2O	3.4608	3.6000	-0.1392	-3.9%
KT06-01	MgO	0.0974	0.1148	-0.0174	-15.2%
KT06-01	MnO	1.2793	1.3828	-0.1036	-7.5%
KT06-01	Na_2O	13.0251	13.2000	-0.1749	-1.3%
KT06-01	Nb_2O_5	0.5858	0.6262	-0.0404	-6.5%
KT06-01	NiO	0.5494	0.6342	-0.0848	-13.4%
KT06-01	PbO	0.0956	0.1215	-0.0259	-21.3%
KT06-01	SiO_2	45.9950	48.4935	-2.4986	-5.2%
KT06-01	SO_4	0.1498	0.1780	-0.0282	-15.9%
KT06-01	TiO_2	5.8505	6.0000	-0.1495	-2.5%
KT06-01	ZnO	0.0520	0.0570	-0.0050	-8.8%
KT06-01	ZrO_2	0.6099	0.7624	-0.1525	-20.0%
KT06-01	Sum	96.0131	100.0000	-3.9869	-4.0%
KT06-02	Al_2O_3	9.5278	9.4568	0.0710	0.8%
KT06-02	B_2O_3	8.2188	8.4000	-0.1812	-2.2%
KT06-02	BaO	0.0173	0.0246	-0.0073	-29.8%
KT06-02	CaO	1.8260	1.7411	0.0849	4.9%
KT06-02	Ce_2O_3	0.0958	0.1014	-0.0056	-5.6%
KT06-02	Cr_2O_3	0.0497	0.0481	0.0016	3.4%
KT06-02	CuO	0.0479	0.0137	0.0341	248.6%
KT06-02	Fe_2O_3	7.1449	7.2593	-0.1143	-1.6%
KT06-02	K_2O	0.0500	0.0392	0.0108	27.6%
KT06-02	La_2O_3	0.0258	0.0376	-0.0118	-31.3%
KT06-02	Li_2O	3.4662	3.6000	-0.1338	-3.7%
KT06-02	MgO	0.0419	0.0545	-0.0127	-23.2%
KT06-02	MnO	1.0749	1.1271	-0.0521	-4.6%

Table A-4. Comparison of Measured versus Targeted Compositions for the KT06-Series Glasses. (continued)

Glass ID	Oxide	Measured (wt%)	Targeted (wt%)	Difference of Measured vs Targeted	% Difference of Measured vs Targeted
KT06-02	Na_2O	12.8296	13.2000	-0.3704	-2.8%
KT06-02	Nb_2O_5	0.0594	0.0808	-0.0214	-26.5%
KT06-02	NiO	1.0460	1.1917	-0.1457	-12.2%
KT06-02	PbO	0.0471	0.0578	-0.0106	-18.4%
KT06-02	SiO_2	45.5671	47.1838	-1.6167	-3.4%
KT06-02	SO_4	0.1498	0.1616	-0.0118	-7.3%
KT06-02	TiO_2	5.9506	6.0000	-0.0494	-0.8%
KT06-02	ZnO	0.0398	0.0271	0.0128	47.2%
KT06-02	ZrO_2	0.1516	0.1939	-0.0423	-21.8%
KT06-02	Sum	97.4279	100.0000	-2.5721	-2.6%
KT06-03	Al_2O_3	5.5457	5.4539	0.0917	1.7%
KT06-03	B_2O_3	4.7252	4.8000	-0.0748	-1.6%
KT06-03	BaO	0.0416	0.0516	-0.0100	-19.4%
KT06-03	CaO	1.2358	1.1959	0.0399	3.3%
KT06-03	Ce_2O_3	0.2018	0.2127	-0.0110	-5.2%
KT06-03	Cr_2O_3	0.0972	0.1010	-0.0038	-3.8%
KT06-03	CuO	0.0401	0.0289	0.0111	38.5%
KT06-03	Fe_2O_3	9.1501	9.2233	-0.0732	-0.8%
KT06-03	K_2O	0.1030	0.0828	0.0202	24.4%
KT06-03	La_2O_3	0.0557	0.0792	-0.0235	-29.7%
KT06-03	Li_2O	4.6772	4.8000	-0.1228	-2.6%
KT06-03	MgO	0.1007	0.1148	-0.0141	-12.3%
KT06-03	MnO	1.2815	1.3828	-0.1013	-7.3%
KT06-03	Na_2O	12.9442	13.2000	-0.2558	-1.9%
KT06-03	Nb_2O_5	0.5765	0.6262	-0.0497	-7.9%
KT06-03	NiO	0.5500	0.6342	-0.0842	-13.3%
KT06-03	PbO	0.0959	0.1215	-0.0256	-21.1%
KT06-03	SiO_2	49.2574	50.8935	-1.6361	-3.2%
KT06-03	SO_4	0.1498	0.1780	-0.0282	-15.9%
KT06-03	TiO_2	5.9464	6.0000	-0.0536	-0.9%
KT06-03	ZnO	0.0532	0.0570	-0.0038	-6.6%
KT06-03	ZrO_2	0.7288	0.7624	-0.0337	-4.4%
KT06-03	Sum	97.5577	100.0000	-2.4423	-2.4%
KT06-04	Al_2O_3	9.7451	9.4568	0.2882	3.0%
KT06-04	B_2O_3	4.8701	4.8000	0.0701	1.5%
KT06-04	BaO	0.0154	0.0246	-0.0093	-37.7%
KT06-04	CaO	1.8469	1.7411	0.1058	6.1%
KT06-04	Ce_2O_3	0.0928	0.1014	-0.0086	-8.5%
KT06-04	Cr_2O_3	0.0504	0.0481	0.0024	4.9%
KT06-04	CuO	0.0407	0.0137	0.0269	196.2%
KT06-04	Fe_2O_3	7.3844	7.2593	0.1251	1.7%
KT06-04	K_2O	0.0530	0.0392	0.0138	35.3%
KT06-04	La_2O_3	0.0240	0.0376	-0.0135	-36.0%
KT06-04	Li_2O	4.7202	4.8000	-0.0798	-1.7%
KT06-04	MgO	0.0410	0.0545	-0.0135	-24.7%
KT06-04	MnO	1.0788	1.1271	-0.0483	-4.3%
KT06-04	Na_2O	11.6332	13.2000	-1.5668	-11.9%
KT06-04	Nb_2O_5	0.0812	0.0808	0.0004	0.5%
KT06-04	NiO	1.0428	1.1917	-0.1489	-12.5%
KT06-04	PbO	0.0471	0.0578	-0.0106	-18.4%
KT06-04	SiO_2	48.8295	49.5838	-0.7542	-1.5%
KT06-04	SO_4	0.1498	0.1616	-0.0118	-7.3%
KT06-04	TiO_2	6.0131	6.0000	0.0131	0.2%
KT06-04	ZnO	0.0386	0.0271	0.0115	42.6%
KT06-04	ZrO_2	0.1898	0.1939	-0.0041	-2.1%
KT06-04	Sum	97.9881	100.0000	-2.0119	-2.0%
KT06-05	Al_2O_3	7.1518	6.9766	0.1752	2.5%
KT06-05	B_2O_3	8.2993	8.4000	-0.1007	-1.2%

Table A-4. Comparison of Measured versus Targeted Compositions for the KT06-Series Glasses. (continued)

Glass ID	Oxide	Measured (wt%)	Targeted (wt%)	Difference of Measured vs Targeted	% Difference of Measured vs Targeted
KT06-05	BaO	0.0179	0.0274	-0.0095	-34.8%
KT06-05	CaO	1.1837	1.0766	0.1072	10.0%
KT06-05	Ce_2O_3	0.1086	0.1127	-0.0040	-3.6%
KT06-05	Cr_2O_3	0.0588	0.0534	0.0054	10.1%
KT06-05	CuO	0.0175	0.0153	0.0023	14.8%
KT06-05	Fe_2O_3	11.2732	10.8972	0.3760	3.5%
KT06-05	K_2O	0.0581	0.0435	0.0146	33.5%
KT06-05	La_2O_3	0.0308	0.0418	-0.0110	-26.3%
KT06-05	Li_2O	4.1120	4.2000	-0.0880	-2.1%
KT06-05	MgO	0.0643	0.0606	0.0037	6.0%
KT06-05	MnO	1.1927	1.2494	-0.0567	-4.5%
KT06-05	Na_2O	10.2448	11.2000	-0.9552	-8.5%
KT06-05	Nb_2O_5	0.5103	0.5450	-0.0347	-6.4%
KT06-05	NiO	0.3703	0.4287	-0.0584	-13.6%
KT06-05	PbO	0.0539	0.0642	-0.0103	-16.1%
KT06-05	SiO_2	46.1019	47.8018	-1.6999	-3.6%
KT06-05	SO_4	0.1498	0.1796	-0.0298	-16.6%
KT06-05	TiO_2	5.9381	6.0000	-0.0619	-1.0%
KT06-05	ZnO	0.0258	0.0301	-0.0042	-14.1%
KT06-05	ZrO_2	0.5900	0.5962	-0.0062	-1.0%
KT06-05	Sum	97.5536	100.0000	-2.4464	-2.4%
KT06-06	Al_2O_3	5.4843	5.3819	0.1024	1.9%
KT06-06	B_2O_3	8.4361	8.4000	0.0361	0.4%
KT06-06	BaO	0.0201	0.0274	-0.0073	-26.6%
KT06-06	CaO	1.1078	1.0766	0.0313	2.9%
KT06-06	Ce_2O_3	0.1122	0.1127	-0.0005	-0.5%
KT06-06	Cr_2O_3	0.0566	0.0534	0.0032	6.0%
KT06-06	CuO	0.0319	0.0153	0.0167	109.1%
KT06-06	Fe_2O_3	12.7208	12.4918	0.2289	1.8%
KT06-06	K_2O	0.0521	0.0435	0.0086	19.6%
KT06-06	La_2O_3	0.0287	0.0418	-0.0130	-31.2%
KT06-06	Li_2O	4.1120	4.2000	-0.0880	-2.1%
KT06-06	MgO	0.0510	0.0606	-0.0096	-15.9%
KT06-06	MnO	1.2570	1.2494	0.0076	0.6%
KT06-06	Na_2O	10.2987	11.2000	-0.9013	-8.0%
KT06-06	Nb_2O_5	0.5364	0.5450	-0.0086	-1.6%
KT06-06	NiO	0.4177	0.4287	-0.0110	-2.6%
KT06-06	PbO	0.0595	0.0642	-0.0047	-7.3%
KT06-06	SiO_2	47.3855	47.8018	-0.4163	-0.9%
KT06-06	SO_4	0.1498	0.1796	-0.0298	-16.6%
KT06-06	TiO_2	6.0799	6.0000	0.0799	1.3%
KT06-06	ZnO	0.0243	0.0301	-0.0058	-19.3%
KT06-06	ZrO_2	0.6109	0.5962	0.0147	2.5%
KT06-06	Sum	99.0333	100.0000	-0.9667	-1.0%
KT06-07	Al_2O_3	9.5089	9.4490	0.0599	0.6%
KT06-07	B_2O_3	8.0739	8.4000	-0.3261	-3.9%
KT06-07	BaO	0.0458	0.0533	-0.0075	-14.1%
KT06-07	CaO	0.7433	0.7104	0.0329	4.6%
KT06-07	Ce_2O_3	0.2252	0.2204	0.0048	2.2%
KT06-07	Cr_2O_3	0.1016	0.1049	-0.0034	-3.2%
KT06-07	CuO	0.0344	0.0299	0.0046	15.3%
KT06-07	Fe_2O_3	6.9233	7.2533	-0.3300	-4.5%
KT06-07	K_2O	0.0909	0.0856	0.0054	6.3%
KT06-07	La_2O_3	0.0654	0.0819	-0.0166	-20.2%
KT06-07	Li_2O	4.1174	4.2000	-0.0826	-2.0%
KT06-07	MgO	0.1132	0.1191	-0.0059	-4.9%
KT06-07	MnO	3.4636	3.4026	0.0610	1.8%
KT06-07	Na_2O	10.2852	11.2000	-0.9148	-8.2%

Table A-4. Comparison of Measured versus Targeted Compositions for the KT06-Series Glasses. (continued)

Glass ID	Oxide	Measured (wt%)	Targeted (wt%)	Difference of Measured vs Targeted	% Difference of Measured vs Targeted
KT06-07	Nb_2O_5	0.0908	0.0807	0.0101	12.5%
KT06-07	NiO	0.1113	0.1171	-0.0057	-4.9%
KT06-07	PbO	0.1126	0.1255	-0.0130	-10.3%
KT06-07	SiO_2	45.7275	46.5835	-0.8559	-1.8%
KT06-07	SO_4	0.1498	0.1615	-0.0117	-7.2%
KT06-07	TiO_2	6.0465	6.0000	0.0465	0.8%
KT06-07	ZnO	0.0507	0.0593	-0.0086	-14.5%
KT06-07	ZrO_2	1.5399	1.5621	-0.0221	-1.4%
KT06-07	Sum	97.6215	100.0000	-2.3785	-2.4%
KT06-08	Al_2O_3	7.1518	6.9766	0.1752	2.5%
KT06-08	B_2O_3	4.7977	4.8000	-0.0023	0.0%
KT06-08	BaO	0.0198	0.0274	-0.0076	-27.6%
KT06-08	CaO	1.1075	1.0766	0.0309	2.9%
KT06-08	Ce_2O_3	0.1127	0.1127	0.0001	0.0%
KT06-08	Cr_2O_3	0.0563	0.0534	0.0028	5.3%
KT06-08	CuO	0.0316	0.0153	0.0163	107.1%
KT06-08	Fe_2O_3	11.0337	10.8972	0.1365	1.3%
KT06-08	K_2O	0.0512	0.0435	0.0076	17.6%
KT06-08	La_2O_3	0.0311	0.0418	-0.0107	-25.6%
KT06-08	Li_2O	5.3177	5.4000	-0.0823	-1.5%
KT06-08	MgO	0.0527	0.0606	-0.0080	-13.1%
KT06-08	MnO	1.2444	1.2494	-0.0050	-0.4%
KT06-08	Na_2O	10.3392	11.2000	-0.8608	-7.7%
KT06-08	Nb_2O_5	0.5407	0.5450	-0.0043	-0.8%
KT06-08	NiO	0.4040	0.4287	-0.0247	-5.8%
KT06-08	PbO	0.0560	0.0642	-0.0082	-12.7%
KT06-08	SiO_2	49.0969	50.2018	-1.1049	-2.2%
KT06-08	SO_4	0.1498	0.1796	-0.0298	-16.6%
KT06-08	TiO_2	6.1466	6.0000	0.1466	2.4%
KT06-08	ZnO	0.0302	0.0301	0.0001	0.4%
KT06-08	ZrO_2	0.6058	0.5962	0.0096	1.6%
KT06-08	Sum	98.3773	100.0000	-1.6227	-1.6%
KT06-09	Al_2O_3	5.5599	5.3819	0.1779	3.3%
KT06-09	B_2O_3	4.8218	4.8000	0.0218	0.5%
KT06-09	BaO	0.0187	0.0274	-0.0087	-31.7%
KT06-09	CaO	1.1152	1.0766	0.0386	3.6%
KT06-09	Ce_2O_3	0.1054	0.1127	-0.0073	-6.4%
KT06-09	Cr_2O_3	0.0523	0.0534	-0.0012	-2.2%
KT06-09	CuO	0.0175	0.0153	0.0023	14.8%
KT06-09	Fe_2O_3	12.2740	12.4918	-0.2178	-1.7%
KT06-09	K_2O	0.0554	0.0435	0.0119	27.2%
KT06-09	La_2O_3	0.0276	0.0418	-0.0142	-34.0%
KT06-09	Li_2O	5.3553	5.4000	-0.0447	-0.8%
KT06-09	MgO	0.0460	0.0606	-0.0146	-24.1%
KT06-09	MnO	1.1921	1.2494	-0.0573	-4.6%
KT06-09	Na_2O	10.9289	11.2000	-0.2711	-2.4%
KT06-09	Nb_2O_5	0.5075	0.5450	-0.0375	-6.9%
KT06-09	NiO	0.3741	0.4287	-0.0546	-12.7%
KT06-09	PbO	0.0512	0.0642	-0.0130	-20.3%
KT06-09	SiO_2	48.5621	50.2018	-1.6397	-3.3%
KT06-09	SO_4	0.1498	0.1796	-0.0298	-16.6%
KT06-09	TiO_2	5.9756	6.0000	-0.0244	-0.4%
KT06-09	ZnO	0.0209	0.0301	-0.0092	-30.7%
KT06-09	ZrO_2	0.5758	0.5962	-0.0204	-3.4%
KT06-09	Sum	97.7869	100.0000	-2.2131	-2.2%
KT06-10	Al_2O_3	9.4806	9.4490	0.0315	0.3%
KT06-10	B_2O_3	4.9103	4.8000	0.1103	2.3%
KT06-10	BaO	0.0435	0.0533	-0.0097	-18.3%

Table A-4. Comparison of Measured versus Targeted Compositions for the KT06-Series Glasses. (continued)

Glass ID	Oxide	Measured (wt%)	Targeted (wt%)	Difference of Measured vs Targeted	% Difference of Measured vs Targeted
KT06-10	CaO	0.7629	0.7104	0.0525	7.4%
KT06-10	Ce_2O_3	0.2129	0.2204	-0.0075	-3.4%
KT06-10	Cr_2O_3	0.1019	0.1049	-0.0030	-2.9%
KT06-10	CuO	0.0582	0.0299	0.0283	94.9%
KT06-10	Fe_2O_3	7.2522	7.2533	-0.0011	0.0%
KT06-10	K_2O	0.1045	0.0856	0.0189	22.1%
KT06-10	La_2O_3	0.0625	0.0819	-0.0195	-23.8%
KT06-10	Li_2O	5.1723	5.4000	-0.2277	-4.2%
KT06-10	MgO	0.1041	0.1191	-0.0150	-12.6%
KT06-10	MnO	3.5250	3.4026	0.1224	3.6%
KT06-10	Na_2O	11.0469	11.2000	-0.1531	-1.4%
KT06-10	Nb_2O_5	0.0833	0.0807	0.0026	3.2%
KT06-10	NiO	0.0977	0.1171	-0.0194	-16.6%
KT06-10	PbO	0.1077	0.1255	-0.0178	-14.2%
KT06-10	SiO_2	47.1181	48.9835	-1.8654	-3.8%
KT06-10	SO_4	0.1498	0.1615	-0.0117	-7.2%
KT06-10	TiO_2	6.1007	6.0000	0.1007	1.7%
KT06-10	ZnO	0.0654	0.0593	0.0060	10.1%
KT06-10	ZrO_2	1.4538	1.5621	-0.1083	-6.9%
KT06-10	Sum	98.0142	100.0000	-1.9858	-2.0%
KT06-11	Al_2O_3	5.4229	5.3317	0.0911	1.7%
KT06-11	B_2O_3	8.3154	8.4000	-0.0846	-1.0%
KT06-11	BaO	0.0195	0.0271	-0.0076	-28.0%
KT06-11	CaO	1.1015	1.0665	0.0350	3.3%
KT06-11	Ce_2O_3	0.1045	0.1116	-0.0071	-6.4%
KT06-11	Cr_2O_3	0.0512	0.0529	-0.0018	-3.3%
KT06-11	CuO	0.0407	0.0151	0.0256	169.0%
KT06-11	Fe_2O_3	14.6115	14.5991	0.0124	0.1%
KT06-11	K_2O	0.0554	0.0431	0.0123	28.4%
KT06-11	La_2O_3	0.0261	0.0414	-0.0153	-36.9%
KT06-11	Li_2O	4.1120	4.2000	-0.0880	-2.1%
KT06-11	MgO	0.0460	0.0600	-0.0140	-23.4%
KT06-11	MnO	1.1889	1.2378	-0.0489	-3.9%
KT06-11	Na_2O	9.4798	9.2000	0.2798	3.0%
KT06-11	Nb_2O_5	0.4753	0.5399	-0.0647	-12.0%
KT06-11	NiO	0.3649	0.4247	-0.0599	-14.1%
KT06-11	PbO	0.0544	0.0636	-0.0092	-14.5%
KT06-11	SiO_2	46.2089	47.7869	-1.5780	-3.3%
KT06-11	SO_4	0.1498	0.1779	-0.0281	-15.8%
KT06-11	TiO_2	6.0048	6.0000	0.0048	0.1%
KT06-11	ZnO	0.0277	0.0298	-0.0021	-7.1%
KT06-11	ZrO_2	0.5521	0.5906	-0.0385	-6.5%
KT06-11	Sum	98.4134	100.0000	-1.5866	-1.6%
KT06-12	Al_2O_3	6.3251	6.2876	0.0375	0.6%
KT06-12	B_2O_3	8.2349	8.4000	-0.1651	-2.0%
KT06-12	BaO	0.0918	0.1066	-0.0148	-13.9%
KT06-12	CaO	1.2079	1.0313	0.1765	17.1%
KT06-12	Ce_2O_3	0.4214	0.4407	-0.0193	-4.4%
KT06-12	Cr_2O_3	0.1809	0.2092	-0.0283	-13.5%
KT06-12	CuO	0.0723	0.0598	0.0125	20.9%
KT06-12	Fe_2O_3	10.3796	10.6649	-0.2852	-2.7%
KT06-12	K_2O	0.2096	0.1711	0.0385	22.5%
KT06-12	La_2O_3	0.1264	0.1641	-0.0377	-23.0%
KT06-12	Li_2O	5.2315	5.4000	-0.1685	-3.1%
KT06-12	MgO	0.2417	0.2379	0.0038	1.6%
KT06-12	MnO	0.5062	0.5274	-0.0212	-4.0%
KT06-12	Na_2O	9.4529	9.2000	0.2529	2.7%
KT06-12	Nb_2O_5	2.2155	2.5016	-0.2861	-11.4%

Table A-4. Comparison of Measured versus Targeted Compositions for the KT06-Series Glasses. (continued)

Glass ID	Oxide	Measured (wt%)	Targeted (wt%)	Difference of Measured vs Targeted	% Difference of Measured vs Targeted
KT06-12	NiO	0.1381	0.1699	-0.0319	-18.8%
KT06-12	PbO	0.2095	0.2508	-0.0413	-16.5%
KT06-12	SiO_2	43.5882	45.5567	-1.9684	-4.3%
KT06-12	SO_4	0.1498	0.2344	-0.0846	-36.1%
KT06-12	TiO_2	5.9798	6.0000	-0.0202	-0.3%
KT06-12	ZnO	0.1123	0.1184	-0.0060	-5.1%
KT06-12	ZrO_2	2.0948	2.2677	-0.1730	-7.6%
KT06-12	Sum	97.1700	100.0000	-2.8300	-2.8%
KT06-13	Al_2O_3	9.5703	9.4424	0.1279	1.4%
KT06-13	B_2O_3	8.4200	8.4000	0.0200	0.2%
KT06-13	BaO	0.0606	0.0734	-0.0128	-17.5%
KT06-13	CaO	0.7447	0.7099	0.0348	4.9%
KT06-13	Ce_2O_3	0.2876	0.3033	-0.0158	-5.2%
KT06-13	Cr_2O_3	0.1348	0.1440	-0.0092	-6.4%
KT06-13	CuO	0.0444	0.0411	0.0033	8.0%
KT06-13	Fe_2O_3	7.3236	7.2482	0.0754	1.0%
KT06-13	K_2O	0.1412	0.1178	0.0235	19.9%
KT06-13	La_2O_3	0.0850	0.1129	-0.0279	-24.7%
KT06-13	Li_2O	5.2208	5.4000	-0.1792	-3.3%
KT06-13	MgO	0.1472	0.1638	-0.0166	-10.1%
KT06-13	MnO	3.3378	3.4002	-0.0625	-1.8%
KT06-13	Na_2O	9.4192	9.2000	0.2192	2.4%
KT06-13	Nb_2O_5	0.0286	0.0803	-0.0517	-64.4%
KT06-13	NiO	0.0983	0.1170	-0.0187	-16.0%
KT06-13	PbO	0.1406	0.1726	-0.0321	-18.6%
KT06-13	SiO_2	47.3855	48.4365	-1.0511	-2.2%
KT06-13	SO_4	0.1498	0.1613	-0.0115	-7.2%
KT06-13	TiO_2	5.8797	6.0000	-0.1203	-2.0%
KT06-13	ZnO	0.0734	0.0815	-0.0080	-9.9%
KT06-13	ZrO_2	0.1101	0.1936	-0.0835	-43.1%
KT06-13	Sum	98.8032	100.0000	-1.1968	-1.2%
KT06-14	Al_2O_3	11.6346	11.4195	0.2151	1.9%
KT06-14	B_2O_3	8.1141	8.4000	-0.2859	-3.4%
KT06-14	BaO	0.0229	0.0298	-0.0069	-23.1%
KT06-14	CaO	2.1828	2.1024	0.0803	3.8%
KT06-14	Ce_2O_3	0.1177	0.1224	-0.0047	-3.9%
KT06-14	Cr_2O_3	0.0552	0.0580	-0.0029	-4.9%
KT06-14	CuO	0.0175	0.0166	0.0009	5.7%
KT06-14	Fe_2O_3	8.2208	8.7659	-0.5451	-6.2%
KT06-14	K_2O	0.0527	0.0473	0.0054	11.4%
KT06-14	La_2O_3	0.0317	0.0454	-0.0137	-30.2%
KT06-14	Li_2O	5.2908	5.4000	-0.1092	-2.0%
KT06-14	MgO	0.0543	0.0659	-0.0115	-17.5%
KT06-14	MnO	0.4451	0.4390	0.0061	1.4%
KT06-14	Na_2O	9.8033	9.2000	0.6033	6.6%
KT06-14	Nb_2O_5	0.1012	0.0976	0.0036	3.7%
KT06-14	NiO	0.1285	0.1415	-0.0129	-9.1%
KT06-14	PbO	0.0584	0.0698	-0.0113	-16.2%
KT06-14	SiO_2	43.4278	45.4634	-2.0356	-4.5%
KT06-14	SO_4	0.1498	0.1951	-0.0453	-23.2%
KT06-14	TiO_2	6.0048	6.0000	0.0048	0.1%
KT06-14	ZnO	0.0230	0.0327	-0.0097	-29.5%
KT06-14	ZrO_2	1.8357	1.8878	-0.0521	-2.8%
KT06-14	Sum	97.7728	100.0000	-2.2272	-2.2%
KT06-15	Al_2O_3	6.2920	6.2876	0.0045	0.1%
KT06-15	B_2O_3	4.6930	4.8000	-0.1070	-2.2%
KT06-15	BaO	0.0955	0.1066	-0.0112	-10.5%
KT06-15	CaO	1.0718	1.0313	0.0405	3.9%

Table A-4. Comparison of Measured versus Targeted Compositions for the KT06-Series Glasses. (continued)

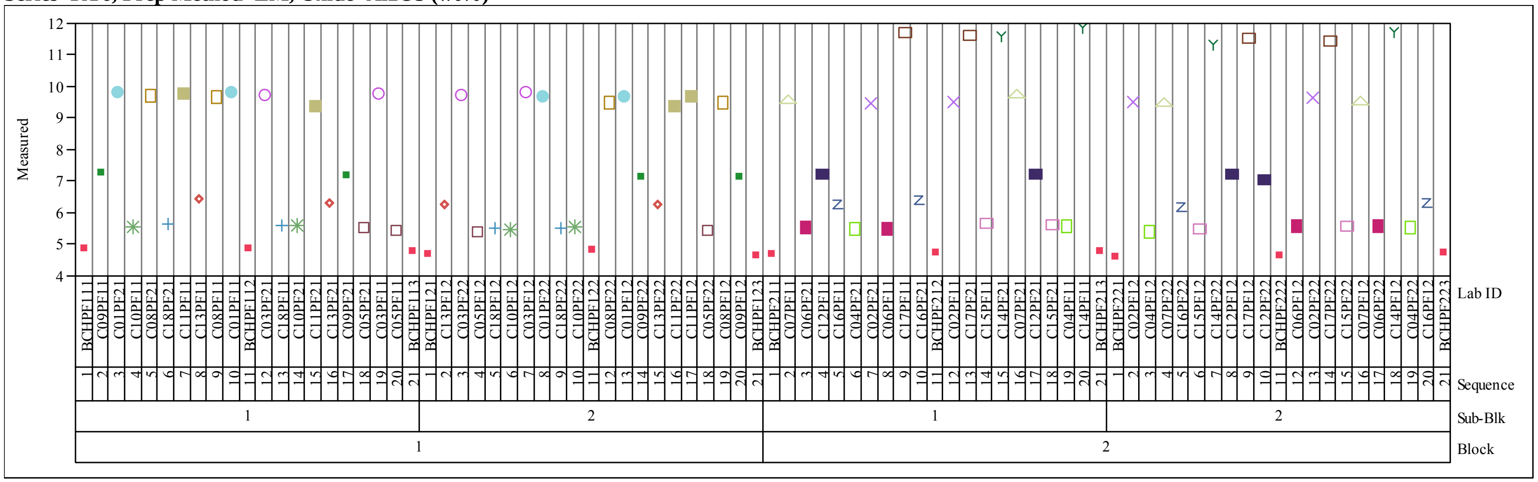
Glass ID	Oxide	Measured (wt%)	Targeted (wt%)	Difference of Measured vs Targeted	% Difference of Measured vs Targeted
KT06-15	Ce_2O_3	0.4302	0.4407	-0.0105	-2.4%
KT06-15	Cr_2O_3	0.1717	0.2092	-0.0375	-17.9%
KT06-15	CuO	0.0879	0.0598	0.0282	47.1%
KT06-15	Fe_2O_3	10.3653	10.6649	-0.2995	-2.8%
KT06-15	K_2O	0.1873	0.1711	0.0162	9.5%
KT06-15	La_2O_3	0.1311	0.1641	-0.0330	-20.1%
KT06-15	Li_2O	6.3995	6.6000	-0.2005	-3.0%
KT06-15	MgO	0.2251	0.2379	-0.0128	-5.4%
KT06-15	MnO	0.5187	0.5274	-0.0086	-1.6%
KT06-15	Na_2O	10.0123	9.2000	0.8123	8.8%
KT06-15	Nb_2O_5	2.3006	2.5016	-0.2010	-8.0%
KT06-15	NiO	0.1514	0.1699	-0.0185	-10.9%
KT06-15	PbO	0.2238	0.2508	-0.0270	-10.8%
KT06-15	SiO_2	45.8880	47.9567	-2.0687	-4.3%
KT06-15	SO_4	0.1498	0.2344	-0.0846	-36.1%
KT06-15	TiO_2	5.8297	6.0000	-0.1703	-2.8%
KT06-15	ZnO	0.1192	0.1184	0.0008	0.7%
KT06-15	ZrO_2	2.0606	2.2677	-0.2071	-9.1%
KT06-15	Sum	97.4045	100.0000	-2.5955	-2.6%
KT06-16	Al_2O_3	9.7640	9.4424	0.3215	3.4%
KT06-16	B_2O_3	4.8299	4.8000	0.0299	0.6%
KT06-16	BaO	0.0597	0.0734	-0.0137	-18.6%
KT06-16	CaO	0.7538	0.7099	0.0439	6.2%
KT06-16	Ce_2O_3	0.2843	0.3033	-0.0190	-6.3%
KT06-16	Cr_2O_3	0.1228	0.1440	-0.0212	-14.7%
KT06-16	CuO	0.0457	0.0411	0.0045	11.1%
KT06-16	Fe_2O_3	7.3379	7.2482	0.0897	1.2%
KT06-16	K_2O	0.1418	0.1178	0.0241	20.4%
KT06-16	La_2O_3	0.0844	0.1129	-0.0285	-25.2%
KT06-16	Li_2O	6.5287	6.6000	-0.0713	-1.1%
KT06-16	MgO	0.1480	0.1638	-0.0158	-9.6%
KT06-16	MnO	3.3926	3.4002	-0.0076	-0.2%
KT06-16	Na_2O	9.8438	9.2000	0.6438	7.0%
KT06-16	Nb_2O_5	0.0765	0.0803	-0.0037	-4.7%
KT06-16	NiO	0.0929	0.1170	-0.0241	-20.6%
KT06-16	PbO	0.1382	0.1726	-0.0345	-20.0%
KT06-16	SiO_2	49.3643	50.8365	-1.4722	-2.9%
KT06-16	SO_4	0.1498	0.1613	-0.0115	-7.2%
KT06-16	TiO_2	6.0048	6.0000	0.0048	0.1%
KT06-16	ZnO	0.0787	0.0815	-0.0027	-3.4%
KT06-16	ZrO_2	0.1834	0.1936	-0.0102	-5.3%
KT06-16	Sum	99.4261	100.0000	-0.5739	-0.6%
KT06-17	Al_2O_3	11.5590	11.4195	0.1395	1.2%
KT06-17	B_2O_3	4.7172	4.8000	-0.0828	-1.7%
KT06-17	BaO	0.0218	0.0298	-0.0080	-26.8%
KT06-17	CaO	2.2807	2.1024	0.1783	8.5%
KT06-17	Ce_2O_3	0.1133	0.1224	-0.0091	-7.4%
KT06-17	Cr_2O_3	0.0581	0.0580	0.0000	0.1%
KT06-17	CuO	0.0253	0.0166	0.0088	52.8%
KT06-17	Fe_2O_3	8.4960	8.7659	-0.2699	-3.1%
KT06-17	K_2O	0.0635	0.0473	0.0162	34.3%
KT06-17	La_2O_3	0.0325	0.0454	-0.0128	-28.3%
KT06-17	Li_2O	6.4264	6.6000	-0.1736	-2.6%
KT06-17	MgO	0.0759	0.0659	0.0100	15.2%
KT06-17	MnO	0.4232	0.4390	-0.0158	-3.6%
KT06-17	Na_2O	9.6719	9.2000	0.4719	5.1%
KT06-17	Nb_2O_5	0.0679	0.0976	-0.0296	-30.4%
KT06-17	NiO	0.1209	0.1415	-0.0206	-14.5%

Table A-4. Comparison of Measured versus Targeted Compositions for the KT06-Series Glasses. (continued)

Glass ID	Oxide	Measured (wt%)	Targeted (wt%)	Difference of Measured vs Targeted	% Difference of Measured vs Targeted
KT06-17	PbO	0.0574	0.0698	-0.0124	-17.8%
KT06-17	SiO_2	45.8345	47.8634	-2.0289	-4.2%
KT06-17	SO_4	0.1498	0.1951	-0.0453	-23.2%
KT06-17	TiO_2	5.9381	6.0000	-0.0619	-1.0%
KT06-17	ZnO	0.0249	0.0327	-0.0078	-23.8%
KT06-17	ZrO_2	1.7061	1.8878	-0.1817	-9.6%
KT06-17	Sum	97.8644	100.0000	-2.1356	-2.1%
KT06-18	Al_2O_3	5.4418	5.3317	0.1100	2.1%
KT06-18	B_2O_3	4.8057	4.8000	0.0057	0.1%
KT06-18	BaO	0.0190	0.0271	-0.0081	-30.0%
KT06-18	CaO	1.1257	1.0665	0.0591	5.5%
KT06-18	Ce_2O_3	0.1042	0.1116	-0.0074	-6.6%
KT06-18	Cr_2O_3	0.0541	0.0529	0.0012	2.2%
KT06-18	CuO	0.0488	0.0151	0.0337	222.8%
KT06-18	Fe_2O_3	14.4150	14.5991	-0.1842	-1.3%
KT06-18	K_2O	0.0608	0.0431	0.0177	41.0%
KT06-18	La_2O_3	0.0281	0.0414	-0.0132	-31.9%
KT06-18	Li_2O	4.6718	4.8000	-0.1282	-2.7%
KT06-18	MgO	0.0489	0.0600	-0.0111	-18.5%
KT06-18	MnO	1.1450	1.2378	-0.0928	-7.5%
KT06-18	Na_2O	9.6416	9.2000	0.4416	4.8%
KT06-18	Nb_2O_5	0.4928	0.5399	-0.0471	-8.7%
KT06-18	NiO	0.3617	0.4247	-0.0630	-14.8%
KT06-18	PbO	0.0533	0.0636	-0.0103	-16.2%
KT06-18	SiO_2	49.0435	50.7869	-1.7434	-3.4%
KT06-18	SO_4	0.1498	0.1779	-0.0281	-15.8%
KT06-18	TiO_2	5.9506	6.0000	-0.0494	-0.8%
KT06-18	ZnO	0.0324	0.0298	0.0026	8.6%
KT06-18	ZrO_2	0.5559	0.5906	-0.0348	-5.9%
KT06-18	Sum	98.2503	100.0000	-1.7497	-1.7%

Exhibit A-1. Measurements in Analytical Sequence for the KT06-Series by Preparation Method by Oxide.

Series=KT6, Prep Method=LM, Oxide=Al2O3 (wt%)



Series=KT6, Prep Method=LM, Oxide=B2O3 (wt%)

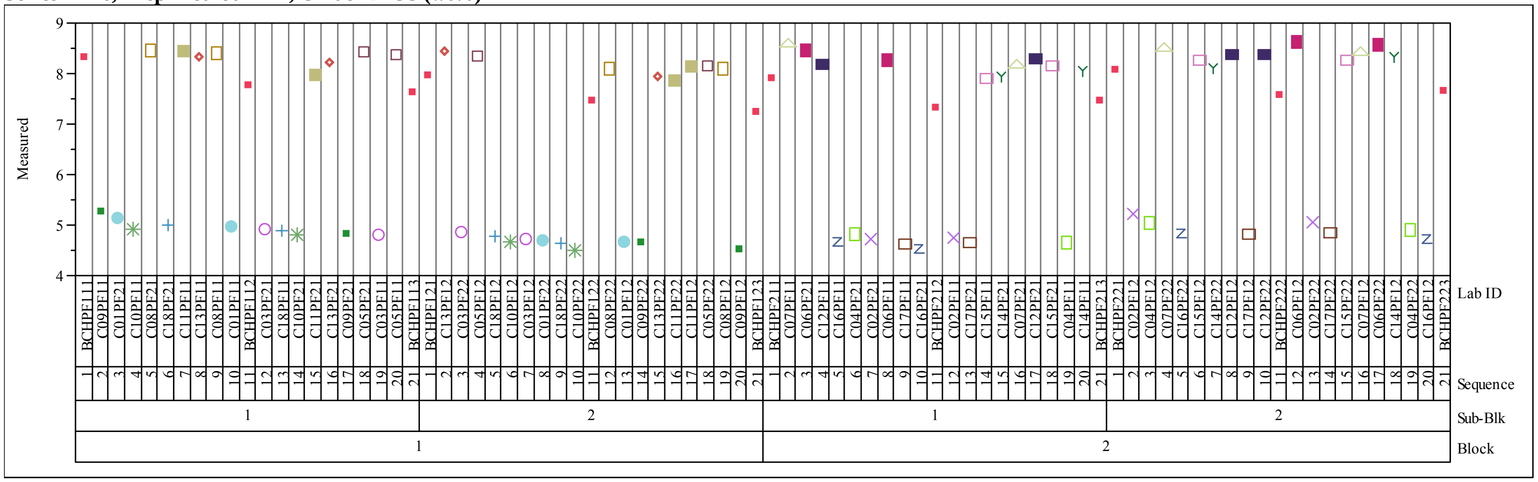
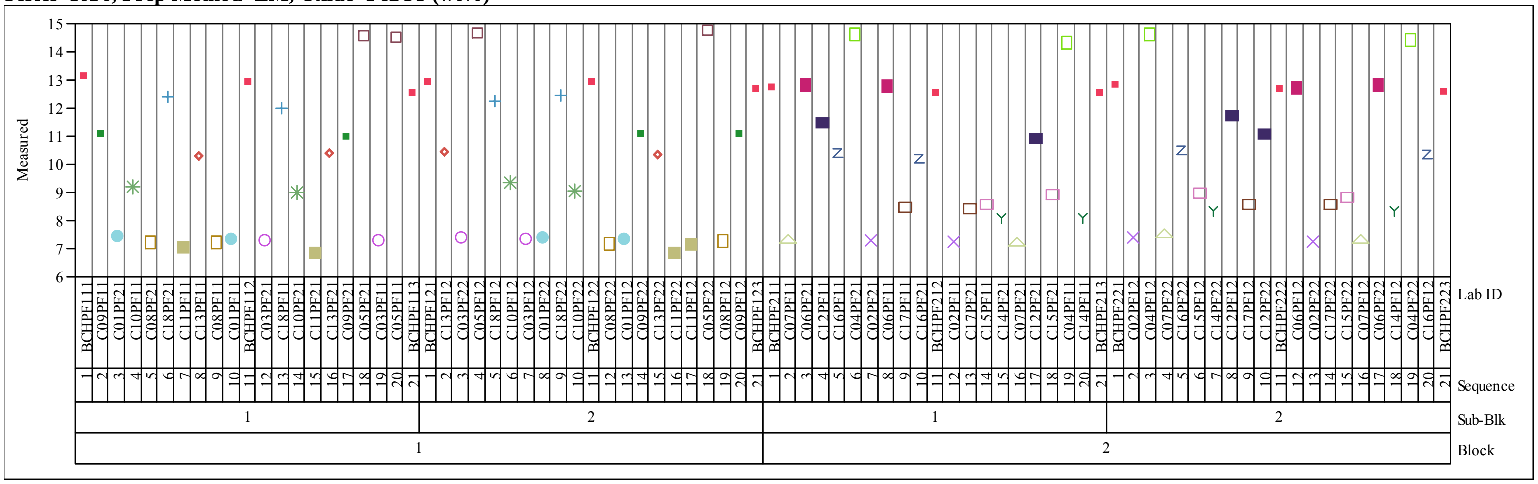


Exhibit A-1. Measurements in Analytical Sequence for the KT06-Series by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=LM, Oxide=Fe2O3 (wt%)



Series=KT6, Prep Method=LM, Oxide=Li2O (wt%)

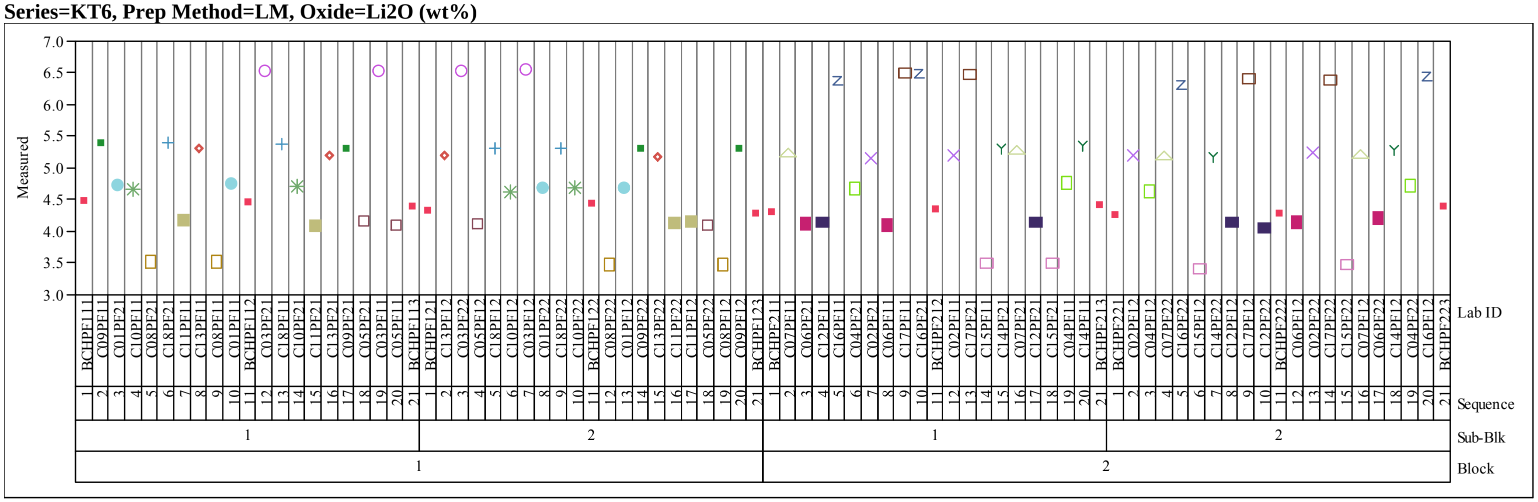
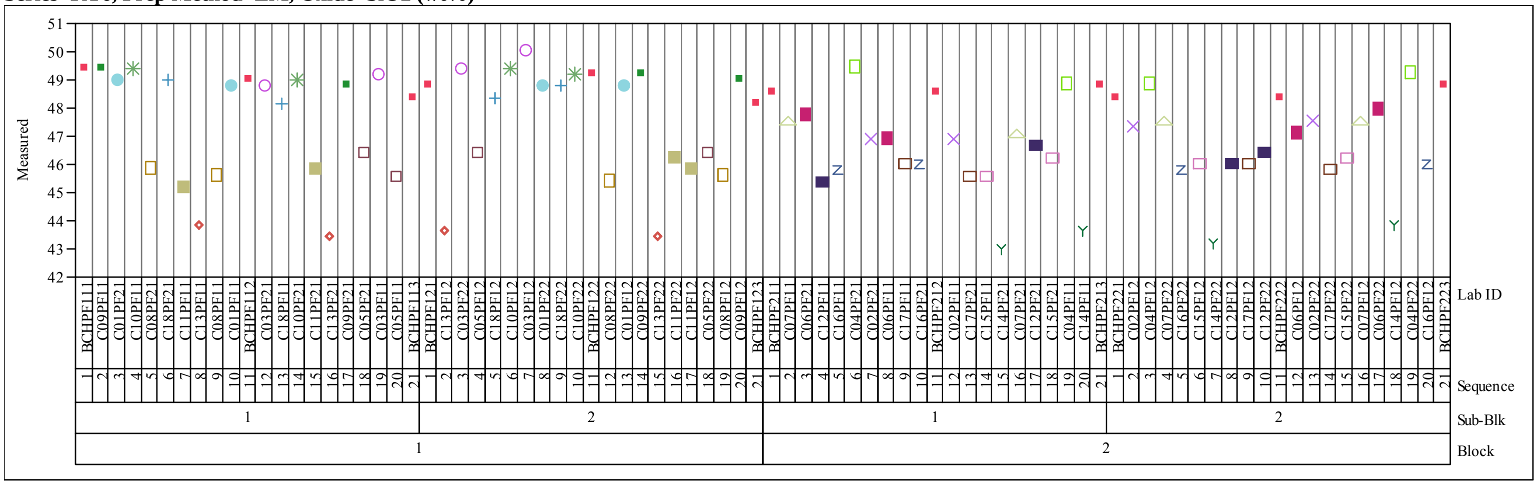


Exhibit A-1. Measurements in Analytical Sequence for the KT06-Series by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=LM, Oxide=SiO2 (wt%)



Series=KT6, Prep Method=PF, Oxide=BaO (wt%)

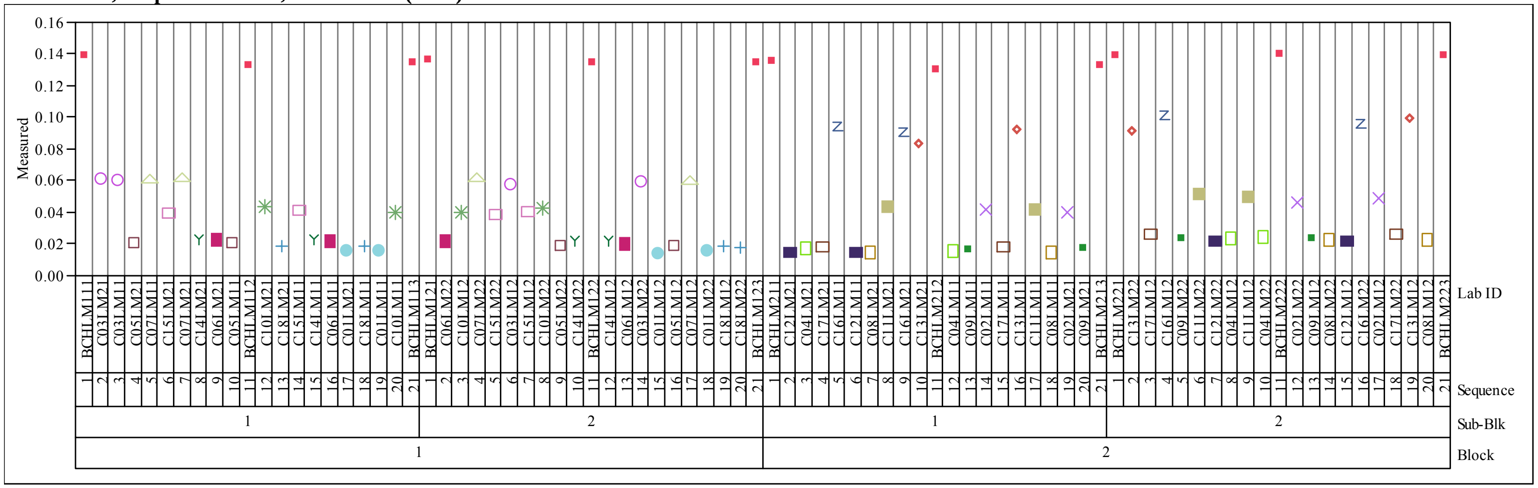
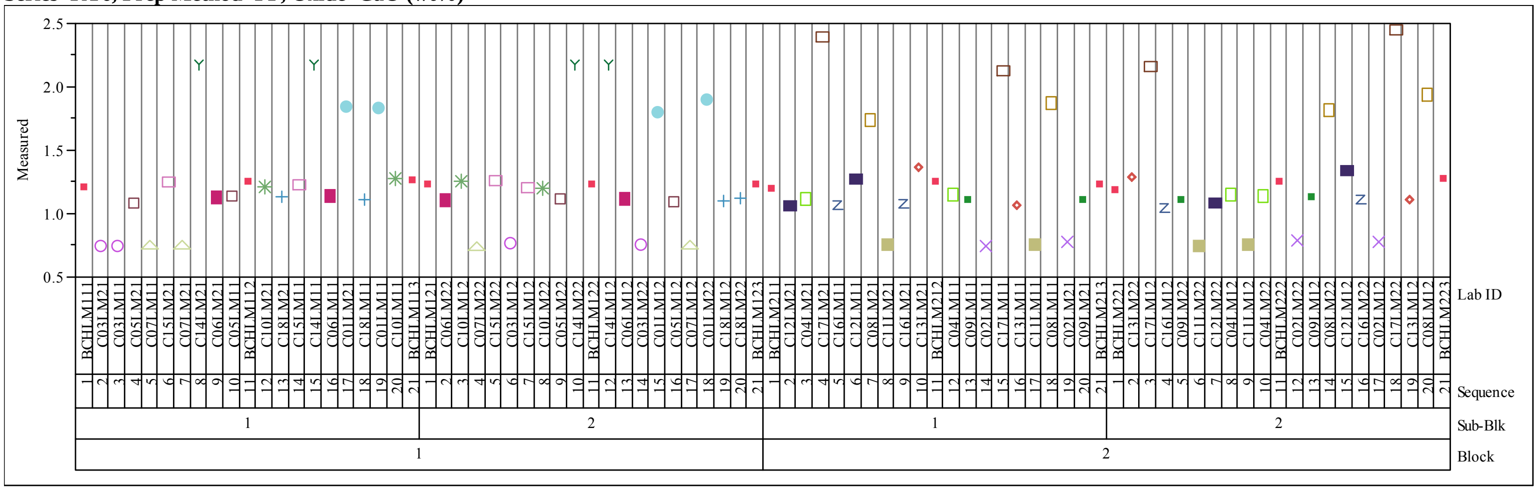


Exhibit A-1. Measurements in Analytical Sequence for the KT06-Series by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=CaO (wt%)



Series=KT6, Prep Method=PF, Oxide=Ce2O3 (wt%)

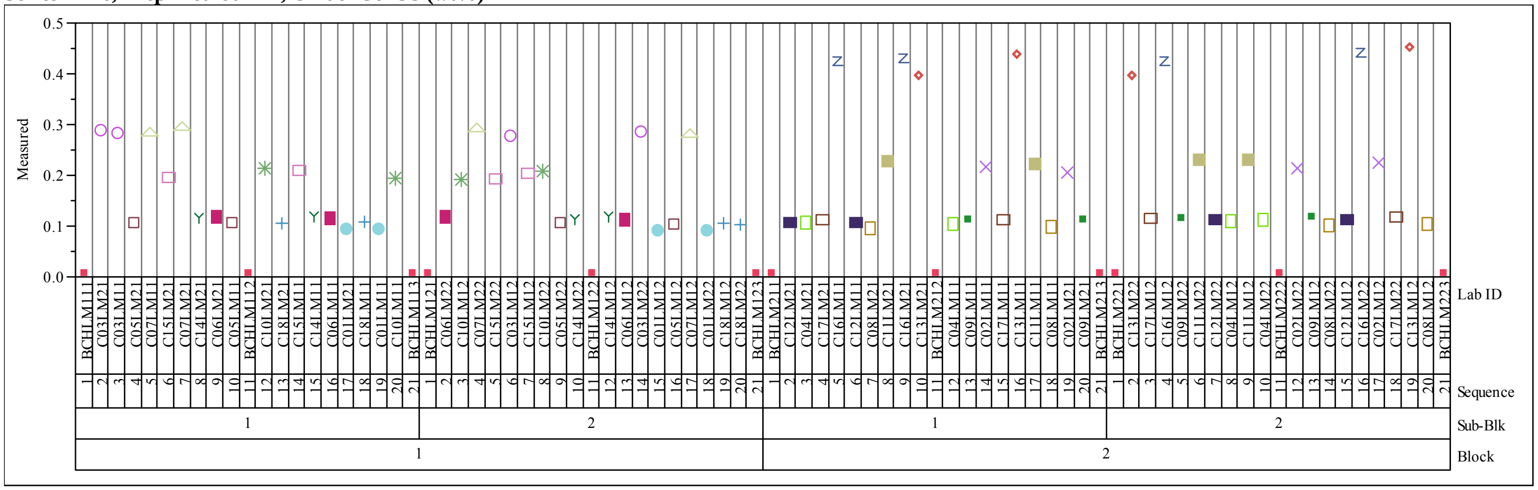
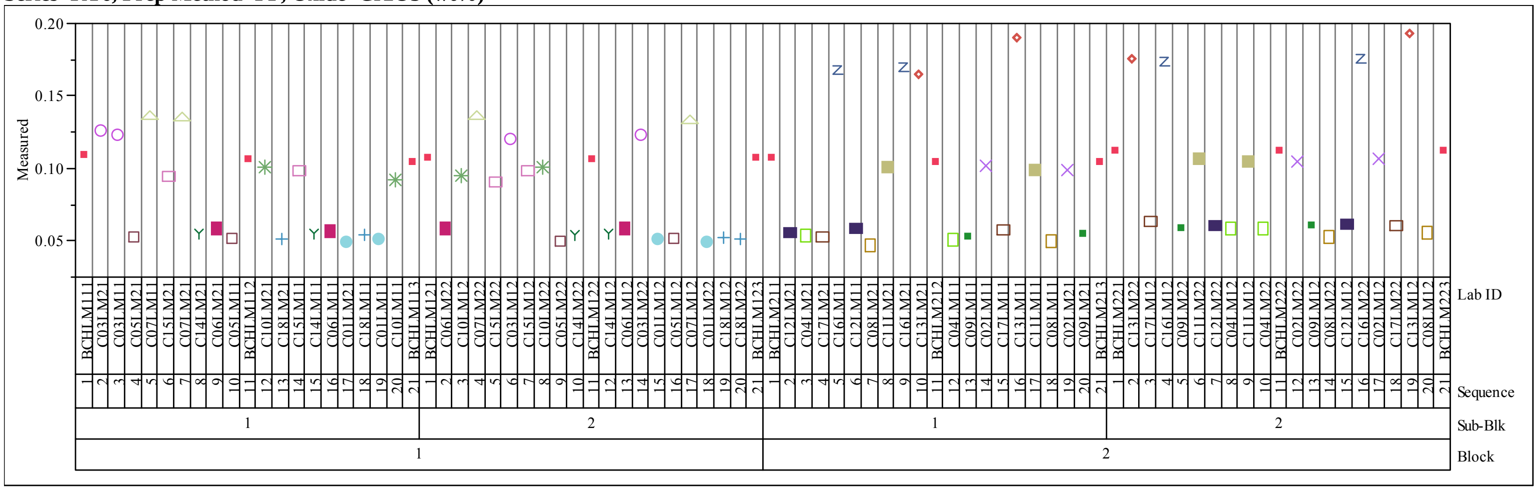


Exhibit A-1. Measurements in Analytical Sequence for the KT06-Series by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=Cr2O3 (wt%)



Series=KT6, Prep Method=PF, Oxide=CuO (wt%)

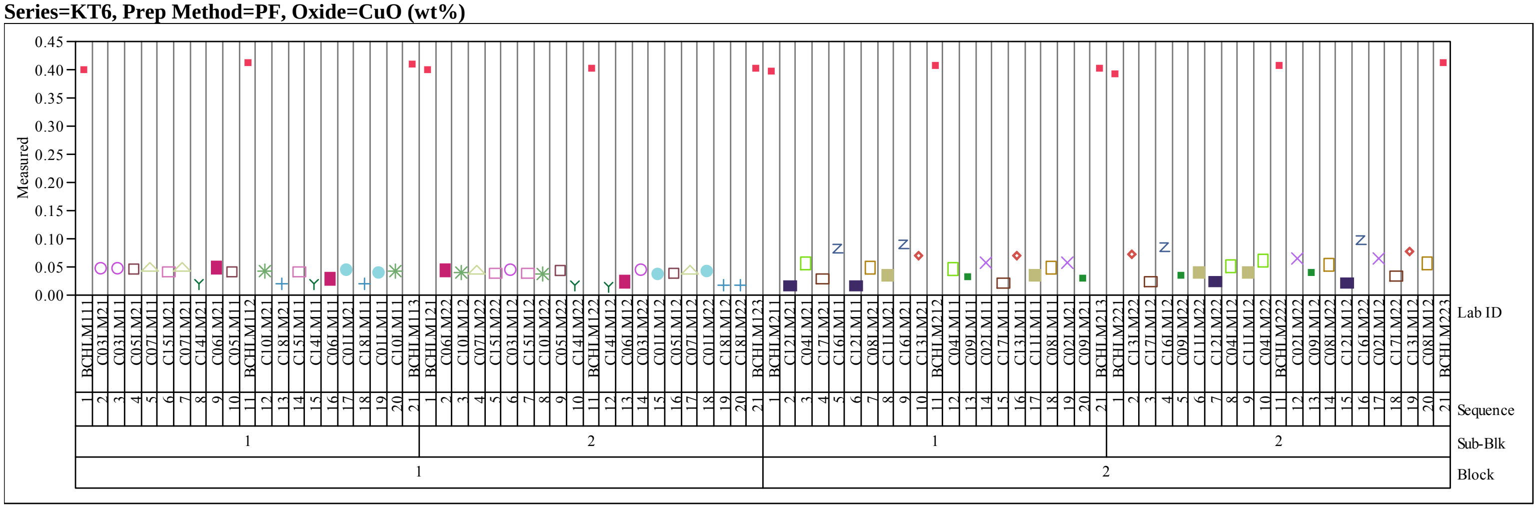
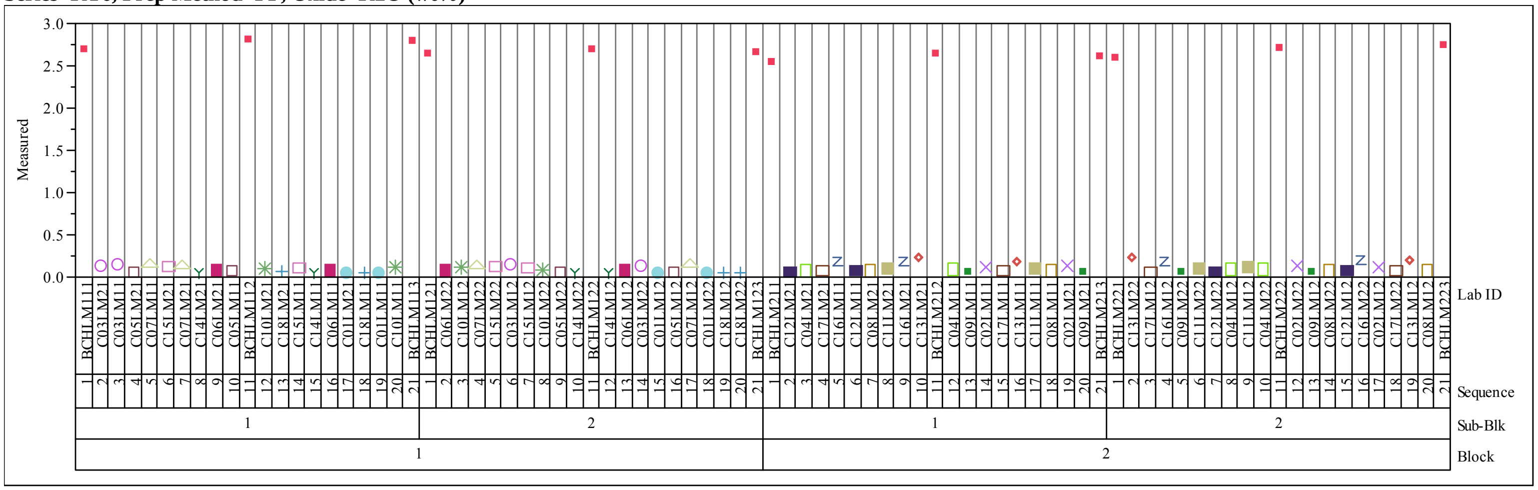


Exhibit A-1. Measurements in Analytical Sequence for the KT06-Series by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=K2O (wt%)



Series=KT6, Prep Method=PF, Oxide=La2O3 (wt%)

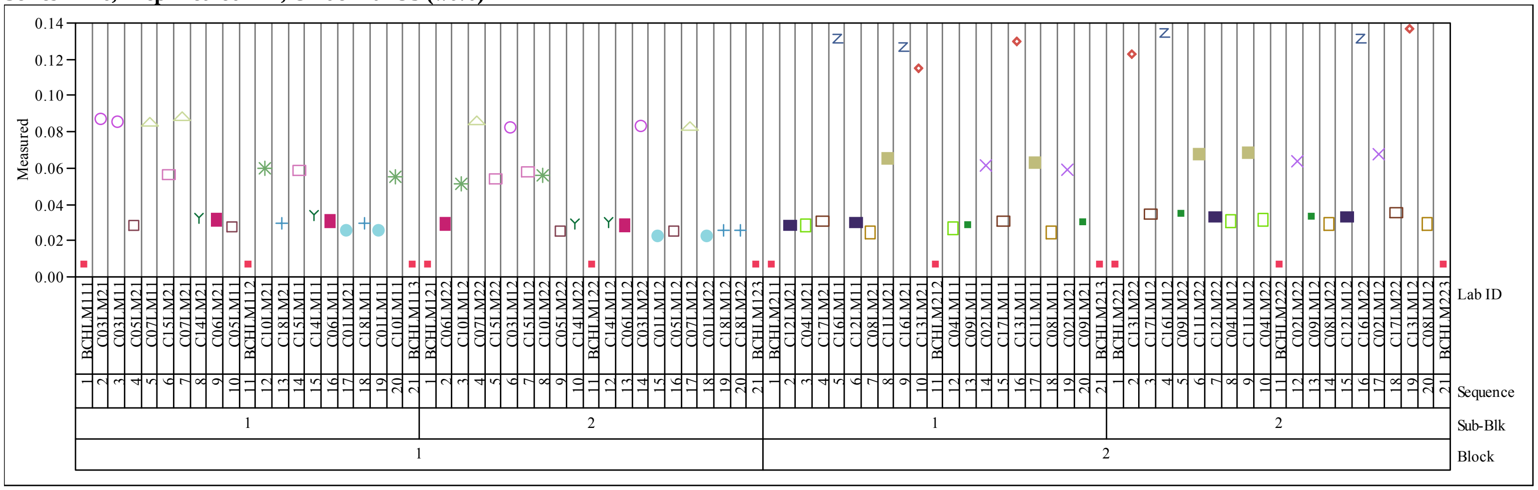
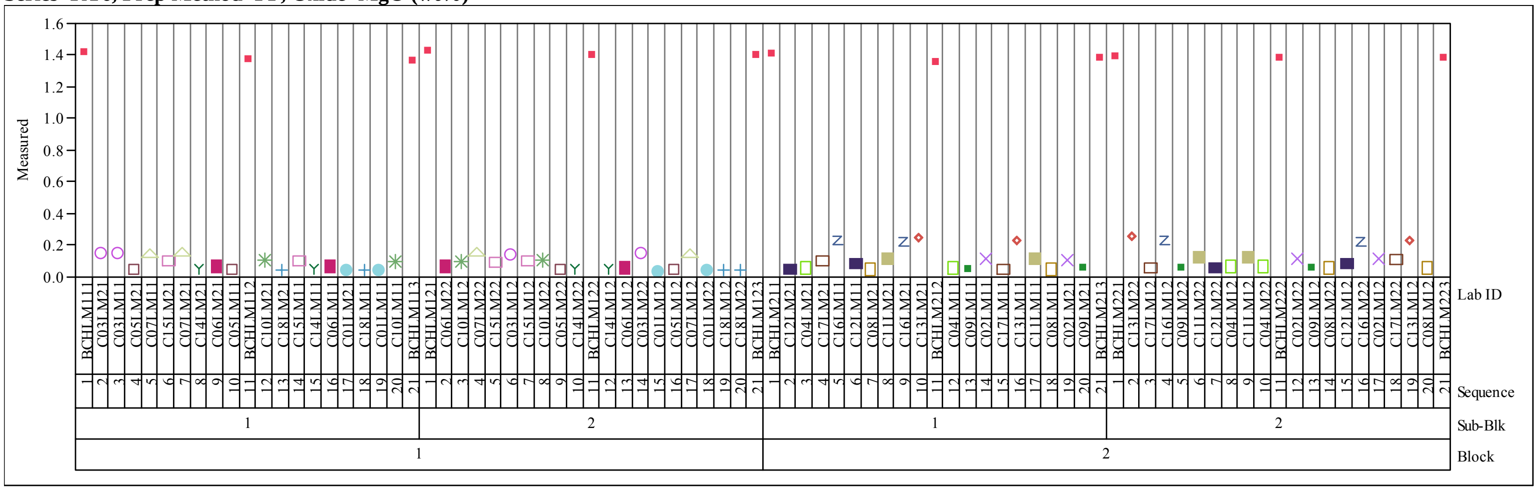


Exhibit A-1. Measurements in Analytical Sequence for the KT06-Series by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=MgO (wt%)



Series=KT6, Prep Method=PF, Oxide=MnO (wt%)

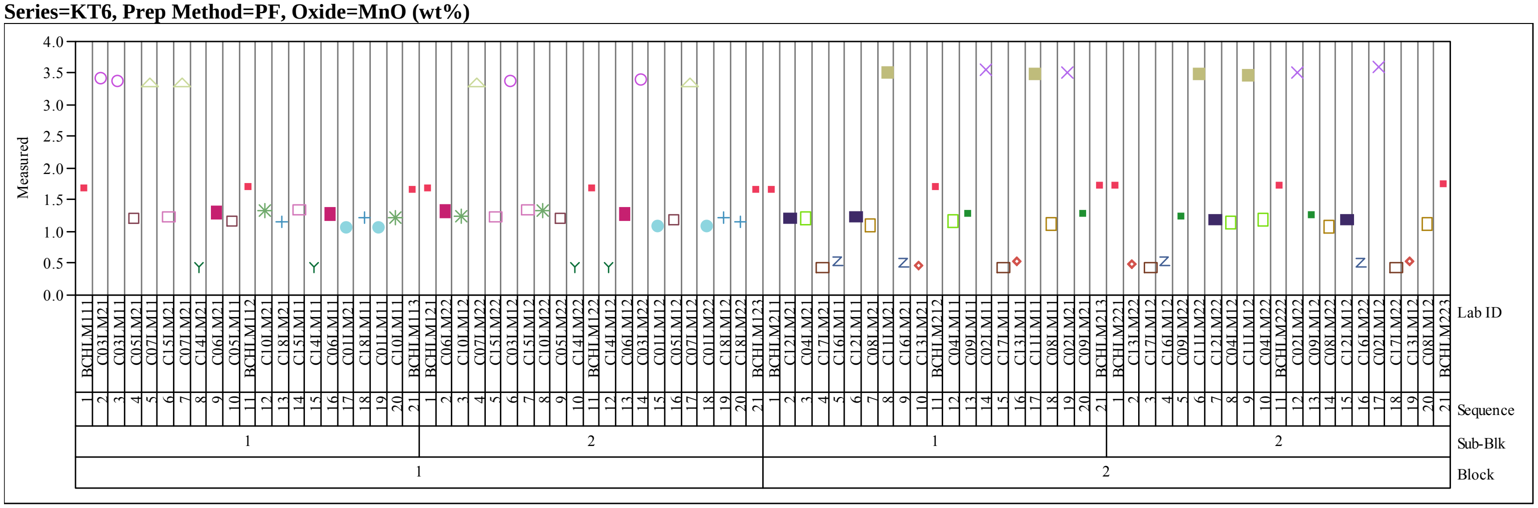
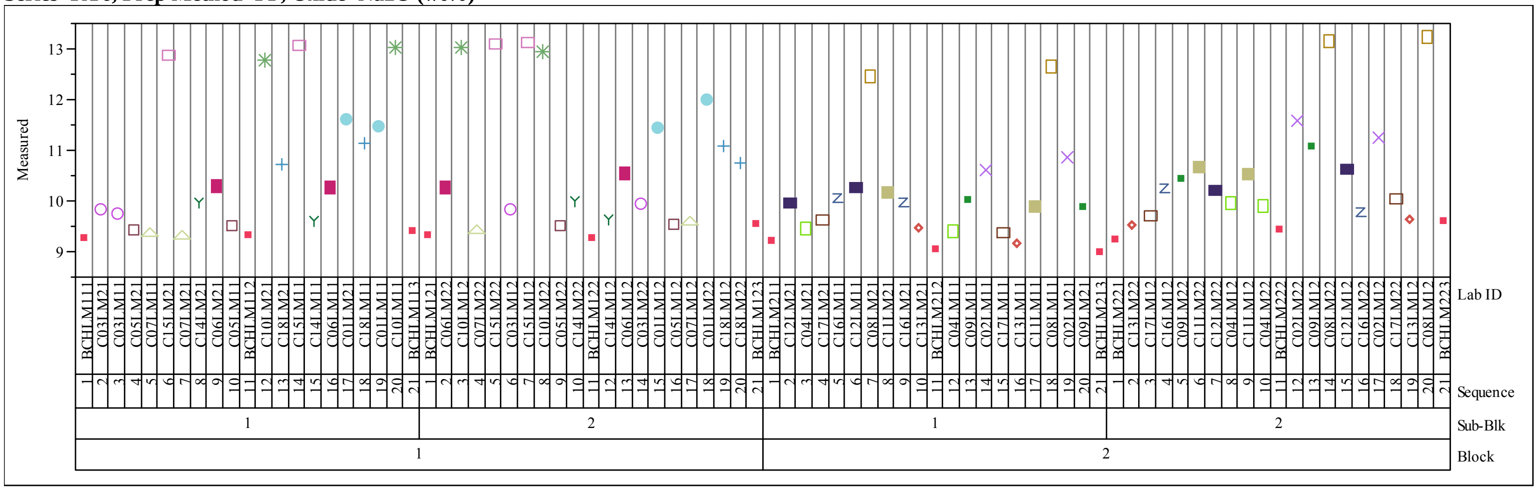


Exhibit A-1. Measurements in Analytical Sequence for the KT06-Series by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=Na2O (wt%)



Series=KT6, Prep Method=PF, Oxide=Nb2O5 (wt%)

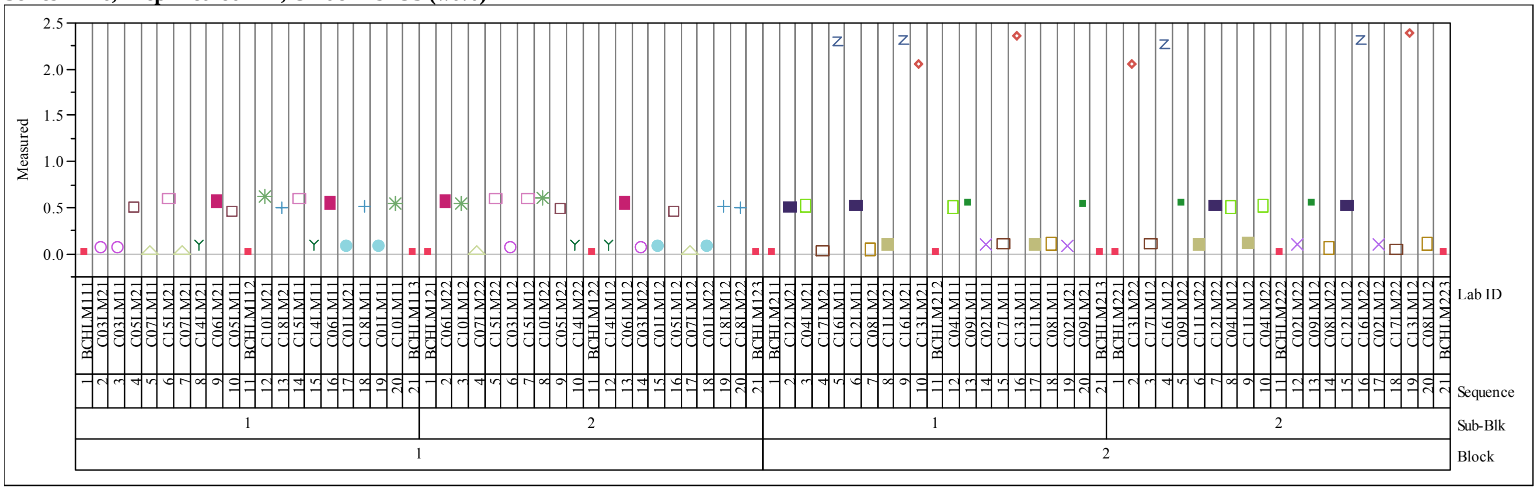
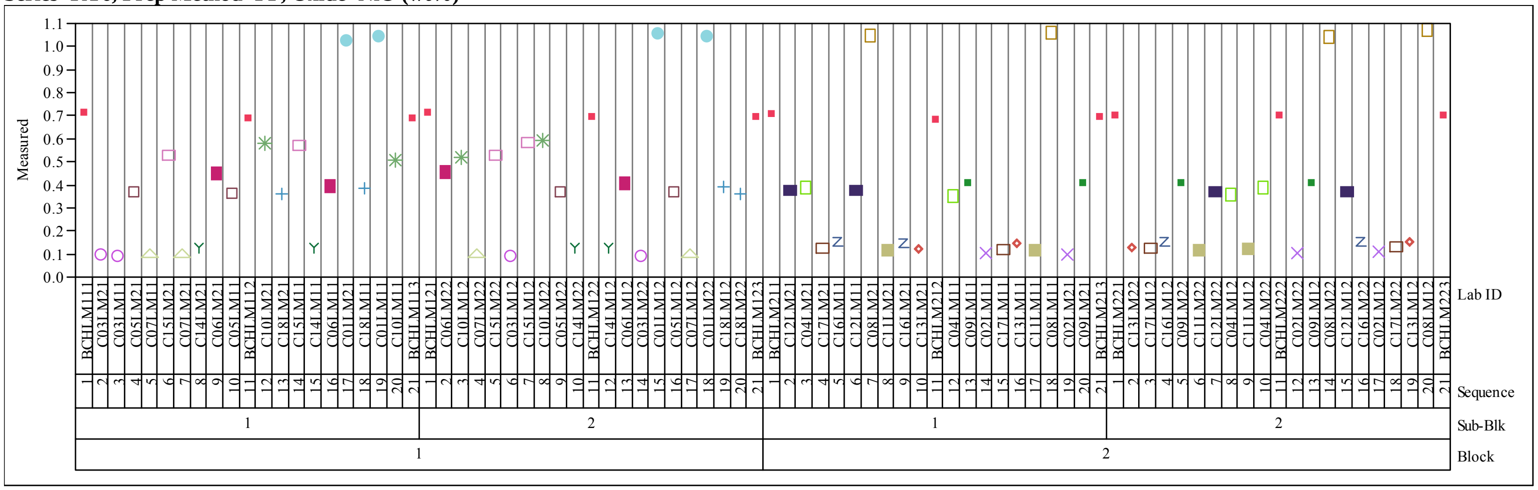


Exhibit A-1. Measurements in Analytical Sequence for the KT06-Series by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=NiO (wt%)



Series=KT6, Prep Method=PF, Oxide=PbO (wt%)

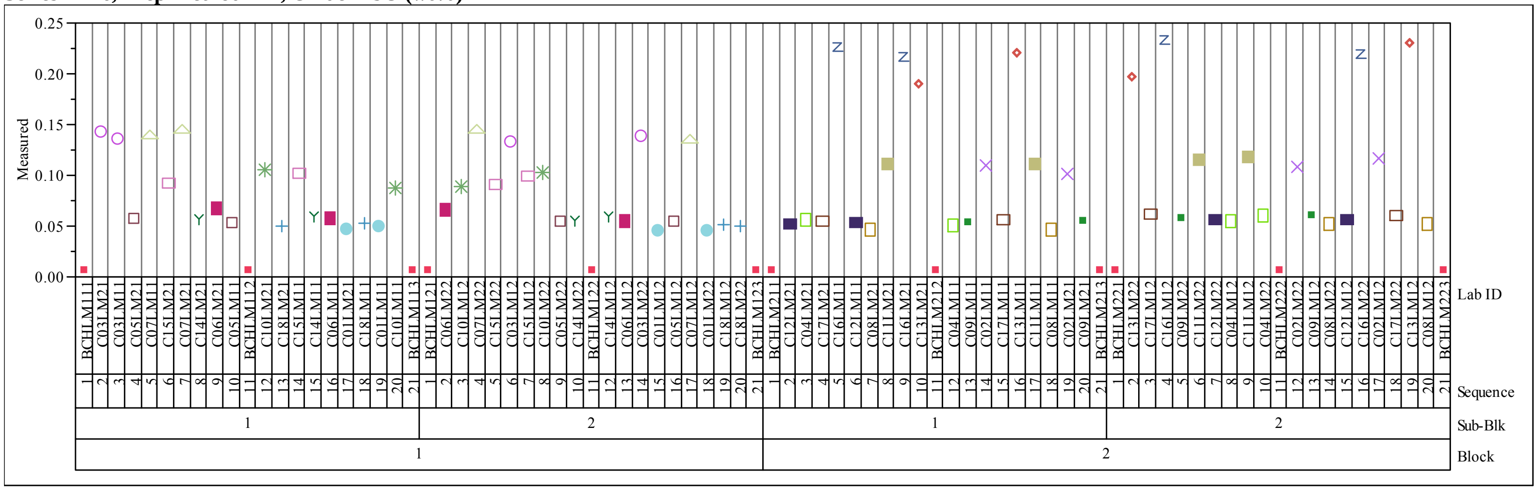
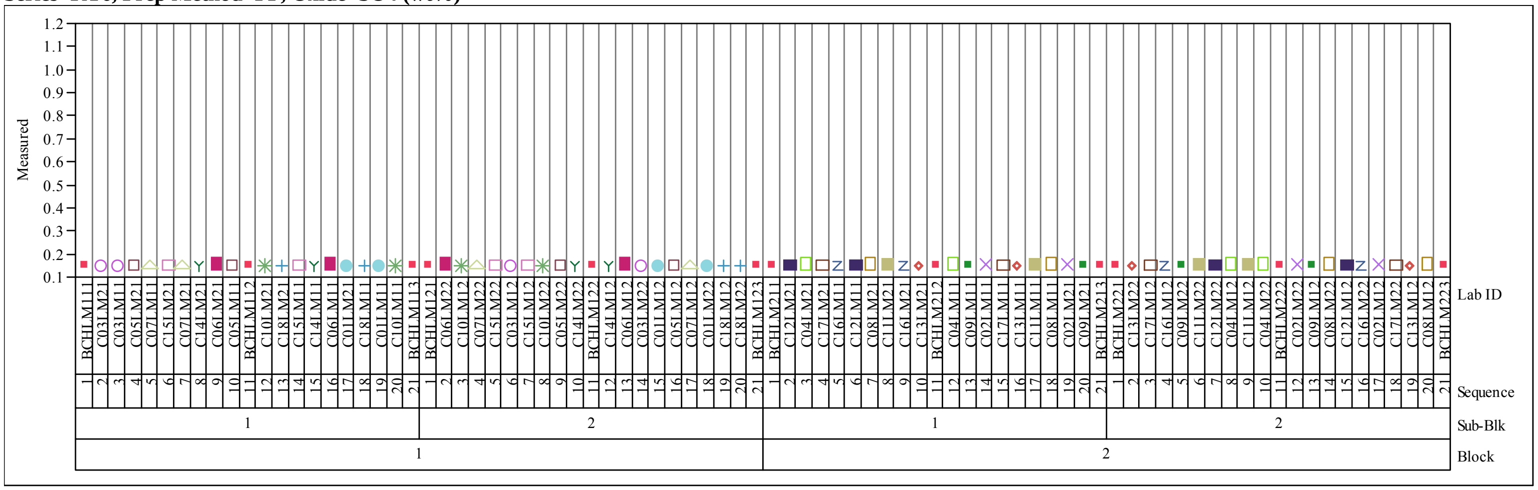


Exhibit A-1. Measurements in Analytical Sequence for the KT06-Series by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=SO4 (wt%)



Series=KT6, Prep Method=PF, Oxide=TiO2 (wt%)

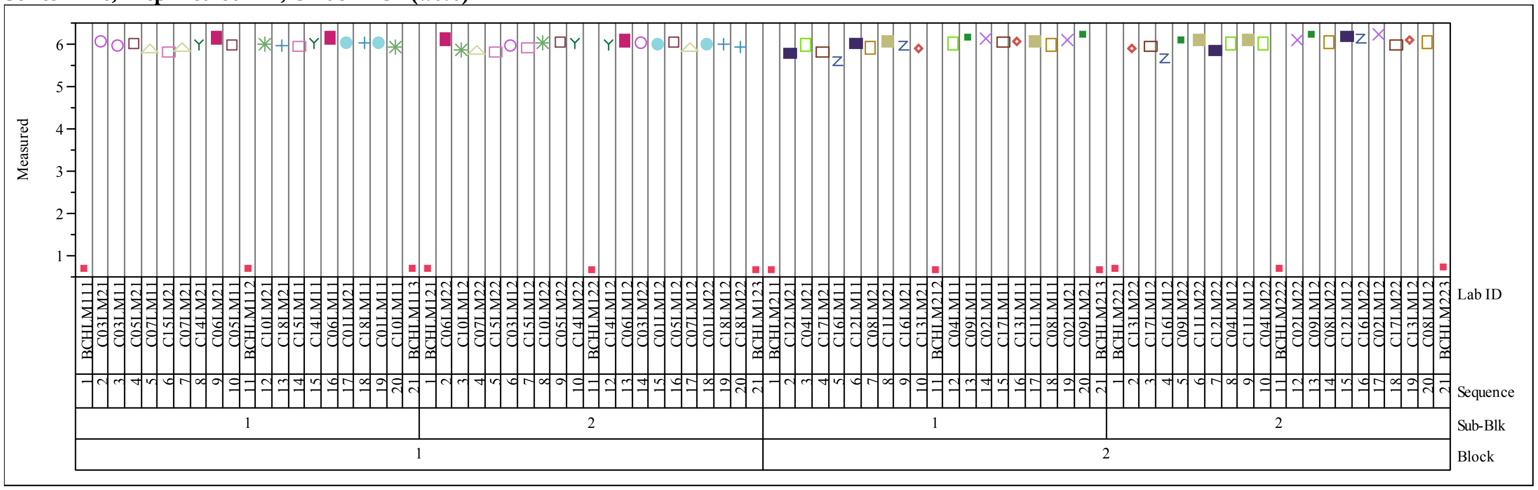
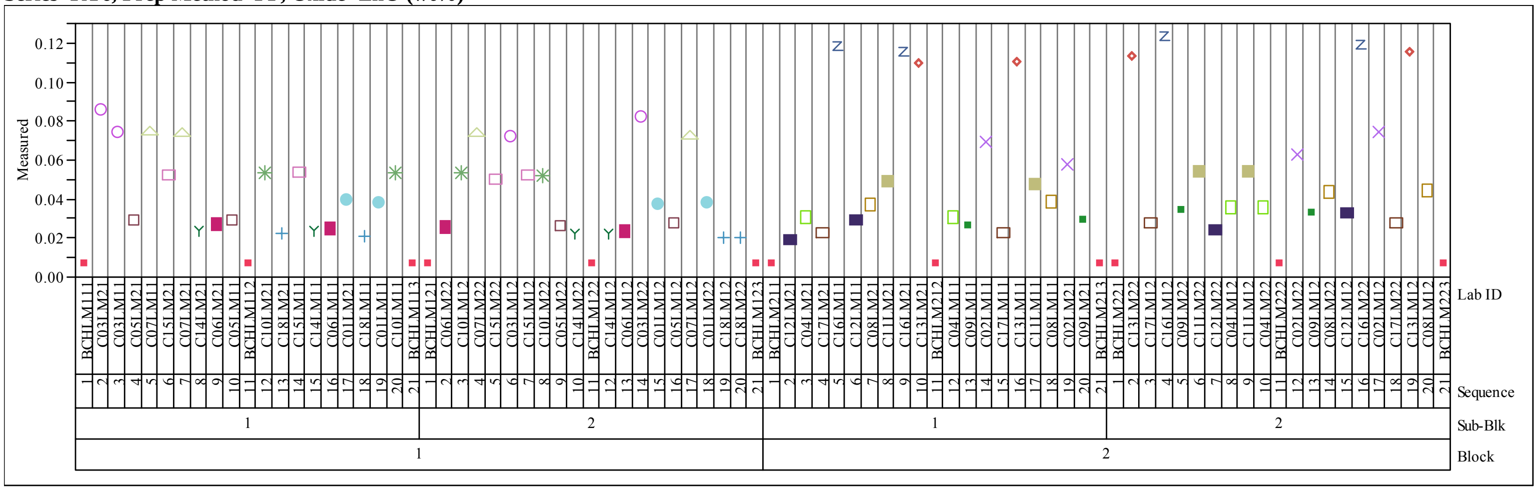


Exhibit A-1. Measurements in Analytical Sequence for the KT06-Series by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=ZnO (wt%)



Series=KT6, Prep Method=PF, Oxide=ZrO2 (wt%)

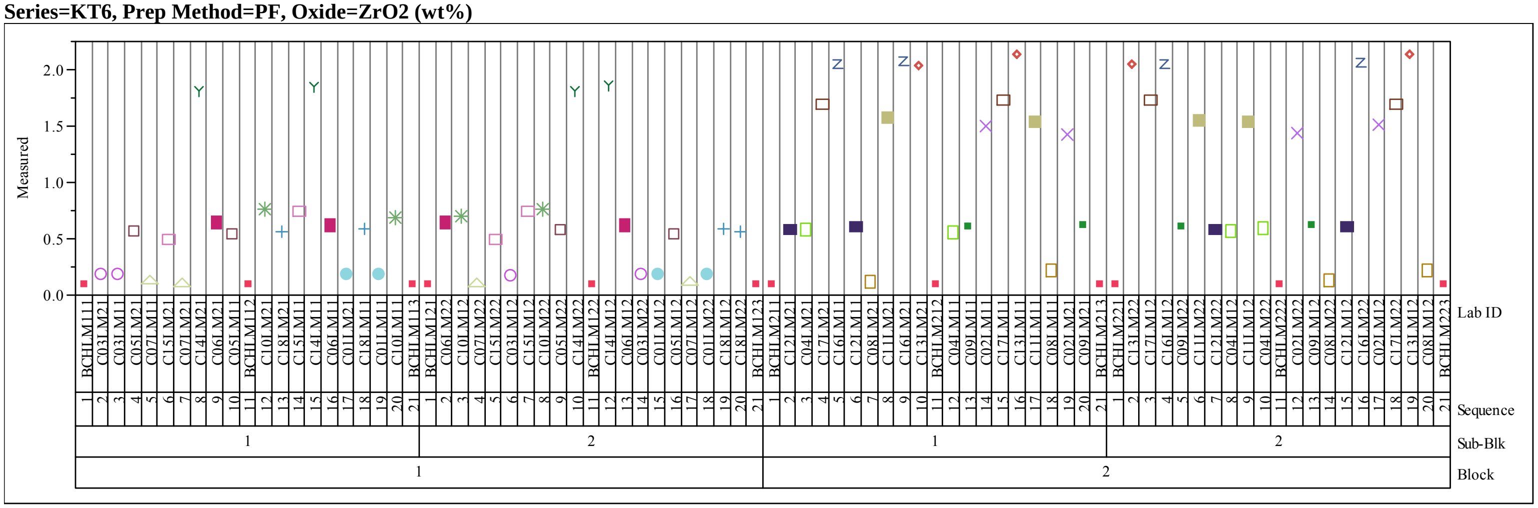
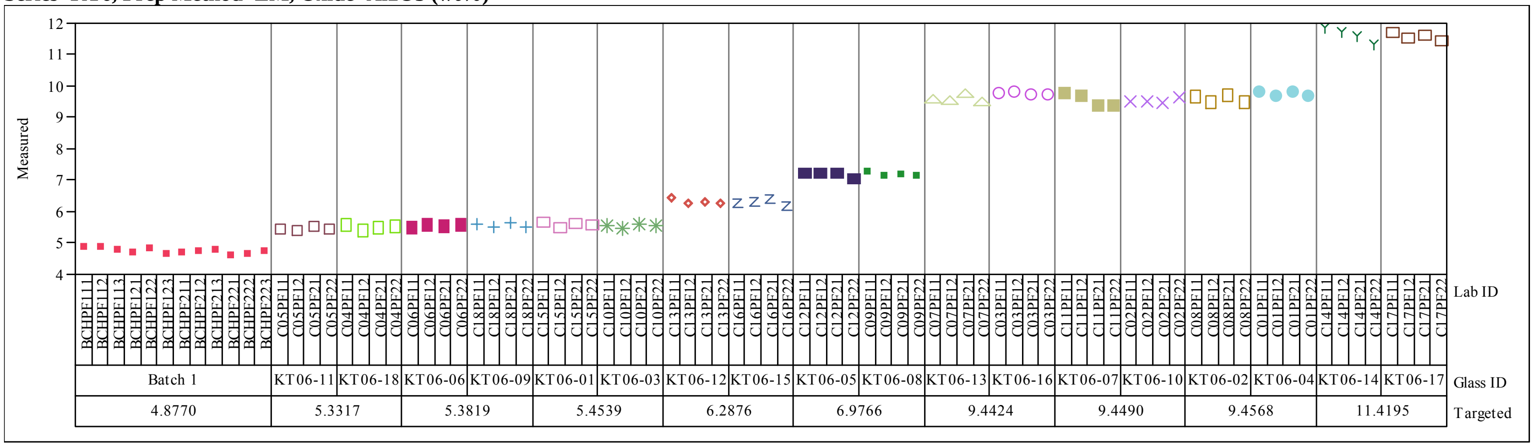


Exhibit A-2. Measurements for Each KT6-Series Glass ID by Preparation Method by Oxide.

Series=KT6, Prep Method=LM, Oxide=Al2O3 (wt%)



Series=KT6, Prep Method=LM, Oxide=B2O3 (wt%)

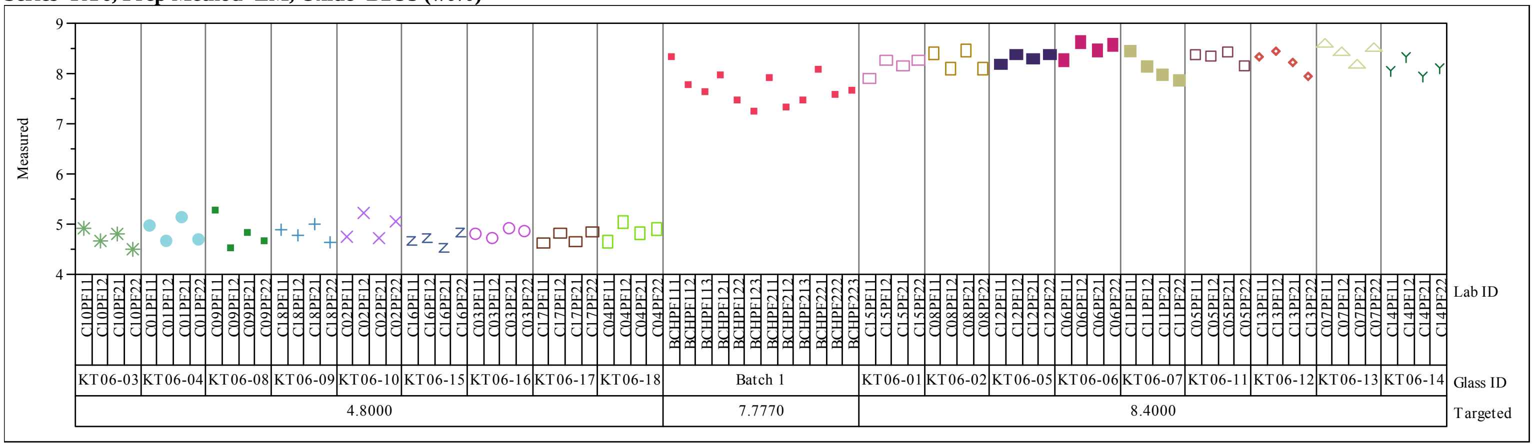
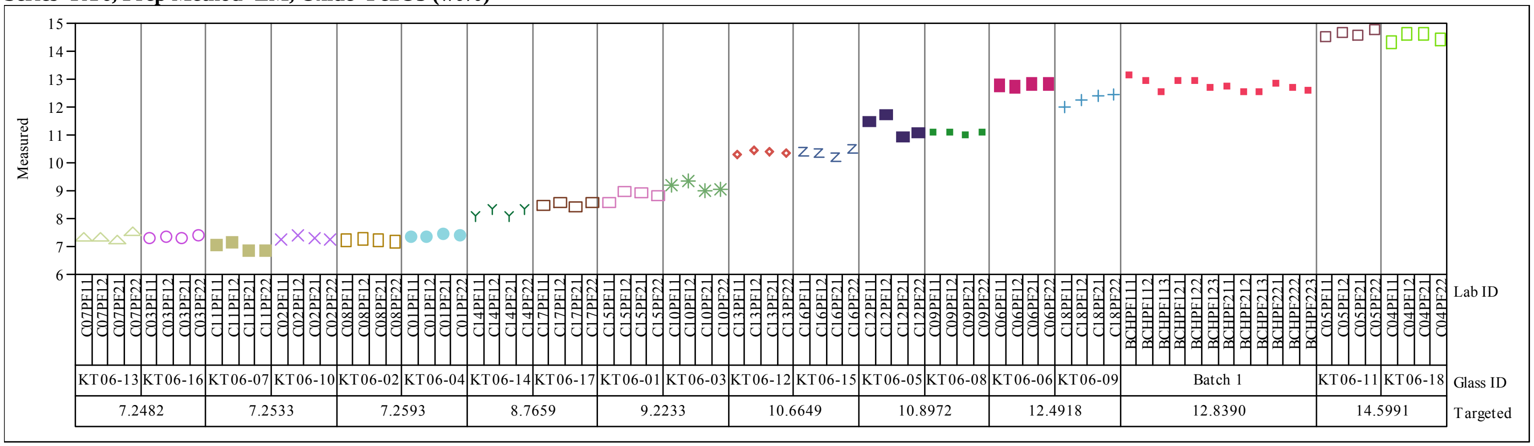


Exhibit A-2. Measurements for Each KT6-Series Glass ID by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=LM, Oxide=Fe2O3 (wt%)



Series=KT6, Prep Method=LM, Oxide=Li2O (wt%)

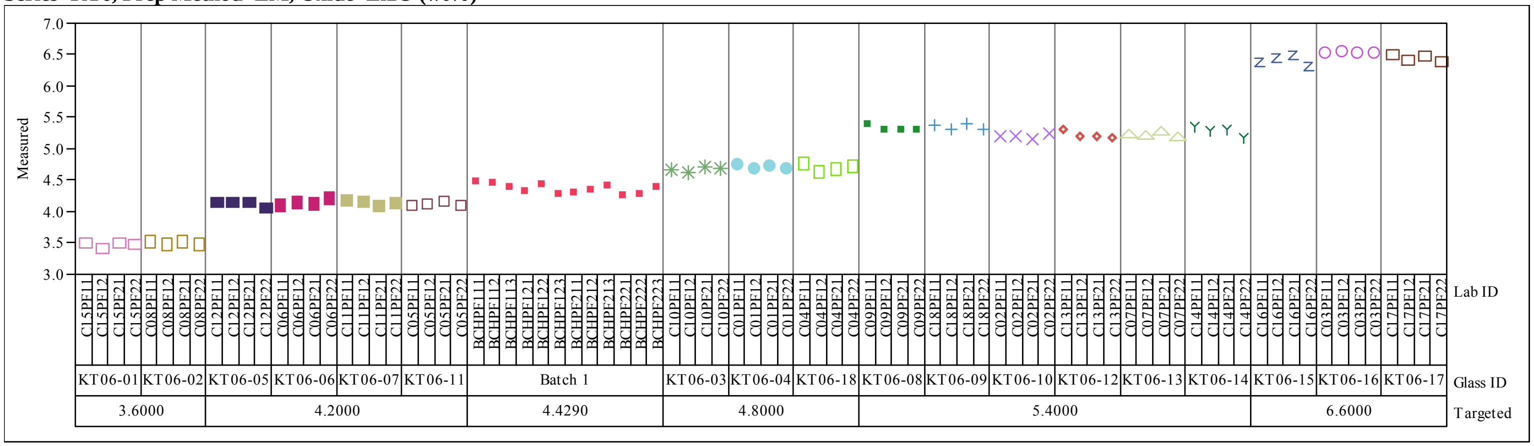
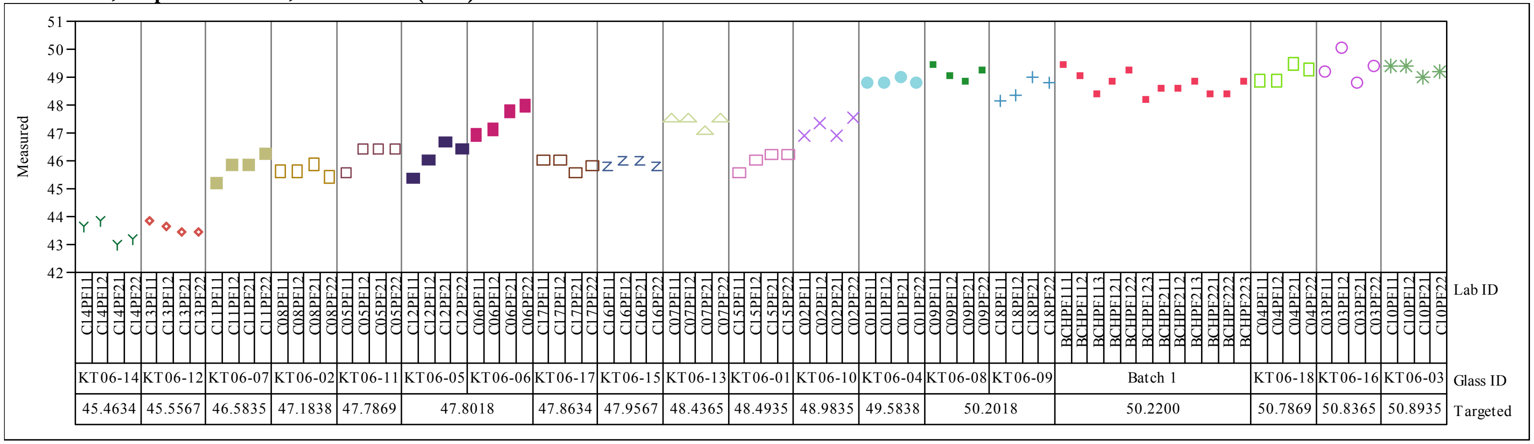


Exhibit A-2. Measurements for Each KT6-Series Glass ID by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=LM, Oxide=SiO2 (wt%)



Series=KT6, Prep Method=PF, Oxide=BaO (wt%)

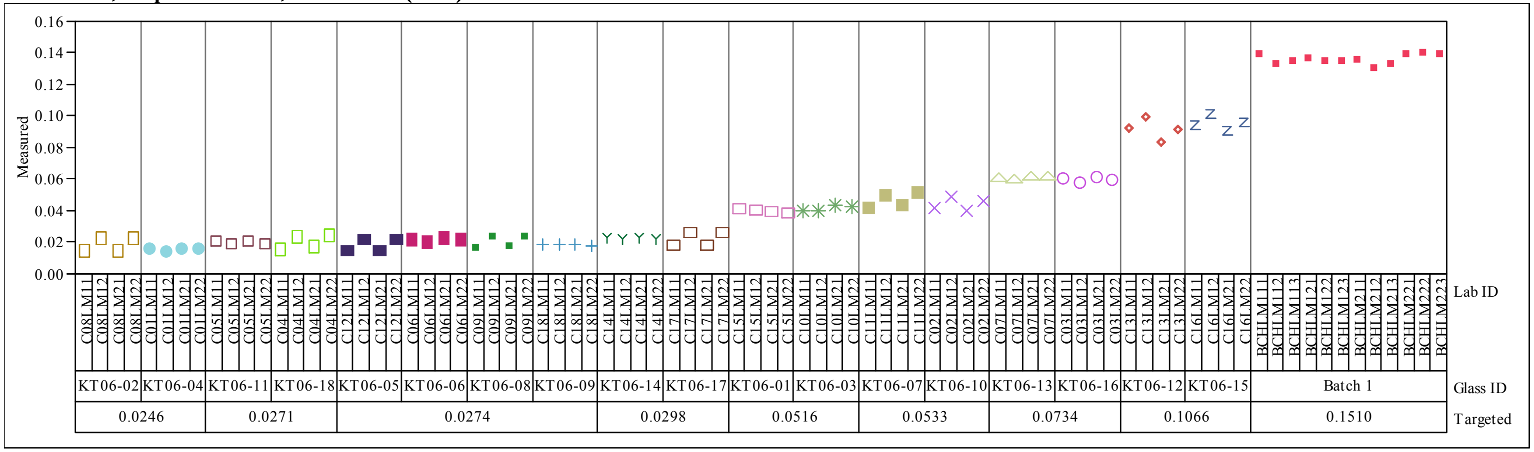
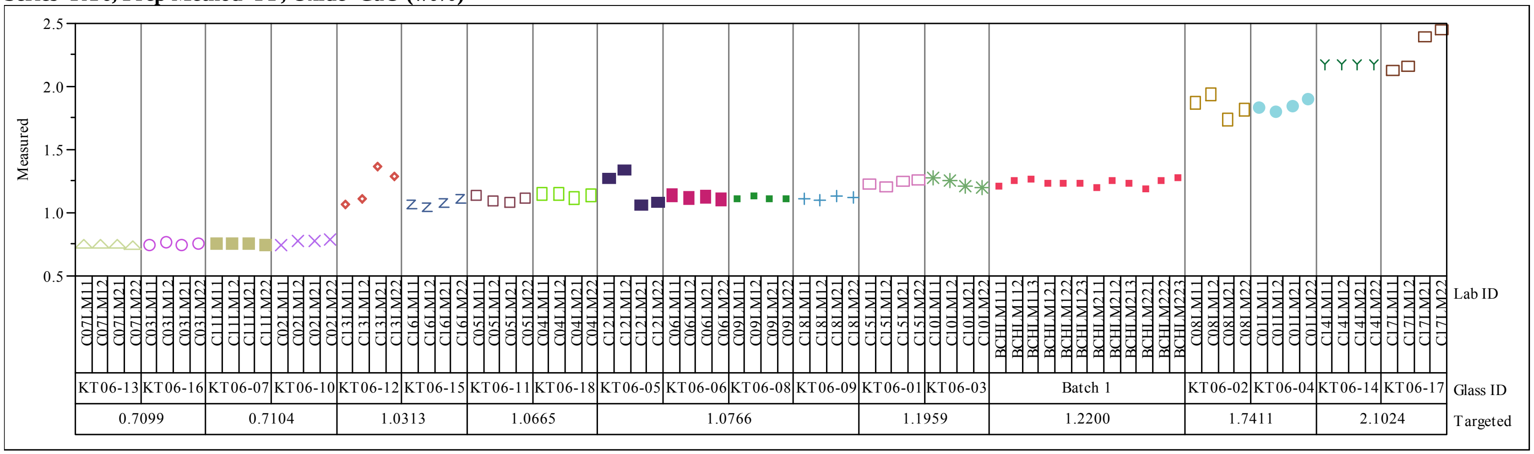


Exhibit A-2. Measurements for Each KT6-Series Glass ID by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=CaO (wt%)



Series=KT6, Prep Method=PF, Oxide=Ce2O3 (wt%)

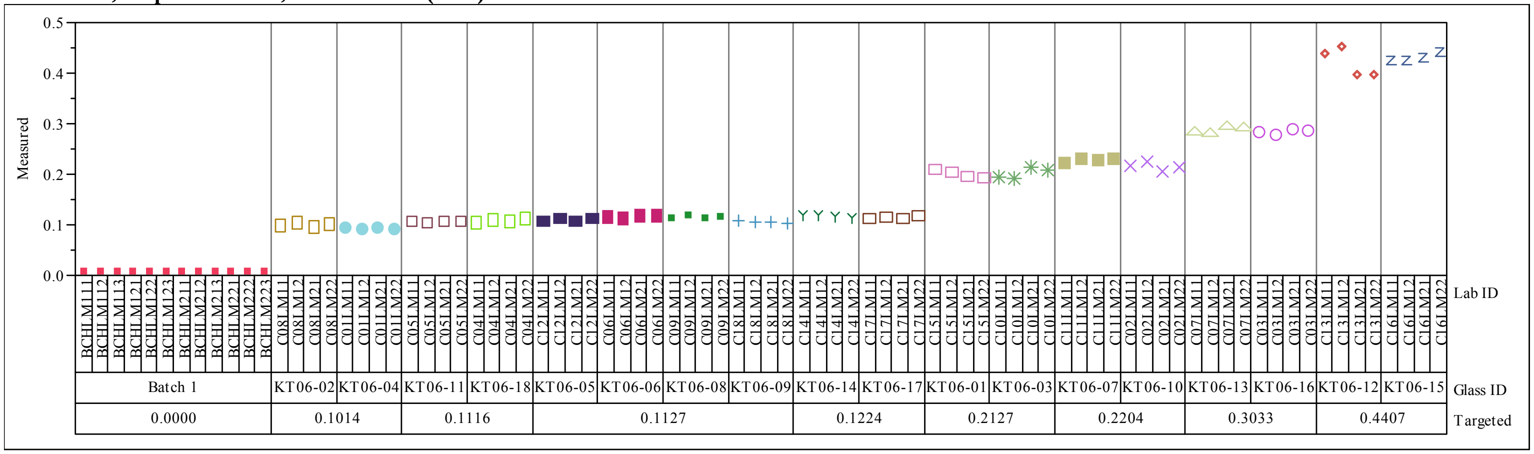
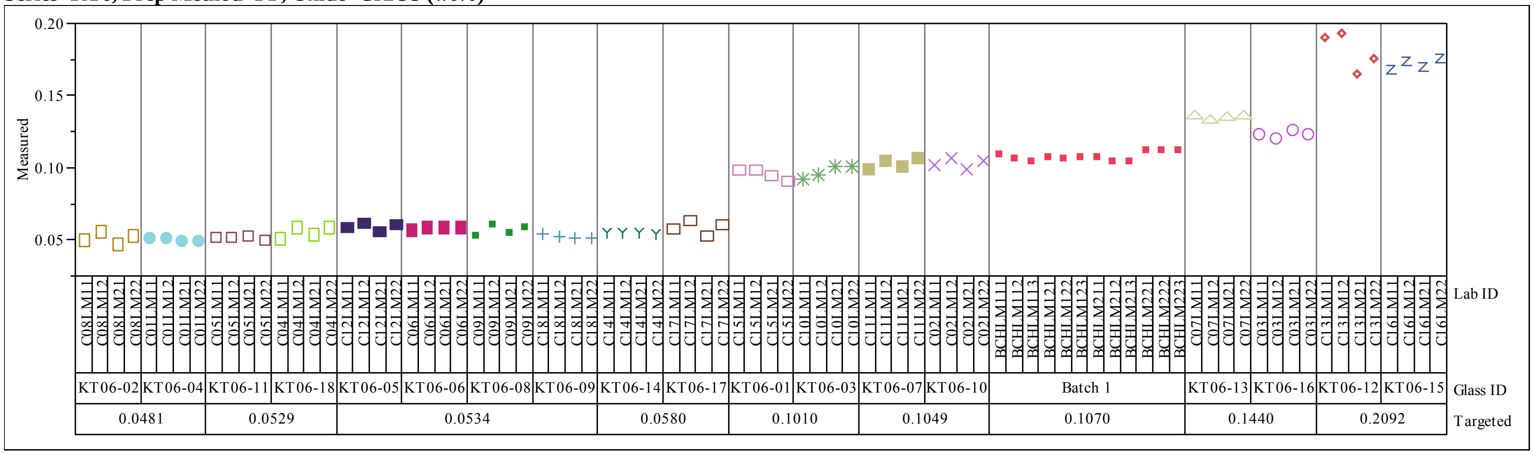


Exhibit A-2. Measurements for Each KT6-Series Glass ID by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=Cr2O3 (wt%)



Series=KT6, Prep Method=PF, Oxide=CuO (wt%)

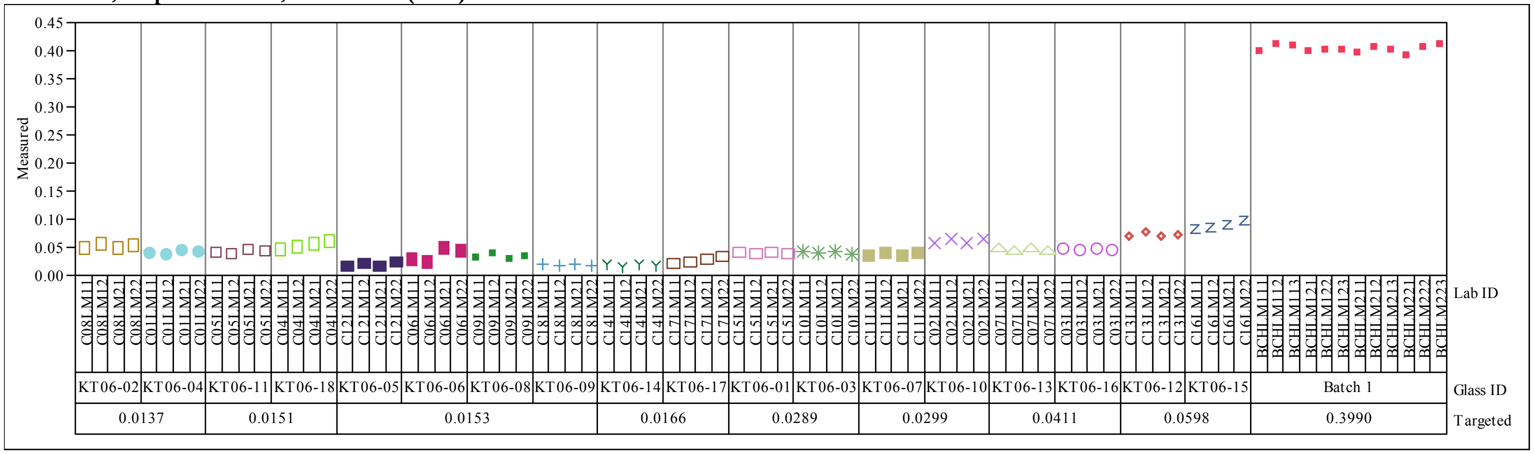
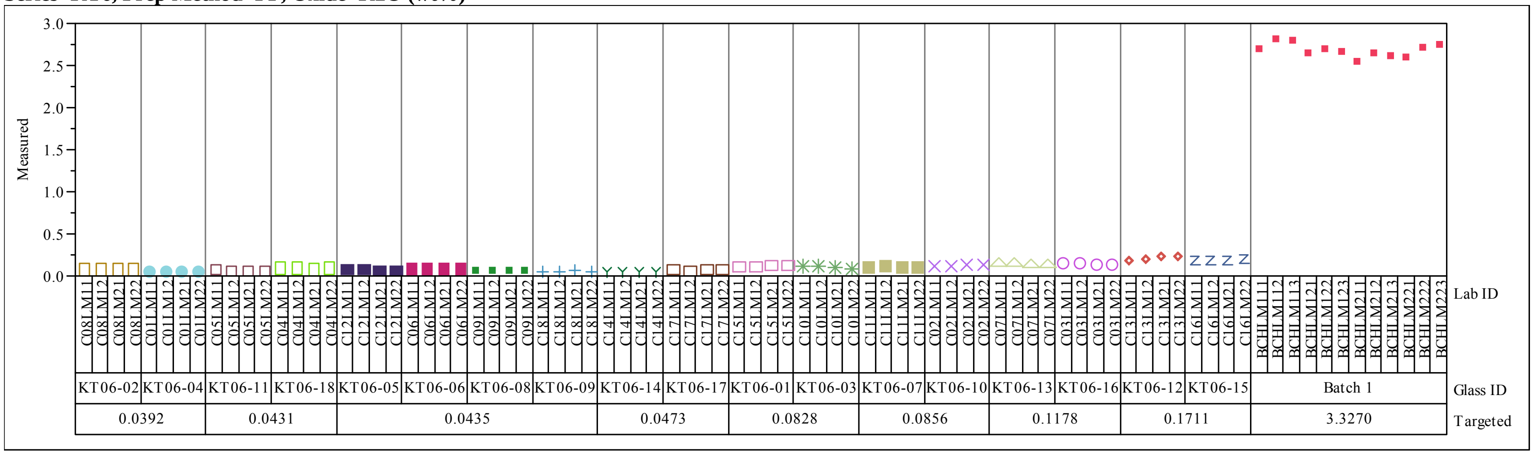


Exhibit A-2. Measurements for Each KT6-Series Glass ID by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=K2O (wt%)



Series=KT6, Prep Method=PF, Oxide=La2O3 (wt%)

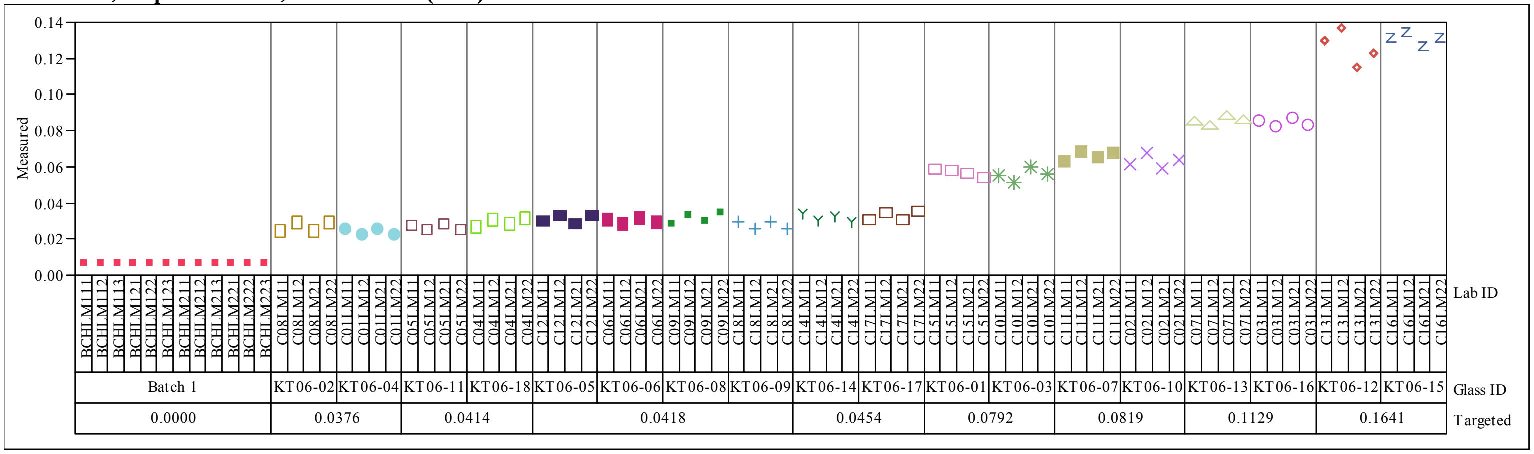
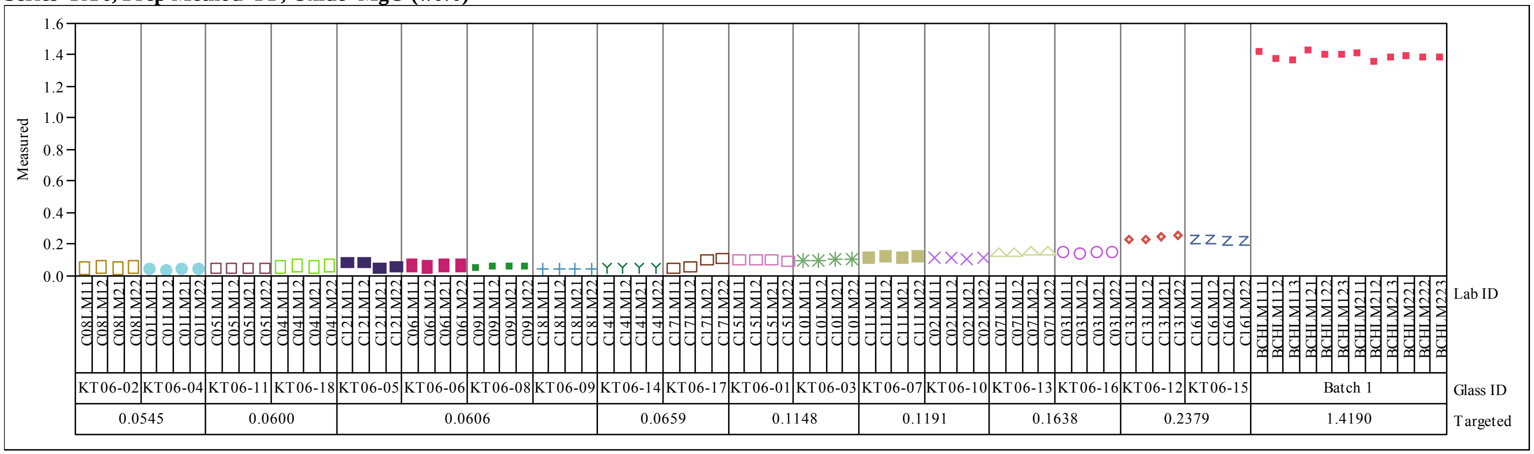


Exhibit A-2. Measurements for Each KT6-Series Glass ID by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=MgO (wt%)



Series=KT6, Prep Method=PF, Oxide=MnO (wt%)

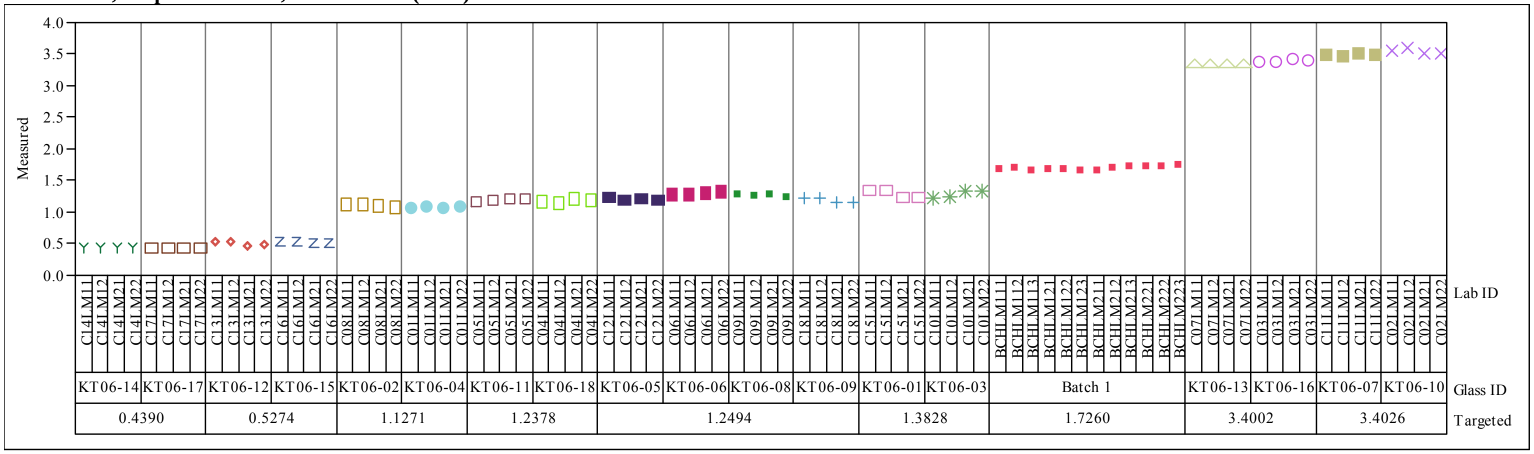
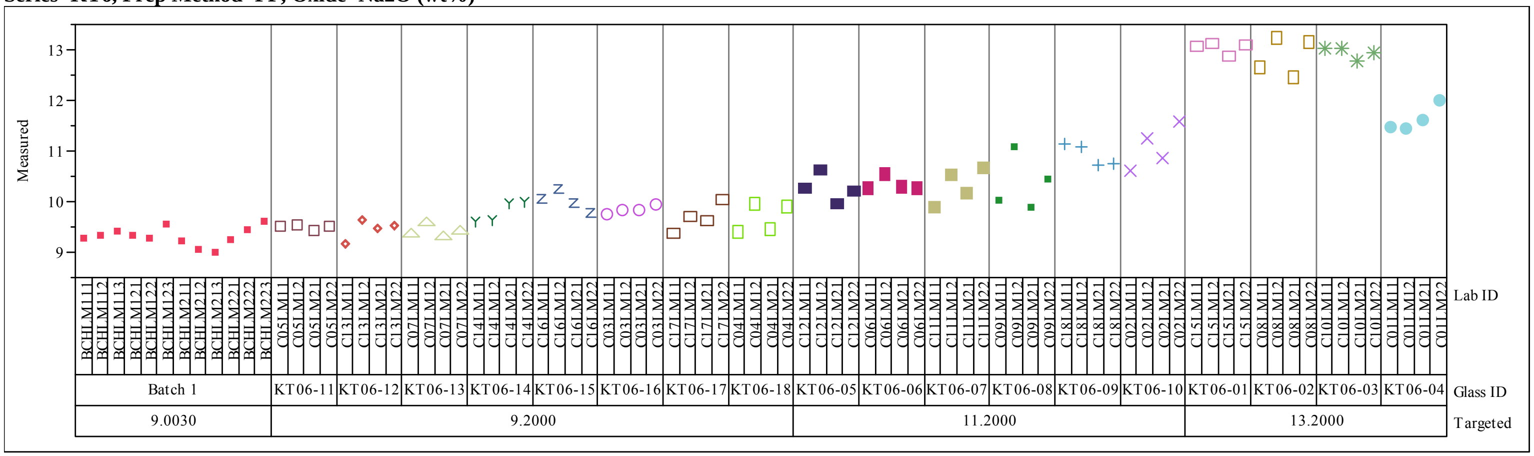


Exhibit A-2. Measurements for Each KT6-Series Glass ID by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=Na2O (wt%)



Series=KT6, Prep Method=PF, Oxide=Nb2O5 (wt%)

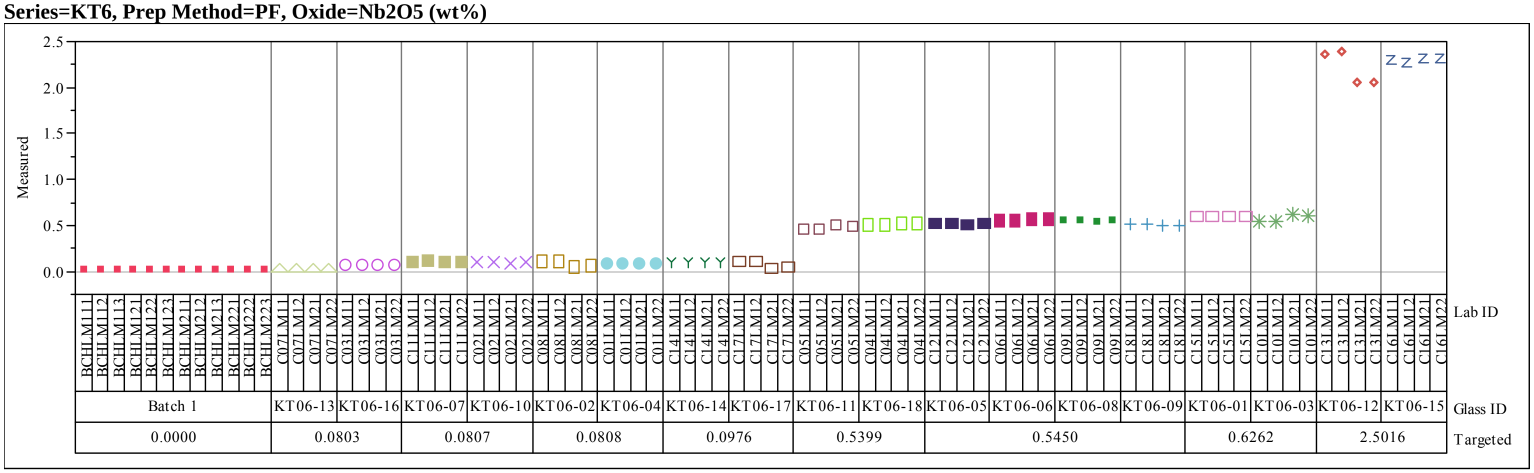
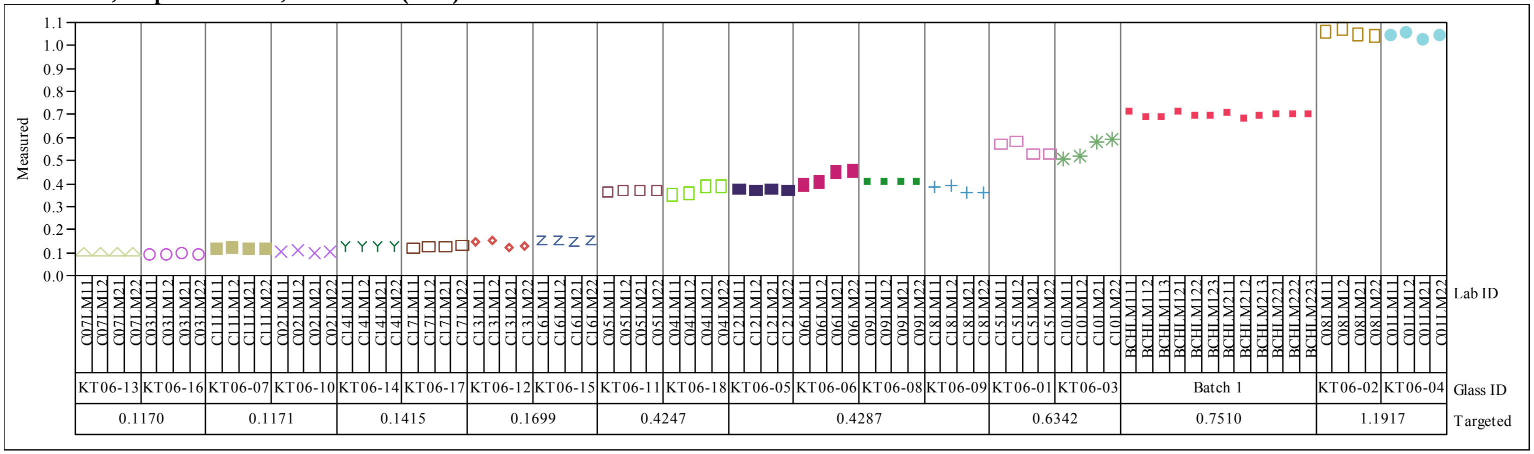


Exhibit A-2. Measurements for Each KT6-Series Glass ID by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=NiO (wt%)



Series=KT6, Prep Method=PF, Oxide=PbO (wt%)

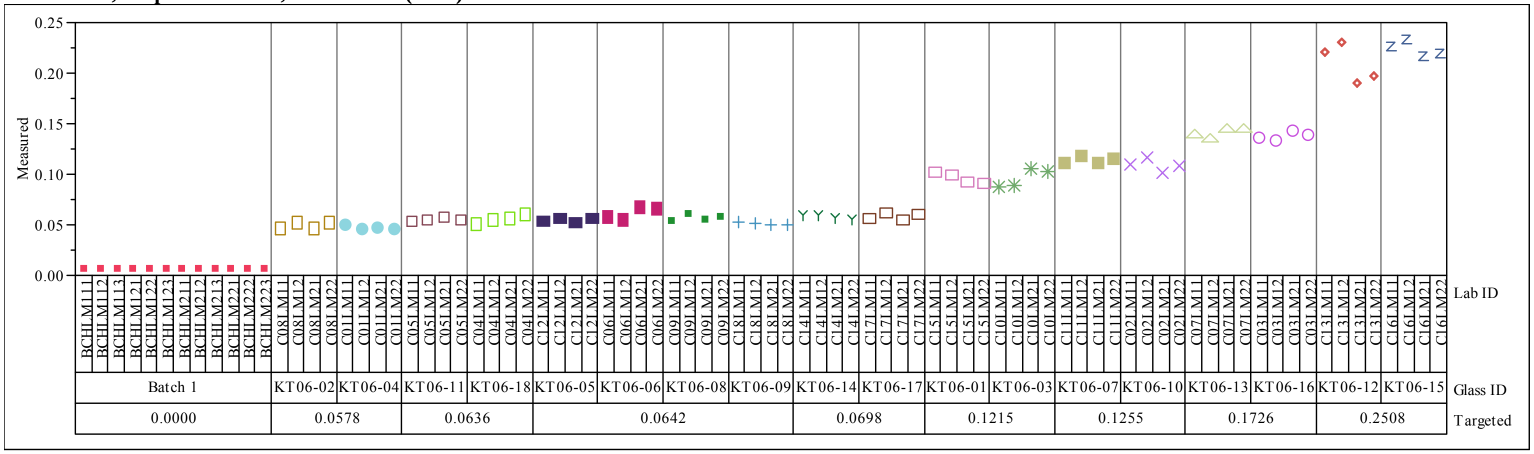
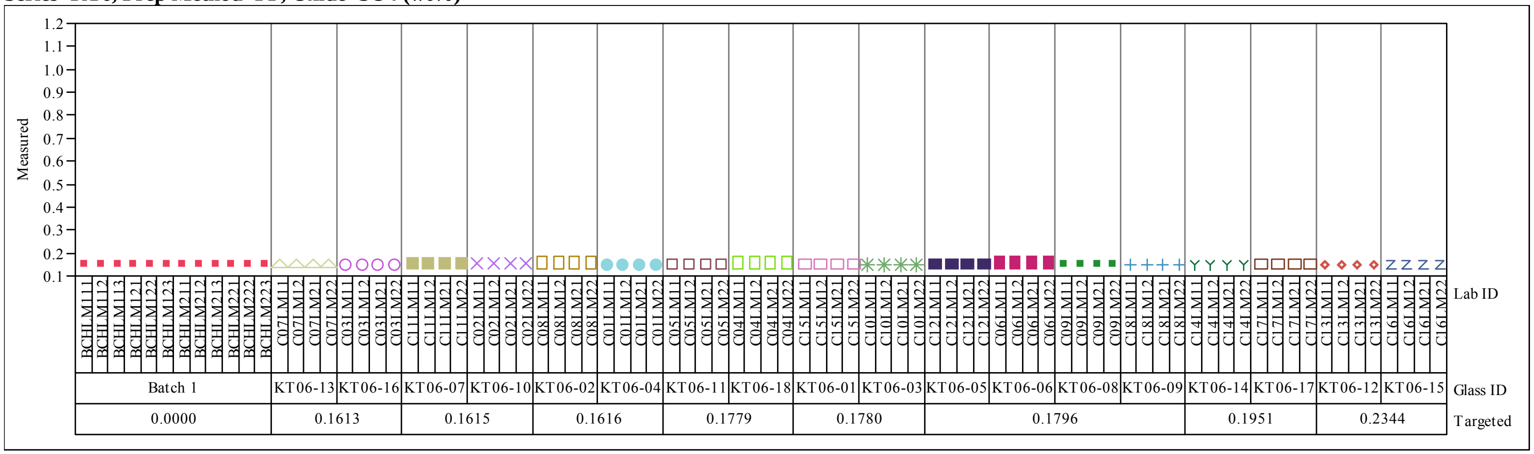


Exhibit A-2. Measurements for Each KT6-Series Glass ID by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=SO4 (wt%)



Series=KT6, Prep Method=PF, Oxide=TiO2 (wt%)

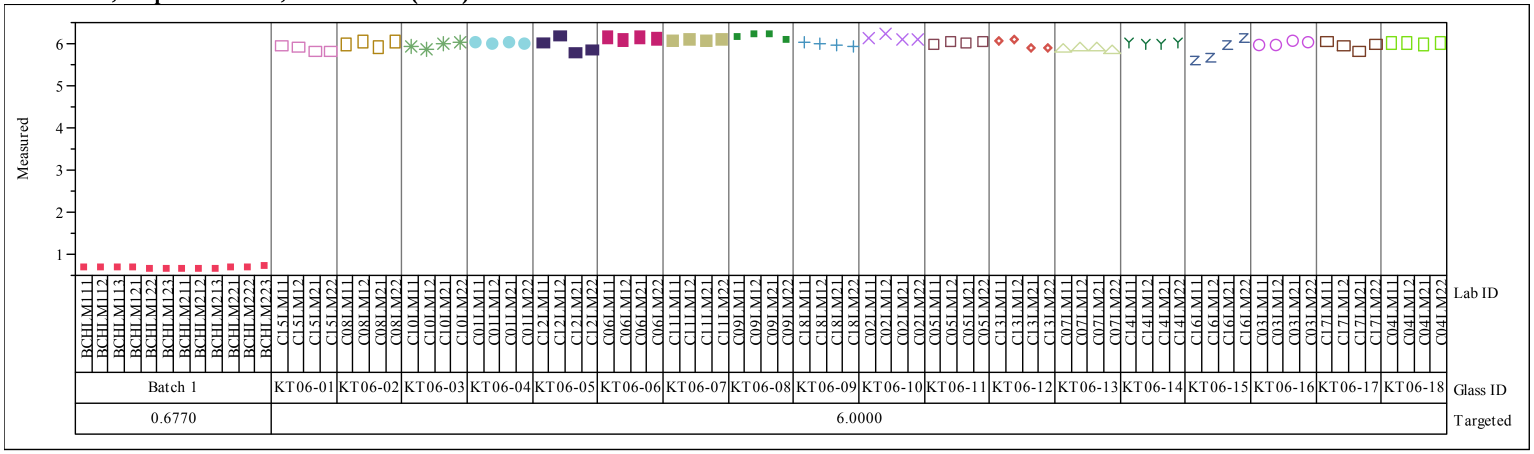
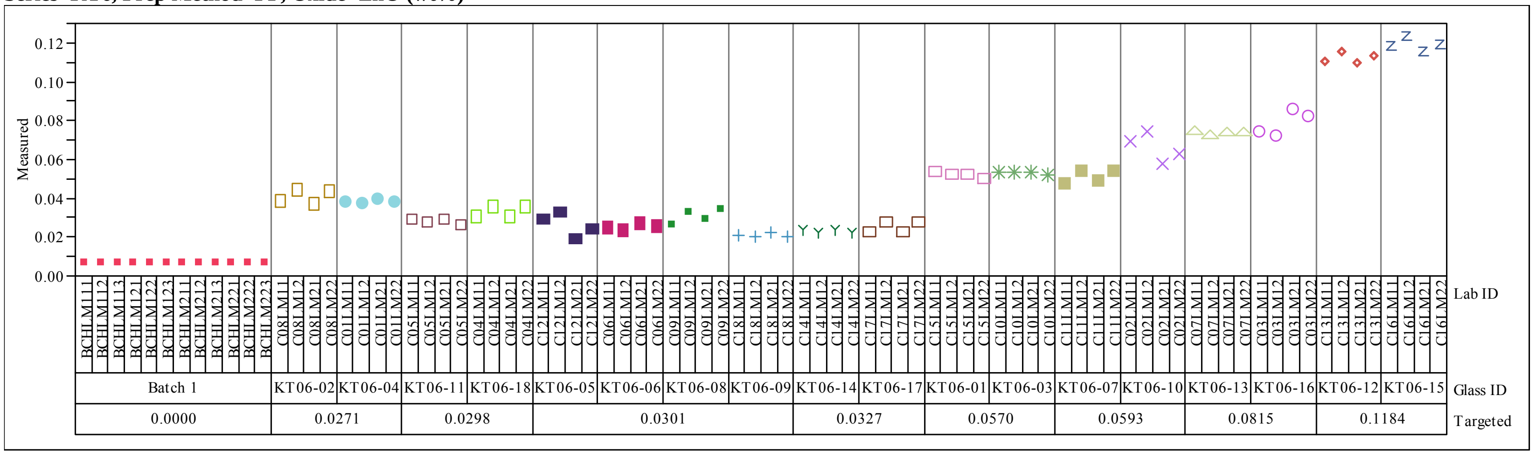


Exhibit A-2. Measurements for Each KT6-Series Glass ID by Preparation Method by Oxide. (continued)

Series=KT6, Prep Method=PF, Oxide=ZnO (wt%)



Series=KT6, Prep Method=PF, Oxide=ZrO2 (wt%)

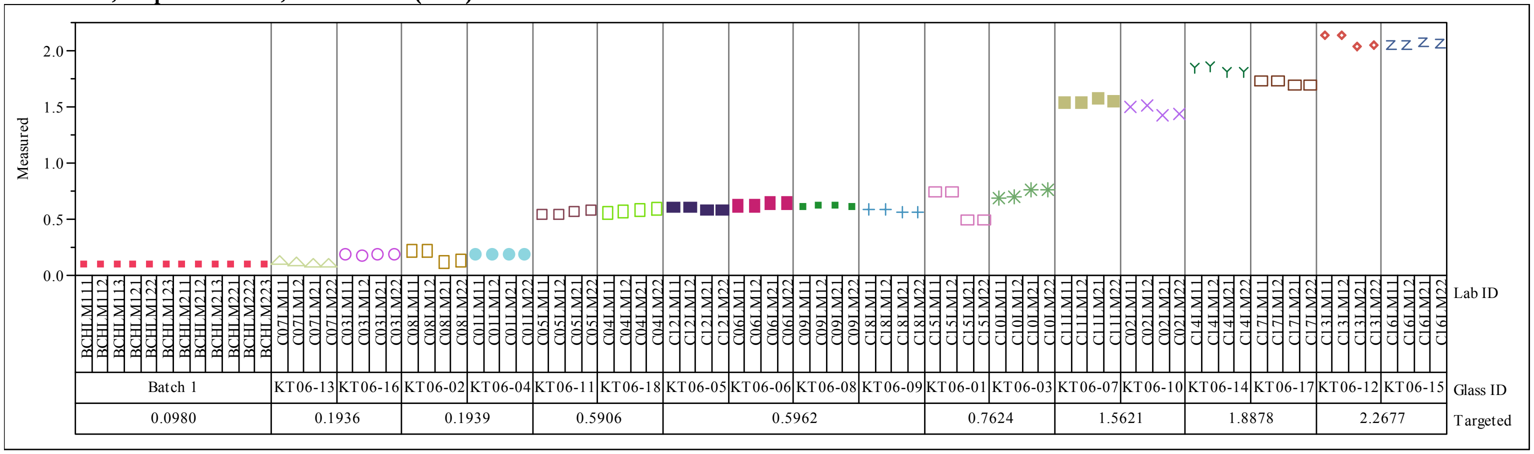
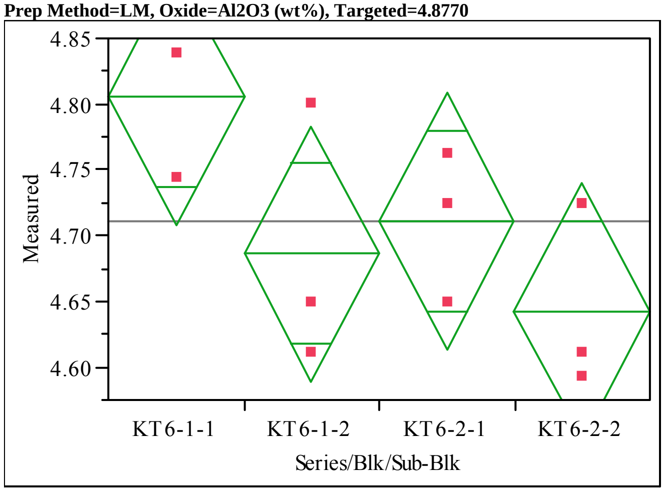


Exhibit A-3. Statistical Evaluation of the ICP-AES Calibration Effects from the KT06 Batch 1 Results by Oxide.

Prep Method=LM, Oxide=Al2O3 (wt%), Targeted=4.8770



Oneway Anova
Summary of Fit

Rsquare	0.501385
Adj Rsquare	0.314404
Root Mean Square Error	0.07318
Mean of Response	4.711153
Observations (or Sum Wgts)	12

Analysis of Variance

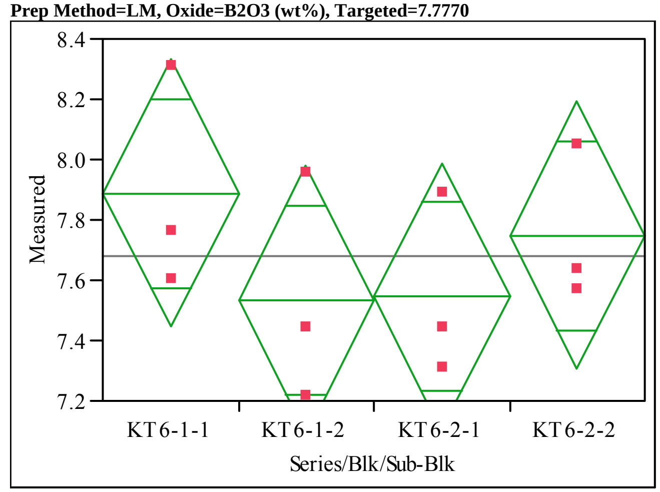
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.04308054	0.014360	2.6815	0.1177
Error	8	0.04284252	0.005355		
C. Total	11	0.08592306			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	4.80563	0.04225	4.7082	4.9031
KT6-1-2	3	4.68596	0.04225	4.5885	4.7834
KT6-2-1	3	4.71115	0.04225	4.6137	4.8086
KT6-2-2	3	4.64187	0.04225	4.5444	4.7393

Std Error uses a pooled estimate of error variance

Prep Method=LM, Oxide=B2O3 (wt%), Targeted=7.7770



Oneway Anova
Summary of Fit

Rsquare	0.228735
Adj Rsquare	-0.06049
Root Mean Square Error	0.332939
Mean of Response	7.679462
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.2629954	0.087665	0.7909	0.5322
Error	8	0.8867887	0.110849		
C. Total	11	1.1497841			

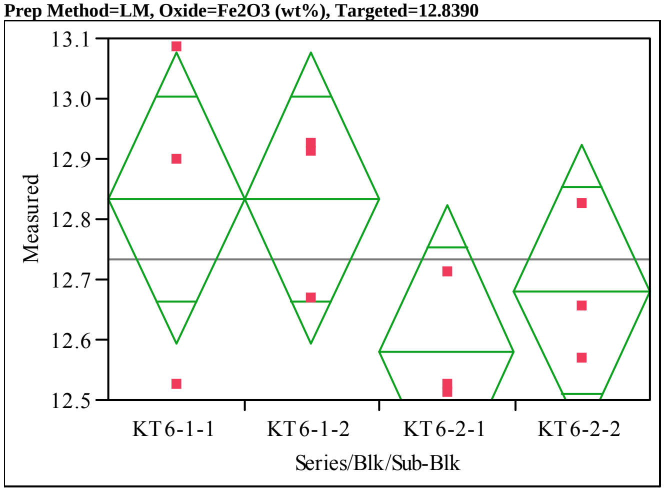
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	7.88876	0.19222	7.4455	8.3320
KT6-1-2	3	7.53457	0.19222	7.0913	7.9778
KT6-2-1	3	7.54530	0.19222	7.1020	7.9886
KT6-2-2	3	7.74923	0.19222	7.3060	8.1925

Std Error uses a pooled estimate of error variance

Exhibit A-3. Statistical Evaluation of the ICP-AES Calibration Effects from the KT06 Batch 1 Results by Oxide. (continued)

Prep Method=LM, Oxide=Fe2O3 (wt%), Targeted=12.8390



Oneway Anova
Summary of Fit

Rsquare	0.344876
Adj Rsquare	0.099204
Root Mean Square Error	0.18108
Mean of Response	12.73267
Observations (or Sum Wgts)	12

Analysis of Variance

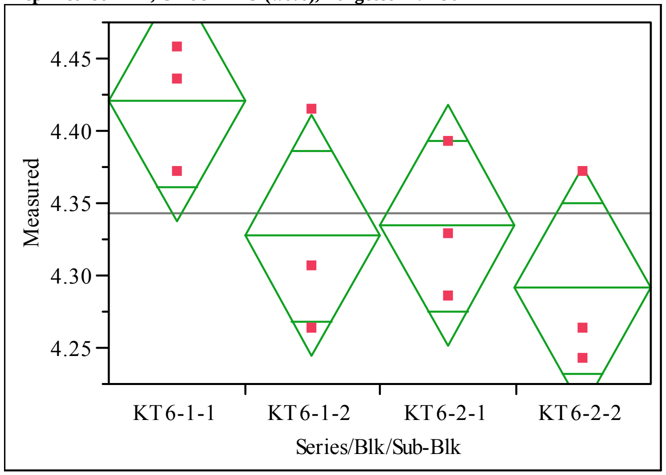
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.13809208	0.046031	1.4038	0.3109
Error	8	0.26231873	0.032790		
C. Total	11	0.40041081			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	12.8339	0.10455	12.593	13.075
KT6-1-2	3	12.8339	0.10455	12.593	13.075
KT6-2-1	3	12.5814	0.10455	12.340	12.822
KT6-2-2	3	12.6814	0.10455	12.440	12.923

Std Error uses a pooled estimate of error variance

Prep Method=LM, Oxide=Li2O (wt%), Targeted=4.4290



Oneway Anova
Summary of Fit

Rsquare	0.461386
Adj Rsquare	0.259406
Root Mean Square Error	0.062767
Mean of Response	4.343476
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.02699875	0.009000	2.2843	0.1558
Error	8	0.03151785	0.003940		
C. Total	11	0.05851660			

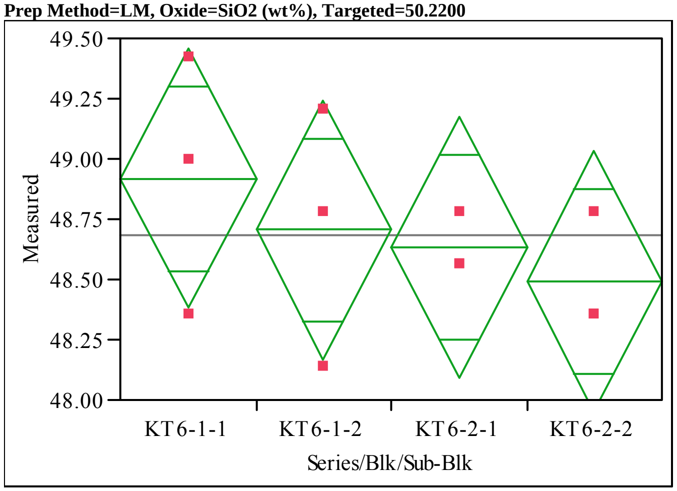
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	4.42062	0.03624	4.3371	4.5042
KT6-1-2	3	4.32733	0.03624	4.2438	4.4109
KT6-2-1	3	4.33451	0.03624	4.2509	4.4181
KT6-2-2	3	4.29145	0.03624	4.2079	4.3750

Std Error uses a pooled estimate of error variance

Exhibit A-3. Statistical Evaluation of the ICP-AES Calibration Effects from the KT06 Batch 1 Results by Oxide. (continued)

Prep Method=LM, Oxide=SiO2 (wt%), Targeted=50.2200



Oneway Anova
Summary of Fit

Rsquare	0.178998
Adj Rsquare	-0.12888
Root Mean Square Error	0.404963
Mean of Response	48.6869
Observations (or Sum Wgts)	12

Analysis of Variance

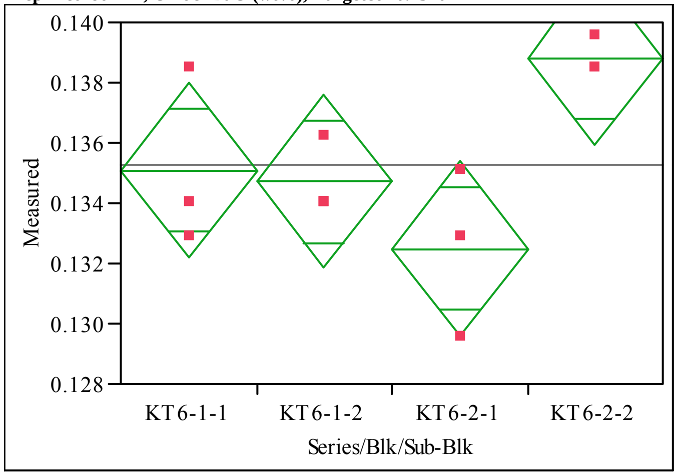
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.2860378	0.095346	0.5814	0.6436
Error	8	1.3119600	0.163995		
C. Total	11	1.5979977			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	48.9187	0.23381	48.380	49.458
KT6-1-2	3	48.7047	0.23381	48.166	49.244
KT6-2-1	3	48.6334	0.23381	48.094	49.173
KT6-2-2	3	48.4908	0.23381	47.952	49.030

Std Error uses a pooled estimate of error variance

Prep Method=PF, Oxide=BaO (wt%), Targeted=0.1510



Oneway Anova
Summary of Fit

Rsquare	0.623431
Adj Rsquare	0.482218
Root Mean Square Error	0.002162
Mean of Response	0.135283
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.00006191	0.000021	4.4148	0.0413
Error	8	0.00003740	4.675e-6		
C. Total	11	0.00009931			

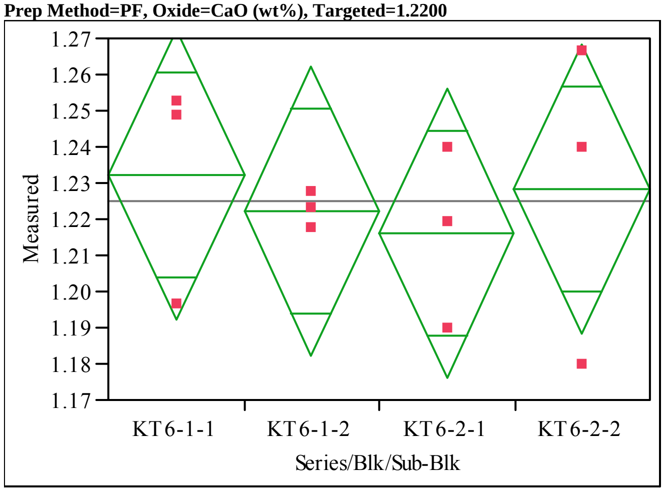
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	0.135097	0.00125	0.13222	0.13798
KT6-1-2	3	0.134724	0.00125	0.13185	0.13760
KT6-2-1	3	0.132491	0.00125	0.12961	0.13537
KT6-2-2	3	0.138818	0.00125	0.13594	0.14170

Std Error uses a pooled estimate of error variance

Exhibit A-3. Statistical Evaluation of the ICP-AES Calibration Effects from the KT06 Batch 1 Results by Oxide. (continued)

Prep Method=PF, Oxide=CaO (wt%), Targeted=1.2200



Oneway Anova
Summary of Fit

Rsquare	0.059963
Adj Rsquare	-0.29255
Root Mean Square Error	0.030048
Mean of Response	1.224766
Observations (or Sum Wgts)	12

Analysis of Variance

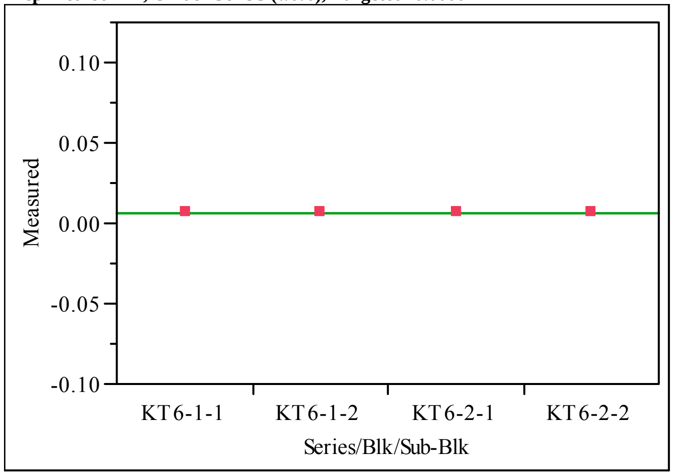
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.00046073	0.000154	0.1701	0.9136
Error	8	0.00722283	0.000903		
C. Total	11	0.00768356			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	1.23223	0.01735	1.1922	1.2722
KT6-1-2	3	1.22243	0.01735	1.1824	1.2624
KT6-2-1	3	1.21590	0.01735	1.1759	1.2559
KT6-2-2	3	1.22850	0.01735	1.1885	1.2685

Std Error uses a pooled estimate of error variance

Prep Method=PF, Oxide=Ce2O3 (wt%), Targeted=0.0000



Oneway Anova
Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.005857
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0	0	.	.
Error	8	0	0		
C. Total	11	0			

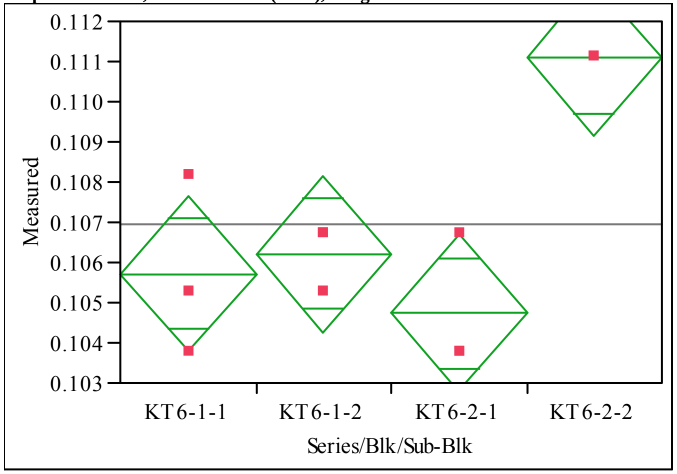
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	0.005857	0	0.00586	0.00586
KT6-1-2	3	0.005857	0	0.00586	0.00586
KT6-2-1	3	0.005857	0	0.00586	0.00586
KT6-2-2	3	0.005857	0	0.00586	0.00586

Std Error uses a pooled estimate of error variance

Exhibit A-3. Statistical Evaluation of the ICP-AES Calibration Effects from the KT06 Batch 1 Results by Oxide. (continued)

Prep Method=PF, Oxide=Cr2O3 (wt%), Targeted=0.1070



Oneway Anova
Summary of Fit

Rsquare	0.808
Adj Rsquare	0.736
Root Mean Square Error	0.001462
Mean of Response	0.10694
Observations (or Sum Wgts)	12

Analysis of Variance

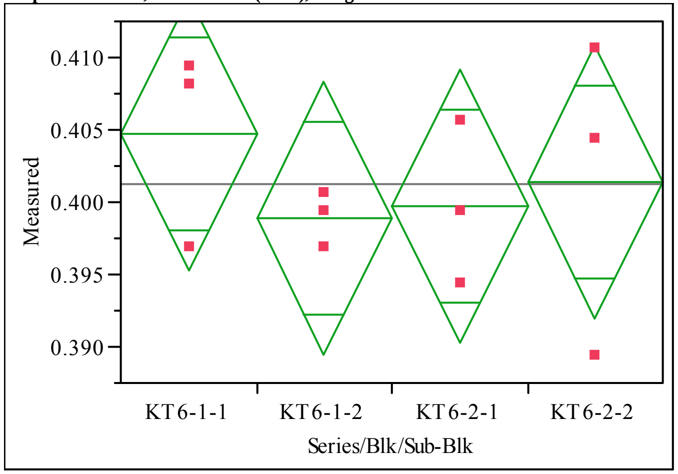
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.00007192	0.000024	11.2222	0.0031
Error	8	0.00001709	2.136e-6		
C. Total	11	0.00008901			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	0.105722	0.00084	0.10378	0.10767
KT6-1-2	3	0.106210	0.00084	0.10426	0.10816
KT6-2-1	3	0.104748	0.00084	0.10280	0.10669
KT6-2-2	3	0.111082	0.00084	0.10914	0.11303

Std Error uses a pooled estimate of error variance

Prep Method=PF, Oxide=CuO (wt%), Targeted=0.3990



Oneway Anova
Summary of Fit

Rsquare	0.129068
Adj Rsquare	-0.19753
Root Mean Square Error	0.007118
Mean of Response	0.401202
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.00006007	0.000020	0.3952	0.7601
Error	8	0.00040533	0.000051		
C. Total	11	0.00046540			

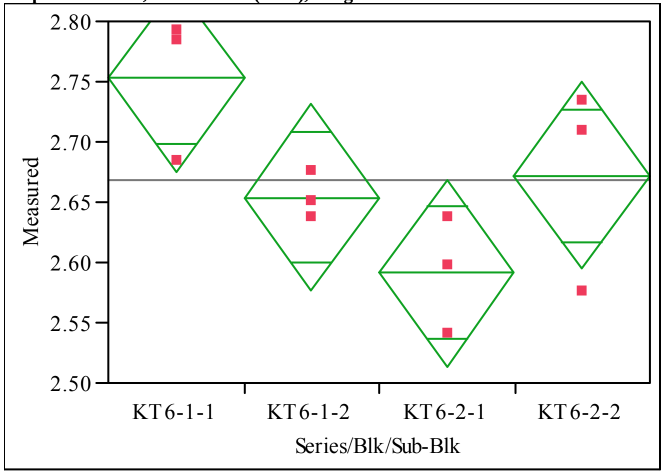
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	0.404749	0.00411	0.39527	0.41423
KT6-1-2	3	0.398907	0.00411	0.38943	0.40838
KT6-2-1	3	0.399741	0.00411	0.39026	0.40922
KT6-2-2	3	0.401411	0.00411	0.39193	0.41089

Std Error uses a pooled estimate of error variance

Exhibit A-3. Statistical Evaluation of the ICP-AES Calibration Effects from the KT06 Batch 1 Results by Oxide. (continued)

Prep Method=PF, Oxide=K2O (wt%), Targeted=3.3270



Oneway Anova
Summary of Fit

Rsquare	0.595687
Adj Rsquare	0.444069
Root Mean Square Error	0.058122
Mean of Response	2.667687
Observations (or Sum Wgts)	12

Analysis of Variance

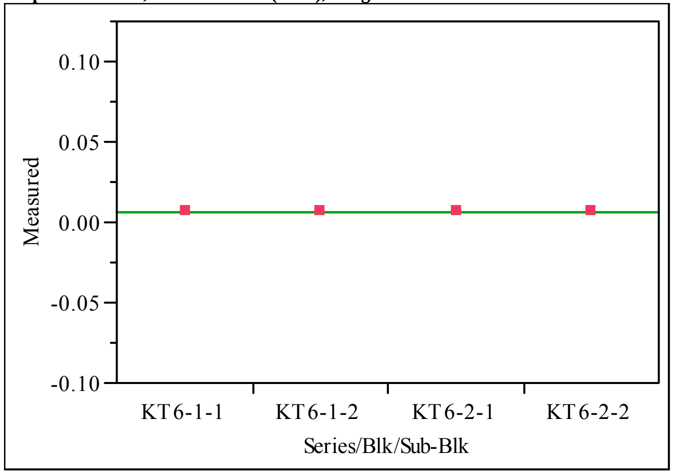
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.03981748	0.013272	3.9289	0.0540
Error	8	0.02702553	0.003378		
C. Total	11	0.06684301			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	2.75291	0.03356	2.6755	2.8303
KT6-1-2	3	2.65414	0.03356	2.5768	2.7315
KT6-2-1	3	2.59150	0.03356	2.5141	2.6689
KT6-2-2	3	2.67220	0.03356	2.5948	2.7496

Std Error uses a pooled estimate of error variance

Prep Method=PF, Oxide=La2O3 (wt%), Targeted=0.0000



Oneway Anova
Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.005864
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0	0	.	.
Error	8	0	0		
C. Total	11	0			

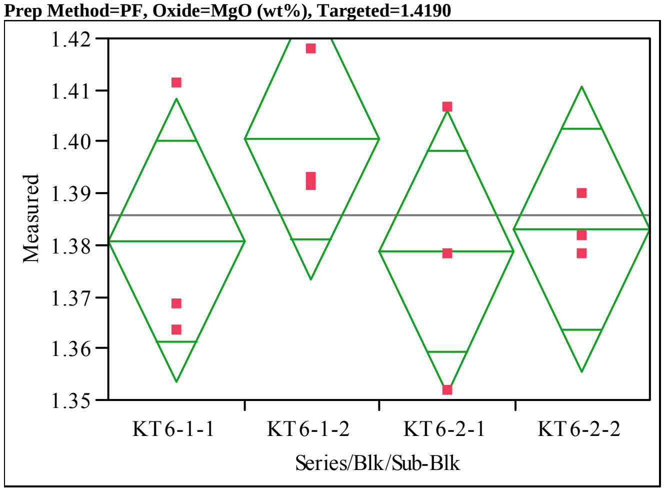
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	0.005864	0	0.00586	0.00586
KT6-1-2	3	0.005864	0	0.00586	0.00586
KT6-2-1	3	0.005864	0	0.00586	0.00586
KT6-2-2	3	0.005864	0	0.00586	0.00586

Std Error uses a pooled estimate of error variance

Exhibit A-3. Statistical Evaluation of the ICP-AES Calibration Effects from the KT06 Batch 1 Results by Oxide. (continued)

Prep Method=PF, Oxide=MgO (wt%), Targeted=1.4190



Oneway Anova
Summary of Fit

Rsquare	0.212532
Adj Rsquare	-0.08277
Root Mean Square Error	0.020646
Mean of Response	1.385786
Observations (or Sum Wgts)	12

Analysis of Variance

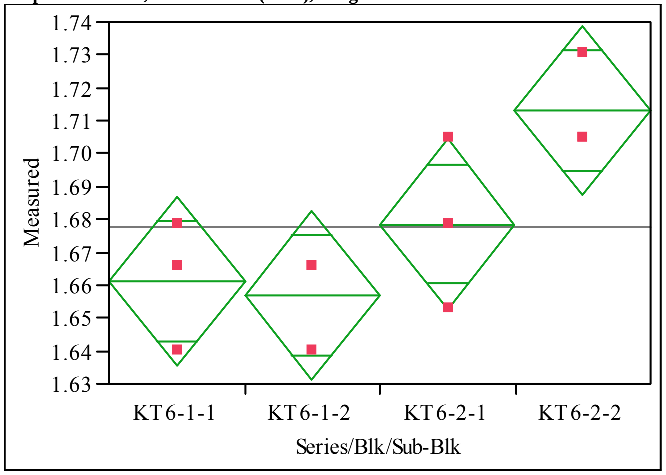
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.00092032	0.000307	0.7197	0.5677
Error	8	0.00340995	0.000426		
C. Total	11	0.00433027			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	1.38081	0.01192	1.3533	1.4083
KT6-1-2	3	1.40071	0.01192	1.3732	1.4282
KT6-2-1	3	1.37860	0.01192	1.3511	1.4061
KT6-2-2	3	1.38302	0.01192	1.3555	1.4105

Std Error uses a pooled estimate of error variance

Prep Method=PF, Oxide=MnO (wt%), Targeted=1.7260



Oneway Anova
Summary of Fit

Rsquare	0.659843
Adj Rsquare	0.532283
Root Mean Square Error	0.019368
Mean of Response	1.677484
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.00582130	0.001940	5.1728	0.0281
Error	8	0.00300096	0.000375		
C. Total	11	0.00882225			

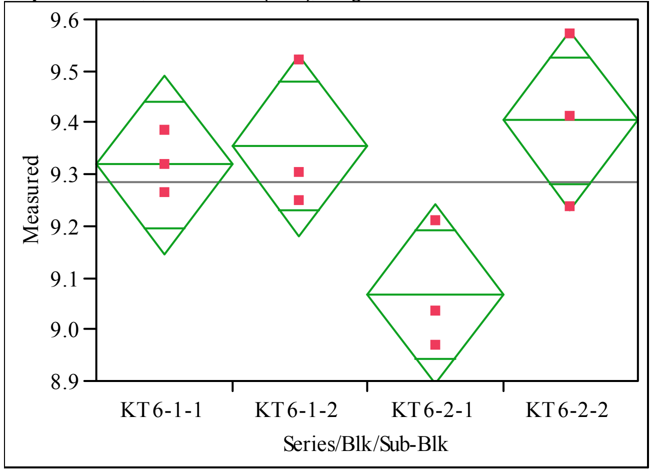
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	1.66134	0.01118	1.6356	1.6871
KT6-1-2	3	1.65704	0.01118	1.6313	1.6828
KT6-2-1	3	1.67856	0.01118	1.6528	1.7043
KT6-2-2	3	1.71299	0.01118	1.6872	1.7388

Std Error uses a pooled estimate of error variance

Exhibit A-3. Statistical Evaluation of the ICP-AES Calibration Effects from the KT06 Batch 1 Results by Oxide. (continued)

Prep Method=PF, Oxide=Na2O (wt%), Targeted=9.0030



Oneway Anova
Summary of Fit

Rsquare	0.598268
Adj Rsquare	0.447619
Root Mean Square Error	0.13052
Mean of Response	9.286597
Observations (or Sum Wgts)	12

Analysis of Variance

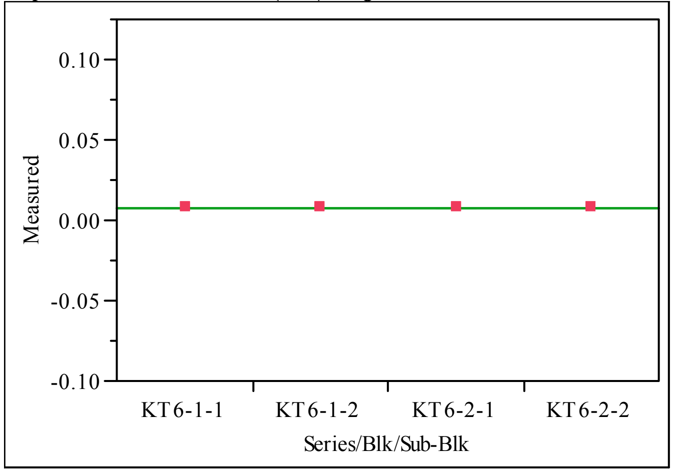
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.20295537	0.067652	3.9713	0.0527
Error	8	0.13628280	0.017035		
C. Total	11	0.33923817			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	9.31917	0.07536	9.1454	9.4929
KT6-1-2	3	9.35512	0.07536	9.1813	9.5289
KT6-2-1	3	9.06755	0.07536	8.8938	9.2413
KT6-2-2	3	9.40455	0.07536	9.2308	9.5783

Std Error uses a pooled estimate of error variance

Prep Method=PF, Oxide=Nb2O5 (wt%), Targeted=0.0000



Oneway Anova
Summary of Fit

Rsquare	0
Adj Rsquare	-0.375
Root Mean Square Error	1.06e-18
Mean of Response	0.007153
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0	0	0.0000	1.0000
Error	8	9.0278e-36	1.128e-36		
C. Total	11	9.0278e-36			

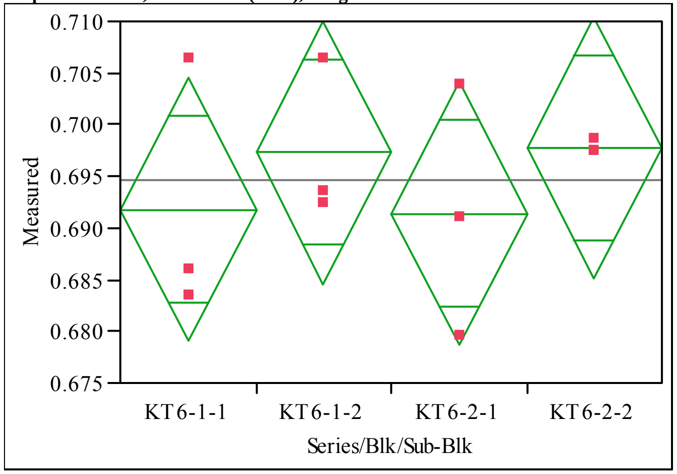
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	0.007153	6.133e-19	0.00715	0.00715
KT6-1-2	3	0.007153	6.133e-19	0.00715	0.00715
KT6-2-1	3	0.007153	6.133e-19	0.00715	0.00715
KT6-2-2	3	0.007153	6.133e-19	0.00715	0.00715

Std Error uses a pooled estimate of error variance

Exhibit A-3. Statistical Evaluation of the ICP-AES Calibration Effects from the KT06 Batch 1 Results by Oxide. (continued)

Prep Method=PF, Oxide=NiO (wt%), Targeted=0.7510



Oneway Anova
Summary of Fit

Rsquare	0.127343
Adj Rsquare	-0.1999
Root Mean Square Error	0.009544
Mean of Response	0.694573
Observations (or Sum Wgts)	12

Analysis of Variance

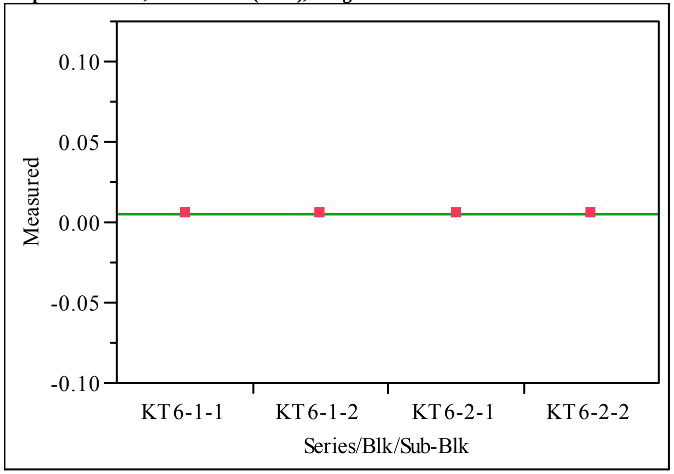
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.00010633	0.000035	0.3891	0.7641
Error	8	0.00072867	0.000091		
C. Total	11	0.00083500			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	0.691816	0.00551	0.67911	0.70452
KT6-1-2	3	0.697330	0.00551	0.68462	0.71004
KT6-2-1	3	0.691392	0.00551	0.67869	0.70410
KT6-2-2	3	0.697754	0.00551	0.68505	0.71046

Std Error uses a pooled estimate of error variance

Prep Method=PF, Oxide=PbO (wt%), Targeted=0.0000



Oneway Anova
Summary of Fit

Rsquare	0
Adj Rsquare	-0.375
Root Mean Square Error	1.06e-18
Mean of Response	0.005386
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0	0	0.0000	1.0000
Error	8	9.0278e-36	1.128e-36		
C. Total	11	9.0278e-36			

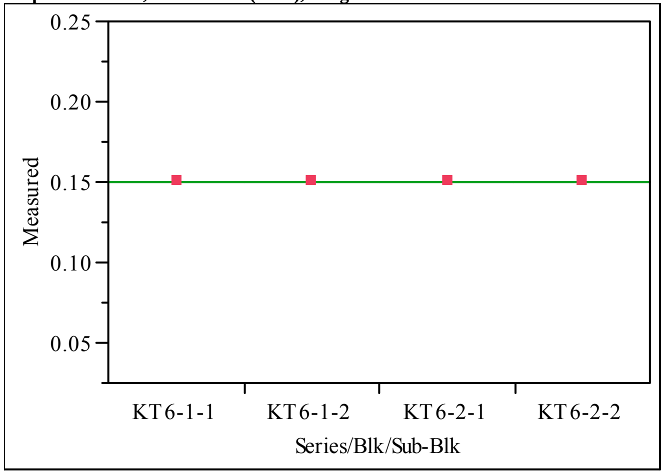
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	0.005386	6.133e-19	0.00539	0.00539
KT6-1-2	3	0.005386	6.133e-19	0.00539	0.00539
KT6-2-1	3	0.005386	6.133e-19	0.00539	0.00539
KT6-2-2	3	0.005386	6.133e-19	0.00539	0.00539

Std Error uses a pooled estimate of error variance

Exhibit A-3. Statistical Evaluation of the ICP-AES Calibration Effects from the KT06 Batch 1 Results by Oxide. (continued)

Prep Method=PF, Oxide=SO4 (wt%), Targeted=0.0000



Oneway Anova
Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.149795
Observations (or Sum Wgts)	12

Analysis of Variance

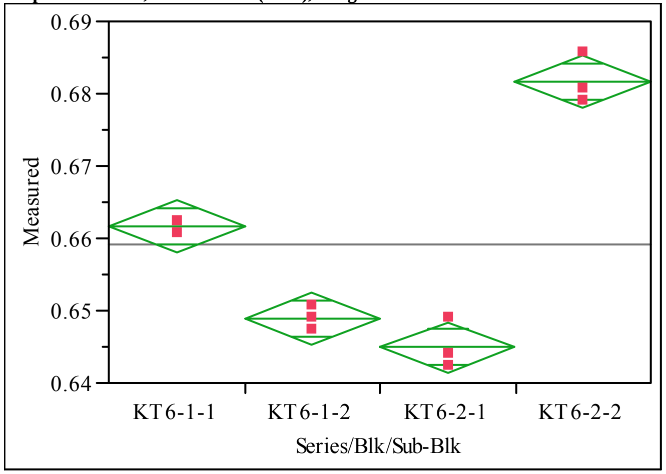
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0	0	.	.
Error	8	0	0		
C. Total	11	0			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	0.149795	0	0.14980	0.14980
KT6-1-2	3	0.149795	0	0.14980	0.14980
KT6-2-1	3	0.149795	0	0.14980	0.14980
KT6-2-2	3	0.149795	0	0.14980	0.14980

Std Error uses a pooled estimate of error variance

Prep Method=PF, Oxide=TiO2 (wt%), Targeted=0.6770



Oneway Anova
Summary of Fit

Rsquare	0.977882
Adj Rsquare	0.969588
Root Mean Square Error	0.002637
Mean of Response	0.659277
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.00246018	0.000820	117.9000	<.0001
Error	8	0.00005564	6.956e-6		
C. Total	11	0.00251583			

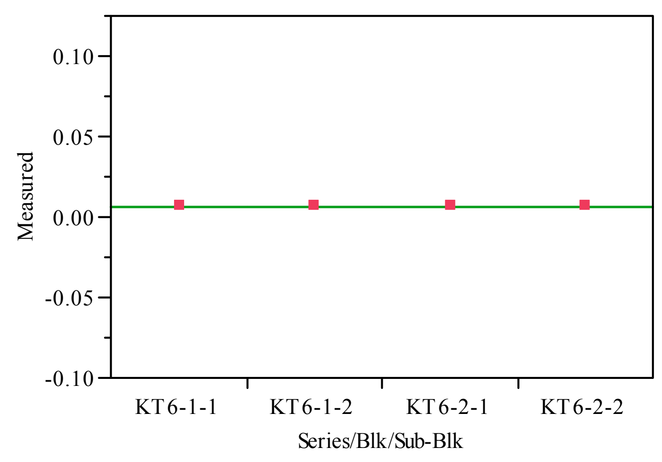
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	0.661640	0.00152	0.65813	0.66515
KT6-1-2	3	0.648852	0.00152	0.64534	0.65236
KT6-2-1	3	0.644960	0.00152	0.64145	0.64847
KT6-2-2	3	0.681656	0.00152	0.67814	0.68517

Std Error uses a pooled estimate of error variance

Exhibit A-3. Statistical Evaluation of the ICP-AES Calibration Effects from the KT06 Batch 1 Results by Oxide. (continued)

Prep Method=PF, Oxide=ZnO (wt%), Targeted=0.0000



Oneway Anova
Summary of Fit

Rsquare	.
Adj Rsquare	.
Root Mean Square Error	0
Mean of Response	0.006224
Observations (or Sum Wgts)	12

Analysis of Variance

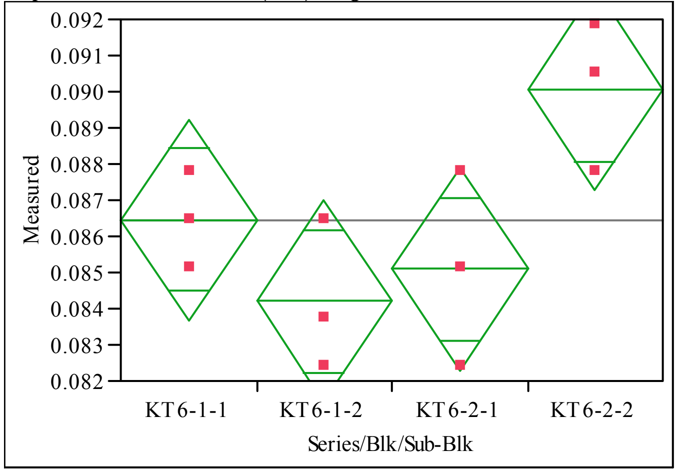
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0	0	.	.
Error	8	0	0		
C. Total	11	0			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	0.006224	0	0.00622	0.00622
KT6-1-2	3	0.006224	0	0.00622	0.00622
KT6-2-1	3	0.006224	0	0.00622	0.00622
KT6-2-2	3	0.006224	0	0.00622	0.00622

Std Error uses a pooled estimate of error variance

Prep Method=PF, Oxide=ZrO2 (wt%), Targeted=0.0980



Oneway Anova
Summary of Fit

Rsquare	0.628205
Adj Rsquare	0.488782
Root Mean Square Error	0.0021
Mean of Response	0.086451
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Series/Blk/Sub-Blk	3	0.00005961	0.000020	4.5057	0.0394
Error	8	0.00003528	4.41e-6		
C. Total	11	0.00009488			

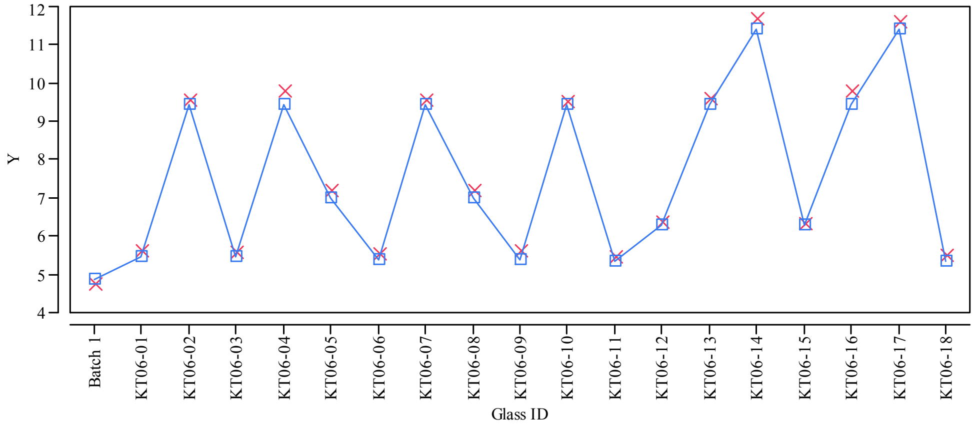
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
KT6-1-1	3	0.086451	0.00121	0.08366	0.08925
KT6-1-2	3	0.084200	0.00121	0.08140	0.08700
KT6-2-1	3	0.085100	0.00121	0.08230	0.08790
KT6-2-2	3	0.090053	0.00121	0.08726	0.09285

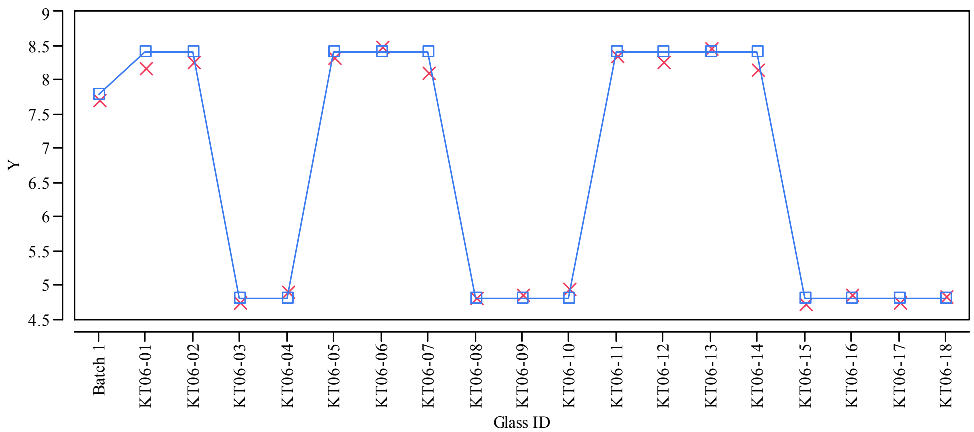
Std Error uses a pooled estimate of error variance

Exhibit A-4. Plots of Measured versus Targeted Concentrations by KT06 Glass ID by Oxide.

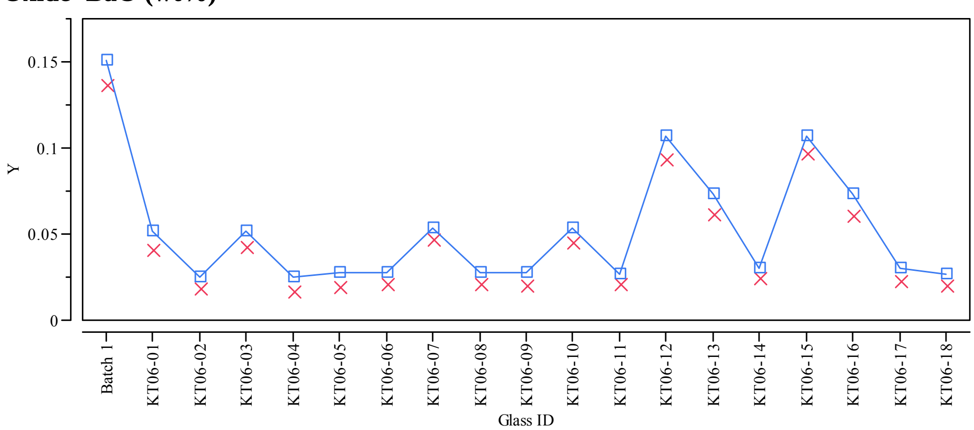
Oxide=Al_2O_3 (wt%)



Oxide=B_2O_3 (wt%)



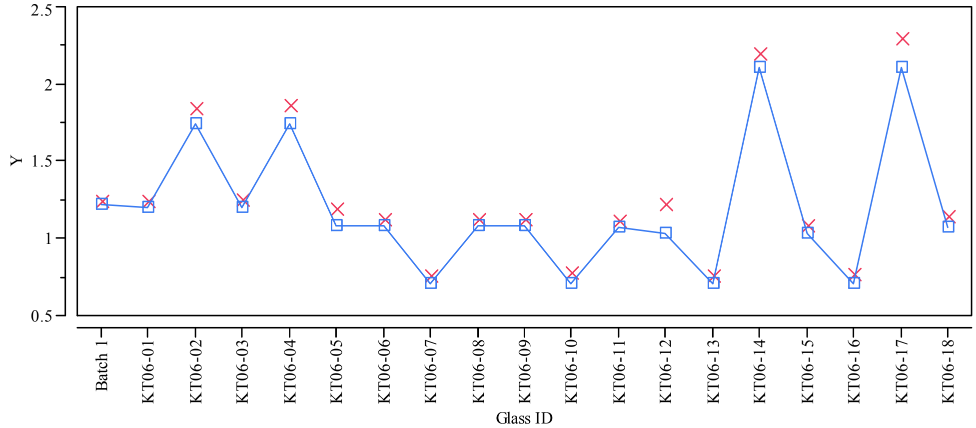
Oxide=BaO (wt%)



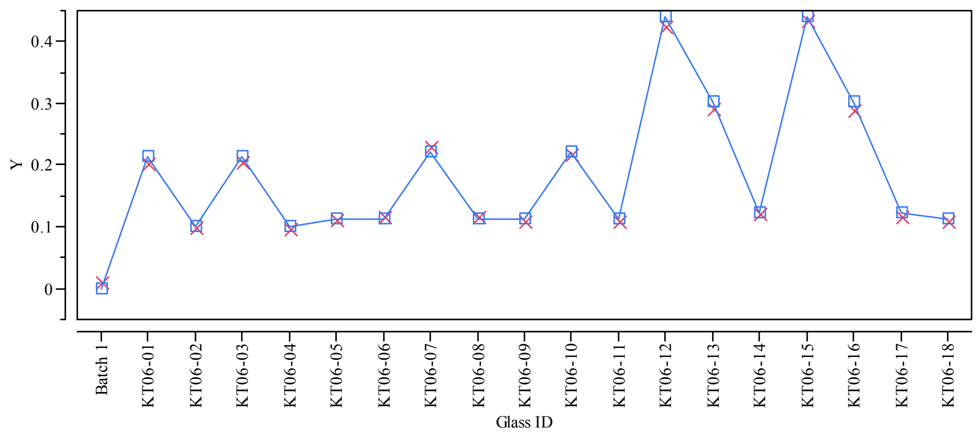
Y × Measured ▫ — Targeted

Exhibit A-4. Plots of Measured versus Targeted Concentrations by KT06 Glass ID by Oxide. (continued)

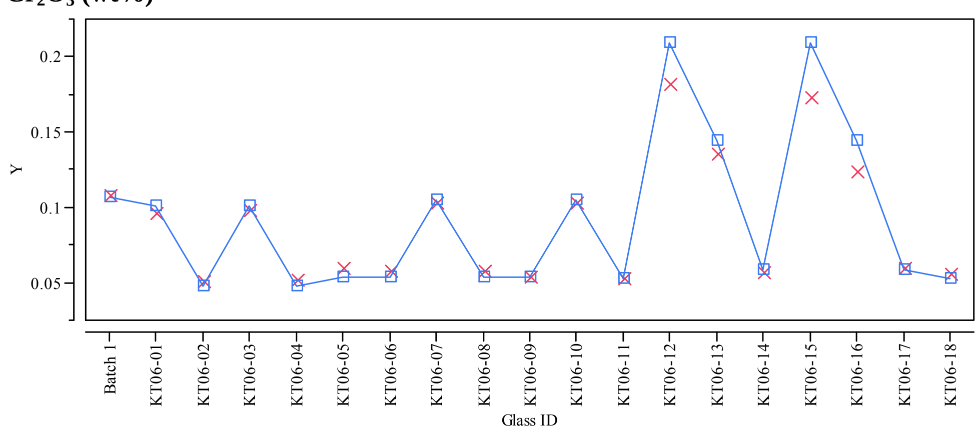
Oxide=CaO (wt%)



Oxide=Ce_2O_3 (wt%)



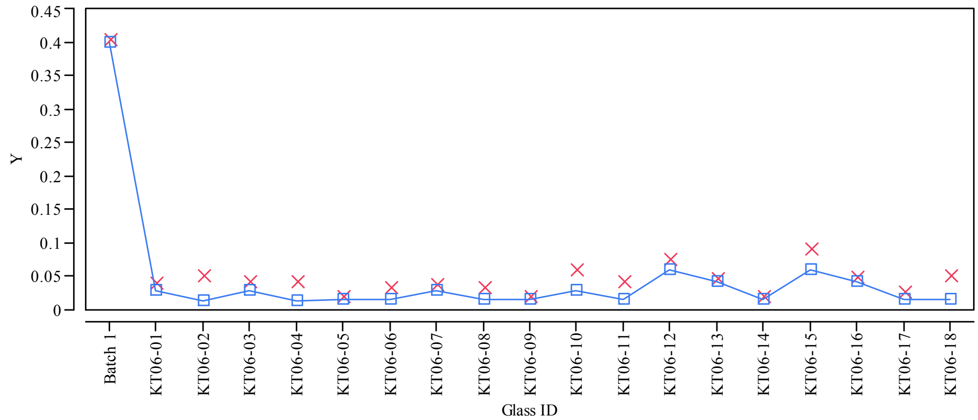
Cr_2O_3 (wt%)



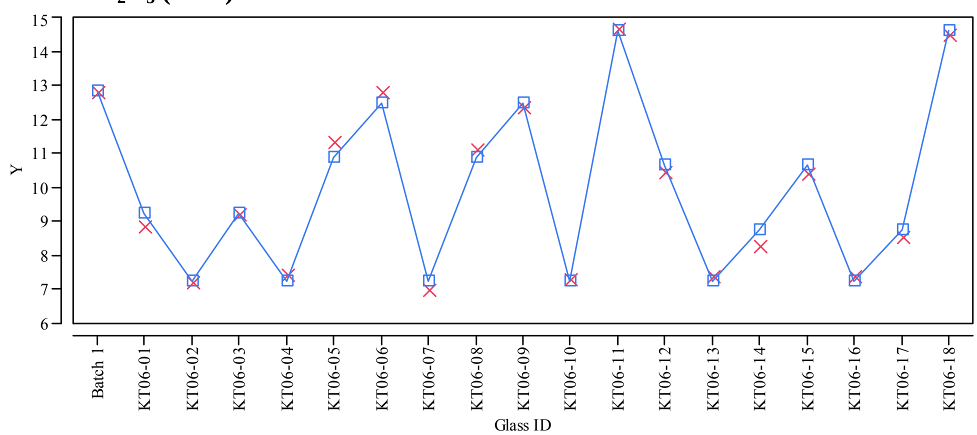
Y × Measured ▫— Targeted

Exhibit A-4. Plots of Measured versus Targeted Concentrations by KT06 Glass ID by Oxide. (continued)

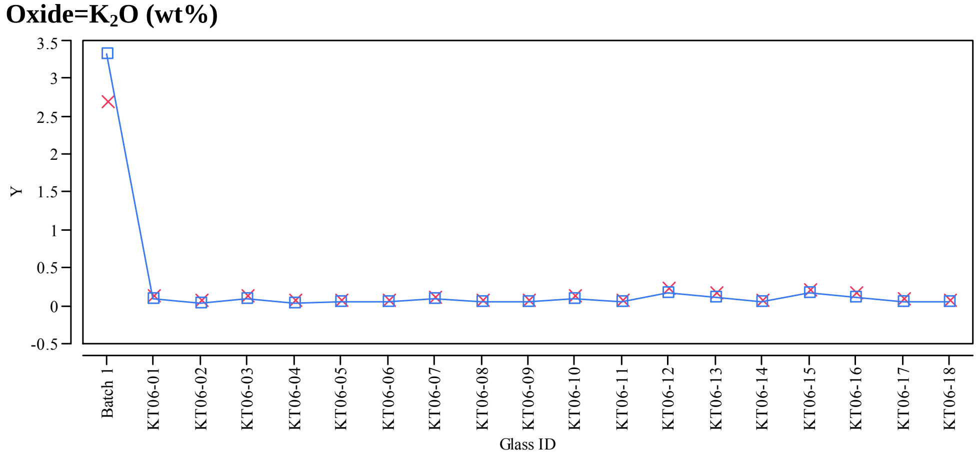
Oxide=CuO (wt%)



Oxide=Fe_2O_3 (wt%)



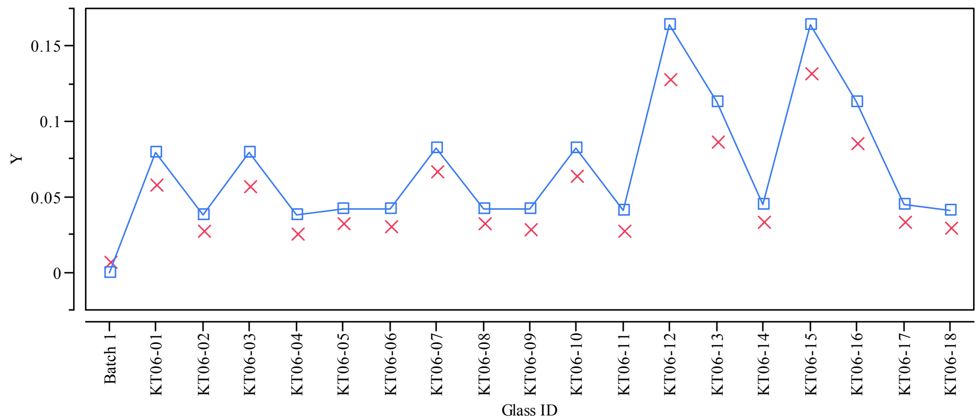
Oxide=K_2O (wt%)



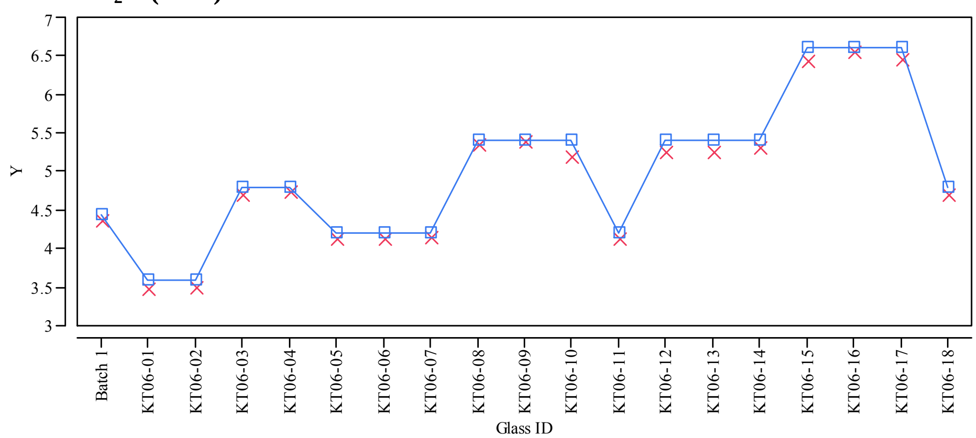
Y × Measured ▫ Targeted

Exhibit A-4. Plots of Measured versus Targeted Concentrations by KT06 Glass ID by Oxide. (continued)

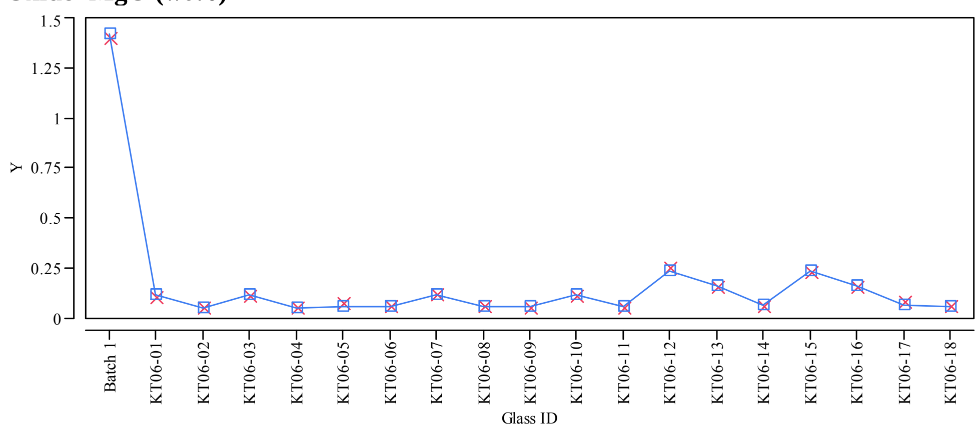
Oxide=La_2O_3 (wt%)



Oxide=Li_2O (wt%)



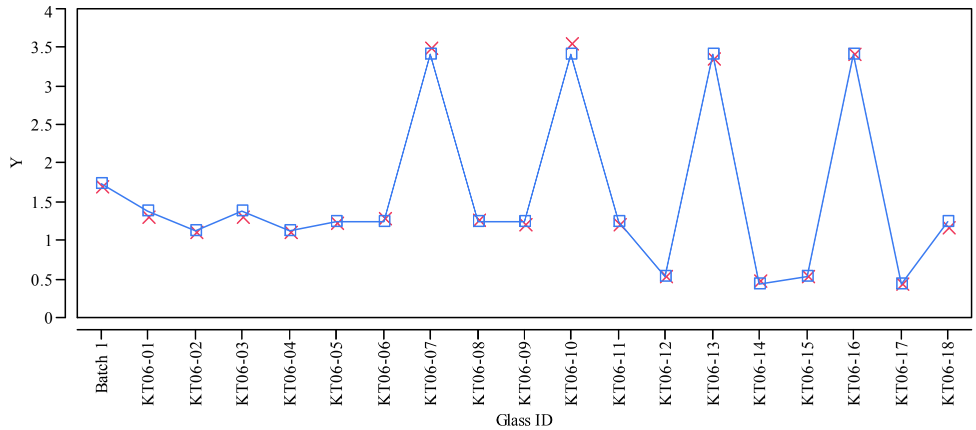
Oxide=MgO (wt%)



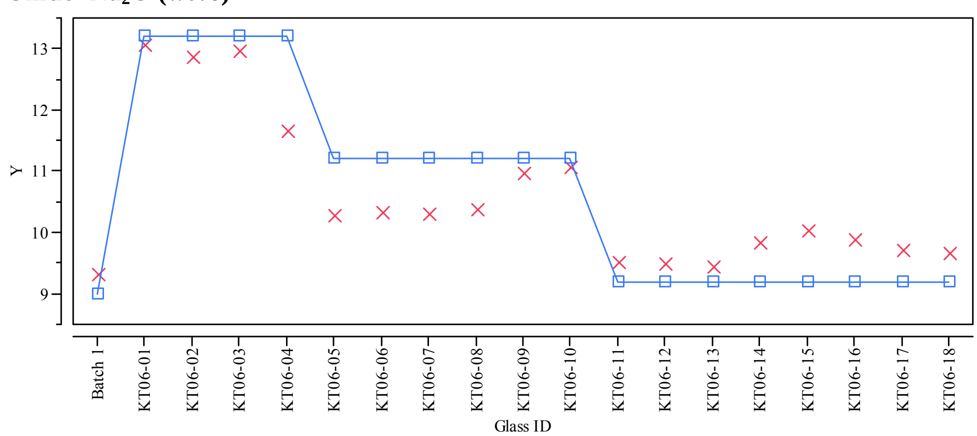
Y × Measured ▫ — Targeted

Exhibit A-4. Plots of Measured versus Targeted Concentrations by KT06 Glass ID by Oxide. (continued)

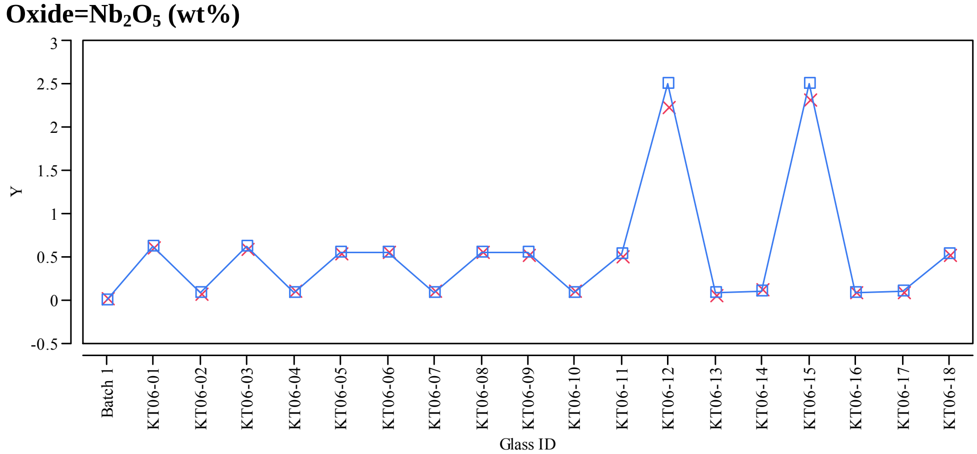
Oxide=MnO (wt%)



Oxide=Na_2O (wt%)



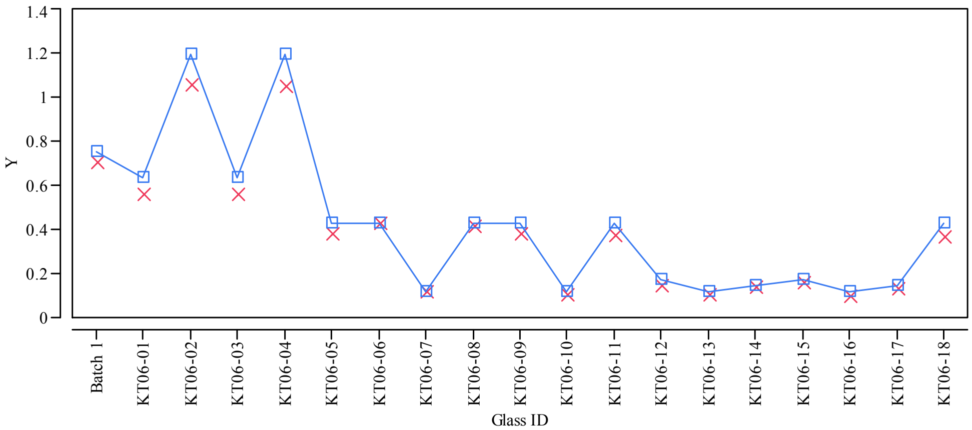
Oxide=Nb_2O_5 (wt%)



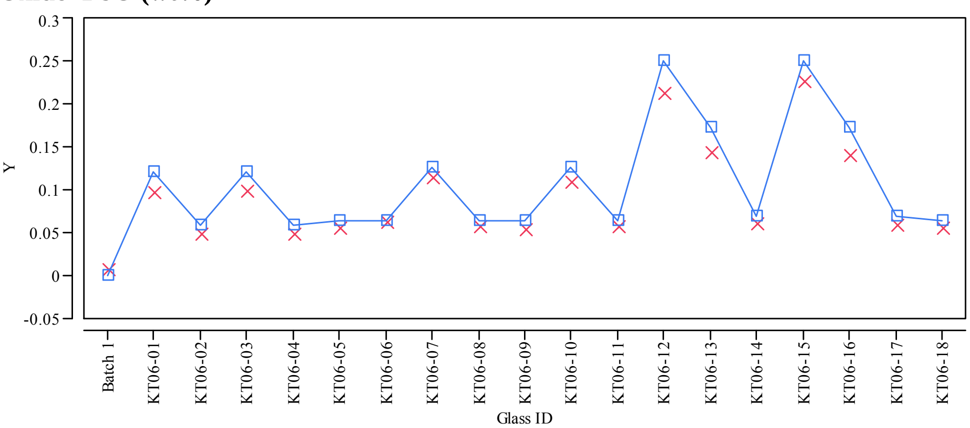
Y × Measured ▫ — Targeted

Exhibit A-4. Plots of Measured versus Targeted Concentrations by KT06 Glass ID by Oxide. (continued)

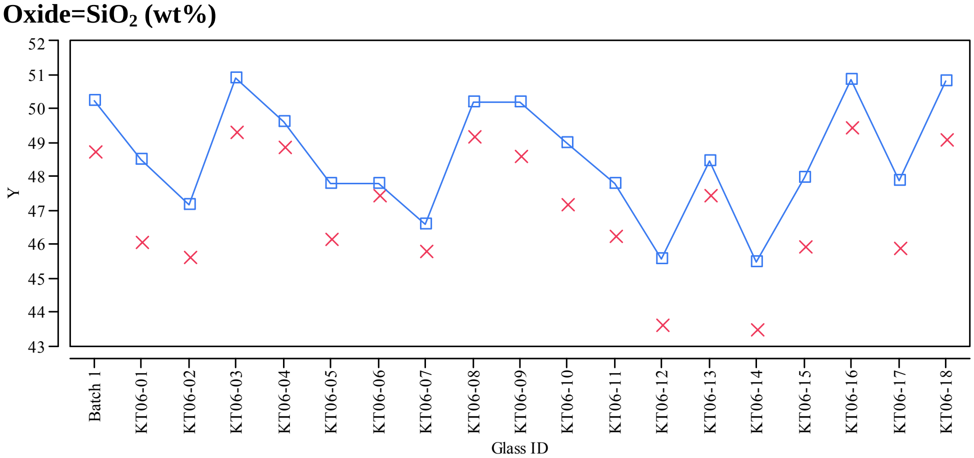
Oxide=NiO (wt%)



Oxide=PbO (wt%)



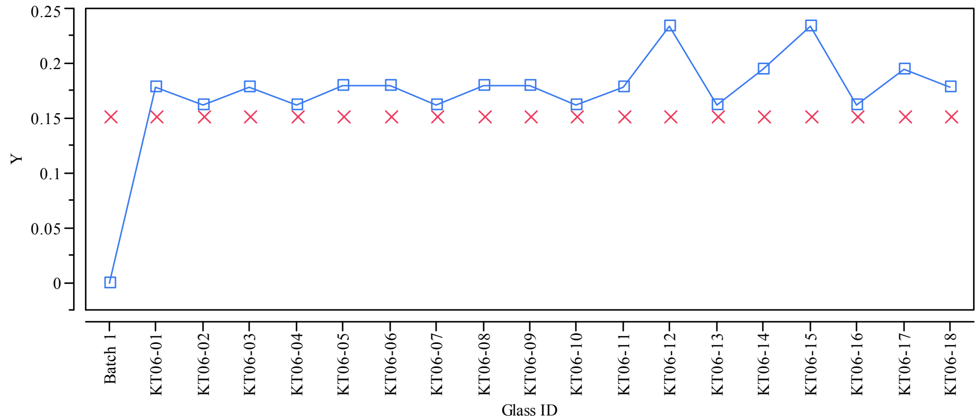
Oxide=SiO_2 (wt%)



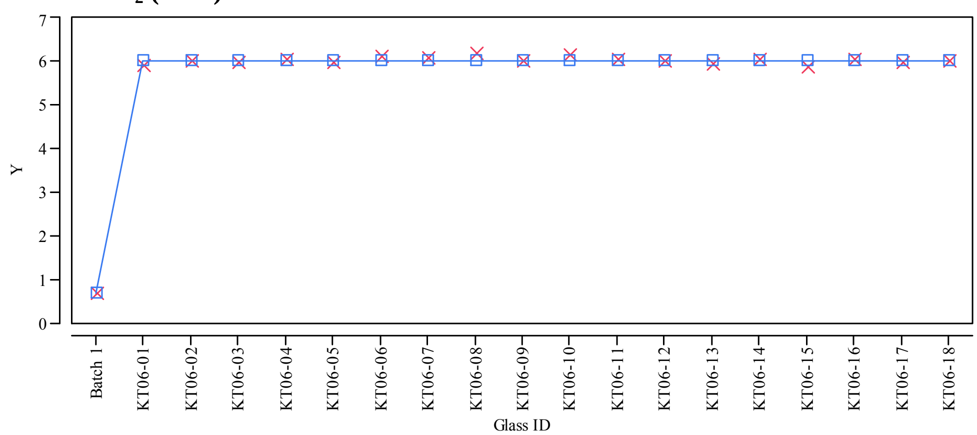
Y × Measured ■ Targeted

Exhibit A-4. Plots of Measured versus Targeted Concentrations by KT06 Glass ID by Oxide. (continued)

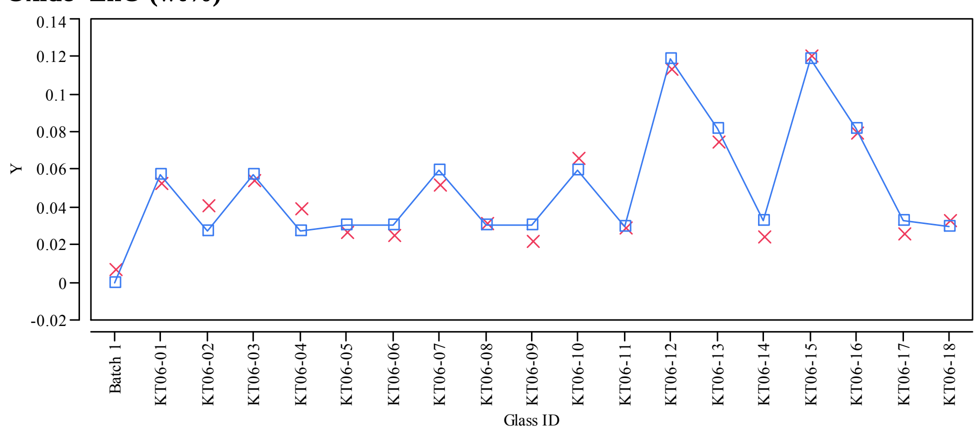
Oxide=SO_4 (wt%)



Oxide=TiO_2 (wt%)



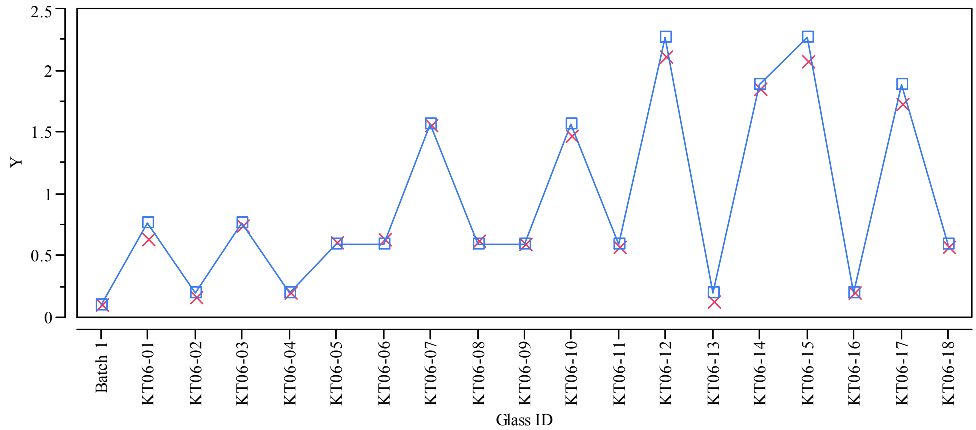
Oxide=ZnO (wt%)



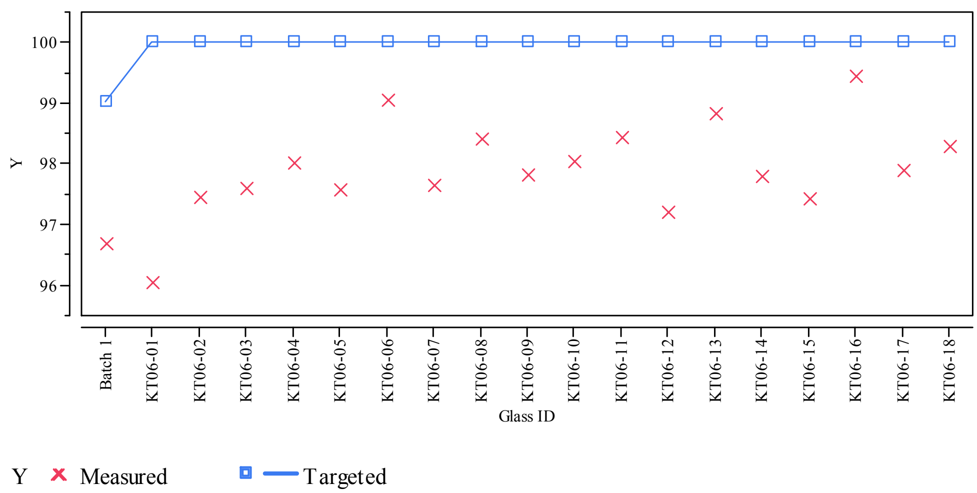
Y × Measured ▪ — Targeted

Exhibit A-4. Plots of Measured versus Targeted Concentrations by KT06 Glass ID by Oxide. (continued)

Oxide=ZrO_2 (wt%)



Sum of Oxides



Appendix B. Data Supporting the PCT Measurements of the KT06-Series Glasses

Table B-1. Measurements of the PCT Solutions for the KT06-Series Glasses As-Received (ar) and After Appropriate Adjustments (ppm).

Glass ID	Heat Treatment	Block	Seq	Lab ID	B (ar)	Li (ar)	Na (ar)	Si (ar)	B (ppm)	Li (ppm)	Na (ppm)	Si (ppm)
Soln Std	ref	1	1	std-11	21.3	9.88	84.5	50.3	21.30	9.88	84.50	50.30
KT06-17	quenched	1	2	d043	4.99	12.5	17.2	50.1	8.32	20.83	28.67	83.50
KT06-17	ccc	1	3	d040	4.80	12.5	17.8	51.4	8.00	20.83	29.67	85.67
blank	ref	1	4	d092	0.116	<1.00	4.01	<0.100	0.19	0.83	6.68	0.08
KT06-11	quenched	1	5	d088	9.32	9.11	18.3	56.1	15.53	15.18	30.50	93.50
KT06-13	quenched	1	6	d050	7.93	10.0	15.8	54.7	13.22	16.67	26.33	91.17
KT06-01	ccc	1	7	d111	8.14	6.27	33.5	52.8	13.57	10.45	55.83	88.00
KT06-15	quenched	1	8	d090	5.23	14.6	20.3	60.7	8.72	24.33	33.83	101.17
KT06-09	ccc	1	9	d103	5.81	12.7	30.2	72.6	9.68	21.17	50.33	121.00
KT06-07	ccc	1	10	d057	6.46	6.59	14.3	44.0	10.77	10.98	23.83	73.33
KT06-03	ccc	1	11	d086	5.09	9.95	43.1	67.9	8.48	16.58	71.83	113.17
Soln Std	ref	1	12	std-12	19.5	9.85	82.3	51.1	19.50	9.85	82.30	51.10
KT06-03	quenched	1	13	d013	5.67	10.1	43.9	69.4	9.45	16.83	73.17	115.67
KT06-05	ccc	1	14	d113	7.56	7.59	18.0	52.2	12.60	12.65	30.00	87.00
KT06-13	ccc	1	15	d003	8.09	9.79	16.6	56.5	13.48	16.32	27.67	94.17
KT06-05	quenched	1	16	d067	7.58	7.78	16.7	50.3	12.63	12.97	27.83	83.84
KT06-09	quenched	1	17	d079	5.78	12.7	30.6	72.6	9.63	21.17	51.00	121.00
KT06-11	ccc	1	18	d110	8.04	8.84	20.9	59.2	13.40	14.73	34.83	98.67
KT06-07	quenched	1	19	d063	6.95	7.62	15.5	46.3	11.58	12.70	25.83	77.17
KT06-01	quenched	1	20	d020	8.02	6.44	34.1	54.7	13.37	10.73	56.83	91.17
KT06-15	ccc	1	21	d085	4.88	14.4	21.0	62.3	8.13	24.00	35.00	103.84
EA	ref	1	22	d054	22.0	7.67	65.9	39.3	366.67	127.83	1098.34	655.00
Soln Std	ref	1	23	std-13	19.4	9.85	83.3	49.8	19.40	9.85	83.30	49.80
Soln Std	ref	2	1	std-21	20.9	10.0	84.5	51.8	20.90	10.00	84.50	51.80
KT06-17	ccc	2	2	d048	5.09	12.1	17.3	51.0	8.48	20.17	28.83	85.00
EA	ref	2	3	d021	22.5	7.87	66.6	41.1	375.00	131.17	1110.00	685.00
KT06-15	ccc	2	4	d008	5.21	14.3	21.8	63.4	8.68	23.83	36.33	105.67
KT06-01	ccc	2	5	d024	8.28	6.37	38.0	55.0	13.80	10.62	63.33	91.67
KT06-15	quenched	2	6	d036	5.39	15.1	20.9	64.4	8.98	25.17	34.83	107.34
KT06-07	quenched	2	7	d112	7.01	7.45	15.6	46.1	11.68	12.42	26.00	76.83
KT06-11	ccc	2	8	d068	8.15	9.09	19.8	61.3	13.58	15.15	33.00	102.17
KT06-03	quenched	2	9	d075	5.30	10.2	44.9	71.3	8.83	17.00	74.83	118.84
KT06-09	quenched	2	10	d058	5.87	12.8	30.5	75.3	9.78	21.33	50.83	125.50
KT06-11	quenched	2	11	d023	8.87	8.97	18.9	56.9	14.78	14.95	31.50	94.84
Soln Std	ref	2	12	std-22	20.1	10.0	83.3	51.8	20.10	10.00	83.30	51.80
KT06-01	quenched	2	13	d005	8.35	6.38	33.4	54.7	13.92	10.63	55.67	91.17
KT06-05	ccc	2	14	d044	7.46	7.39	18.8	51.7	12.43	12.32	31.33	86.17
KT06-07	ccc	2	15	d073	6.47	6.59	14.9	45.3	10.78	10.98	24.83	75.50
KT06-09	ccc	2	16	d004	5.77	12.7	28.8	74.8	9.62	21.17	48.00	124.67
KT06-13	quenched	2	17	d026	7.57	10.0	16.6	56.5	12.62	16.67	27.67	94.17
KT06-13	ccc	2	18	d089	7.62	9.76	17.0	57.9	12.70	16.27	28.33	96.50
KT06-17	quenched	2	19	d082	4.26	12.6	17.0	51.6	7.10	21.00	28.33	86.00
KT06-05	quenched	2	20	d105	7.41	8.09	19.6	53.7	12.35	13.48	32.67	89.50
KT06-03	ccc	2	21	d038	4.93	10.0	43.1	70.1	8.22	16.67	71.83	116.84
Soln Std	ref	2	22	std-33	19.6	10.1	86.6	52.2	19.60	10.10	86.60	52.20
Soln Std	ref	3	1	std-31	19.0	9.85	81.1	49.0	19.00	9.85	81.10	49.00
KT06-17	quenched	3	2	d104	2.86	12.7	17.2	49.5	4.77	21.17	28.67	82.50
KT06-03	quenched	3	3	d081	3.73	10.2	44.2	69.3	6.22	17.00	73.67	115.50
KT06-09	quenched	3	4	d039	4.01	12.5	30.4	71.1	6.68	20.83	50.67	118.50
KT06-07	quenched	3	5	d041	5.25	7.44	14.8	43.1	8.75	12.40	24.67	71.83
KT06-03	ccc	3	6	d049	3.41	9.90	43.0	66.1	5.68	16.50	71.67	110.17
KT06-13	quenched	3	7	d070	5.75	10.1	16.9	52.6	9.58	16.83	28.17	87.67
KT06-15	ccc	3	8	d102	3.32	14.3	21.8	60.1	5.53	23.83	36.33	100.17
KT06-05	ccc	3	9	d107	5.31	7.34	17.4	47.8	8.85	12.23	29.00	79.67
KT06-15	quenched	3	10	d016	3.34	14.6	23.4	59.8	5.57	24.33	39.00	99.67
KT06-01	ccc	3	11	d017	5.75	6.08	32.4	49.3	9.58	10.13	54.00	82.17
Soln Std	ref	3	12	std-32	17.6	9.60	79.1	46.7	17.60	9.60	79.10	46.70
KT06-13	ccc	3	13	d097	6.43	9.87	18.5	54.6	10.72	16.45	30.83	91.00
KT06-17	ccc	3	14	d019	2.53	12.0	16.8	46.3	4.22	20.00	28.00	77.17

Table B-1. Measurements of the PCT Solutions for the KT06-Series Glasses As-Received (ar) and After Appropriate Adjustments (ppm). (continued)

Glass ID	Heat Treatment	Block	Seq	Lab ID	B (ar)	Li (ar)	Na (ar)	Si (ar)	B (ppm)	Li (ppm)	Na (ppm)	Si (ppm)
KT06-05	quenched	3	15	d018	5.84	7.99	16.9	48.9	9.73	13.32	28.17	81.50
KT06-11	ccc	3	16	d047	6.51	9.11	19.4	57.3	10.85	15.18	32.33	95.50
EA	ref	3	17	d022	29.8	9.91	88.7	44.9	496.67	165.17	1478.34	748.33
KT06-07	ccc	3	18	d055	4.88	6.60	15.1	40.7	8.13	11.00	25.17	67.83
KT06-11	quenched	3	19	d032	7.27	8.91	18.0	51.9	12.12	14.85	30.00	86.50
KT06-09	ccc	3	20	d091	4.14	13.1	31.2	73.0	6.90	21.83	52.00	121.67
KT06-01	quenched	3	21	d011	6.16	6.38	34.4	50.1	10.27	10.63	57.33	83.50
Soln Std	ref	3	22	std-33	17.8	9.69	81.4	45.7	17.80	9.69	81.40	45.70
Soln Std	ref	4	1	std-41	21.2	9.81	80.5	50.7	21.20	9.81	80.50	50.70
KT06-16	ccc	4	2	d046	5.84	12.7	21.2	67.9	9.73	21.17	35.33	113.17
KT06-18	quenched	4	3	d099	5.32	9.24	19.4	58.7	8.87	15.40	32.33	97.84
ARM-1	ref	4	4	d066	9.81	7.79	21.6	34.8	16.35	12.98	36.00	58.00
KT06-06	ccc	4	5	d108	8.70	8.08	20.1	55.1	14.50	13.47	33.50	91.84
KT06-16	quenched	4	6	d095	5.34	13.3	21.2	69.5	8.90	22.17	35.33	115.84
KT06-14	quenched	4	7	d002	7.62	10.0	14.2	43.6	12.70	16.67	23.67	72.67
KT06-12	ccc	4	8	d115	8.72	10.5	19.4	52.2	14.53	17.50	32.33	87.00
KT06-12	quenched	4	9	d093	9.01	11.2	19.1	52.7	15.02	18.67	31.83	87.84
KT06-04	ccc	4	10	d069	3.93	7.62	28.3	51.1	6.55	12.70	47.17	85.17
KT06-06	quenched	4	11	d098	8.51	8.20	19.6	53.4	14.18	13.67	32.67	89.00
Soln Std	ref	4	12	std-42	19.0	9.70	80.1	49.2	19.00	9.70	80.10	49.20
KT06-10	quenched	4	13	d078	5.06	10.7	27.1	59.0	8.43	17.83	45.17	98.34
KT06-08	ccc	4	14	d042	5.23	11.4	24.0	67.0	8.72	19.00	40.00	111.67
KT06-10	ccc	4	15	d014	5.04	11.0	28.8	62.2	8.40	18.33	48.00	103.67
KT06-18	ccc	4	16	d096	4.91	9.22	20.4	61.4	8.18	15.37	34.00	102.34
KT06-14	ccc	4	17	d084	6.75	9.46	14.0	42.7	11.25	15.77	23.33	71.17
KT06-02	quenched	4	18	d060	7.30	5.85	30.1	47.6	12.17	9.75	50.17	79.33
KT06-02	ccc	4	19	d116	6.69	5.26	28.7	46.0	11.15	8.77	47.83	76.67
KT06-04	quenched	4	20	d100	4.84	8.85	28.5	56.6	8.07	14.75	47.50	94.34
KT06-08	quenched	4	21	d064	5.04	10.7	21.8	63.1	8.40	17.83	36.33	105.17
Soln Std	ref	4	22	std-43	19.7	9.79	81.2	49.6	19.70	9.79	81.20	49.60
Soln Std	ref	5	1	std-51	19.9	10.0	80.3	50.3	19.90	10.00	80.30	50.30
KT06-12	quenched	5	2	d074	9.19	11.7	19.4	55.6	15.32	19.50	32.33	92.67
KT06-08	ccc	5	3	d071	5.34	11.8	22.3	70.1	8.90	19.67	37.17	116.84
KT06-02	ccc	5	4	d001	6.69	5.46	28.7	47.0	11.15	9.10	47.83	78.33
KT06-04	ccc	5	5	d053	3.86	8.03	25.6	52.9	6.43	13.38	42.67	88.17
KT06-16	ccc	5	6	d012	5.08	13.3	22.0	70.3	8.47	22.17	36.67	117.17
KT06-02	quenched	5	7	d034	7.51	6.22	31.7	49.5	12.52	10.37	52.83	82.50
KT06-18	ccc	5	8	d006	4.94	9.78	22.1	64.1	8.23	16.30	36.83	106.84
KT06-14	quenched	5	9	d114	7.45	10.4	14.7	44.6	12.42	17.33	24.50	74.33
ARM-1	ref	5	10	d065	9.94	8.39	21.3	36.9	16.57	13.98	35.50	61.50
KT06-04	quenched	5	11	d101	4.86	9.42	28.5	59.3	8.10	15.70	47.50	98.84
Soln Std	ref	5	12	std-52	20.0	10.3	82.4	51.5	20.00	10.30	82.40	51.50
KT06-18	quenched	5	13	d109	5.46	10.0	18.5	62.0	9.10	16.67	30.83	103.34
KT06-10	quenched	5	14	d035	5.22	12.0	29.0	64.9	8.70	20.00	48.33	108.17
KT06-10	ccc	5	15	d077	4.86	11.0	26.5	61.5	8.10	18.33	44.17	102.50
KT06-06	ccc	5	16	d072	8.38	8.43	21.9	56.3	13.97	14.05	36.50	93.84
KT06-12	ccc	5	17	d056	8.35	10.9	17.7	53.0	13.92	18.17	29.50	88.34
KT06-08	quenched	5	18	d015	5.03	11.6	23.3	66.9	8.38	19.33	38.83	111.50
KT06-14	ccc	5	19	d083	7.09	10.4	14.2	45.8	11.82	17.33	23.67	76.33
KT06-16	quenched	5	20	d025	5.23	14.3	22.1	73.5	8.72	23.83	36.83	122.50
KT06-06	quenched	5	21	d087	8.47	8.62	19.9	54.8	14.12	14.37	33.17	91.34
Soln Std	ref	5	22	std-53	20.1	10.5	81.2	52.1	20.10	10.50	81.20	52.10
Soln Std	ref	6	1	std-61	19.6	9.86	79.9	50.4	19.60	9.86	79.90	50.40
KT06-12	quenched	6	2	d059	8.69	11.1	18.5	52.6	14.48	18.50	30.83	87.67
KT06-04	ccc	6	3	d076	3.64	7.98	27.1	53.2	6.07	13.30	45.17	88.67
KT06-14	ccc	6	4	d045	6.59	10.0	13.5	45.1	10.98	16.67	22.50	75.17
KT06-06	quenched	6	5	d051	8.07	8.20	18.8	53.8	13.45	13.67	31.33	89.67
KT06-18	quenched	6	6	d007	4.65	9.66	18.1	60.8	7.75	16.10	30.17	101.34
KT06-02	ccc	6	7	d031	6.01	5.31	28.0	45.7	10.02	8.85	46.67	76.17
KT06-02	quenched	6	8	d052	7.04	6.04	29.8	48.9	11.73	10.07	49.67	81.50

Table B-1. Measurements of the PCT Solutions for the KT06-Series Glasses As-Received (ar) and After Appropriate Adjustments (ppm). (continued)

Glass ID	Heat Treatment	Block	Seq	Lab ID	B (ar)	Li (ar)	Na (ar)	Si (ar)	B (ppm)	Li (ppm)	Na (ppm)	Si (ppm)
KT06-16	quenched	6	9	d094	5.51	15.3	42.2	78.7	9.18	25.50	70.33	131.17
KT06-14	quenched	6	10	d037	7.38	10.7	15.7	46.2	12.30	17.83	26.17	77.00
KT06-12	ccc	6	11	d029	7.89	10.5	19.0	51.8	13.15	17.50	31.67	86.34
Soln Std	ref	6	12	std-62	19.6	10.1	83.3	51.1	19.60	10.10	83.30	51.10
KT06-08	quenched	6	13	d027	5.38	11.0	21.3	64.3	8.97	18.33	35.50	107.17
KT06-16	ccc	6	14	d080	4.82	13.1	20.7	69.7	8.03	21.83	34.50	116.17
KT06-10	quenched	6	15	d062	4.35	11.1	28.4	61.7	7.25	18.50	47.33	102.84
KT06-10	ccc	6	16	d028	4.45	10.8	27.1	61.6	7.42	18.00	45.17	102.67
KT06-04	quenched	6	17	d030	4.30	9.12	28.4	58.2	7.17	15.20	47.33	97.00
KT06-06	ccc	6	18	d106	7.65	7.81	18.9	52.9	12.75	13.02	31.50	88.17
ARM-1	ref	6	19	d061	9.09	8.06	20.2	35.7	15.15	13.43	33.67	59.50
KT06-08	ccc	6	20	d033	4.96	11.9	22.5	70.5	8.27	19.83	37.50	117.50
blank	ref	6	21	d009	<0.100	<1.00	<0.100	<0.100	0.08	0.83	0.08	0.08
KT06-18	ccc	6	22	d010	4.22	9.62	19.0	63.0	7.03	16.03	31.67	105.00
Soln Std	ref	6	23	std-63	19.7	10.1	80.8	51.3	19.70	10.10	80.80	51.30

Table B-2. Normalized PCT Results for the KT06-Series Glasses by Heat Treatment by Compositional View.

Glass ID	Heat Treatment	Comp View	log NL [B (g/L)]	log NL [Li(g/L)]	log NL [Na (g/L)]	log NL [Si (g/L)]	NL B(g/L)	NL Li (g/L)	NL Na (g/L)	NL Si (g/L)
ARM	ref	reference	-0.3408	-0.2438	-0.3112	-0.5616	0.456	0.570	0.488	0.274
EA	ref	reference	1.0662	0.8511	0.9897	0.4845	11.647	7.097	9.765	3.051
KT06-01	ccc	measured	-0.3176	-0.1892	-0.2248	-0.3920	0.481	0.647	0.596	0.406
KT06-02	ccc	measured	-0.3752	-0.2572	-0.3024	-0.4416	0.422	0.553	0.498	0.362
KT06-03	ccc	measured	-0.3006	-0.1173	-0.1264	-0.3078	0.500	0.763	0.748	0.492
KT06-04	ccc	measured	-0.3771	-0.2229	-0.2832	-0.4173	0.420	0.599	0.521	0.383
KT06-05	ccc	measured	-0.3639	-0.1877	-0.4023	-0.4081	0.433	0.649	0.396	0.391
KT06-06	ccc	measured	-0.2810	-0.1506	-0.3545	-0.3851	0.524	0.707	0.442	0.412
KT06-07	ccc	measured	-0.4075	-0.2406	-0.4915	-0.4717	0.391	0.575	0.322	0.338
KT06-08	ccc	measured	-0.2375	-0.1027	-0.3027	-0.2989	0.579	0.789	0.498	0.502
KT06-09	ccc	measured	-0.2394	-0.0656	-0.2092	-0.2681	0.576	0.860	0.618	0.539
KT06-10	ccc	measured	-0.2823	-0.1201	-0.2532	-0.3303	0.522	0.758	0.558	0.467
KT06-11	ccc	measured	-0.3135	-0.1043	-0.3237	-0.3400	0.486	0.786	0.475	0.457
KT06-12	ccc	measured	-0.2662	-0.1372	-0.3525	-0.3685	0.542	0.729	0.444	0.428
KT06-13	ccc	measured	-0.3296	-0.1713	-0.3832	-0.3729	0.468	0.674	0.414	0.424
KT06-14	ccc	measured	-0.3466	-0.1710	-0.4969	-0.4372	0.450	0.675	0.318	0.365
KT06-15	ccc	measured	-0.2996	-0.0949	-0.3159	-0.3178	0.502	0.804	0.483	0.481
KT06-16	ccc	measured	-0.2358	-0.1450	-0.3134	-0.3006	0.581	0.716	0.486	0.500
KT06-17	ccc	measured	-0.3470	-0.1668	-0.3960	-0.4144	0.450	0.681	0.402	0.385
KT06-18	ccc	measured	-0.2820	-0.1352	-0.3217	-0.3403	0.522	0.733	0.477	0.457
KT06-01	ccc	targeted	-0.3318	-0.2063	-0.2306	-0.4149	0.466	0.622	0.588	0.385
KT06-02	ccc	targeted	-0.3847	-0.2737	-0.3147	-0.4567	0.412	0.533	0.484	0.349
KT06-03	ccc	targeted	-0.3074	-0.1285	-0.1349	-0.3219	0.493	0.744	0.733	0.477
KT06-04	ccc	targeted	-0.3709	-0.2301	-0.3380	-0.4240	0.426	0.589	0.459	0.377
KT06-05	ccc	targeted	-0.3691	-0.1968	-0.4410	-0.4238	0.427	0.636	0.362	0.377
KT06-06	ccc	targeted	-0.2791	-0.1597	-0.3910	-0.3889	0.526	0.692	0.406	0.408
KT06-07	ccc	targeted	-0.4247	-0.2493	-0.5285	-0.4797	0.376	0.563	0.296	0.331
KT06-08	ccc	targeted	-0.2377	-0.1094	-0.3374	-0.3086	0.578	0.777	0.460	0.491
KT06-09	ccc	targeted	-0.2374	-0.0692	-0.2198	-0.2825	0.579	0.853	0.603	0.522
KT06-10	ccc	targeted	-0.2724	-0.1388	-0.2591	-0.3472	0.534	0.726	0.551	0.450
KT06-11	ccc	targeted	-0.3179	-0.1135	-0.3107	-0.3545	0.481	0.770	0.489	0.442
KT06-12	ccc	targeted	-0.2748	-0.1509	-0.3407	-0.3877	0.531	0.706	0.456	0.410
KT06-13	ccc	targeted	-0.3285	-0.1860	-0.3730	-0.3824	0.469	0.652	0.424	0.415
KT06-14	ccc	targeted	-0.3616	-0.1799	-0.4693	-0.4570	0.435	0.661	0.339	0.349
KT06-15	ccc	targeted	-0.3094	-0.1083	-0.2792	-0.3369	0.490	0.779	0.526	0.460
KT06-16	ccc	targeted	-0.2331	-0.1497	-0.2840	-0.3134	0.585	0.708	0.520	0.486
KT06-17	ccc	targeted	-0.3545	-0.1784	-0.3743	-0.4332	0.442	0.663	0.422	0.369
KT06-18	ccc	targeted	-0.2815	-0.1469	-0.3013	-0.3555	0.523	0.713	0.500	0.441
KT06-01	quenched	measured	-0.3086	-0.1781	-0.2322	-0.3853	0.491	0.664	0.586	0.412
KT06-02	quenched	measured	-0.3229	-0.2043	-0.2721	-0.4194	0.475	0.625	0.535	0.381
KT06-03	quenched	measured	-0.2615	-0.1079	-0.1138	-0.2953	0.548	0.780	0.769	0.507
KT06-04	quenched	measured	-0.2895	-0.1588	-0.2598	-0.3730	0.513	0.694	0.550	0.424
KT06-05	quenched	measured	-0.3507	-0.1587	-0.4113	-0.4046	0.446	0.694	0.388	0.394
KT06-06	quenched	measured	-0.2749	-0.1381	-0.3728	-0.3912	0.531	0.728	0.424	0.406
KT06-07	quenched	measured	-0.3748	-0.1845	-0.4761	-0.4535	0.422	0.654	0.334	0.352
KT06-08	quenched	measured	-0.2397	-0.1258	-0.3182	-0.3277	0.576	0.749	0.481	0.470
KT06-09	quenched	measured	-0.2423	-0.0713	-0.2027	-0.2710	0.572	0.849	0.627	0.536
KT06-10	quenched	measured	-0.2746	-0.1075	-0.2421	-0.3299	0.531	0.781	0.573	0.468
KT06-11	quenched	measured	-0.2639	-0.1051	-0.3605	-0.3729	0.545	0.785	0.436	0.424
KT06-12	quenched	measured	-0.2336	-0.1095	-0.3454	-0.3580	0.584	0.777	0.451	0.439
KT06-13	quenched	measured	-0.3496	-0.1614	-0.4069	-0.3865	0.447	0.690	0.392	0.411
KT06-14	quenched	measured	-0.3055	-0.1532	-0.4680	-0.4345	0.495	0.703	0.340	0.368
KT06-15	quenched	measured	-0.2838	-0.0820	-0.3167	-0.3200	0.520	0.828	0.482	0.479
KT06-16	quenched	measured	-0.2252	-0.1053	-0.2096	-0.2732	0.595	0.785	0.617	0.533
KT06-17	quenched	measured	-0.3494	-0.1527	-0.4001	-0.4067	0.447	0.704	0.398	0.392
KT06-18	quenched	measured	-0.2419	-0.1311	-0.3617	-0.3568	0.573	0.740	0.435	0.440
KT06-01	quenched	targeted	-0.3228	-0.1953	-0.2380	-0.4083	0.476	0.638	0.578	0.391
KT06-02	quenched	targeted	-0.3324	-0.2208	-0.2844	-0.4345	0.465	0.602	0.520	0.368
KT06-03	quenched	targeted	-0.2684	-0.1192	-0.1223	-0.3095	0.539	0.760	0.755	0.490
KT06-04	quenched	targeted	-0.2832	-0.1660	-0.3147	-0.3796	0.521	0.682	0.485	0.417
KT06-05	quenched	targeted	-0.3560	-0.1679	-0.4501	-0.4204	0.441	0.679	0.355	0.380
KT06-06	quenched	targeted	-0.2730	-0.1473	-0.4093	-0.3950	0.533	0.712	0.390	0.403
KT06-07	quenched	targeted	-0.3920	-0.1931	-0.5131	-0.4615	0.406	0.641	0.307	0.346
KT06-08	quenched	targeted	-0.2400	-0.1324	-0.3529	-0.3374	0.576	0.737	0.444	0.460
KT06-09	quenched	targeted	-0.2403	-0.0749	-0.2134	-0.2854	0.575	0.842	0.612	0.518
KT06-10	quenched	targeted	-0.2648	-0.1262	-0.2481	-0.3468	0.544	0.748	0.565	0.450
KT06-11	quenched	targeted	-0.2683	-0.1143	-0.3475	-0.3874	0.539	0.769	0.449	0.410

Table B-2. Normalized PCT Results for the KT06-Series Glasses by Heat Treatment by Compositional View. (continued)

Glass ID	Heat Treatment	Comp View	log NL [B (g/L)]	log NL [Li(g/L)]	log NL [Na (g/L)]	log NL [Si (g/L)]	NL B(g/L)	NL Li (g/L)	NL Na (g/L)	NL Si (g/L)
KT06-12	quenched	targeted	-0.2422	-0.1233	-0.3336	-0.3771	0.572	0.753	0.464	0.420
KT06-13	quenched	targeted	-0.3486	-0.1761	-0.3967	-0.3960	0.448	0.667	0.401	0.402
KT06-14	quenched	targeted	-0.3205	-0.1620	-0.4404	-0.4544	0.478	0.689	0.363	0.351
KT06-15	quenched	targeted	-0.2936	-0.0954	-0.2800	-0.3391	0.509	0.803	0.525	0.458
KT06-16	quenched	targeted	-0.2225	-0.1100	-0.1802	-0.2860	0.599	0.776	0.660	0.518
KT06-17	quenched	targeted	-0.3569	-0.1643	-0.3784	-0.4255	0.440	0.685	0.418	0.375
KT06-18	quenched	targeted	-0.2414	-0.1428	-0.3414	-0.3720	0.574	0.720	0.456	0.425

Exhibit B-1. KT06 PCT Measurements (as Common Logarithms) in Analytical Sequence by Element.

Variability Chart for log[B ppm]

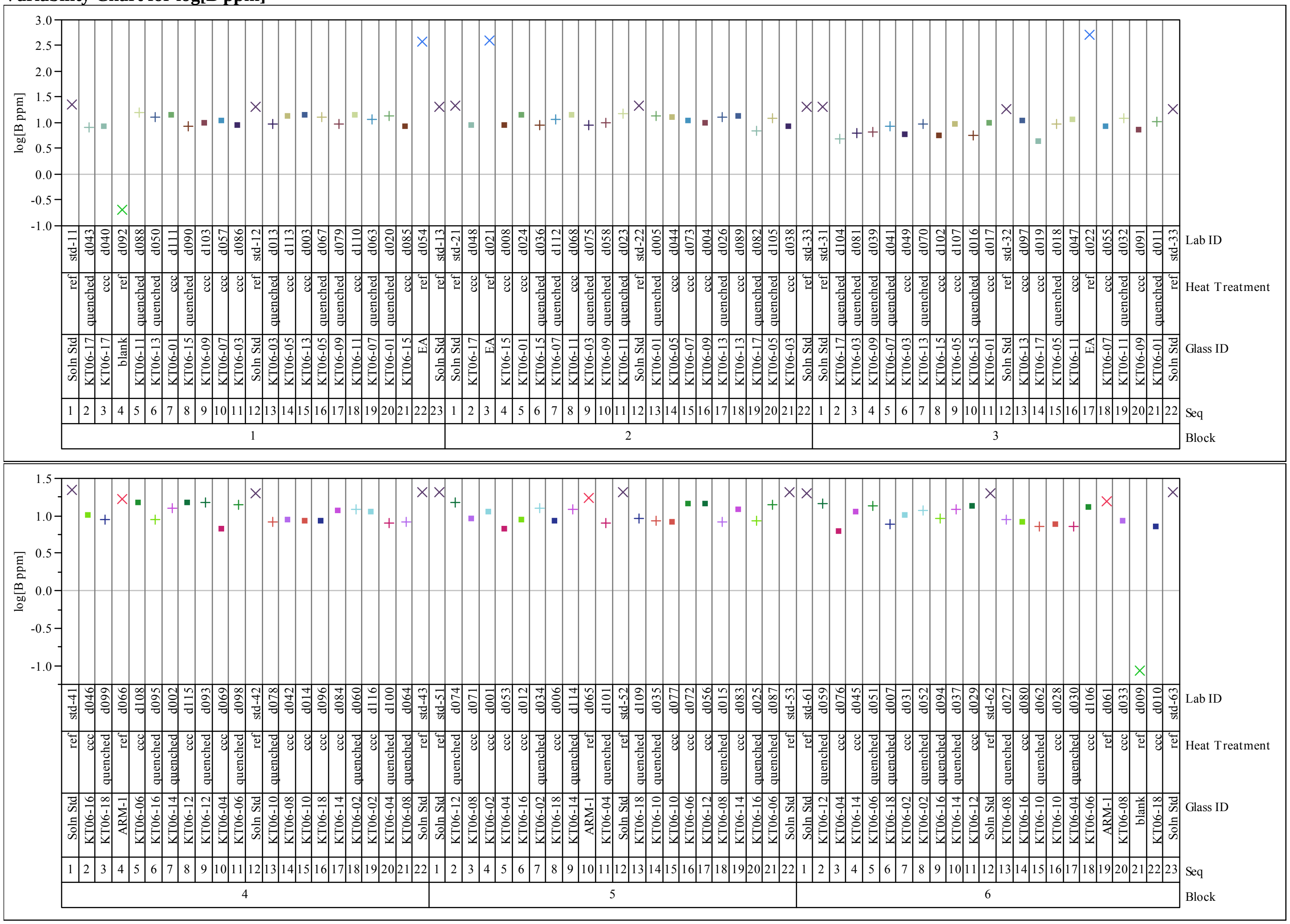


Exhibit B-1. KT06 PCT Measurements (as Common Logarithms) in Analytical Sequence by Element. (continued)

Variability Chart for log[Li ppm]

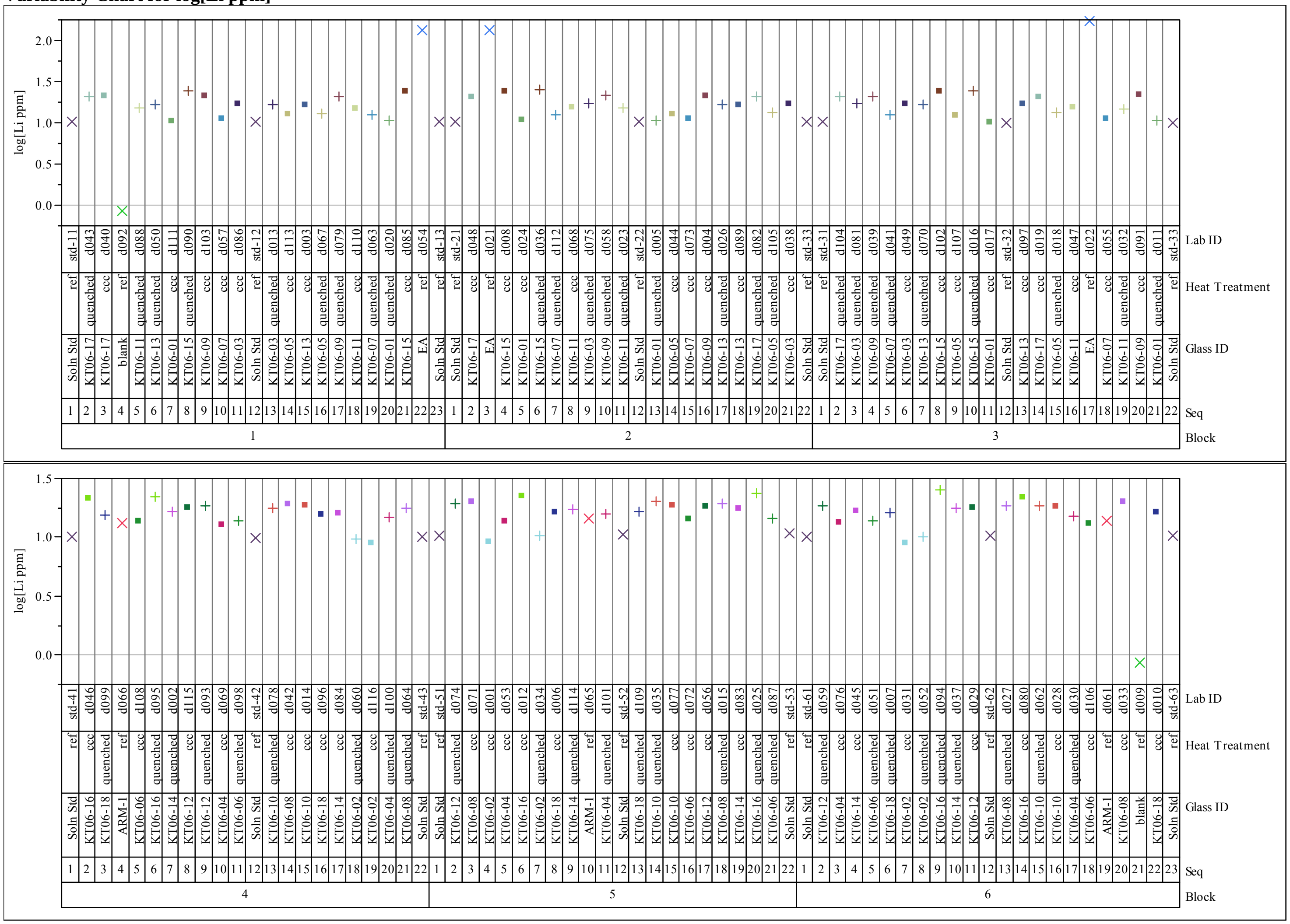


Exhibit B-1. KT06 PCT Measurements (as Common Logarithms) in Analytical Sequence by Element. (continued)

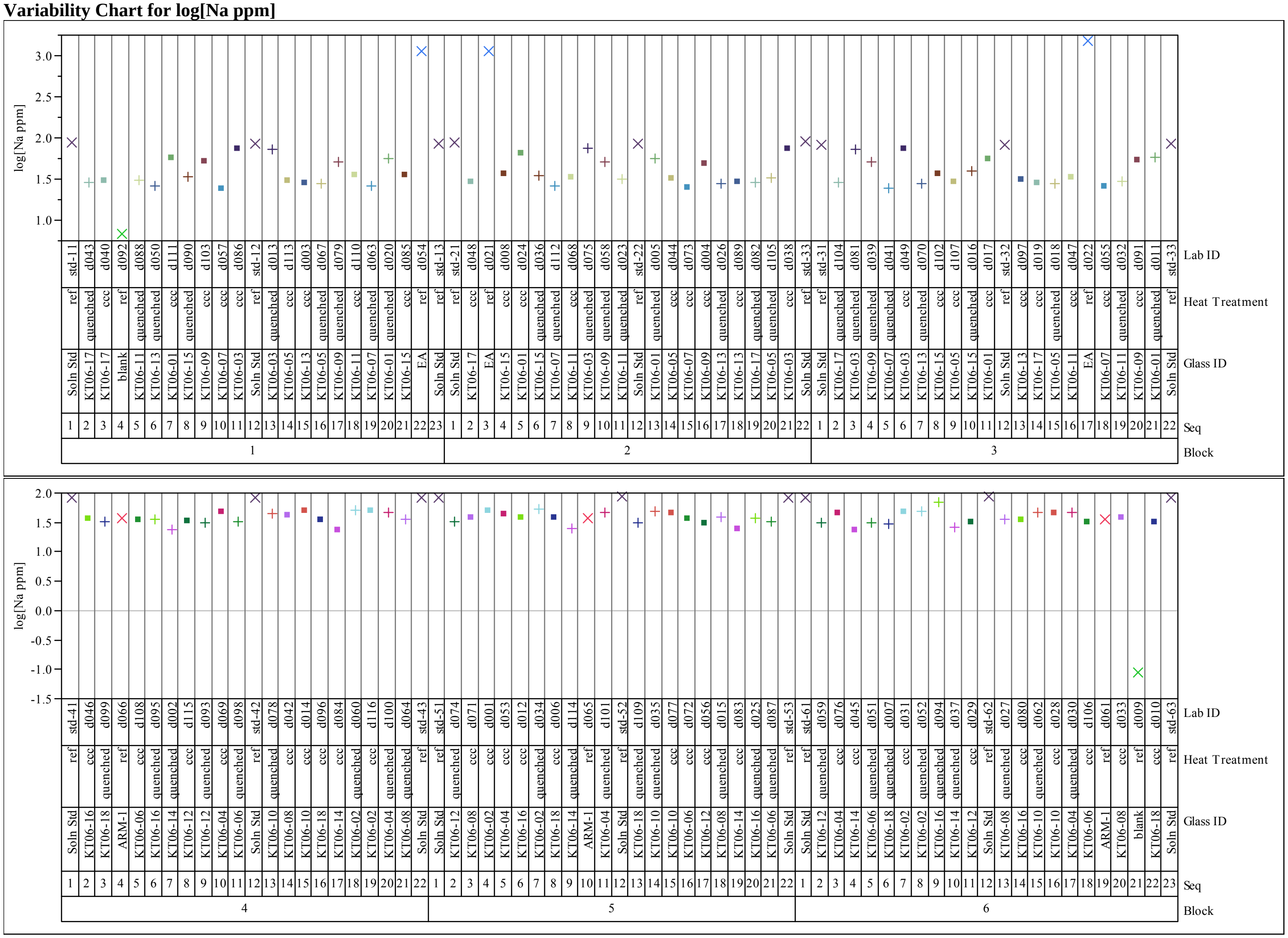


Exhibit B-1. KT06 PCT Measurements (as Common Logarithms) in Analytical Sequence by Element. (continued)

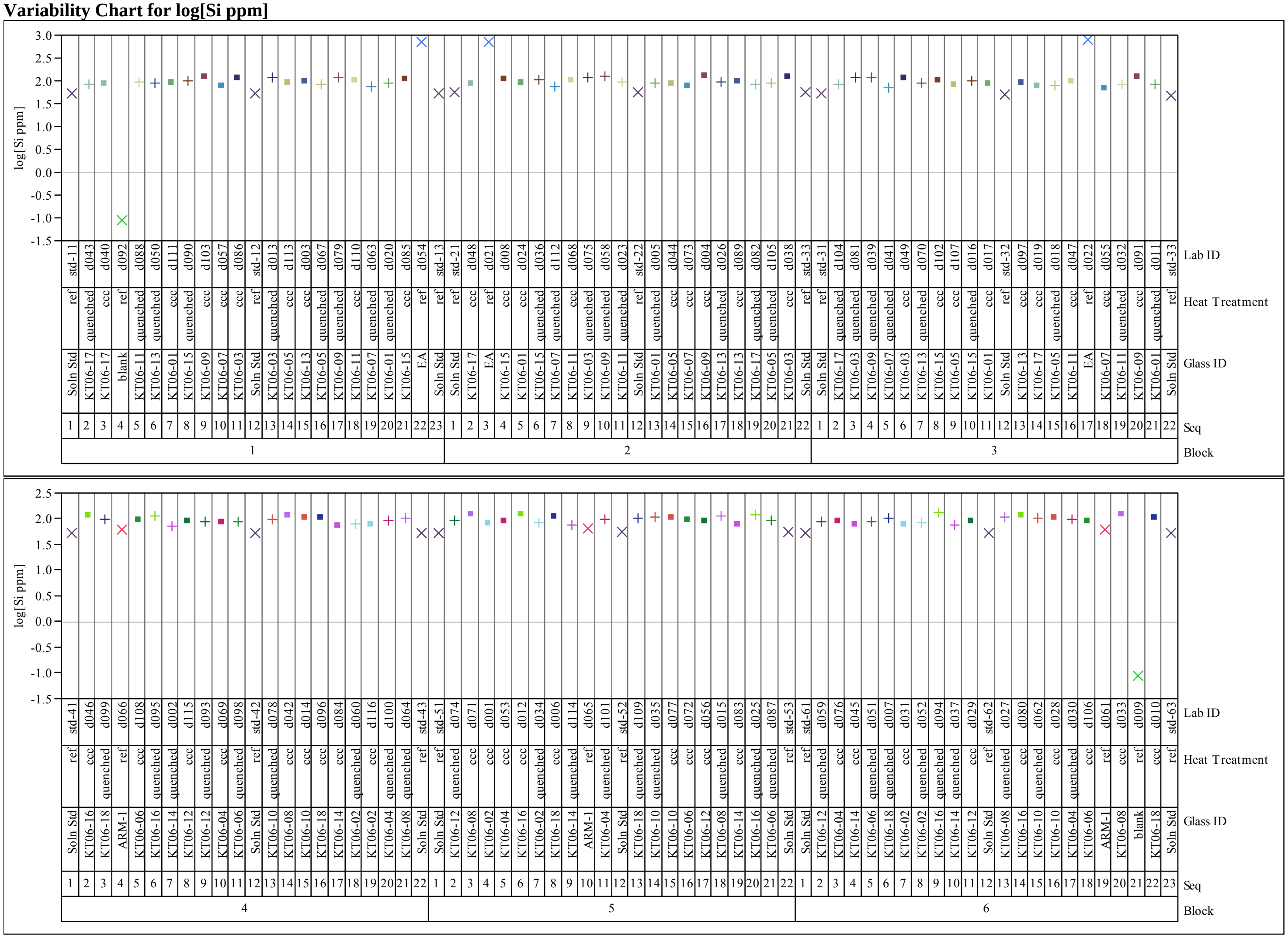
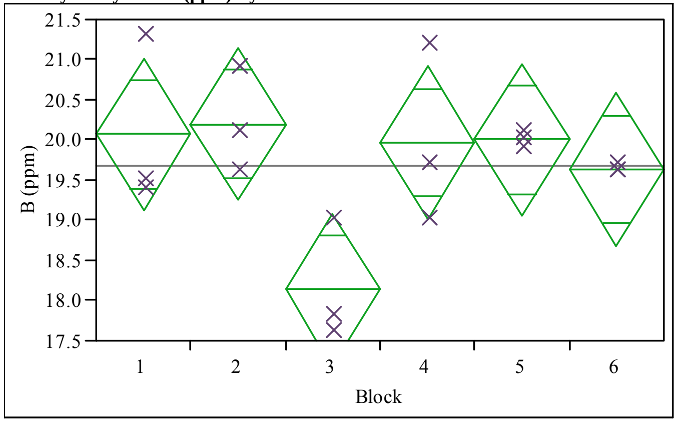


Exhibit B-2. Statistical Evaluation of the ICP-AES Calibration Effects from the Multi-Element Standard Solution Results by Oxide.

Oneway Analysis of B (ppm) By Block



Oneway Anova
Summary of Fit

Rsquare	0.567761
Adj Rsquare	0.387661
Root Mean Square Error	0.755351
Mean of Response	19.66667
Observations (or Sum Wgts)	18

Analysis of Variance

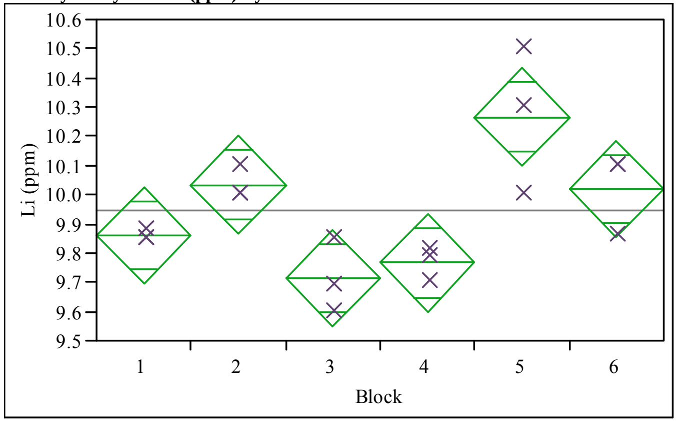
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	8.993333	1.79867	3.1525	0.0479
Error	12	6.846667	0.57056		
C. Total	17	15.840000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	20.0667	0.43610	19.116	21.017
2	3	20.2000	0.43610	19.250	21.150
3	3	18.1333	0.43610	17.183	19.084
4	3	19.9667	0.43610	19.016	20.917
5	3	20.0000	0.43610	19.050	20.950
6	3	19.6333	0.43610	18.683	20.584

Std Error uses a pooled estimate of error variance

Oneway Analysis of Li (ppm) By Block



Oneway Anova
Summary of Fit

Rsquare	0.748492
Adj Rsquare	0.643697
Root Mean Square Error	0.132686
Mean of Response	9.943333
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	0.62873333	0.125747	7.1424	0.0026
Error	12	0.21126667	0.017606		
C. Total	17	0.84000000			

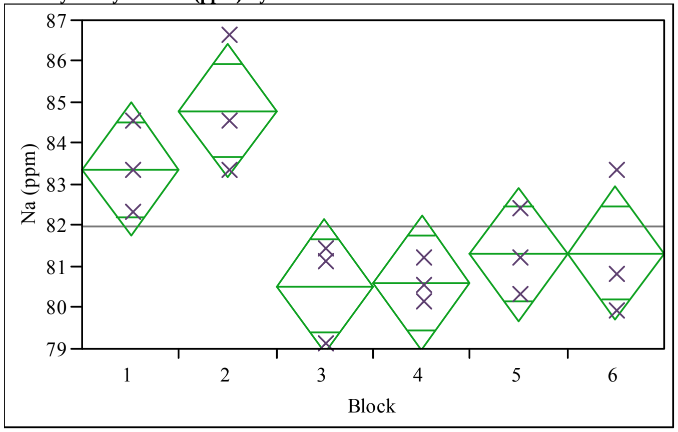
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	9.8600	0.07661	9.693	10.027
2	3	10.0333	0.07661	9.866	10.200
3	3	9.7133	0.07661	9.546	9.880
4	3	9.7667	0.07661	9.600	9.934
5	3	10.2667	0.07661	10.100	10.434
6	3	10.0200	0.07661	9.853	10.187

Std Error uses a pooled estimate of error variance

Exhibit B-2. Statistical Evaluation of the ICP-AES Calibration Effects from the Multi-Element Standard Solution Results by Oxide. (continued)

Oneway Analysis of Na (ppm) By Block Series=KT6



Oneway Anova
Summary of Fit

Rsquare	0.68683
Adj Rsquare	0.556342
Root Mean Square Error	1.296791
Mean of Response	81.98889
Observations (or Sum Wgts)	18

Analysis of Variance

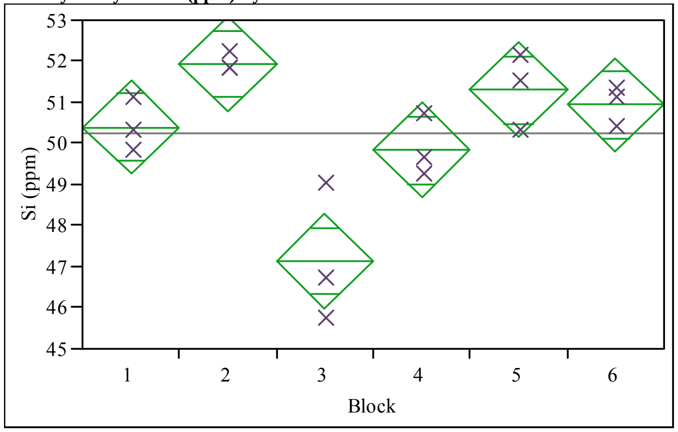
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	44.257778	8.85156	5.2636	0.0087
Error	12	20.180000	1.68167		
C. Total	17	64.437778			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	83.3667	0.74870	81.735	84.998
2	3	84.8000	0.74870	83.169	86.431
3	3	80.5333	0.74870	78.902	82.165
4	3	80.6000	0.74870	78.969	82.231
5	3	81.3000	0.74870	79.669	82.931
6	3	81.3333	0.74870	79.702	82.965

Std Error uses a pooled estimate of error variance

Oneway Analysis of Si (ppm) By Block Series=KT6



Oneway Anova
Summary of Fit

Rsquare	0.810691
Adj Rsquare	0.731812
Root Mean Square Error	0.914087
Mean of Response	50.25556
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Block	5	42.937778	8.58756	10.2777	0.0005
Error	12	10.026667	0.83556		
C. Total	17	52.964444			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	3	50.4000	0.52775	49.250	51.550
2	3	51.9333	0.52775	50.783	53.083
3	3	47.1333	0.52775	45.983	48.283
4	3	49.8333	0.52775	48.683	50.983
5	3	51.3000	0.52775	50.150	52.450
6	3	50.9333	0.52775	49.783	52.083

Std Error uses a pooled estimate of error variance

Exhibit B-3. KT06 PCT Results (as common logarithms) Grouped by Glass ID and Heat Treatment.

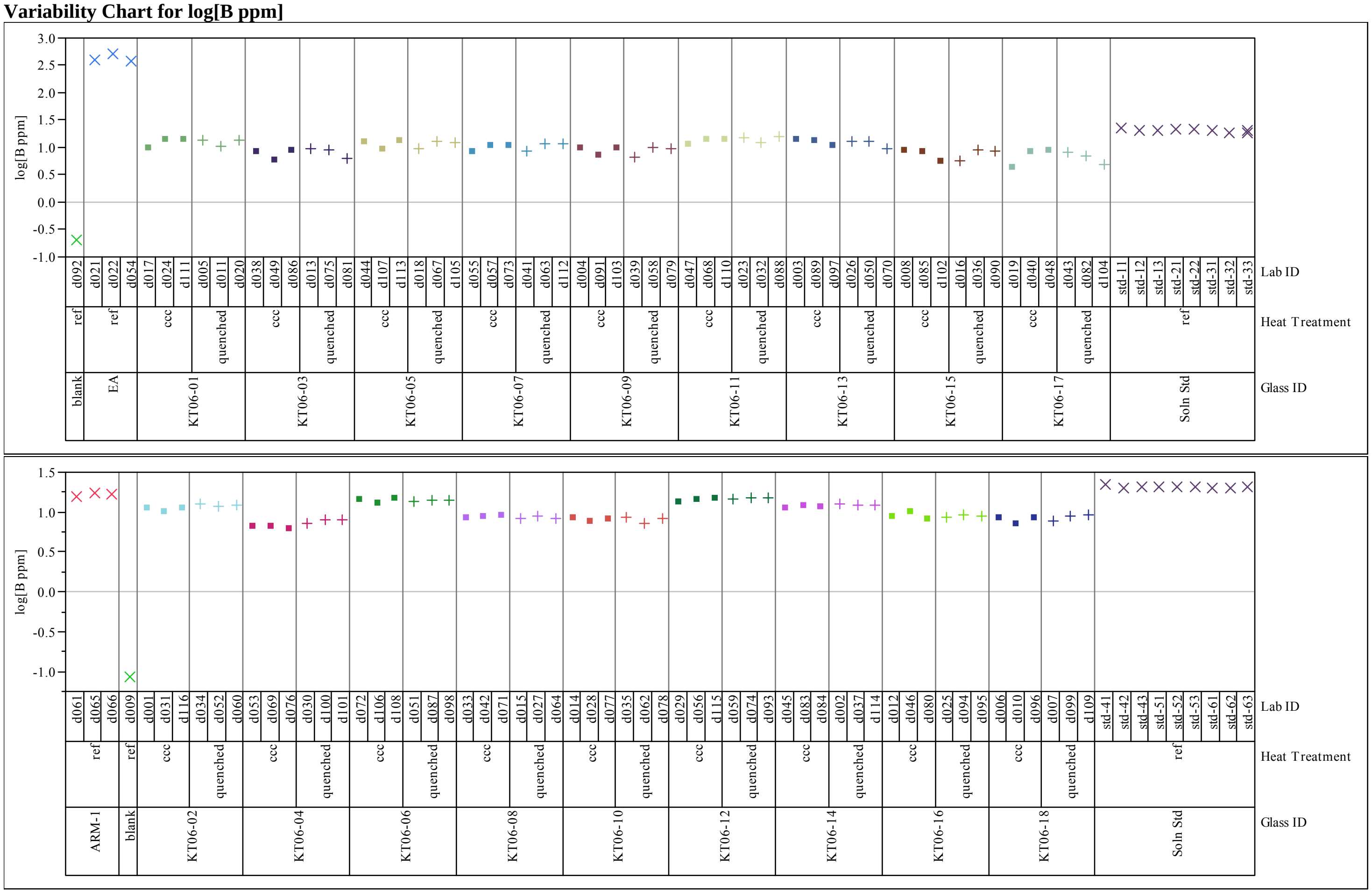


Exhibit B-3. KT06 PCT Results (as common logarithms) Grouped by Glass ID and Heat Treatment. (continued)

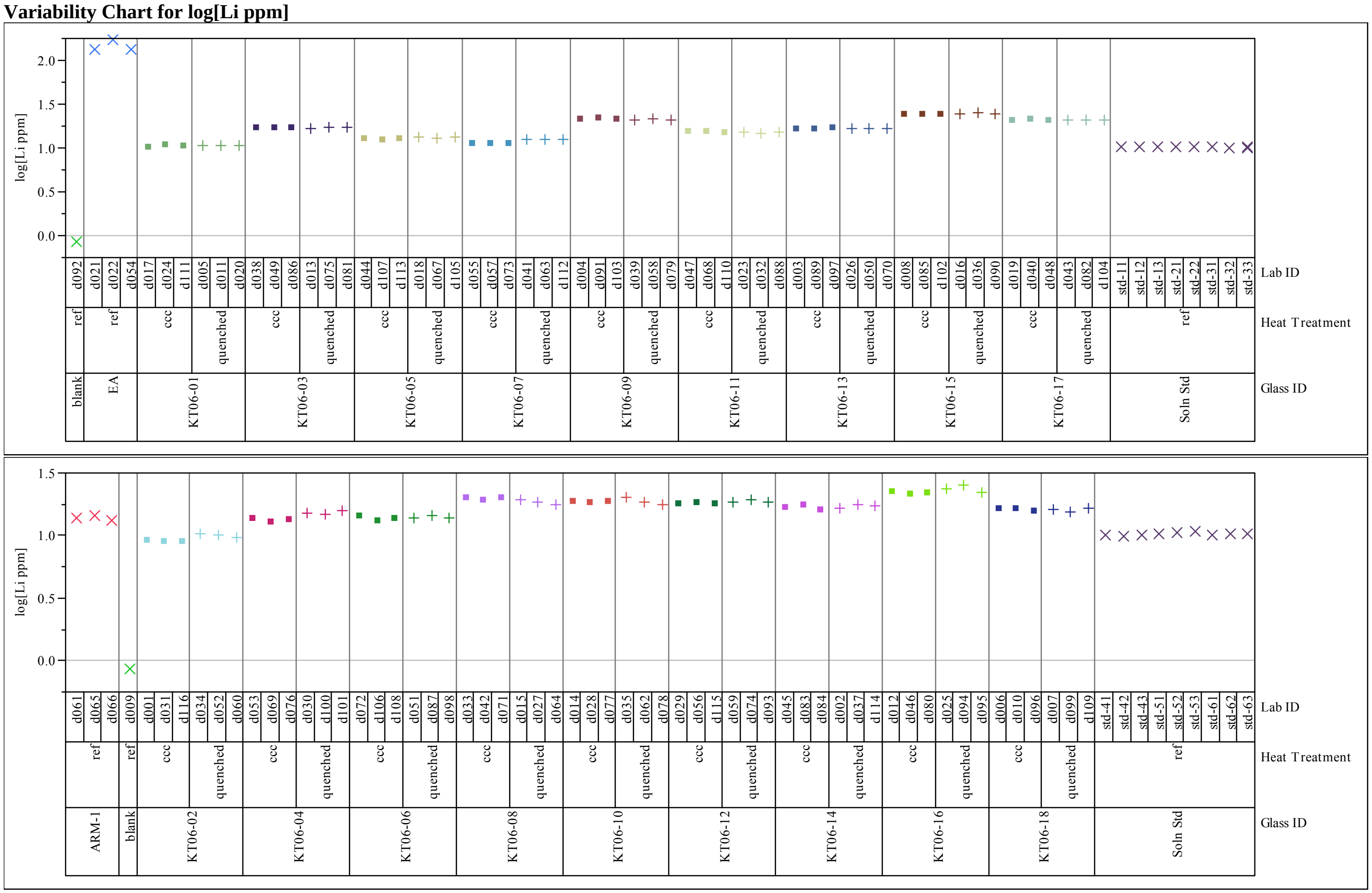


Exhibit B-3. KT06 PCT Results (as common logarithms) Grouped by Glass ID and Heat Treatment. (continued)

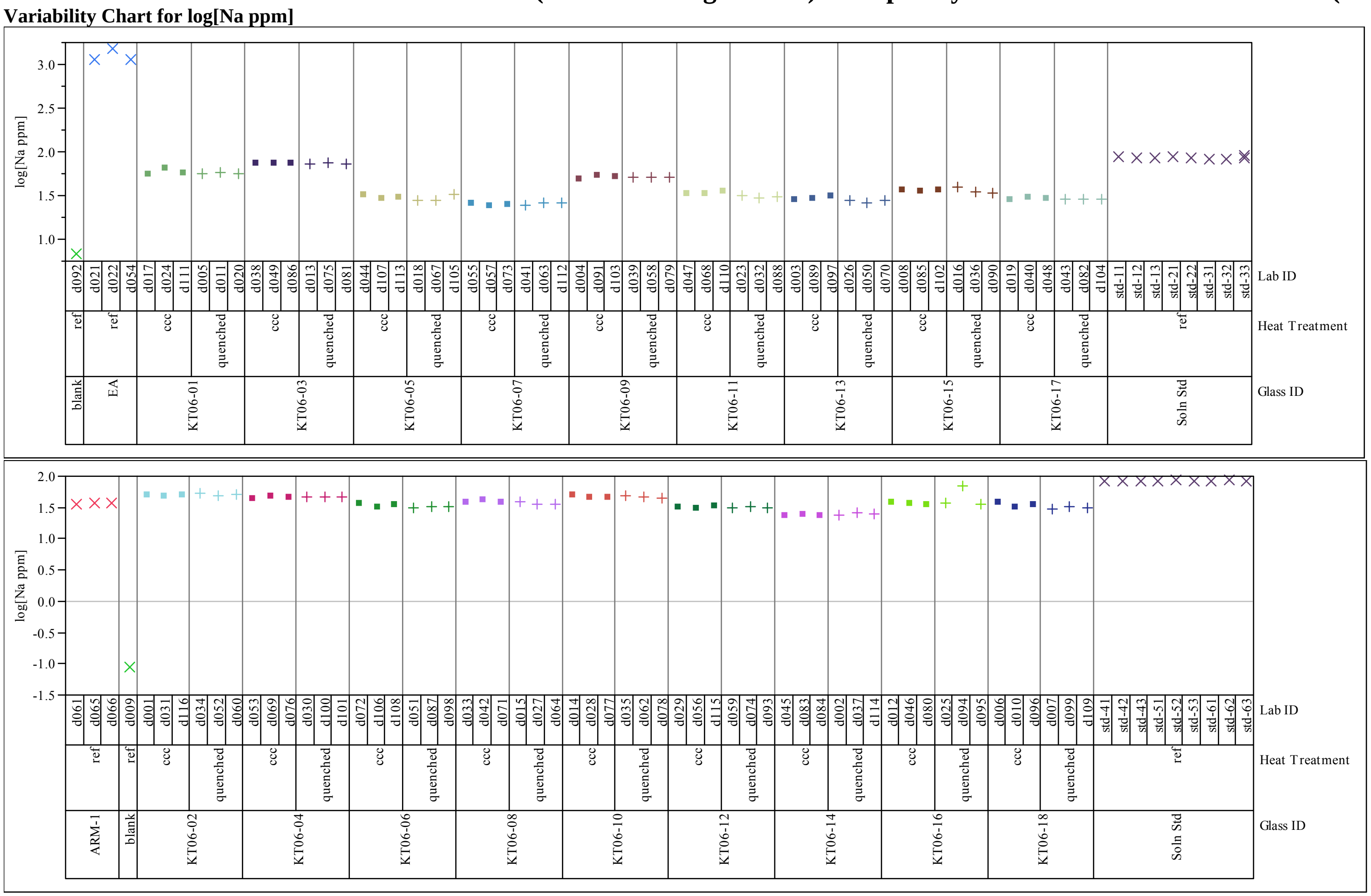


Exhibit B-3. KT06 PCT Results (as common logarithms) Grouped by Glass ID and Heat Treatment. (continued)

Variability Chart for log[Si ppm]

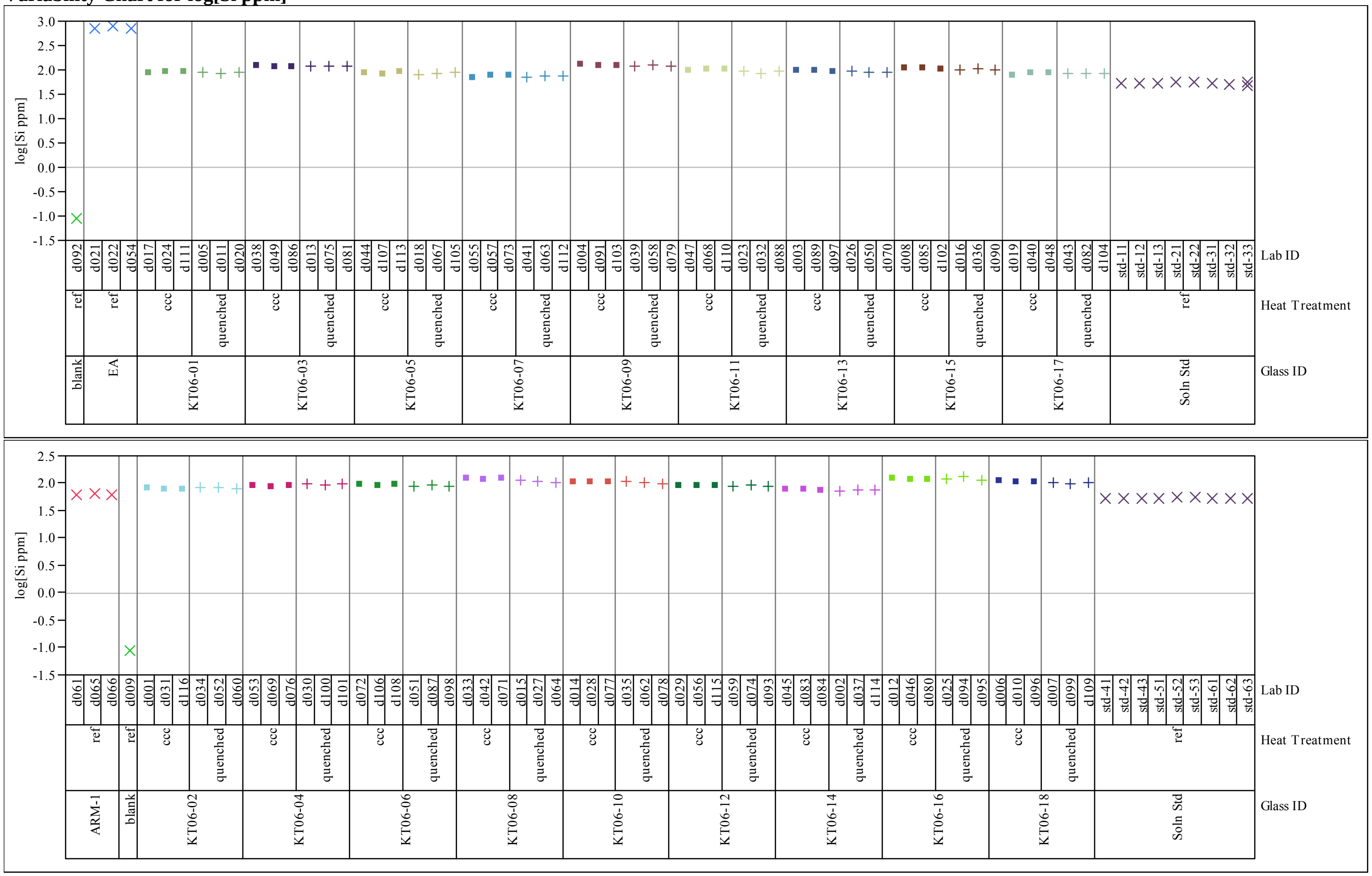


Exhibit B-4. Correlations and Scatter Plots of the KT06 Normalized PCTs Over All Compositional Views and Heat Treatments.

Multivariate Correlations

	log NL[B (g/L)]	log NL[Li(g/L)]	log NL[Na (g/L)]	log NL[Si (g/L)]
log NL[B (g/L)]	1.0000	0.9733	0.8979	0.9447
log NL[Li(g/L)]	0.9733	1.0000	0.8744	0.9609
log NL[Na (g/L)]	0.8979	0.8744	1.0000	0.9113
log NL[Si (g/L)]	0.9447	0.9609	0.9113	1.0000

Scatterplot Matrix

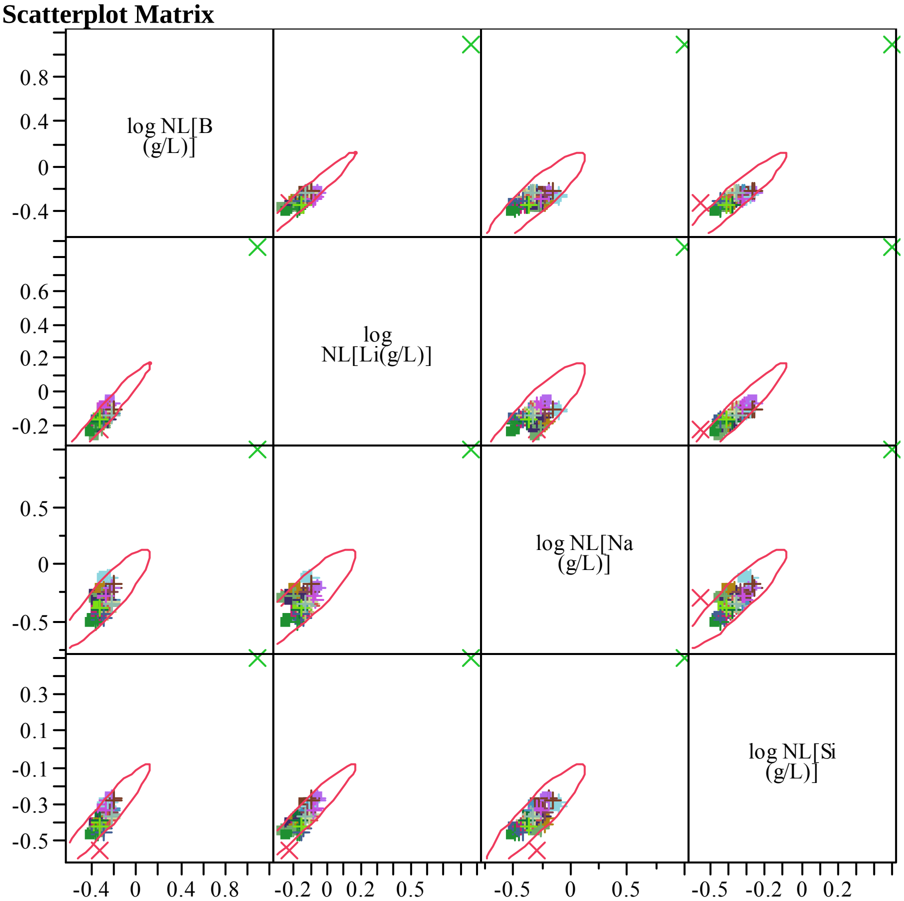
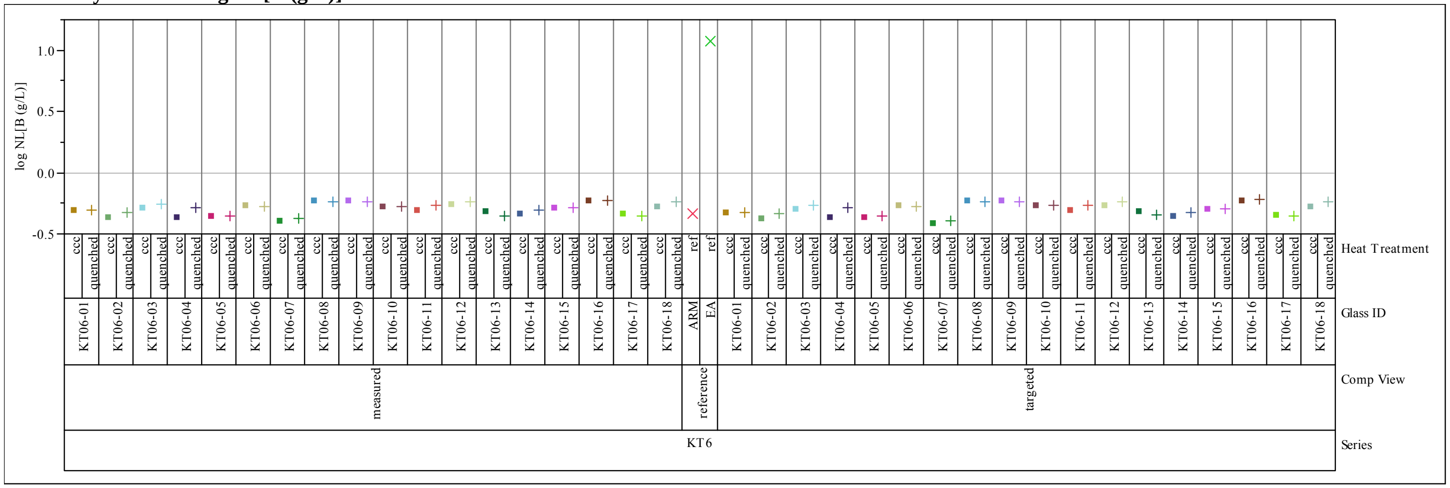


Exhibit B-5. Effects of Heat Treatment for the KT06 Glasses by Compositional View.

Variability Chart for log NL[B (g/L)]



Variability Chart for log NL[Li(g/L)]

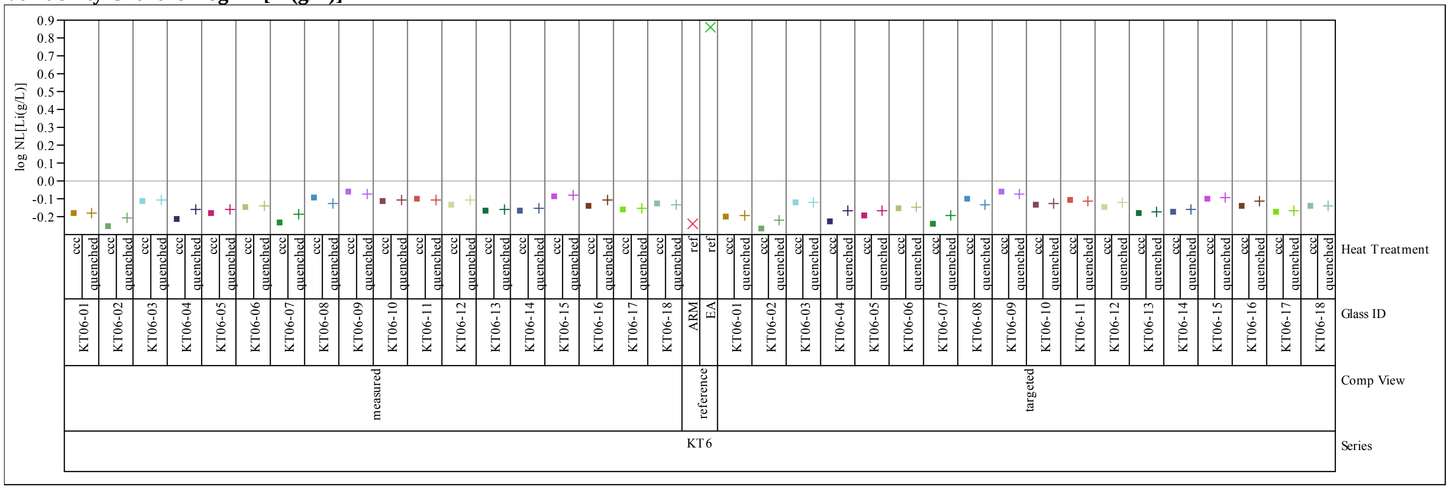
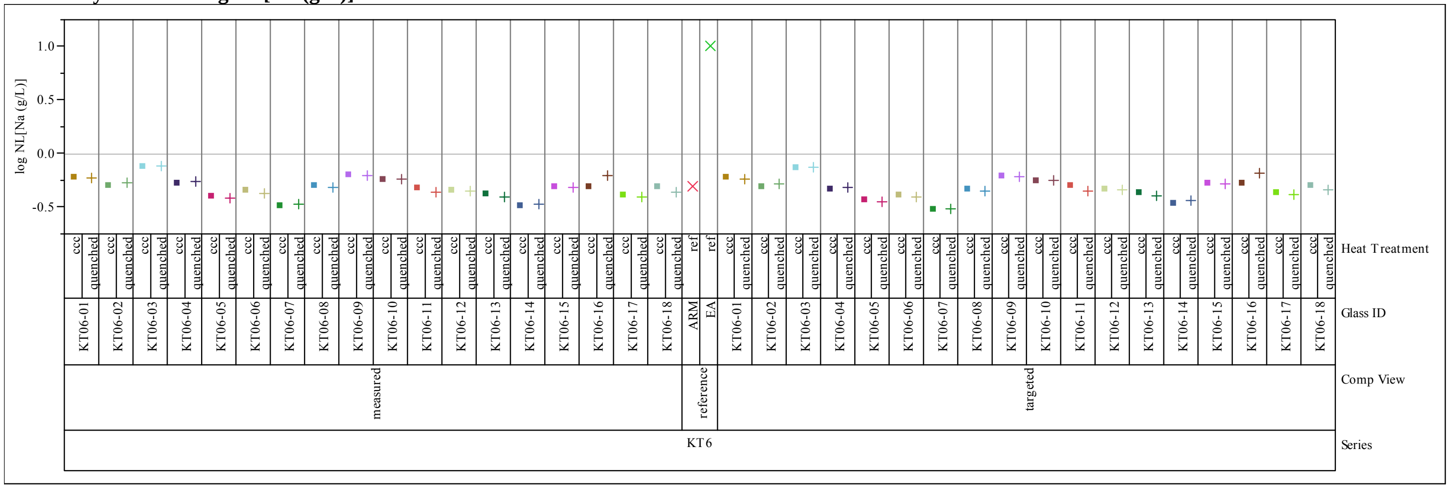


Exhibit B-5. Effects of Heat Treatment for the KT06 Glasses by Compositional View. (continued)

Variability Chart for log NL[Na (g/L)]



Variability Chart for log NL[Si (g/L)]

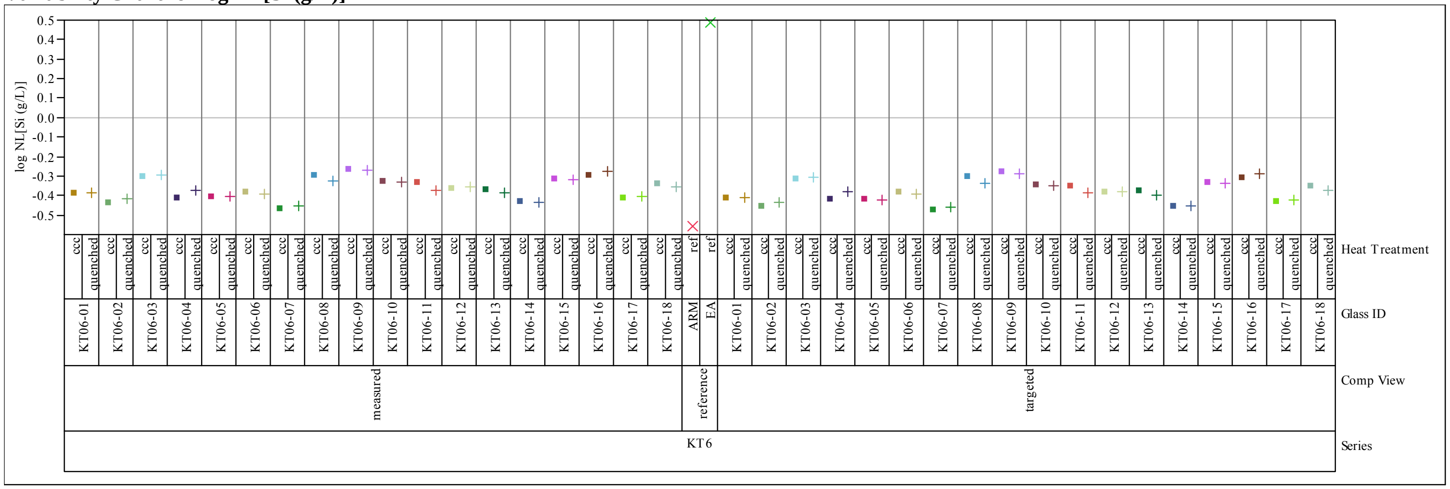
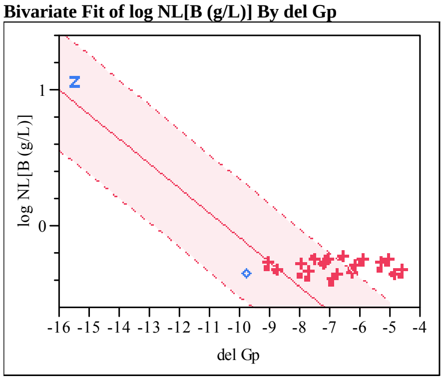


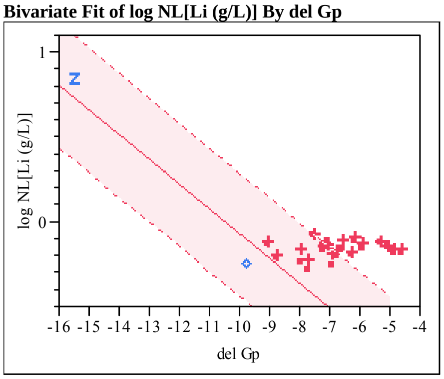
Exhibit B-6. PCT Measurements versus Durability Model Predictions.

Based Upon Targeted Compositions

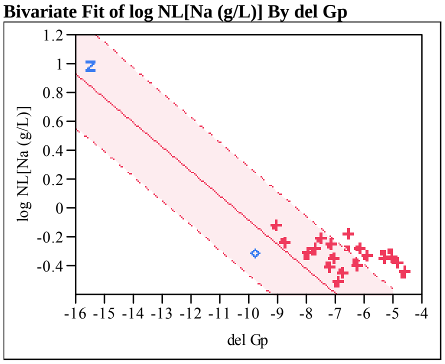
Bivariate Fit of log NL[B (g/L)] By del Gp



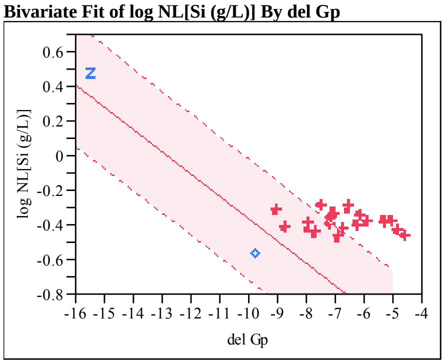
Bivariate Fit of log NL[Li (g/L)] By del Gp



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

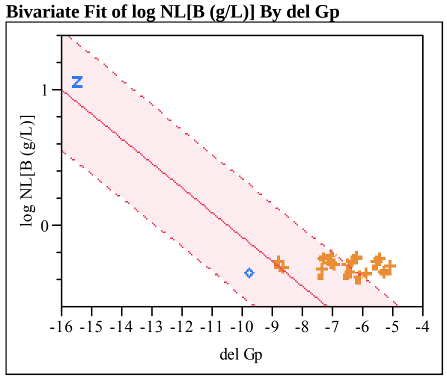


Bivariate Fit of log NL[Si (g/L)] By del Gp

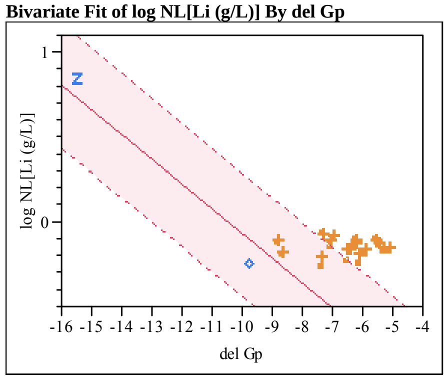


Based Upon Measured Compositions

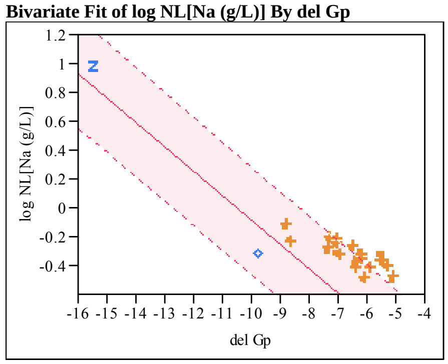
Bivariate Fit of log NL[B (g/L)] By del Gp



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



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



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

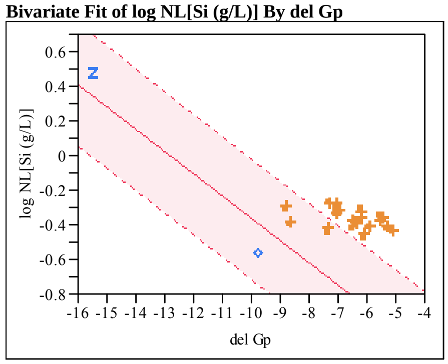
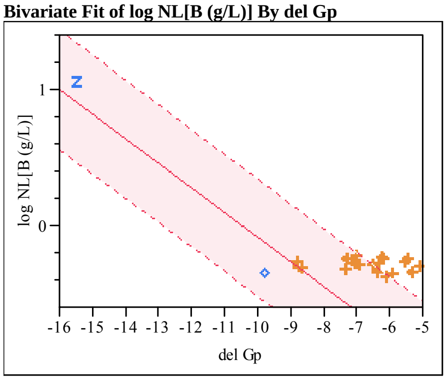


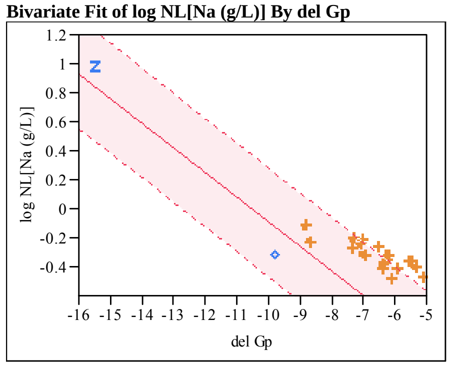
Exhibit B-7. PCT Measurements versus Durability Model Predictions for Amorphous Glasses Only.

Based Upon Measured Compositions

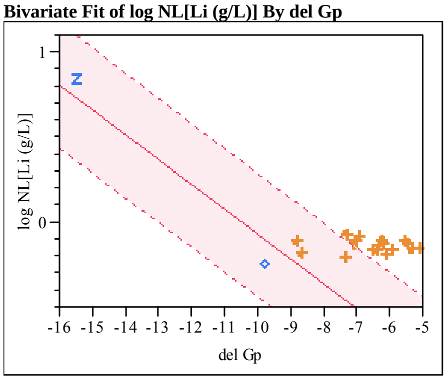
Bivariate Fit of log NL[B (g/L)] By del Gp



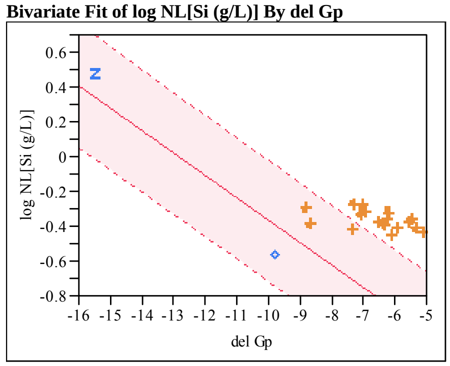
Bivariate Fit of log NL[Na (g/L)] By del Gp



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



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



Appendix C. Results from Fitting Fulcher Equations to the Viscosity Measurements for the KT06 Glasses

Exhibit C-1. Results from Fitting Fulcher Equations to the Viscosity Measurements of the KT01-Series Glasses.

Nonlinear Fit Glass ID=KT06-01
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

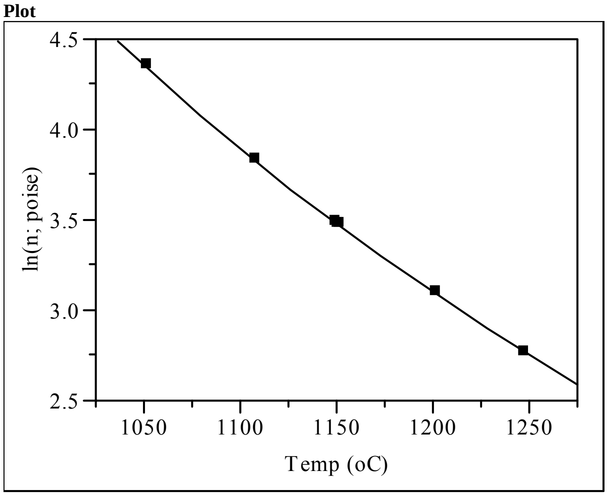
Criterion	Current	Stop Limit
Iteration	3	60
Obj Change	1.0012123e-7	1e-15
Relative Gradient	5.3609982e-8	0.000001
Gradient	4.5132715e-8	0.000001

Parameter	Current Value
C	108.1080501
B	8645.0393806
A	-4.816767547

SSE
0.0001099675
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	108.1080501	64.1049	192.315
B	8645.0393806	3212.47	9637.41
A	-4.816767547	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0001099675	4	0.0000275	0.0052433

Parameter	Estimate	ApproxStdErr
C	108.1080501	65.2270667
B	8645.0393806	1094.49324
A	-4.816767547	0.52998279

Solved By: Analytic NR

Nonlinear Fit Glass ID=KT06-02
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

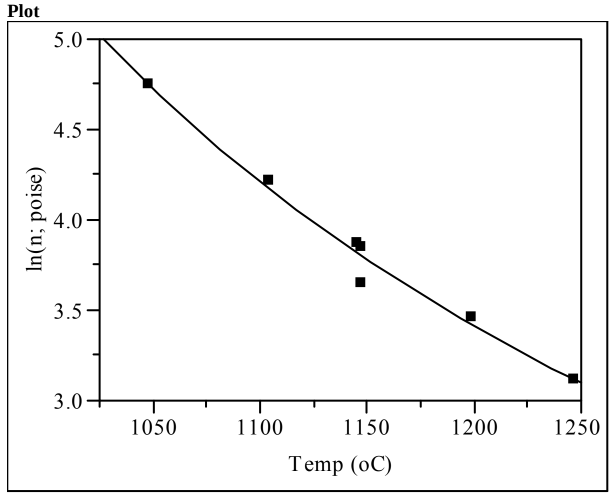
Criterion	Current	Stop Limit
Iteration	6	60
Obj Change	1.459831e-11	1e-15
Relative Gradient	1.0536288e-8	0.000001
Gradient	1.728015e-10	0.000001

Parameter	Current Value
C	529.60887529
B	3050.7651249
A	-1.139625268

SSE
0.029289771
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	529.60887529	64.1049	192.315
B	3050.7651249	3212.47	9637.41
A	-1.139625268	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.029289771	4	0.0073224	0.0855713

Parameter	Estimate	ApproxStdErr
C	529.60887529	353.411964
B	3050.7651249	3599.51034
A	-1.139625268	2.98491592

Solved By: Analytic NR

Exhibit C-1. Results from Fitting Fulcher Equations to the Viscosity Measurements of the KT01-Series Glasses. (continued)

Nonlinear Fit Glass ID=KT06-03
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

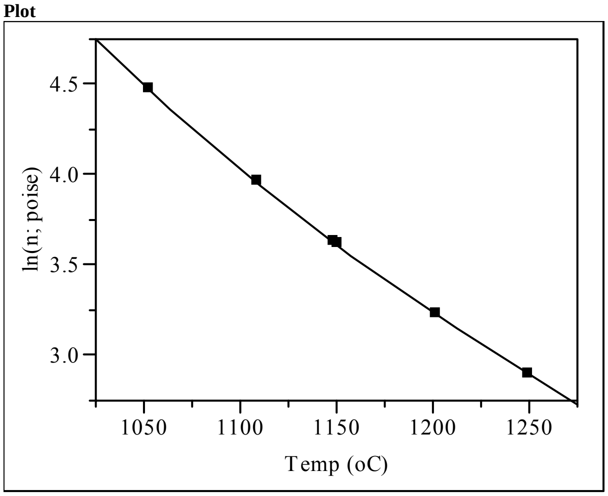
Criterion	Current	Stop Limit
Iteration	3	60
Obj Change	3.3021931e-8	1e-15
Relative Gradient	2.0388062e-8	0.000001
Gradient	1.5342992e-8	0.000001

Parameter	Current Value
C	112.89433533
B	8554.7013715
A	-4.633337345

SSE
0.0001169631
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	112.89433533	64.1049	192.315
B	8554.7013715	3212.47	9637.41
A	-4.633337345	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0001169631	4	2.9241e-5	0.0054075

Parameter	Estimate	ApproxStdErr
C	112.89433533	66.3521316
B	8554.7013715	1104.99365
A	-4.633337345	0.53666196

Solved By: Analytic NR

Nonlinear Fit Glass ID=KT06-04
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

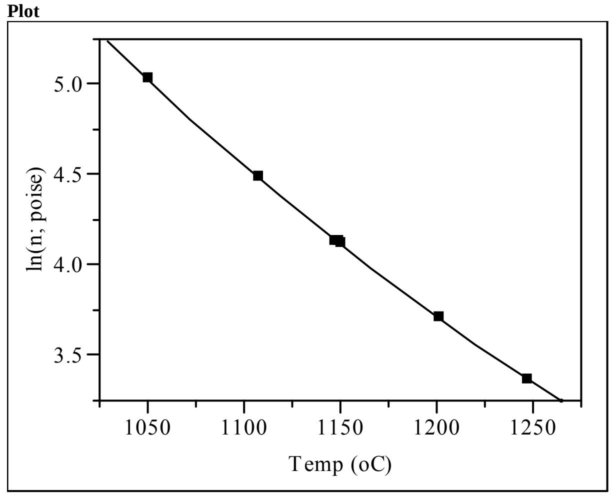
Criterion	Current	Stop Limit
Iteration	4	60
Obj Change	1.001375e-11	1e-15
Relative Gradient	2.8286483e-9	0.000001
Gradient	8.377294e-10	0.000001

Parameter	Current Value
C	59.337387311
B	9903.6695129
A	-4.970422512

SSE
0.0001382723
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	59.337387311	64.1049	192.315
B	9903.6695129	3212.47	9637.41
A	-4.970422512	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0001382723	4	3.4568e-5	0.0058795

Parameter	Estimate	ApproxStdErr
C	59.337387311	75.8068405
B	9903.6695129	1391.039
A	-4.970422512	0.64311336

Solved By: Analytic NR

Exhibit C-1. Results from Fitting Fulcher Equations to the Viscosity Measurements of the KT01-Series Glasses. (continued)

Nonlinear Fit Glass ID=KT06-05
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

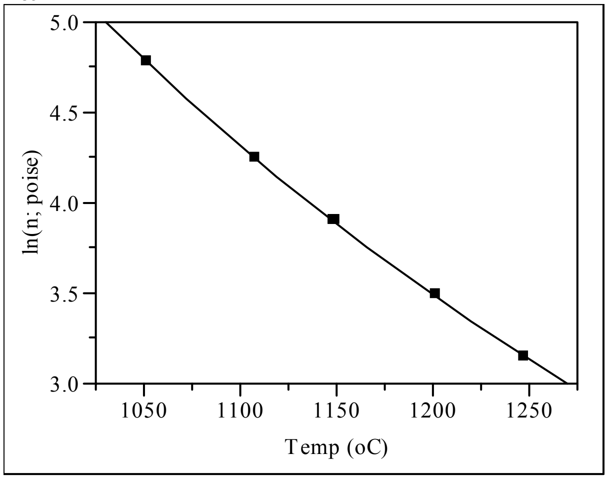
Criterion	Current	Stop Limit
Iteration	3	60
Obj Change	1.6432356e-7	1e-15
Relative Gradient	7.5320653e-8	0.000001
Gradient	6.5193569e-8	0.000001

Parameter	Current Value
C	108.86841303
B	8936.0294424
A	-4.69981947

SSE
0.0001063459
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	108.86841303	64.1049	192.315
B	8936.0294424	3212.47	9637.41
A	-4.69981947	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0001063459	4	2.6586e-5	0.0051562

Parameter	Estimate	ApproxStdErr
C	108.86841303	62.0097185
B	8936.0294424	1075.58235
A	-4.69981947	0.52087726

Solved By: Analytic NR

Nonlinear Fit Glass ID=KT06-06
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

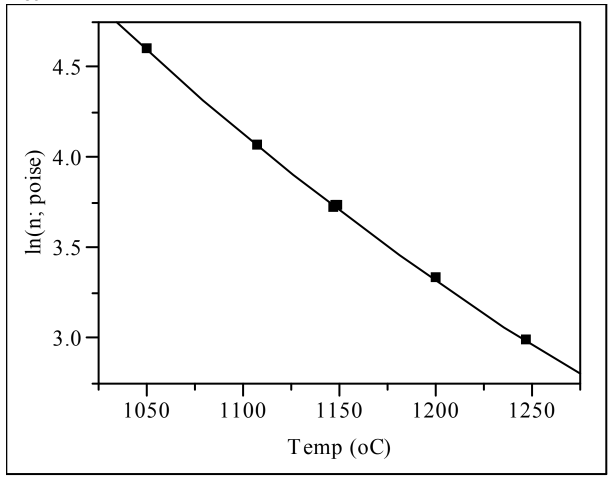
Criterion	Current	Stop Limit
Iteration	4	60
Obj Change	2.451809e-12	1e-15
Relative Gradient	4.2207197e-9	0.000001
Gradient	6.637577e-10	0.000001

Parameter	Current Value
C	65.149514454
B	9512.0492134
A	-5.059277163

SSE
0.0004102031
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	65.149514454	64.1049	192.315
B	9512.0492134	3212.47	9637.41
A	-5.059277163	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0004102031	4	0.0001026	0.0101267

Parameter	Estimate	ApproxStdErr
C	65.149514454	133.769261
B	9512.0492134	2369.80395
A	-5.059277163	1.10132245

Solved By: Analytic NR

Exhibit C-1. Results from Fitting Fulcher Equations to the Viscosity Measurements of the KT01-Series Glasses. (continued)

Nonlinear Fit Glass ID=KT06-07
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

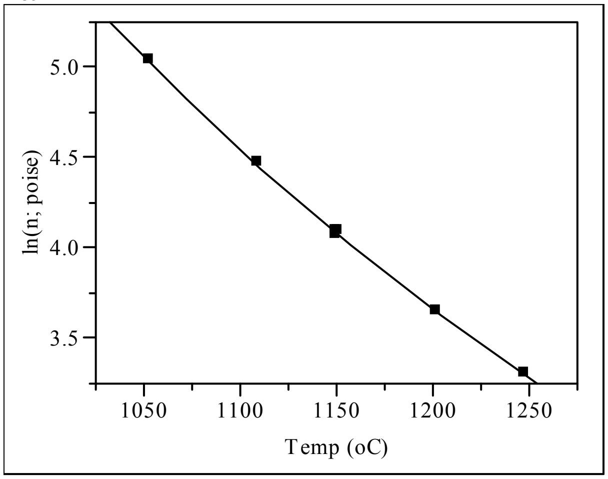
Criterion	Current	Stop Limit
Iteration	3	60
Obj Change	6.381076e-10	1e-15
Relative Gradient	6.4114377e-9	0.000001
Gradient	2.4081156e-9	0.000001

Parameter	Current Value
C	124.5733804
B	9256.6741608
A	-4.945823937

SSE
0.0008306287
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	124.5733804	64.1049	192.315
B	9256.6741608	3212.47	9637.41
A	-4.945823937	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0008306287	4	0.0002077	0.0144103

Parameter	Estimate	ApproxStdErr
C	124.5733804	158.882779
B	9256.6741608	2898.80444
A	-4.945823937	1.42538288

Solved By: Analytic NR

Nonlinear Fit Glass ID=KT06-08
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

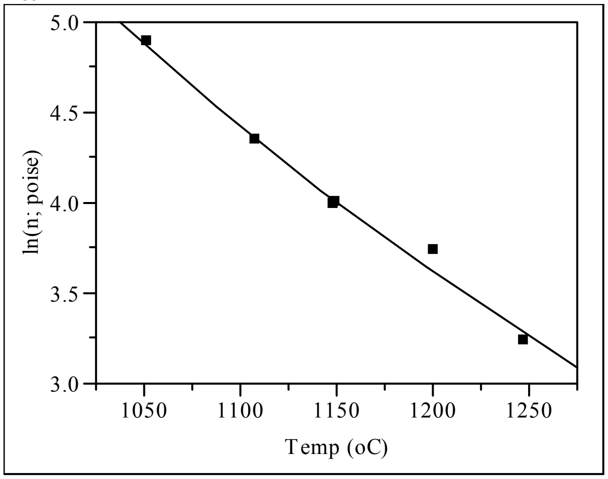
Criterion	Current	Stop Limit
Iteration	3	60
Obj Change	4.2860891e-6	1e-15
Relative Gradient	3.268761e-7	0.000001
Gradient	2.7315175e-7	0.000001

Parameter	Current Value
C	-39.37251677
B	11378.589737
A	-5.56474221

SSE
0.019573786
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	-39.37251677	64.1049	192.315
B	11378.589737	3212.47	9637.41
A	-5.56474221	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.019573786	4	0.0048934	0.0699532

Parameter	Estimate	ApproxStdErr
C	-39.37251677	1130.39579
B	11378.589737	21811.0042
A	-5.56474221	9.23196321

Solved By: Analytic NR

Exhibit C-1. Results from Fitting Fulcher Equations to the Viscosity Measurements of the KT01-Series Glasses. (continued)

Nonlinear Fit Glass ID=KT06-09
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

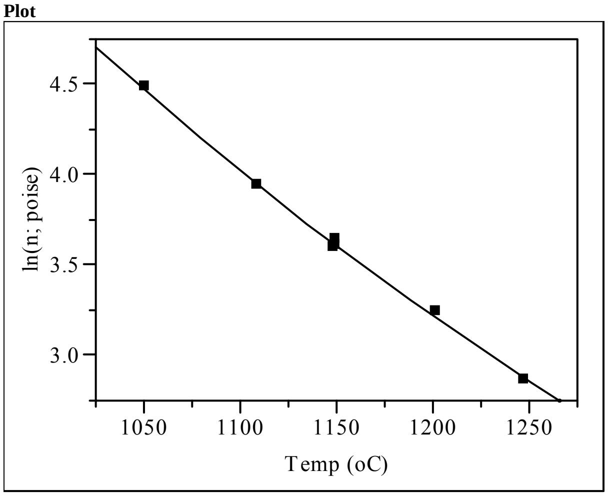
Criterion	Current	Stop Limit
Iteration	4	60
Obj Change	7.14427e-10	1e-15
Relative Gradient	6.3623313e-8	0.000001
Gradient	2.7059003e-8	0.000001

Parameter	Current Value
C	-188.0831575
B	14348.941785
A	-7.117875179

SSE
0.0025068054
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	-188.0831575	64.1049	192.315
B	14348.941785	3212.47	9637.41
A	-7.117875179	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0025068054	4	0.0006267	0.025034

Parameter	Estimate	ApproxStdErr
C	-188.0831575	504.180804
B	14348.941785	10891.6768
A	-7.117875179	4.09430865

Solved By: Analytic NR

Nonlinear Fit Glass ID=KT06-10
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

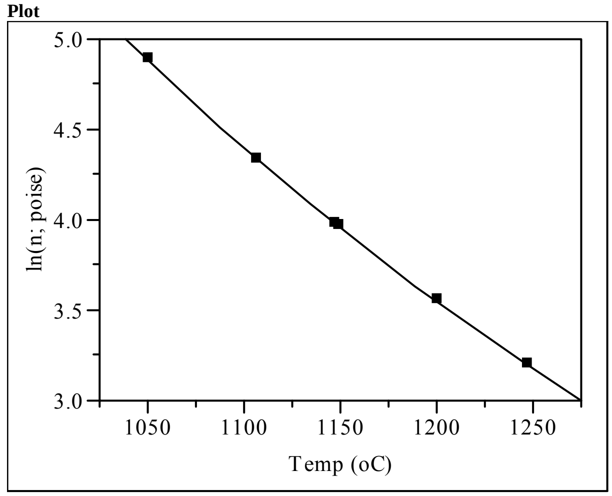
Criterion	Current	Stop Limit
Iteration	4	60
Obj Change	1.2966667e-9	1e-15
Relative Gradient	1.8089428e-8	0.000001
Gradient	1.3350403e-8	0.000001

Parameter	Current Value
C	-5.007398934
B	11292.391022
A	-5.819824006

SSE
0.0000508457
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	-5.007398934	64.1049	192.315
B	11292.391022	3212.47	9637.41
A	-5.819824006	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0000508457	4	1.2711e-5	0.0035653

Parameter	Estimate	ApproxStdErr
C	-5.007398934	50.7088139
B	11292.391022	1000.96951
A	-5.819824006	0.43669951

Solved By: Analytic NR

Exhibit C-1. Results from Fitting Fulcher Equations to the Viscosity Measurements of the KT01-Series Glasses. (continued)

Nonlinear Fit Glass ID=KT06-11
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

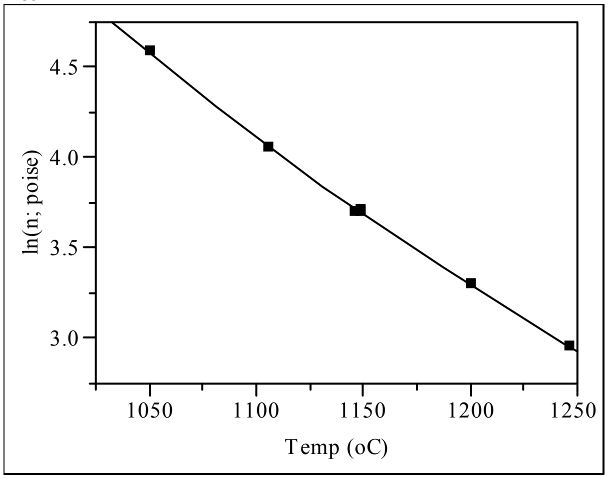
Criterion	Current	Stop Limit
Iteration	4	60
Obj Change	3.796496e-10	1e-15
Relative Gradient	3.6436222e-8	0.000001
Gradient	1.6726894e-8	0.000001

Parameter	Current Value
C	-10.77775943
B	11030.053637
A	-5.821668946

SSE
0.0007573307
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	-10.77775943	64.1049	192.315
B	11030.053637	3212.47	9637.41
A	-5.821668946	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0007573307	4	0.0001893	0.0137598

Parameter	Estimate	ApproxStdErr
C	-10.77775943	206.783435
B	11030.053637	3967.62395
A	-5.821668946	1.72260641

Solved By: Analytic NR

Nonlinear Fit Glass ID=KT06-12
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

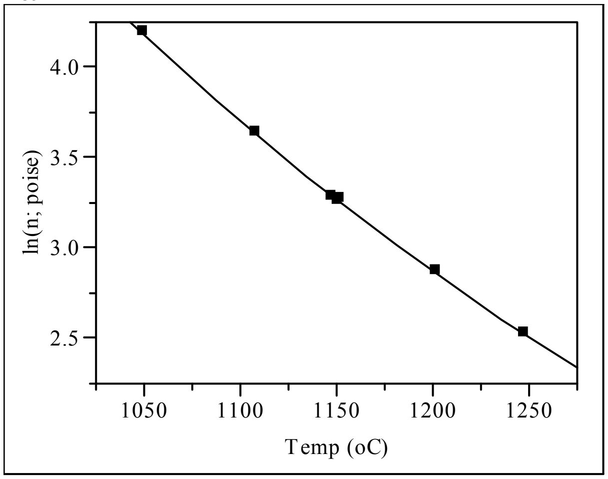
Criterion	Current	Stop Limit
Iteration	3	60
Obj Change	4.9477401e-7	1e-15
Relative Gradient	2.216726e-7	0.000001
Gradient	2.0106223e-7	0.000001

Parameter	Current Value
C	103.08147322
B	9077.0685633
A	-5.405028617

SSE
0.0002133274
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	103.08147322	64.1049	192.315
B	9077.0685633	3212.47	9637.41
A	-5.405028617	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0002133274	4	5.3332e-5	0.0073029

Parameter	Estimate	ApproxStdErr
C	103.08147322	85.6645481
B	9077.0685633	1503.64105
A	-5.405028617	0.72536955

Solved By: Analytic NR

Exhibit C-1. Results from Fitting Fulcher Equations to the Viscosity Measurements of the KT01-Series Glasses. (continued)

Nonlinear Fit Glass ID=KT06-13
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

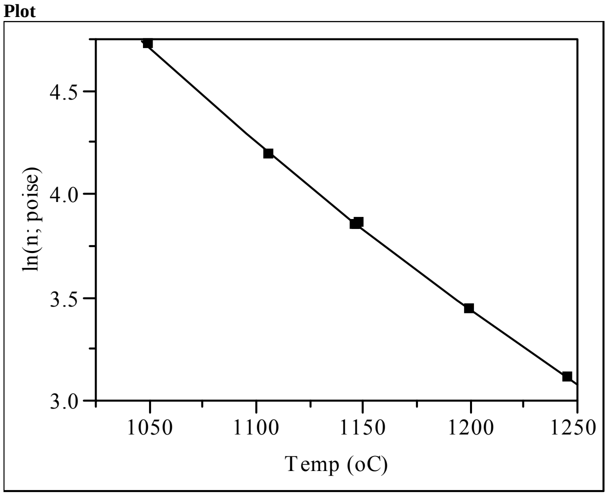
Criterion	Current	Stop Limit
Iteration	4	60
Obj Change	7.88137e-10	1e-15
Relative Gradient	4.53236e-9	0.000001
Gradient	2.7481551e-9	0.000001

Parameter	Current Value
C	-83.16379188
B	12323.504901
A	-6.168897744

SSE
0.0005047595
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	-83.16379188	64.1049	192.315
B	12323.504901	3212.47	9637.41
A	-6.168897744	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0005047595	4	0.0001262	0.0112334

Parameter	Estimate	ApproxStdErr
C	-83.16379188	191.892877
B	12323.504901	3871.26926
A	-6.168897744	1.58205027

Solved By: Analytic NR

Nonlinear Fit Glass ID=KT06-14
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

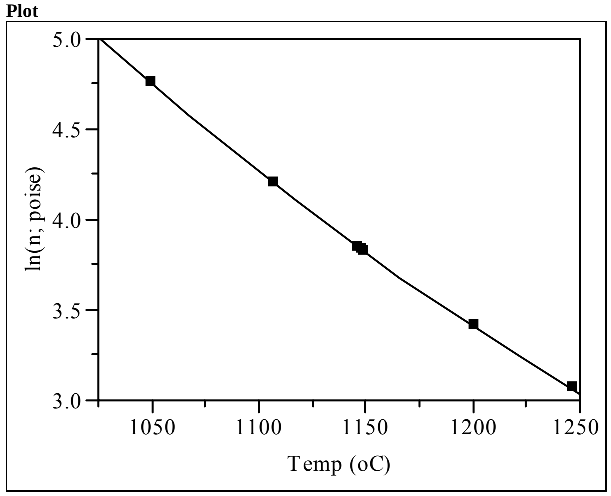
Criterion	Current	Stop Limit
Iteration	4	60
Obj Change	1.633893e-11	1e-15
Relative Gradient	3.0015462e-9	0.000001
Gradient	1.0786786e-9	0.000001

Parameter	Current Value
C	59.619445334
B	10079.025372
A	-5.429908656

SSE
0.0001159275
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	59.619445334	64.1049	192.315
B	10079.025372	3212.47	9637.41
A	-5.429908656	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0001159275	4	2.8982e-5	0.0053835

Parameter	Estimate	ApproxStdErr
C	59.619445334	68.2566338
B	10079.025372	1275.85851
A	-5.429908656	0.59042161

Solved By: Analytic NR

Exhibit C-1. Results from Fitting Fulcher Equations to the Viscosity Measurements of the KT01-Series Glasses. (continued)

Nonlinear Fit Glass ID=KT06-15
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

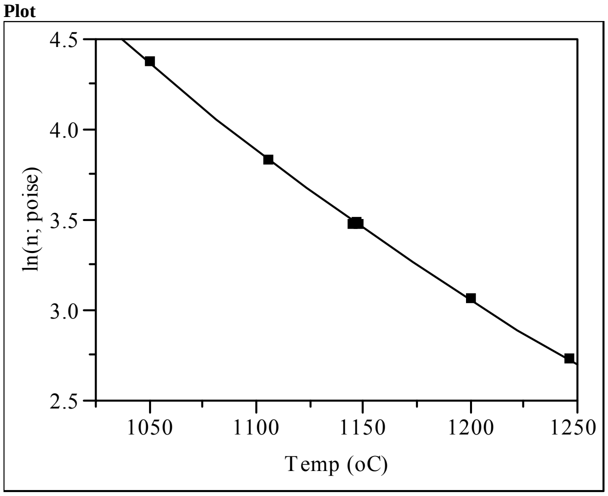
Criterion	Current	Stop Limit
Iteration	4	60
Obj Change	1.78937e-11	1e-15
Relative Gradient	9.9857348e-9	0.000001
Gradient	3.6968543e-9	0.000001

Parameter	Current Value
C	179.81569185
B	7803.4872106
A	-4.597184693

SSE
0.0007417575
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	179.81569185	64.1049	192.315
B	7803.4872106	3212.47	9637.41
A	-4.597184693	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0007417575	4	0.0001854	0.0136176

Parameter	Estimate	ApproxStdErr
C	179.81569185	140.780686
B	7803.4872106	2293.90396
A	-4.597184693	1.19461821

Solved By: Analytic NR

Nonlinear Fit Glass ID=KT06-16
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

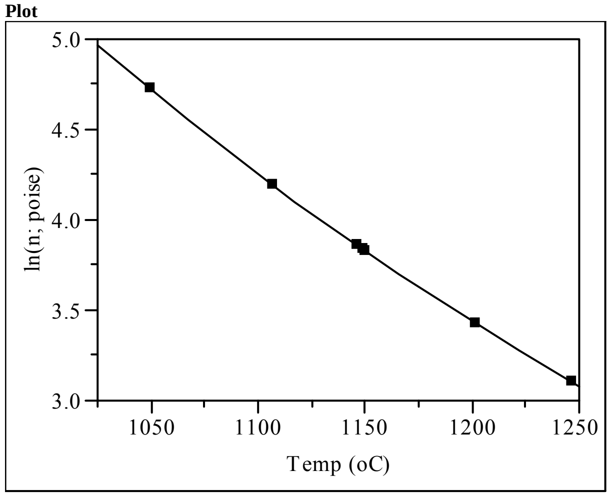
Criterion	Current	Stop Limit
Iteration	4	60
Obj Change	4.772505e-12	1e-15
Relative Gradient	3.110408e-10	0.000001
Gradient	1.138865e-10	0.000001

Parameter	Current Value
C	56.897815914
B	9720.4074591
A	-5.06987605

SSE
0.000063212
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	56.897815914	64.1049	192.315
B	9720.4074591	3212.47	9637.41
A	-5.06987605	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.000063212	4	0.0000158	0.0039753

Parameter	Estimate	ApproxStdErr
C	56.897815914	52.7114438
B	9720.4074591	947.918354
A	-5.06987605	0.43758944

Solved By: Analytic NR

Exhibit C-1. Results from Fitting Fulcher Equations to the Viscosity Measurements of the KT01-Series Glasses. (continued)

Nonlinear Fit Glass ID=KT06-17
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

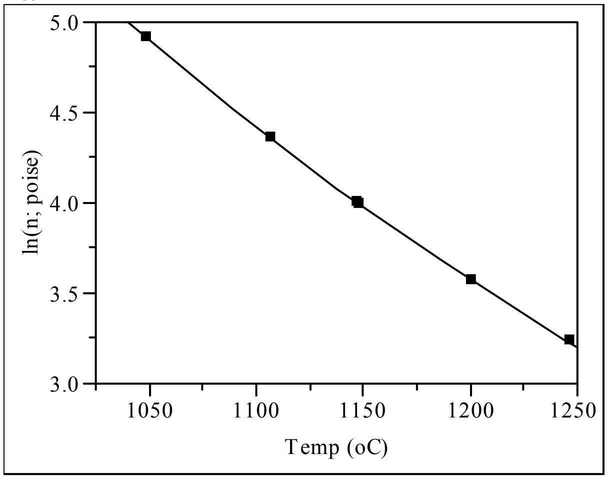
Criterion	Current	Stop Limit
Iteration	4	60
Obj Change	3.728305e-10	1e-15
Relative Gradient	1.5907572e-9	0.000001
Gradient	6.239785e-10	0.000001

Parameter	Current Value
C	13.713939506
B	10883.481557
A	-5.605416231

SSE
0.0000324259
N 7

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	13.713939506	64.1049	192.315
B	10883.481557	3212.47	9637.41
A	-5.605416231	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0000324259	4	8.1065e-6	0.0028472

Parameter	Estimate	ApproxStdErr
C	13.713939506	39.0604168
B	10883.481557	756.299777
A	-5.605416231	0.33578853

Solved By: Analytic NR

Nonlinear Fit Glass ID=KT06-18
Response: ln(n; poise), Predictor: ln(n; VTF)

Control Panel

Converged in Gradient

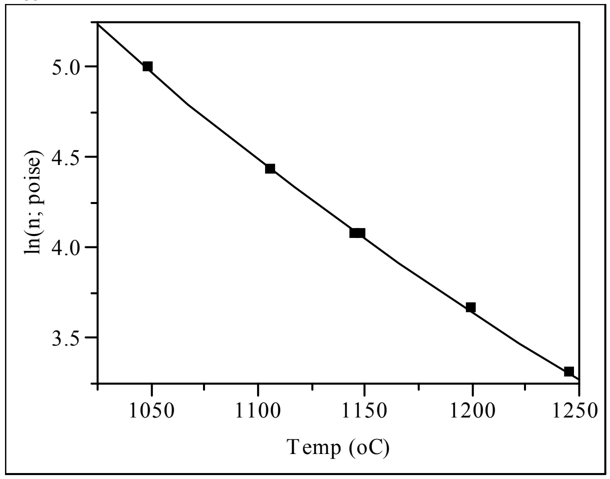
Criterion	Current	Stop Limit
Iteration	4	60
Obj Change	2.161358e-11	1e-15
Relative Gradient	1.4893385e-8	0.000001
Gradient	3.7219823e-9	0.000001

Parameter	Current Value
C	57.53734767
B	10060.914529
A	-5.165750055

SSE
0.0006461491
N 6

Edit Alpha
0.050Convergence Criterion
0.00001Goal SSE for CL

Plot



Parameter	Estimate	Low	High
C	57.53734767	64.1049	192.315
B	10060.914529	3212.47	9637.41
A	-5.165750055	-5.8424	-1.9475

Solution

SSE	DFE	MSE	RMSE
0.0006461491	3	0.0002154	0.0146759

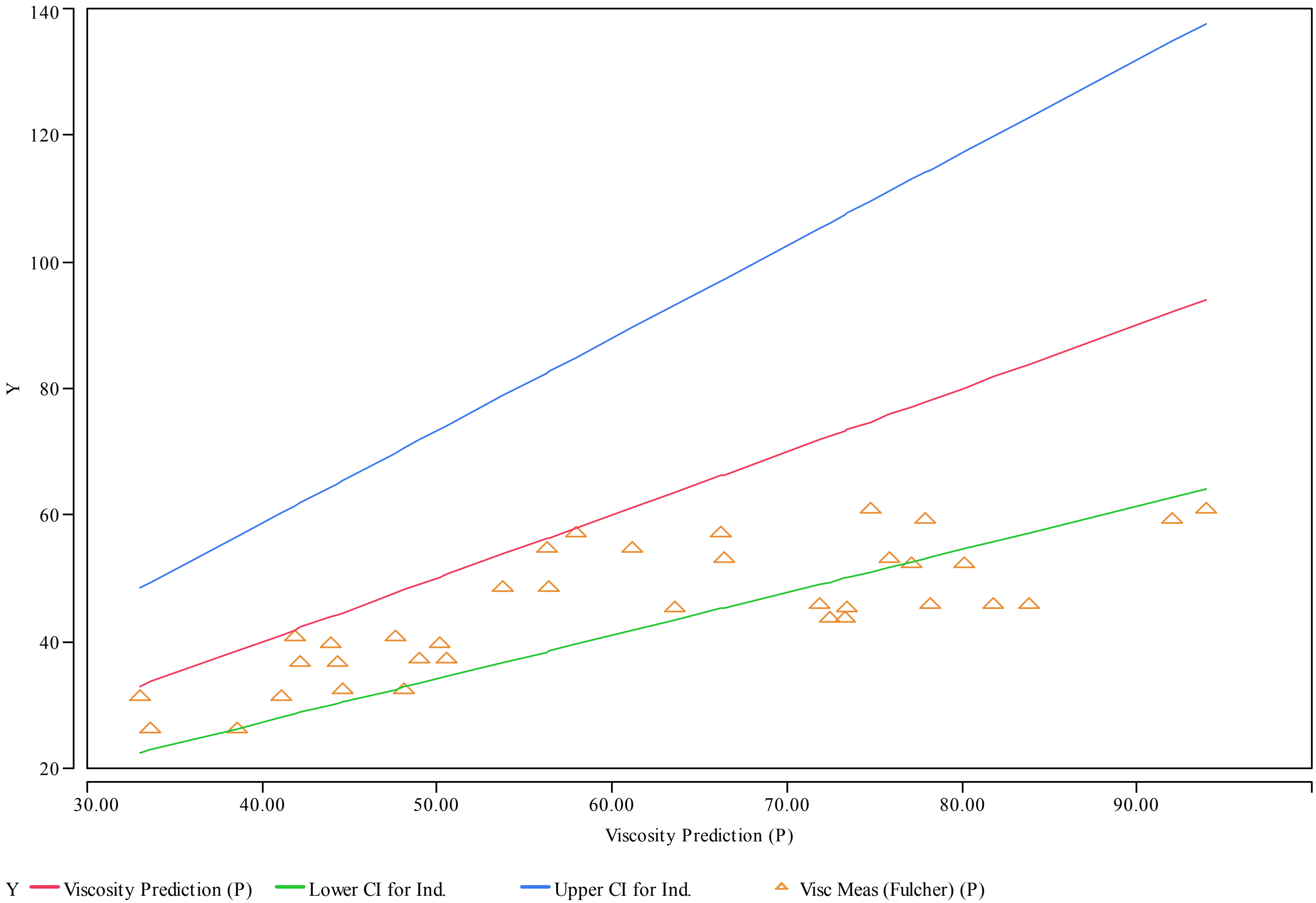
Parameter	Estimate	ApproxStdErr
C	57.53734767	197.289853
B	10060.914529	3677.83742
A	-5.165750055	1.69945312

Solved By: Analytic NR

Exhibit C-2. Model Predicted Viscosities with Confidence Intervals (CI) and Measured Viscosities (Fulcher Fits) at 1150 °C for the KT06-Series Glasses by Compositional View.

Compositional View	Glass ID	Viscosity Prediction (P)	Lower CI for Prediction (P)	Upper CI for Prediction (P)	Meas. Visc. (Fulcher) (P)	Model Predictable?
measured	KT06-01	44.58	30.41	65.37	32.48	yes
measured	KT06-02	73.29	50.01	107.41	43.72	no
measured	KT06-03	49.00	33.42	71.83	37.16	yes
measured	KT06-04	93.93	64.08	137.69	60.95	no
measured	KT06-05	56.41	38.49	82.68	48.58	yes
measured	KT06-06	47.65	32.50	69.86	40.8	yes
measured	KT06-07	92.04	62.79	134.90	59.22	no
measured	KT06-08	61.14	41.72	89.61	54.72	yes
measured	KT06-09	42.21	28.78	61.90	36.8	yes
measured	KT06-10	77.09	52.61	112.98	52.3	no
measured	KT06-11	43.91	29.94	64.38	39.67	yes
measured	KT06-12	33.63	22.92	49.35	26.19	yes
measured	KT06-13	78.15	53.32	114.53	45.81	no
measured	KT06-14	63.54	43.35	93.11	45.32	yes
measured	KT06-15	32.97	22.47	48.39	31.38	yes
measured	KT06-16	71.88	49.05	105.34	45.72	no
measured	KT06-17	66.39	45.30	97.30	53.13	yes
measured	KT06-18	57.93	39.53	84.91	57.03	yes
targeted	KT06-01	48.12	32.82	70.55	32.48	no
targeted	KT06-02	72.43	49.42	106.14	43.72	no
targeted	KT06-03	50.58	34.51	74.15	37.16	yes
targeted	KT06-04	74.74	51.00	109.54	60.95	yes
targeted	KT06-05	53.78	36.69	78.83	48.58	yes
targeted	KT06-06	41.85	28.54	61.37	40.8	yes
targeted	KT06-07	77.88	53.14	114.13	59.22	yes
targeted	KT06-08	56.27	38.39	82.48	54.72	yes
targeted	KT06-09	44.32	30.23	64.98	36.8	yes
targeted	KT06-10	80.11	54.67	117.41	52.3	no
targeted	KT06-11	50.14	34.21	73.50	39.67	yes
targeted	KT06-12	38.53	26.27	56.51	26.19	no
targeted	KT06-13	81.79	55.81	119.87	45.81	no
targeted	KT06-14	73.45	50.12	107.65	45.32	no
targeted	KT06-15	41.08	28.01	60.25	31.38	yes
targeted	KT06-16	83.85	57.22	122.90	45.72	no
targeted	KT06-17	75.84	51.75	111.14	53.13	yes
targeted	KT06-18	66.21	45.18	97.03	57.03	yes

Exhibit C-3. KT06-Series Measured Versus Predicted Viscosity Values Based on Measured and Target Compositions.



Distribution:

J. W. Amoroso, 999-W
C. J. Bannochie, 773-42A
A. B. Barnes, 999-W
A. L. Billings, 999-W
J. M. Bricker, 704-27S
M. A. Broome, 704-29S
C. L. Crawford, 773-42A
D. A. Crowley, 773-43A
R. E. Edwards, 766-H
T. B. Edwards, 999-W
A. P. Fellinger, 773-41A
T. L. Fellinger, 704-26S
S. D. Fink, 773-A
K. M. Fox, 999-W
B. J. Giddings, 786-5A
J. M. Gillam, 766-H
B. A. Hamm, 766-H
C. C. Herman, 999-W
D. T. Herman, 735-11A
R. N. Hinds, 704-S
E. W. Holtzscheiter, 704-15S
T. H. Huff, 766-H
J. F. Iaukea, 704-30S
P. R. Jackson, 703-46A
C. M. Jantzen, 773-A
F. C. Johnson, 999-W
D. C. Koopman, 999-W
D. D. Larsen, 766-H
T. E. Laupa, 766-H
P. L. Lee, 703-41A
S. L. Marra, 773-A
D. H. Miller, 999-W
J. E. Occhipinti, 704-S
D. K. Peeler, 999-W
F. M. Pennebaker, 773-42A
J. W. Ray, 704-S
M. A. Rios-Armstrong, 766-H
H. B. Shah, 766-H
D. C. Sherburne, 704-S
A. V. Staub, 704-27S
M. E. Stone, 999-W
J. P. Vaughan, 773-41A
W. R. Wilmarth, 773-A