Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

Disclaimer:

We put science to work.™

Savannah River National Laboratory™

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

A U.S. DEPARTMENT OF ENERGY NATIONAL LABORATORY • SAVANNAH RIVER SITE • AIKEN, SC

Chemical Composition Measurements of the Low Activity Waste (LAW) EPA-Series Glasses

K. M. Fox

T. B. Edwards

March 2016

SRNL-STI-2016-00095, Revision 0

SRNL.DOE.GOV

DISCLAIMER

Printed in the United States of America

Prepared for
U.S. Department of Energy

SRNL-STI-2016-00095
Revision 0

Keywords: *Low activity waste glass, Hanford, WTP*

Retention: *Permanent*

Chemical Composition Measurements of the Low Activity Waste (LAW) EPA-Series Glasses

K. M. Fox
T. B. Edwards

March 2016

Prepared for the U.S. Department of Energy under contract number DE-AC09-08SR22470.

Savannah River National Laboratory™
OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

REVIEWS AND APPROVALS

AUTHORS:

K. M. Fox, Hanford Mission Programs Date

T. B. Edwards, Engineering Process Development Date

TECHNICAL REVIEW:

D. L. McClane, Engineering Process Development, Reviewed per E7 2.60 Date

APPROVAL:

C. C. Herman, Director, Hanford Mission Programs Date

ACKNOWLEDGEMENTS

The authors thank Phyllis Workman, Madison Caldwell, Kim Wyszynski, Beverly Wall, and Whitney Riley at Savannah River National Laboratory for their assistance with the laboratory analyses described in this report. The authors thank Mike Schweiger at the Pacific Northwest National Laboratory for helpful discussions and review of these data. Funding for this work by the U.S. Department of Energy Office of River Protection Waste Treatment & Immobilization Plant Project through Inter-Entity Work Order M0SRV00101 managed by Albert A. Kruger is gratefully acknowledged.

EXECUTIVE SUMMARY

In this report, the Savannah River National Laboratory provides chemical analysis results for a series of simulated low activity waste glasses provided by Pacific Northwest National Laboratory as part of an ongoing development task.

The measured chemical composition data are reported and compared with the targeted values for each component for each glass. A detailed review showed no indications of errors in the preparation or measurement of the study glasses. All of the measured sums of oxides for the study glasses fell within the interval of 100.2 to 100.8 wt %, indicating recovery of all components. Comparisons of the targeted and measured chemical compositions showed that the measured values for the glasses met the targeted concentrations within 10% for those components present at more than 5 wt %.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

BDL	Below Detection Limit
DOE	U.S. Department of Energy
HLW	High Level Waste
IC	Ion Chromatography
ICP-MS	Inductively Coupled Plasma – Mass Spectroscopy
ICP-OES	Inductively Coupled Plasma – Optical Emission Spectroscopy
KH	Potassium hydroxide fusion
LAW	Low Activity Waste
LM	Lithium Metaborate fusion
LRM	Low-level Reference Material
ORP	U.S. Department of Energy – Office of River Protection
PF	Sodium Peroxide Fusion
PNNL	Pacific Northwest National Laboratory
SRNL	Savannah River National Laboratory
TTQAP	Task Technical and Quality Assurance Plan
wt %	Weight Percent
WTP	Hanford Waste Treatment and Immobilization Plant

1.0 Introduction

The U.S. Department of Energy (DOE) Office of River Protection (ORP) is building the Waste Treatment and Immobilization Plant (WTP) at the Hanford Site in Washington to remediate 55 million gallons of radioactive waste that is temporarily stored in 177 underground tanks. The low-activity waste (LAW) fraction will be partitioned from the high-level waste (HLW). Both the LAW and HLW will then be vitrified in borosilicate glass with Joule-heated ceramic melters.

Efforts are being made to increase the loading of Hanford tank wastes in glass while maintaining the ability to meet processing, regulatory compliance, and product quality requirements. DOE-ORP has requested that the Savannah River National Laboratory (SRNL) support the advancement of glass formulations and process control strategies in key technical areas, as defined in the Task Technical and Quality Assurance Plan (TTQAP).[1] One of these areas is the development of advanced, predictive models for the chemical durability performance of glasses formulated at high waste concentrations.

In this report, SRNL provides chemical analysis results for a series of simulated LAW glasses provided by Pacific Northwest National Laboratory (PNNL) as part of an ongoing development task.[2]

2.0 Experimental Procedure

2.1 Glasses Selected for Study

PNNL provided three glasses for the analyses described in this report. The identifiers for these glasses are given in Table 2-1. Heat treatment information for the glasses was not provided.

Table 2-1. Identifiers for PNNL LAW EPA Glasses Characterized in this Study

Glass Identifier
LAWA23-EPA
LAWA44-EPA
ORPLB2-EPA

In the sections that follow, the methods used for measuring chemical composition are described and statistical reviews of the resulting data are provided. Detailed data from these analyses are included as appendices.

2.2 Chemical Composition Analysis

Chemical analysis was performed under the auspices of an analytical plan[3] on a representative sample of each of the study glasses to allow for comparisons with the targeted compositions. Three preparation techniques, sodium peroxide fusion (PF), lithium metaborate fusion (LM), and potassium hydroxide fusion (KH), were used to prepare the glass samples, in duplicate, for analysis. Note that two preparation methods for iron measurements were requested in the analytical plan[3] due to the potential for crystalline phases to be present in the study glasses and uncertainty regarding the dissolution of those phases. The analytical data from each method were reviewed in order to select the most appropriate method for iron. The preparation methods used for each of the reported glass components are summarized in Table 2-2.

Each of the samples prepared in duplicate by PF and LM was analyzed, twice for each element of interest, by Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES). The samples prepared in duplicate by KH were analyzed, twice for each element of interest, by Ion Chromatography (IC). A glass standard was intermittently measured to assess the performance of the ICP-OES and IC instruments over

the course of these analyses. Specifically, several samples of the low-level reference material (LRM)[4] were included as part of the analytical plan. The samples of glass ORPLB2-EPA prepared in duplicate by PF were also analyzed for cesium concentrations using Inductively Coupled Plasma – Mass Spectroscopy (ICP-MS).

Table 2-2. Preparation Methods Used in Reporting the Concentrations of Each of the Components of the Study Glasses

Component	Preparation Method
Al	PF
B	PF
Ca	LM
Cl	KH
Cr	LM
Cs	PF
F	KH
Fe	PF
K	LM
Li	PF
Mg	LM
Mn	LM
Mo	LM
Na	LM
Ni	LM
P	LM
Re	LM
S	LM
Si	PF
Sn	LM
Ti	LM
V	LM
Zn	LM
Zr	LM

2.3 Quality Assurance

Requirements for performing reviews of technical reports and the extent of review are established in Savannah River Site Manual E7 2.60. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2. Laboratory data for this study were recorded in the SRNL Electronic Laboratory Notebook system, experiment C3489-00079-11.

3.0 Results and Discussion

3.1 Review and Evaluation of Chemical Composition Measurements

Table A-1 in Appendix A provides the elemental concentration measurements in weight percent (wt %) for the study glasses that were prepared by PF and measured by ICP-OES. Table A-2 in Appendix A provides the elemental cesium concentration measurements for glass ORPLB2-EPA as prepared by PF and measured by ICP-MS. Table A-3 in Appendix A provides the elemental concentration measurements for the study glasses that were prepared by KH and measured by IC. Table A-4 and Table A-5 in Appendix A provide the elemental concentration measurements for the study glasses that were prepared by LM and measured by ICP-OES. Elemental measurements for samples of the LRM standard glass are

also provided in the tables of Appendix A (with the exception of the ICP-MS measurements). These unprocessed data are provided as appendices to this report so that the values are readily available should they be of interest for future reviews.

In the sections that follow, the analytical sequences of the measurements are explored, the measurements of the LRM standard glass are investigated, the measurements for each glass are reviewed, the average chemical composition for each glass is determined, and comparisons are made between the measurements and the targeted compositions for the glasses. JMP Pro Version 11.2.1 (SAS Institute, Inc.)[5] was used to support these analyses.

3.1.1 Treatment of Detection Limits

The elemental concentrations in Table A-1 through Table A-5 of Appendix A were converted to oxide concentrations by multiplying the values for each element by the gravimetric factor for the corresponding oxide.[a] During the process of converting to oxide concentrations, an elemental concentration that was reported to be below the detection limit of the analytical process used was set to the detection limit as the oxide concentration was determined for the purposes of statistical review and calculating a sum of oxides for each glass. Those oxides with measured concentrations that were below the associated detection limit will be denoted with a less than symbol (<) as the measured compositions are reported.

3.1.2 Measurements in Analytical Sequence

Exhibit A-1 in Appendix A provides plots of the wt % measurements generated for prepared samples by oxide and analytical block. The plots are in analytical sequence within each calibration block with different symbols and colors being used to represent each of the study and standard glasses. These plots include all of the measurement data from Table A-1 through Table A-5 of Appendix A, with each plotted point identified by its Lab ID. Plotting the data in this format provides an opportunity to identify gross trends in performance of the analytical instrument within and among calibration blocks. There do not appear to be any gross patterns or trends in the analytical process that would indicate an issue with performance of the measurements.

3.1.3 Composition Measurements by Glass Identifier

Exhibit A-2 in Appendix A provides plots of the oxide concentration measurements by the PNNL Glass ID (including the LRM reference glass) by Lab ID grouped by targeted concentration. Different symbols and colors are used to represent the different glasses. These plots show the individual measurements across the duplicates of each preparation method and the two instrument calibrations for each glass. Plotting the data in this format provides an opportunity to review the values for each individual glass as a function of the duplicate preparations and duplicate measurements. A review of the plots presented in these exhibits reveals the repeatability of the four individual values for each oxide for each glass and leads to the following observations:

- The measured Cl concentrations are below the targeted values, which may be due to volatilization during melting.
- As mentioned earlier, data from the PF preparation method is used in reporting the Fe_2O_3 concentrations for the study glasses.

None of the observations noted above from Exhibit A-2 indicated an error in preparation or measurement that had to be addressed in treatment of the data. Therefore, the entire set of measurement data was used in determining representative, measured compositions for all of the oxides for the study glasses.

[a] Note that manganese, typically reported as MnO by SRNL, is reported as MnO_2 for consistency with the targeted compositions provided by PNNL.

3.1.4 Results for the LRM Standard

Exhibit A-3 in Appendix A provides a review of the LRM results against acceptability limits utilized by SRNL. The review is in the form of plots of the measurements arranged by preparation method and element, framed by upper and lower acceptability limits for the concentration of the element in question. The results show that all of the measurements for the elements present in the LRM standard glass were within the acceptability limits utilized by SRNL in conducting instrument and procedure assessments during the execution of these measurements.

3.1.5 Measured versus Targeted Compositions

From the discussion of Section 3.1.3, all of the measurements for each oxide for each glass (i.e., all of the measurements in Appendix A, Table A-1 through Table A-5), 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 a graphical representation of the results for each glass for each oxide to allow PNNL to draw comparisons between the measured and targeted values.

Table A-6 in Appendix A provides a summary of the average compositions as well as the targeted compositions and some associated differences and relative differences. All of the measured sums of oxides for the study glasses fall within the interval of 100.2 to 100.8 wt %, indicating recovery of all components. Entries in Table A-6 show the relative differences between the measured values and the targeted values for the oxides with targeted values above 5 wt %. The relative differences are typically shaded if they are 10% or more.[a] The measurements of the glasses in this study all exceeded these criteria, thus there are no shaded values found in Table A-6.

4.0 Summary

In this report, SRNL provides chemical analysis results for a series of simulated LAW glasses provided by PNNL as part of an ongoing development task.[2]

The measured chemical composition data are reported and compared with the targeted values for each component for each glass. A detailed review showed no indications of errors in the preparation or measurement of the study glasses. All of the measured sums of oxides for the study glasses fell within the interval of 100.2 to 100.8 wt %, indicating recovery of all components. Comparisons of the targeted and measured chemical compositions showed that the measured values for the glasses met the targeted concentrations within 10% for those components present at more than 5 wt %.

[a] These criteria were selected arbitrarily for the purpose of highlighting differences from targeted concentrations that may be of practical concern.

5.0 References

1. Fox, K. M. and D. K. Peeler, "Task Technical and Quality Assurance Plan for Hanford HLW Glass Development and Characterization," *U.S. Department of Energy Report SRNL-RP-2013-00692, Revision 0,* Savannah River National Laboratory, Aiken, SC (2013).

2. Peeler, D. K., D. S. Kim, J. D. Vienna, M. J. Schweiger, and G. F. Piepel, "Office of River Protection Advanced Low-Activity Waste Glass Research and Development Plan," *U.S. Department of Energy Report PNNL-24883, EWG-RPT-008,* Pacific Northwest National Laboratory, Richland, WA (2015).

3. Edwards, T. B., "An Analytical Plan for Measuring the Chemical Compositions of the PNNL EPA LAW Glasses," *U.S. Department of Energy Memorandum SRNL-L3100-2015-00221,* Savannah River National Laboratory, Aiken, SC (2015).

4. Ebert, W. L. and S. F. Wolfe, "Round-robin Testing of a Reference Glass for Low-Activity Waste Forms," *U.S. Department of Energy Report ANL-99/22,* Argonne National Laboratory, Argonne, IL (1999).

5. **JMP™ Pro, Ver. 11.2.1,** [Computer Software] SAS Institute Inc., Cary, NC (2014).

Appendix A Tables and Exhibits Supporting the Chemical Composition Measurements

Table A-1. Measurements from the PF Preparation Method

ID	Block	Sequence	Lab ID	Al (wt%)	B (wt%)	Fe (wt%)	Li (wt%)	Si (wt%)
LRM	1	1	LRMPF11	5.04	2.48	1.00	<0.100	25.1
ORPLB2-EPA	1	2	E02PF21	5.20	2.26	0.757	<0.100	18.8
LAWA44-EPA	1	3	E01PF11	3.18	2.67	4.81	<0.100	20.0
LAWA23-EPA	1	4	E03PF21	5.12	1.29	5.05	0.895	18.8
LAWA44-EPA	1	5	E01PF21	3.20	2.72	4.86	<0.100	20.3
ORPLB2-EPA	1	6	E02PF11	5.15	2.21	0.748	<0.100	18.6
LAWA23-EPA	1	7	E03PF11	5.03	1.30	5.02	0.881	18.6
LRM	1	8	LRMPF12	5.05	2.38	0.991	<0.100	25.3
LRM	2	1	LRMPF21	4.95	2.47	1.03	0.106	24.6
ORPLB2-EPA	2	2	E02PF22	5.17	2.33	0.810	<0.100	18.7
LAWA23-EPA	2	3	E03PF12	5.03	1.39	5.04	0.928	18.5
LAWA23-EPA	2	4	E03PF22	5.05	1.36	5.06	0.930	18.6
LAWA44-EPA	2	5	E01PF22	3.21	2.74	4.88	<0.100	20.2
ORPLB2-EPA	2	6	E02PF12	5.18	2.26	0.812	<0.100	18.6
LAWA44-EPA	2	7	E01PF12	3.20	2.69	4.83	<0.100	20.0
LRM	2	8	LRMPF22	5.13	2.45	1.05	0.107	25.4

Table A-2. Cesium Measurements, PF Preparation Method

Glass ID	Block	Sequence	Lab ID	Cs (wt%)
ORPLB2-EPA	1	1	E02PF1	0.1216
ORPLB2-EPA	2	1	E02PF2	0.1224

Table A-3. Measurements from the KH Preparation Method

ID	Block	Sequence	Lab ID	Cl (wt%) ar	F (wt%) ar
LRM	1	1	LRMKH11	<0.010	0.881
LAWA23-EPA	1	2	E03KH21	0.204	0.097
LAWA44-EPA	1	3	E01KH11	0.494	<0.010
ORPLB2-EPA	1	4	E02KH21	0.067	0.411
LAWA44-EPA	1	5	E01KH21	0.497	<0.010
ORPLB2-EPA	1	6	E02KH11	0.066	0.415
LAWA23-EPA	1	7	E03KH11	0.201	0.095
LRM	1	8	LRMKH12	<0.010	0.889
LRM	2	1	LRMKH21	<0.010	0.879
LAWA44-EPA	2	2	E01KH22	0.495	<0.010
LAWA23-EPA	2	3	E03KH12	0.199	0.095
ORPLB2-EPA	2	4	E02KH22	0.066	0.409
LAWA44-EPA	2	5	E01KH12	0.492	<0.010
LAWA23-EPA	2	6	E03KH22	0.203	0.097
ORPLB2-EPA	2	7	E02KH12	0.069	0.411
LRM	2	8	LRMKH22	<0.010	0.881

Table A-4. Measurements from the LM Preparation Method (part 1)

ID	Block	Sequence	Lab ID	Ca (wt%)	Cr (wt%)	Fe (wt%)	K (wt%)	Mg (wt%)	Mn (wt%)	Mo (wt%)	Na (wt%)	Ni (wt%)
LRM	1	1	LRMLM11	0.352	0.135	0.992	1.17	<0.100	<0.100	<0.100	16.2	0.136
LAWA23-EPA	1	2	E03LM21	3.17	<0.100	4.96	2.58	1.09	<0.100	<0.100	15.5	<0.100
ORPLB2-EPA	1	3	E02LM11	0.876	0.322	0.738	0.126	0.604	<0.100	<0.100	19.4	<0.100
LAWA44-EPA	1	4	E01LM21	1.44	<0.100	4.82	0.495	1.08	<0.100	<0.100	15.8	<0.100
LAWA23-EPA	1	5	E03LM11	3.17	<0.100	4.98	2.54	1.10	<0.100	<0.100	14.8	<0.100
ORPLB2-EPA	1	6	E02LM21	0.749	0.328	0.719	0.136	0.589	<0.100	<0.100	19.3	<0.100
LAWA44-EPA	1	7	E01LM11	1.42	<0.100	4.83	0.489	1.08	<0.100	<0.100	15.6	<0.100
LRM	1	8	LRMLM12	0.366	0.136	1.01	1.21	<0.100	<0.100	<0.100	15.6	0.138
LRM	2	1	LRMLM21	0.347	0.131	1.04	1.25	<0.100	<0.100	<0.100	16.0	0.133
ORPLB2-EPA	2	2	E02LM22	0.739	0.325	0.708	0.133	0.585	<0.100	<0.100	19.5	<0.100
LAWA23-EPA	2	3	E03LM12	3.17	<0.100	4.99	2.57	1.11	<0.100	<0.100	15.1	<0.100
ORPLB2-EPA	2	4	E02LM12	0.892	0.323	0.742	0.130	0.607	<0.100	<0.100	19.1	<0.100
LAWA44-EPA	2	5	E01LM12	1.46	<0.100	4.89	0.481	1.11	<0.100	<0.100	15.9	<0.100
LAWA23-EPA	2	6	E03LM22	3.15	<0.100	4.96	2.59	1.10	<0.100	<0.100	15.6	<0.100
LAWA44-EPA	2	7	E01LM22	1.43	<0.100	4.80	0.504	1.09	<0.100	<0.100	15.5	<0.100
LRM	2	8	LRMLM22	0.352	0.133	1.02	1.22	<0.100	<0.100	<0.100	15.8	0.135

Table A-5. Measurements from the LM Preparation Method (part 2)

ID	Block	Sequence	Lab ID	P (wt%)	Re (wt%)	S (wt%)	Sn (wt%)	Ti (wt%)	V (wt%)	Zn (wt%)	Zr (wt%)
LRM	1	1	LRMLM11	0.178	<0.100	0.090	<0.100	<0.100	<0.100	<0.100	0.571
LAWA23-EPA	1	2	E03LM21	<0.100	<0.100	<0.050	<0.100	<0.100	<0.100	2.54	2.12
ORPLB2-EPA	1	3	E02LM11	<0.100	<0.100	0.187	0.687	<0.100	1.07	2.86	3.70
LAWA44-EPA	1	4	E01LM21	<0.100	<0.100	<0.050	<0.100	1.16	<0.100	2.33	2.15
LAWA23-EPA	1	5	E03LM11	<0.100	<0.100	<0.050	<0.100	<0.100	<0.100	2.55	2.14
ORPLB2-EPA	1	6	E02LM21	<0.100	<0.100	0.195	0.763	<0.100	1.09	2.87	3.98
LAWA44-EPA	1	7	E01LM11	<0.100	<0.100	<0.050	<0.100	1.16	<0.100	2.33	2.16
LRM	1	8	LRMLM12	0.185	<0.100	0.092	<0.100	<0.100	<0.100	<0.100	0.593
LRM	2	1	LRMLM21	0.175	<0.100	0.082	<0.100	<0.100	<0.100	<0.100	0.598
ORPLB2-EPA	2	2	E02LM22	<0.100	<0.100	0.189	0.756	<0.100	1.12	2.94	4.00
LAWA23-EPA	2	3	E03LM12	<0.100	<0.100	<0.050	<0.100	<0.100	<0.100	2.55	2.15
ORPLB2-EPA	2	4	E02LM12	<0.100	<0.100	0.190	0.691	<0.100	1.06	2.82	3.63
LAWA44-EPA	2	5	E01LM12	<0.100	<0.100	<0.050	<0.100	1.20	<0.100	2.37	2.19
LAWA23-EPA	2	6	E03LM22	<0.100	<0.100	<0.050	<0.100	<0.100	<0.100	2.55	2.13
LAWA44-EPA	2	7	E01LM22	<0.100	<0.100	<0.050	<0.100	1.17	<0.100	2.33	2.14
LRM	2	8	LRMLM22	0.179	<0.100	0.085	<0.100	<0.100	<0.100	<0.100	0.602

Table A-6. Comparison of Targeted and Measured Glass Compositions

Glass ID	Oxide	BDL (<)	Measured (wt%)	Targeted (wt%)	Difference of Measured versus Targeted	% Difference of Measured versus Targeted
LAWA23-EPA	Al_2O_3		9.556	9.840	-0.284	-2.9%
LAWA23-EPA	B_2O_3		4.299	4.220	0.079	
LAWA23-EPA	CaO		4.428	4.370	0.058	
LAWA23-EPA	Cl		0.202	0.360	-0.158	
LAWA23-EPA	Cr_2O_3	<	0.146	0.100	0.046	
LAWA23-EPA	F		0.096	0.120	-0.024	
LAWA23-EPA	Fe_2O_3		7.209	7.290	-0.081	-1.1%
LAWA23-EPA	K_2O		3.096	3.090	0.006	
LAWA23-EPA	Li_2O		1.956	2.040	-0.084	
LAWA23-EPA	MgO		1.824	2.040	-0.216	
LAWA23-EPA	MnO_2	<	0.158	0.000	0.158	
LAWA23-EPA	MoO_3	<	0.150	0.000	0.150	
LAWA23-EPA	Na_2O		20.557	19.970	0.587	2.9%
LAWA23-EPA	NiO	<	0.127	0.000	0.127	
LAWA23-EPA	P_2O_5	<	0.229	0.080	0.149	
LAWA23-EPA	Re_2O_7	<	0.130	0.100	0.030	
LAWA23-EPA	SiO_2		39.844	40.080	-0.236	-0.6%
LAWA23-EPA	SnO_2	<	0.127	0.000	0.127	
LAWA23-EPA	SO_3	<	0.125	0.040	0.085	
LAWA23-EPA	TiO_2	<	0.167	0.000	0.167	
LAWA23-EPA	V_2O_5	<	0.179	0.000	0.179	
LAWA23-EPA	ZnO		3.171	3.270	-0.099	
LAWA23-EPA	ZrO_2		2.884	2.980	-0.096	
LAWA23-EPA	Sum		100.661	99.990	0.671	0.7%
LAWA44-EPA	Al_2O_3		6.042	6.200	-0.158	-2.6%
LAWA44-EPA	B_2O_3		8.710	8.900	-0.190	-2.1%
LAWA44-EPA	CaO		2.011	1.990	0.021	
LAWA44-EPA	Cl		0.495	0.650	-0.156	
LAWA44-EPA	Cr_2O_3	<	0.146	0.100	0.046	
LAWA44-EPA	F	<	0.010	0.010	0.000	
LAWA44-EPA	Fe_2O_3		6.927	6.980	-0.053	-0.8%
LAWA44-EPA	K_2O		0.593	0.500	0.093	
LAWA44-EPA	Li_2O	<	0.215	0.000	0.215	
LAWA44-EPA	MgO		1.808	1.990	-0.182	
LAWA44-EPA	MnO_2	<	0.158	0.000	0.158	
LAWA44-EPA	MoO_3	<	0.150	0.010	0.140	
LAWA44-EPA	Na_2O		21.164	19.990	1.174	5.9%
LAWA44-EPA	NiO	<	0.127	0.000	0.127	
LAWA44-EPA	P_2O_5	<	0.229	0.030	0.199	
LAWA44-EPA	Re_2O_7	<	0.130	0.100	0.030	
LAWA44-EPA	SiO_2		43.053	44.530	-1.477	-3.3%
LAWA44-EPA	SnO_2	<	0.127	0.000	0.127	
LAWA44-EPA	SO_3	<	0.125	0.100	0.025	
LAWA44-EPA	TiO_2		1.956	1.990	-0.034	
LAWA44-EPA	V_2O_5	<	0.179	0.000	0.179	

Table A-6. Comparison of Targeted and Measured Glass Compositions (continued)

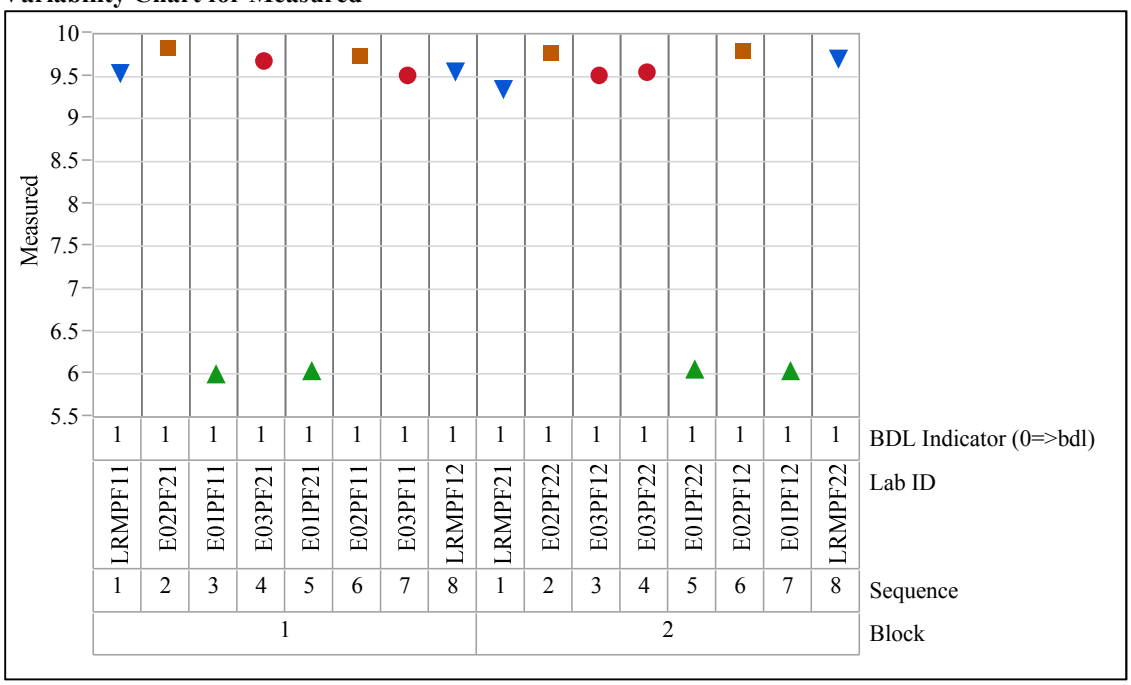
Glass ID	Oxide	BDL (<)	Measured (wt%)	Targeted (wt%)	Difference of Measured versus Targeted	% Difference of Measured versus Targeted
LAWA44-EPA	ZnO		2.913	2.960	-0.047	
LAWA44-EPA	ZrO_2		2.918	2.990	-0.072	
LAWA44-EPA	Sum		100.185	100.020	0.165	0.2%
LRM	Al_2O_3		9.528	9.510	0.018	0.2%
LRM	B_2O_3		7.873	7.850	0.023	0.3%
LRM	CaO		0.496	0.540	-0.044	
LRM	Cl	<	0.010	0.000	0.010	
LRM	Cr_2O_3		0.195	0.190	0.005	
LRM	F		0.883	0.860	0.023	
LRM	Fe_2O_3		1.455	1.380	0.075	
LRM	K_2O		1.461	1.480	-0.019	
LRM	Li_2O	<	0.222	0.110	0.112	
LRM	MgO	<	0.166	0.100	0.066	
LRM	MnO_2	<	0.158	0.098	0.060	
LRM	MoO_3	<	0.150	0.000	0.150	
LRM	Na_2O		21.433	20.030	1.403	7.0%
LRM	NiO		0.172	0.190	-0.018	
LRM	P_2O_5		0.411	0.540	-0.129	
LRM	Re_2O_7	<	0.130	0.000	0.130	
LRM	SiO_2		53.696	54.200	-0.504	-0.9%
LRM	SnO_2	<	0.127	0.000	0.127	
LRM	SO_3		0.218	0.300	-0.082	
LRM	TiO_2	<	0.167	0.000	0.167	
LRM	V_2O_5	<	0.179	0.000	0.179	
LRM	ZnO	<	0.124	0.000	0.124	
LRM	ZrO_2		0.798	0.930	-0.132	
LRM	Sum		100.052	98.308	1.744	1.8%
ORPLB2-EPA	Al_2O_3		9.778	10.000	-0.222	-2.2%
ORPLB2-EPA	B_2O_3		7.293	7.300	-0.007	-0.1%
ORPLB2-EPA	CaO		1.139	1.100	0.039	
ORPLB2-EPA	Cl		0.067	0.110	-0.043	
ORPLB2-EPA	Cr_2O_3		0.474	0.520	-0.046	
ORPLB2-EPA	Cs_2O		0.129	0.150	-0.021	
ORPLB2-EPA	F		0.412	0.490	-0.079	
ORPLB2-EPA	Fe_2O_3		1.118	1.100	0.018	
ORPLB2-EPA	K_2O		0.158	0.120	0.038	
ORPLB2-EPA	Li_2O	<	0.215	0.000	0.215	
ORPLB2-EPA	MgO		0.989	1.100	-0.111	
ORPLB2-EPA	MnO_2	<	0.158	0.060	0.098	
ORPLB2-EPA	MoO_3	<	0.150	0.000	0.150	
ORPLB2-EPA	Na_2O		26.050	25.000	1.050	4.2%
ORPLB2-EPA	NiO	<	0.127	0.040	0.087	
ORPLB2-EPA	P_2O_5	<	0.229	0.230	-0.001	
ORPLB2-EPA	Re_2O_7	<	0.130	0.100	0.030	
ORPLB2-EPA	SiO_2		39.951	39.880	0.071	0.2%
ORPLB2-EPA	SnO_2		0.920	1.080	-0.160	

Table A-6. Comparison of Targeted and Measured Glass Compositions (continued)

Glass ID	Oxide	BDL (<)	Measured (wt%)	Targeted (wt%)	Difference of Measured versus Targeted	% Difference of Measured versus Targeted
ORPLB2-EPA	SO_3		0.475	0.520	-0.045	
ORPLB2-EPA	TiO_2	<	0.167	0.000	0.167	
ORPLB2-EPA	V_2O_5		1.937	2.000	-0.063	
ORPLB2-EPA	ZnO		3.576	3.650	-0.074	
ORPLB2-EPA	ZrO_2		5.170	5.440	-0.270	-5.0%
ORPLB2-EPA	Sum		100.813	99.990	0.823	0.8%

Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence

Analyte=Al2O3 (wt%), Prep Method=PF
Variability Chart for Measured



Analyte=B2O3 (wt%), Prep Method=PF
Variability Chart for Measured

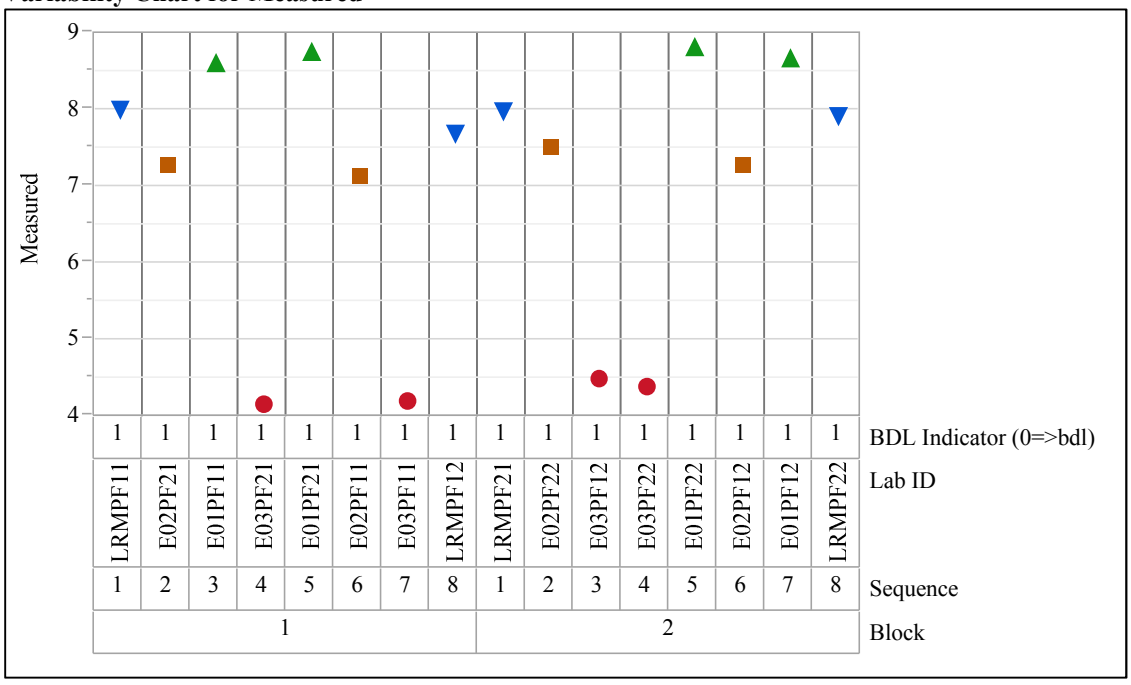
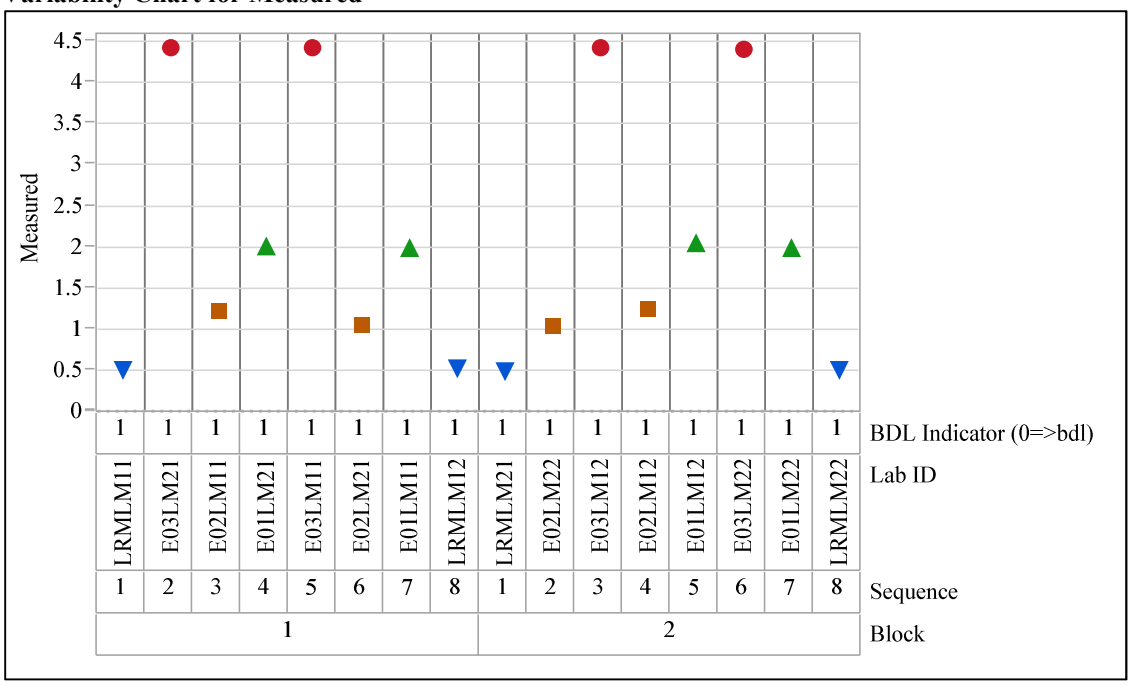


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

Analyte=CaO (wt%), Prep Method=LM
Variability Chart for Measured



Analyte=Cl (wt%), Prep Method=KH
Variability Chart for Measured

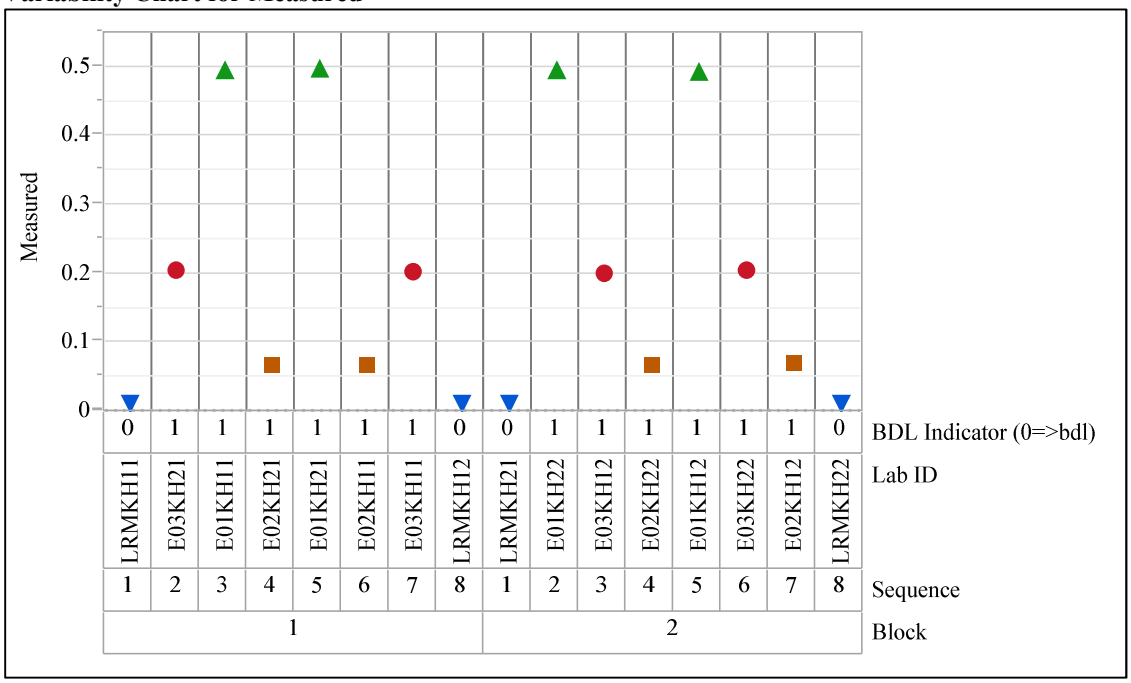
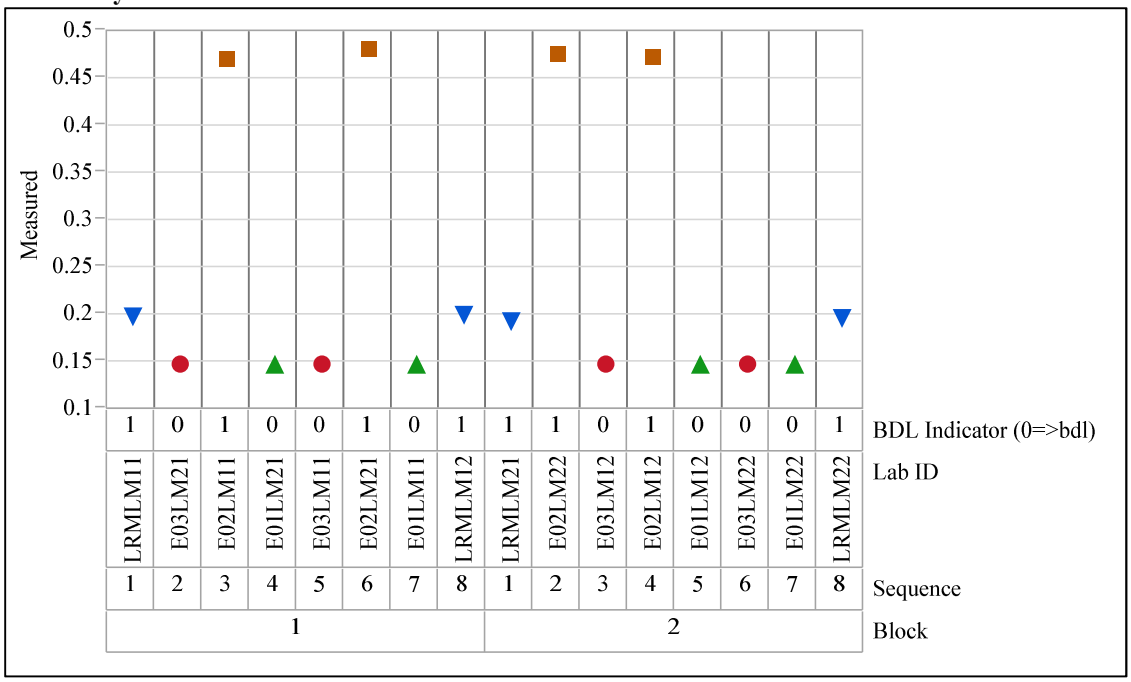


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

Analyte=Cr2O3 (wt%), Prep Method=LM
Variability Chart for Measured



Analyte=Cs2O (wt%), Prep Method=AD
Variability Chart for Measured

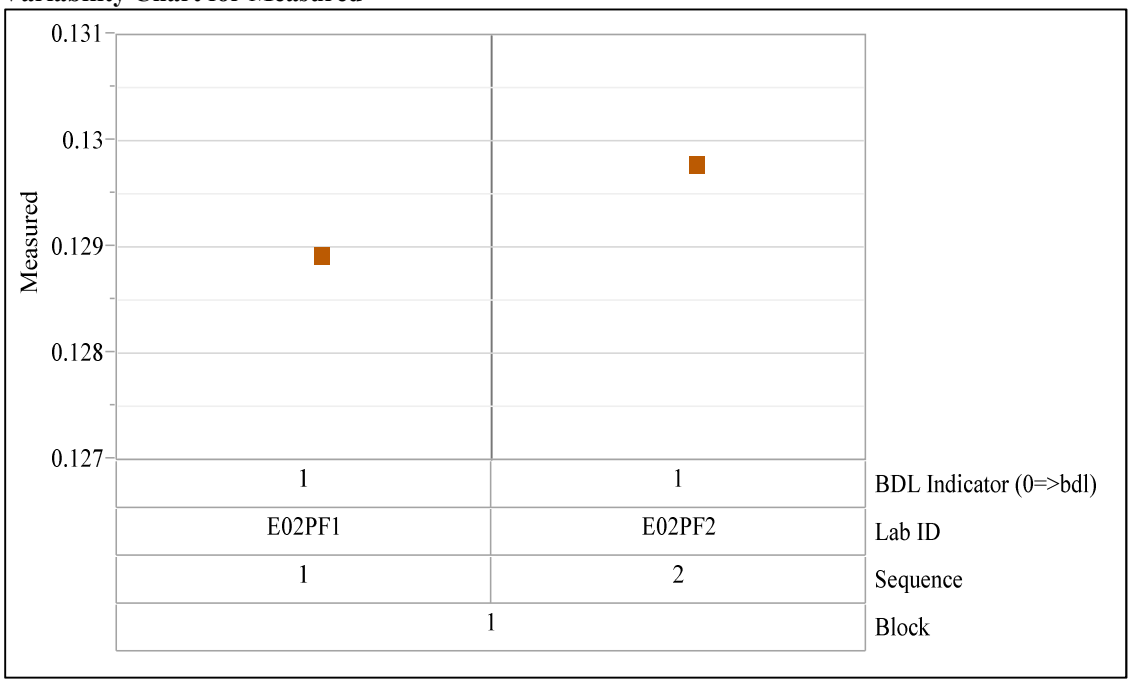
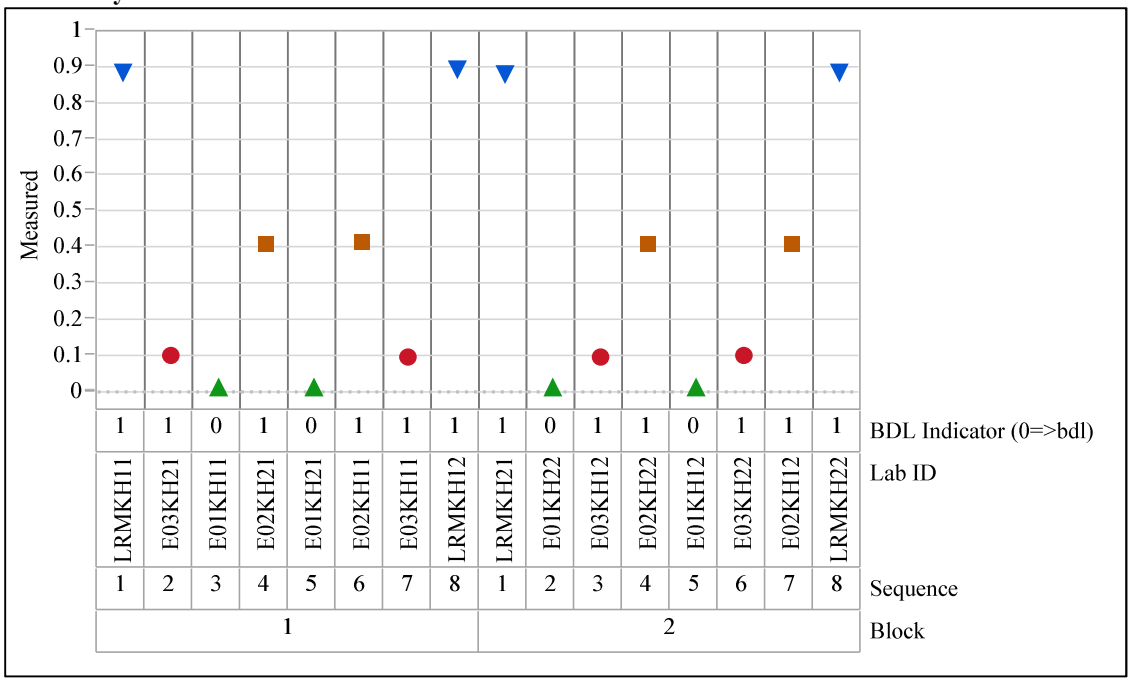


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

Analyte=F (wt%), Prep Method=KH
Variability Chart for Measured



Analyte=Fe2O3 (wt%), Prep Method=LM
Variability Chart for Measured

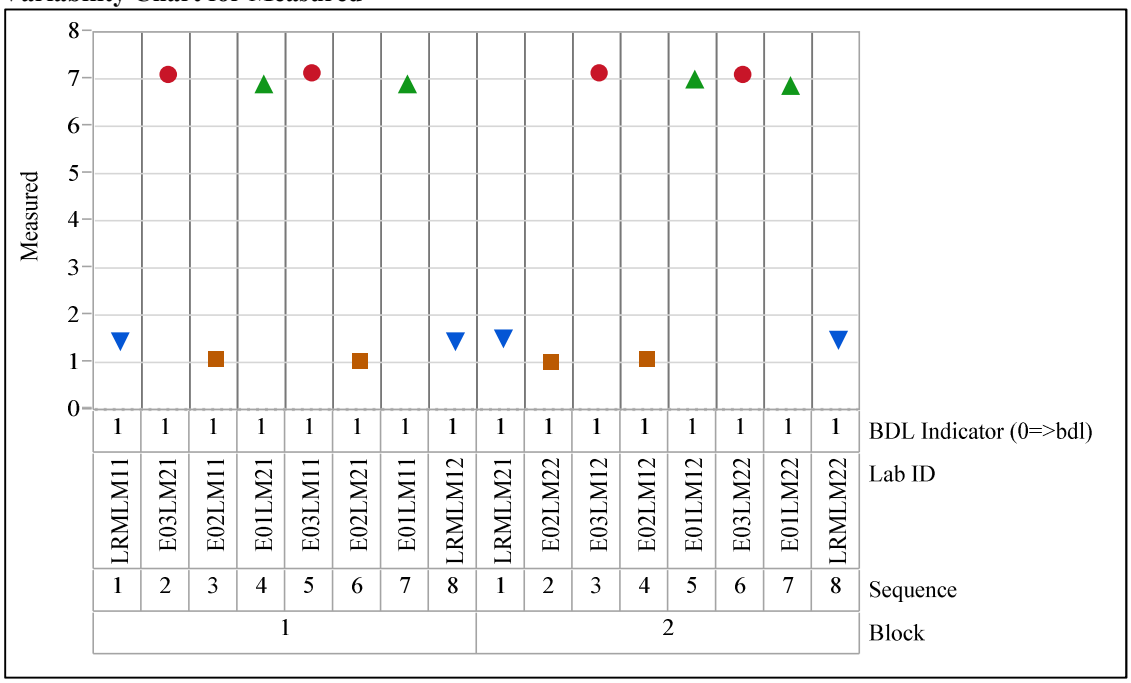
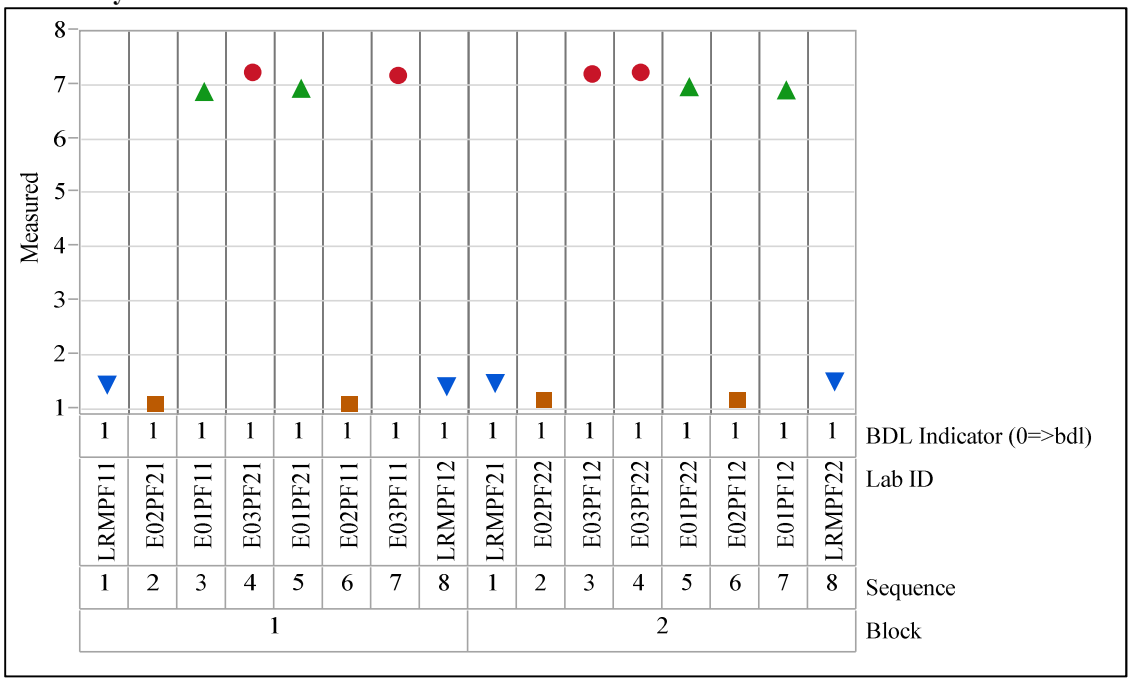


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

Analyte=Fe2O3 (wt%), Prep Method=PF
Variability Chart for Measured



Analyte=K2O (wt%), Prep Method=LM
Variability Chart for Measured

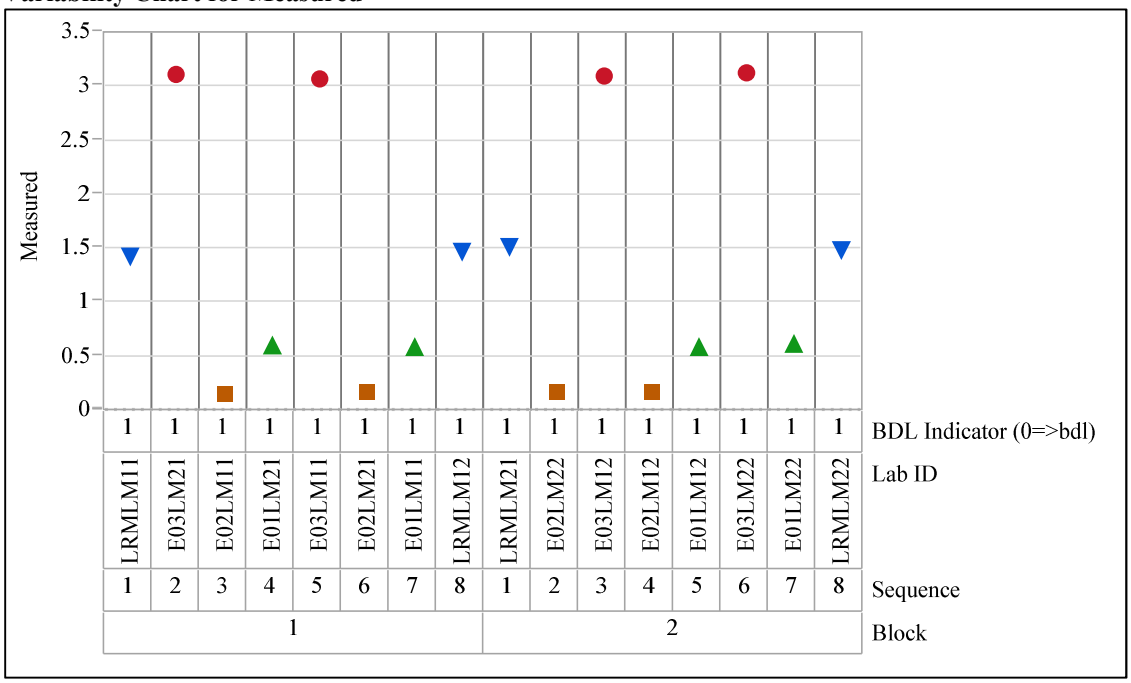
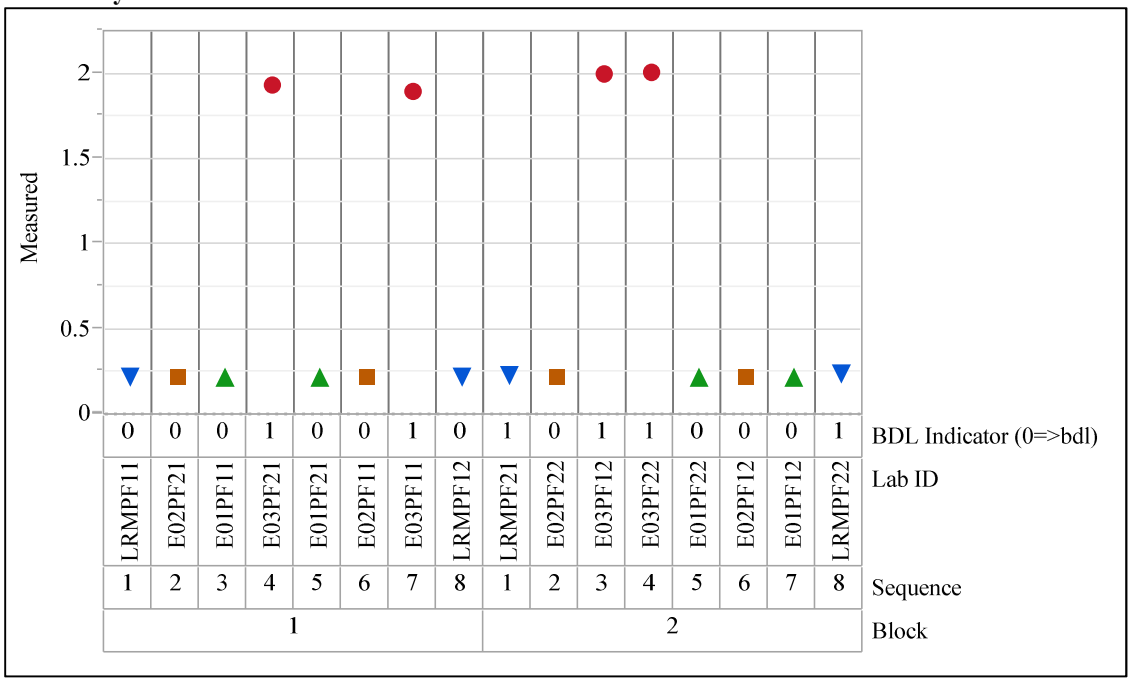


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

Analyte=Li2O (wt%), Prep Method=PF
Variability Chart for Measured



Analyte=MgO (wt%), Prep Method=LM
Variability Chart for Measured

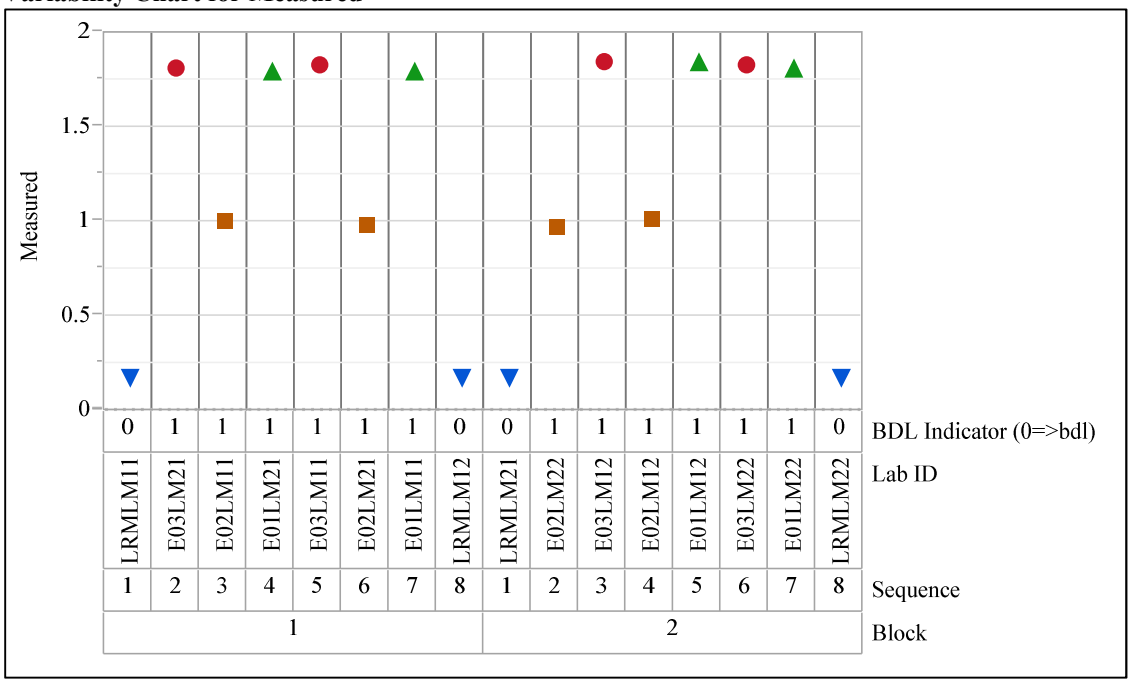
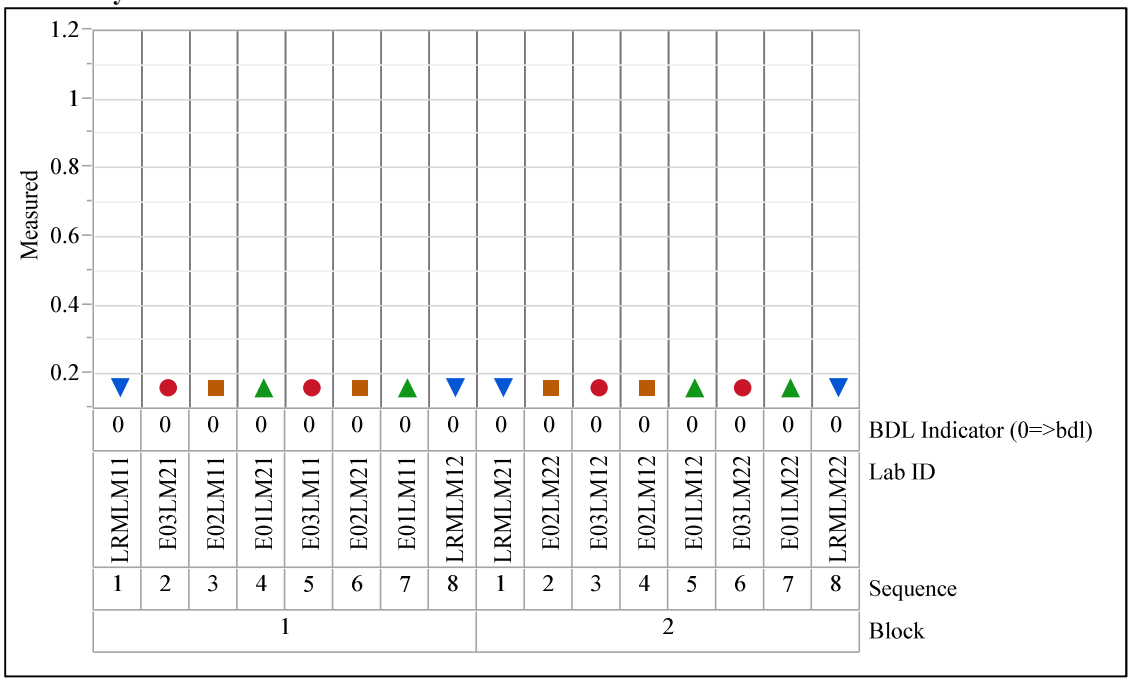


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

Analyte=MnO2 (wt%), Prep Method=LM
Variability Chart for Measured



Analyte=MoO3 (wt%), Prep Method=LM
Variability Chart for Measured

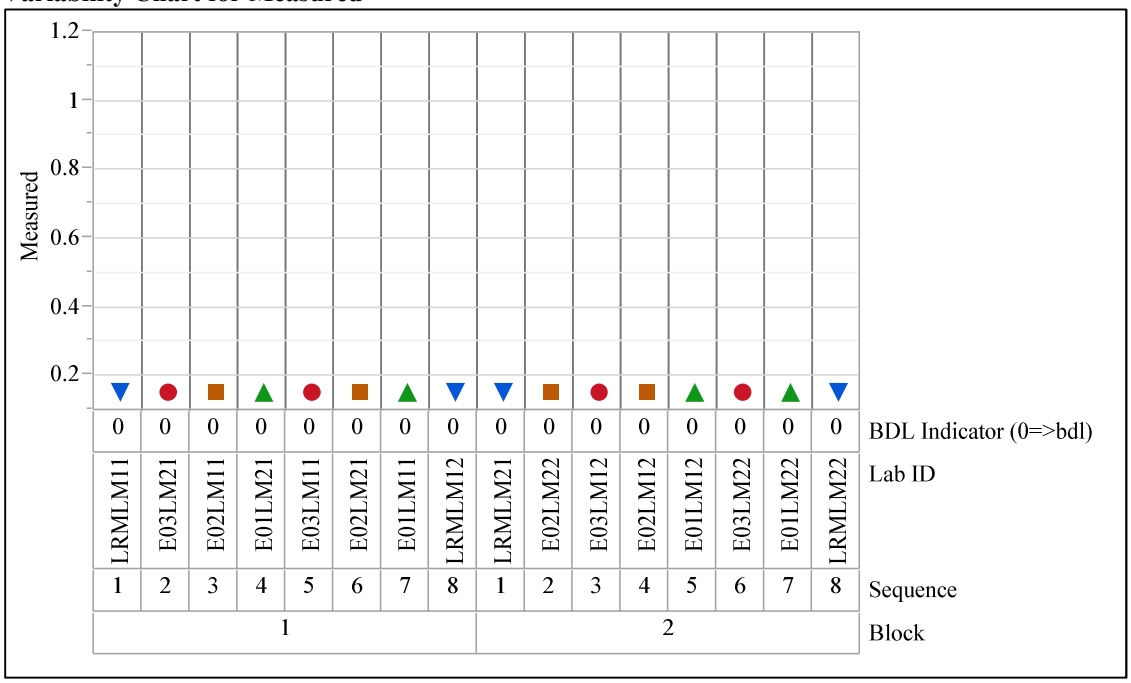
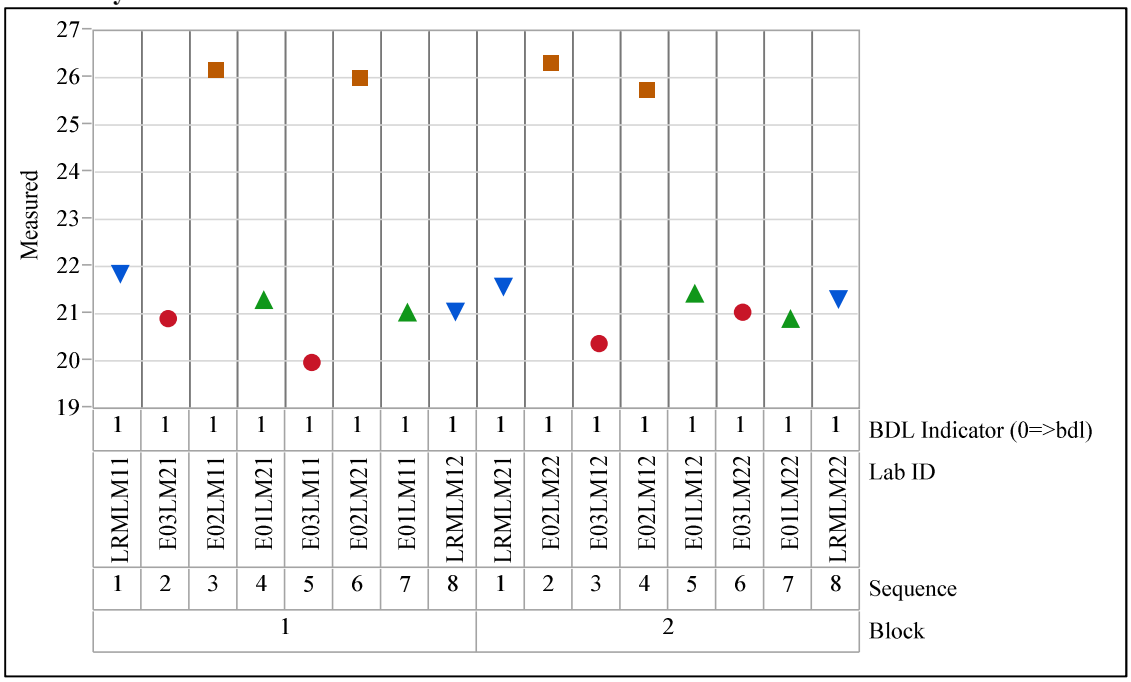


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

Analyte=Na2O (wt%), Prep Method=LM
Variability Chart for Measured



Analyte=NiO (wt%), Prep Method=LM
Variability Chart for Measured

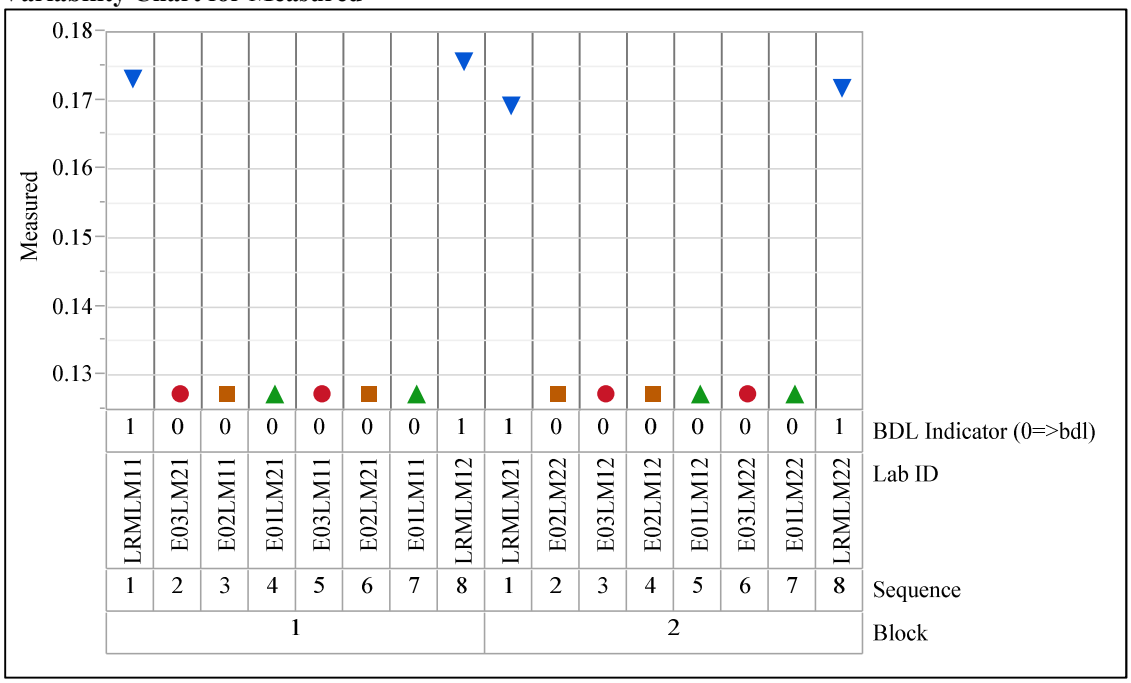
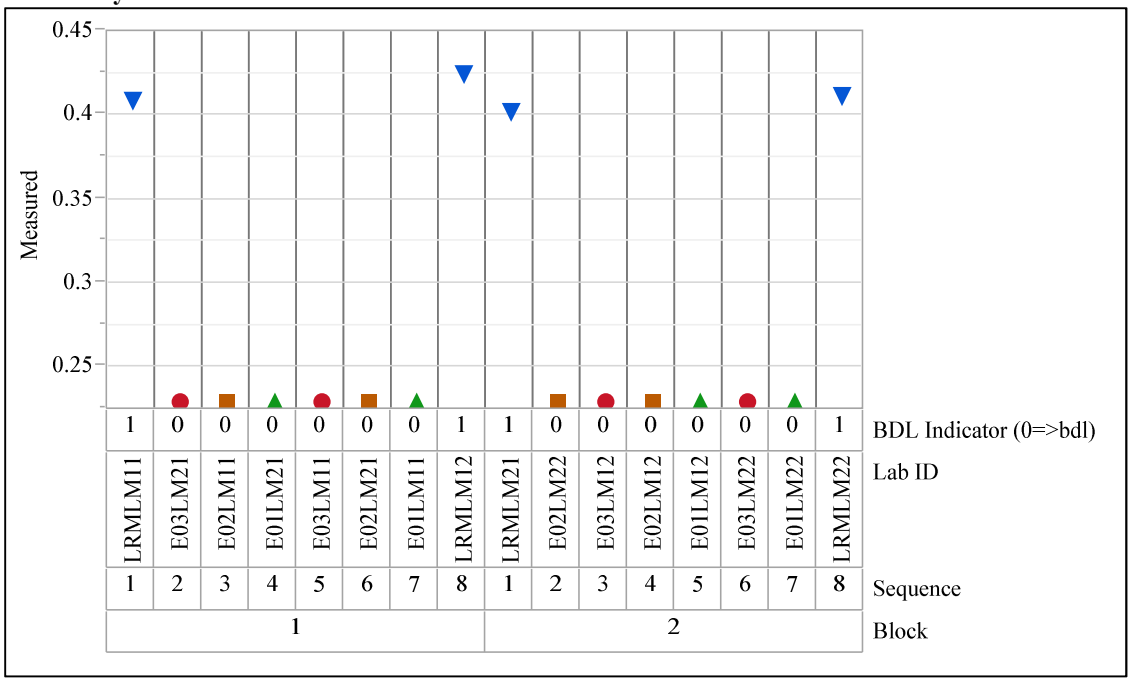


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

Analyte=P2O5 (wt%), Prep Method=LM
Variability Chart for Measured



Analyte=Re2O7 (wt%), Prep Method=LM
Variability Chart for Measured

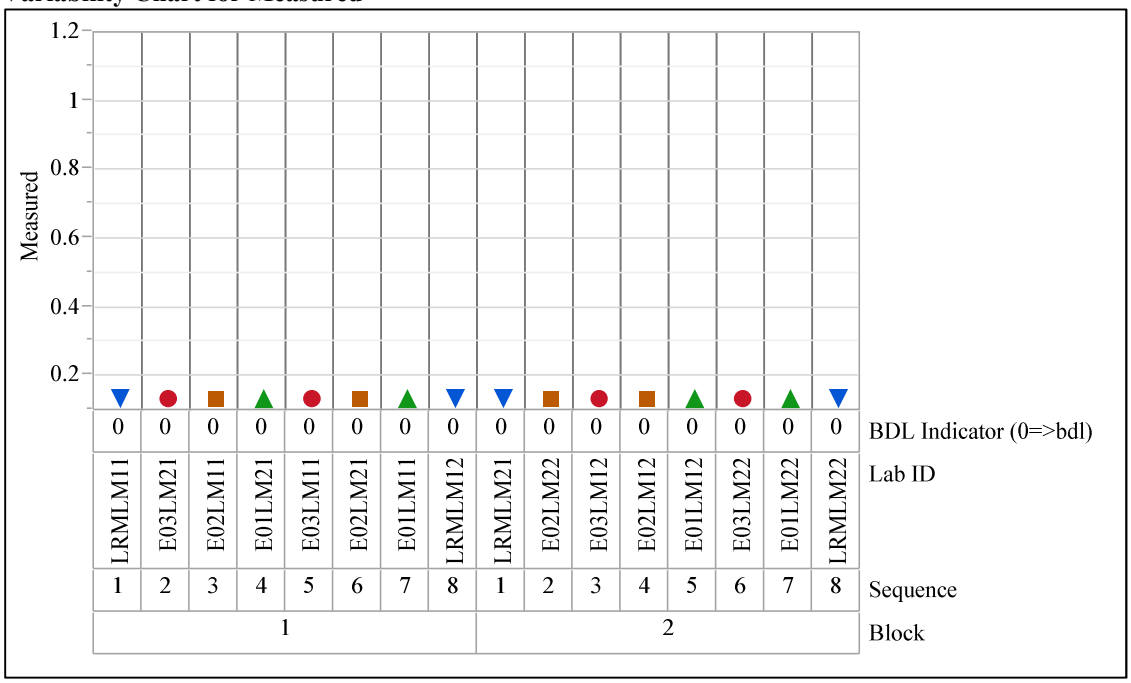
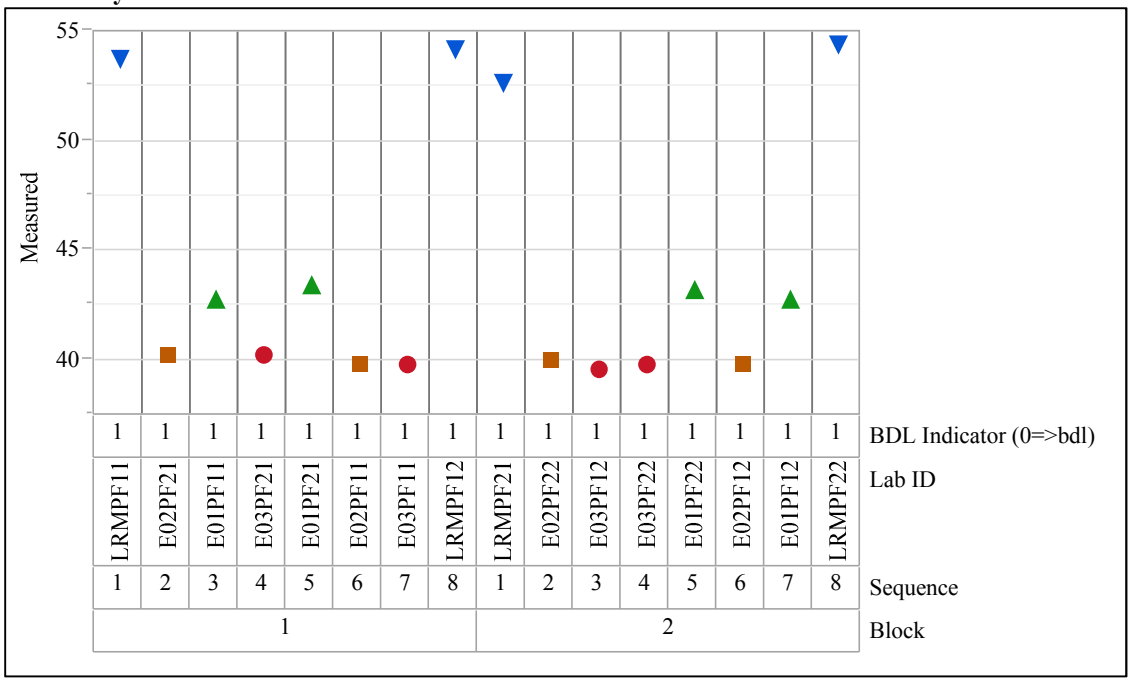


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

Analyte=SiO2 (wt%), Prep Method=PF
Variability Chart for Measured



Analyte=SnO2 (wt%), Prep Method=LM
Variability Chart for Measured

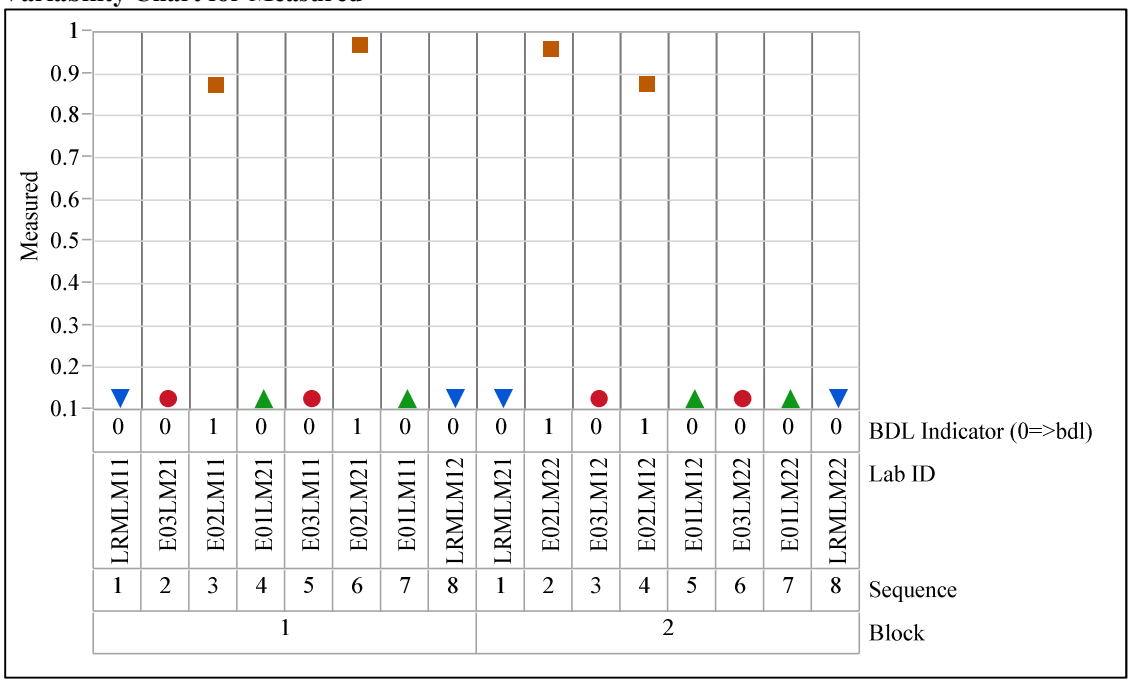
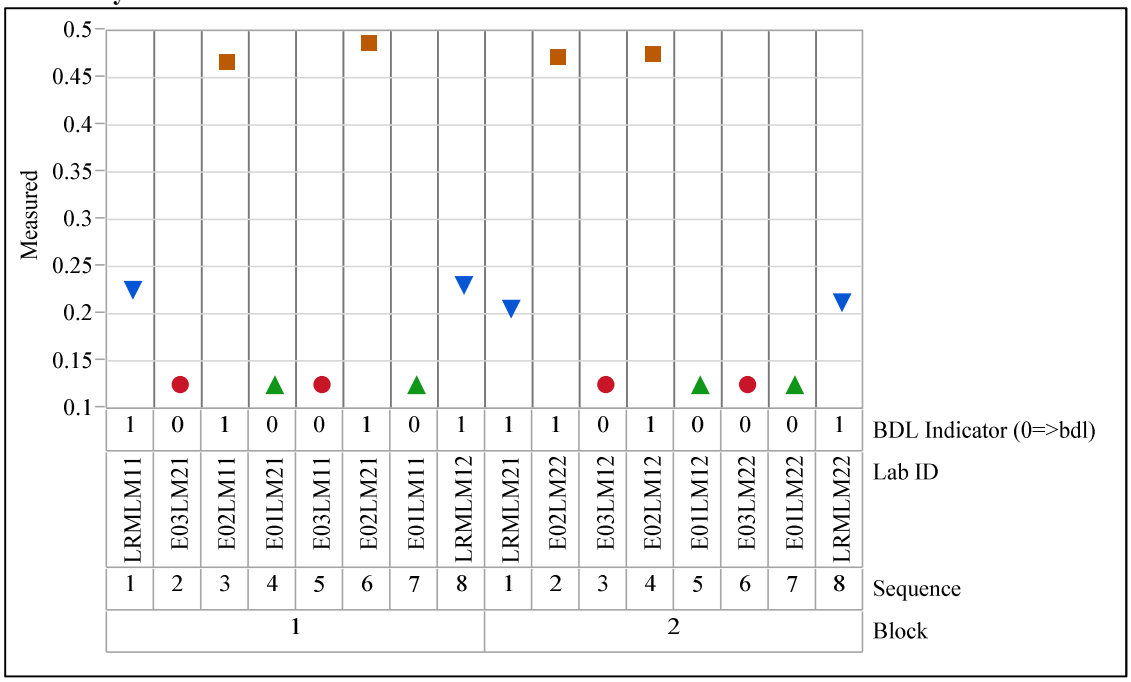


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

Analyte=SO3 (wt%), Prep Method=LM
Variability Chart for Measured



Analyte=TiO2 (wt%), Prep Method=LM
Variability Chart for Measured

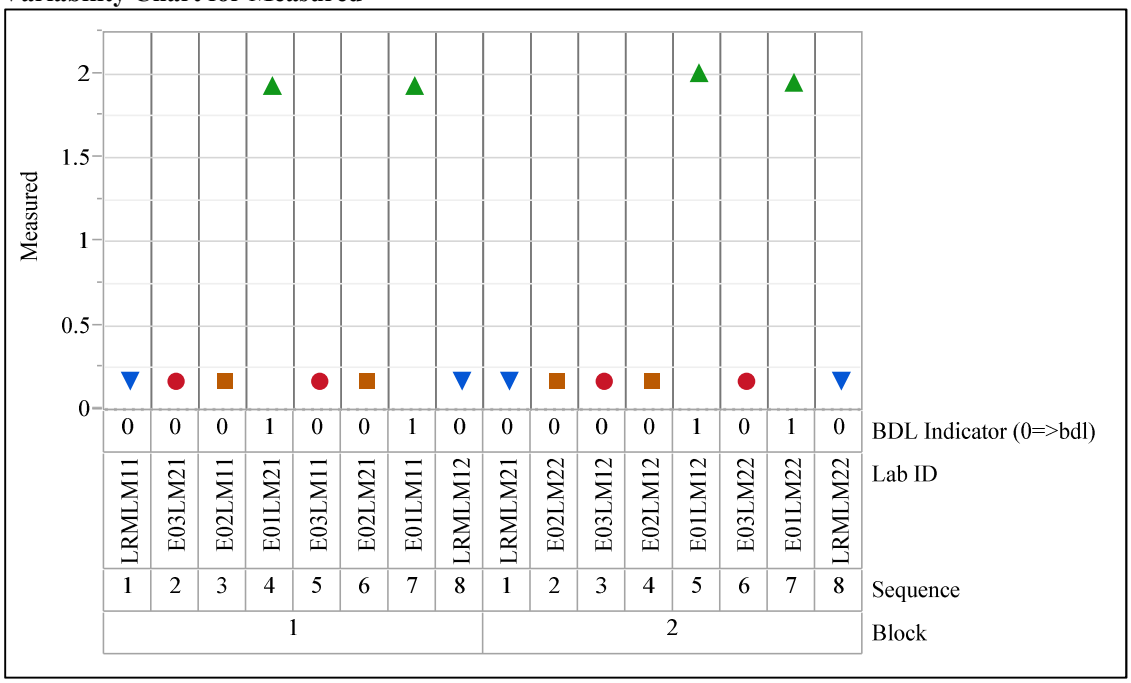
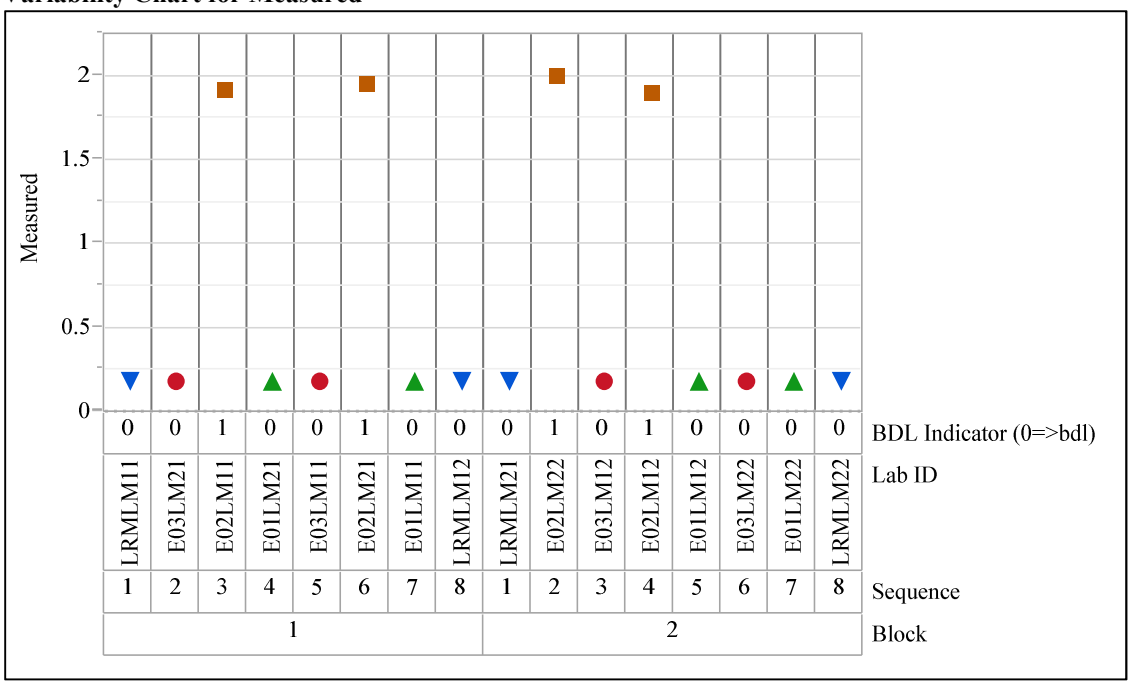


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

Analyte=V2O5 (wt%), Prep Method=LM
Variability Chart for Measured



Analyte=ZnO (wt%), Prep Method=LM
Variability Chart for Measured

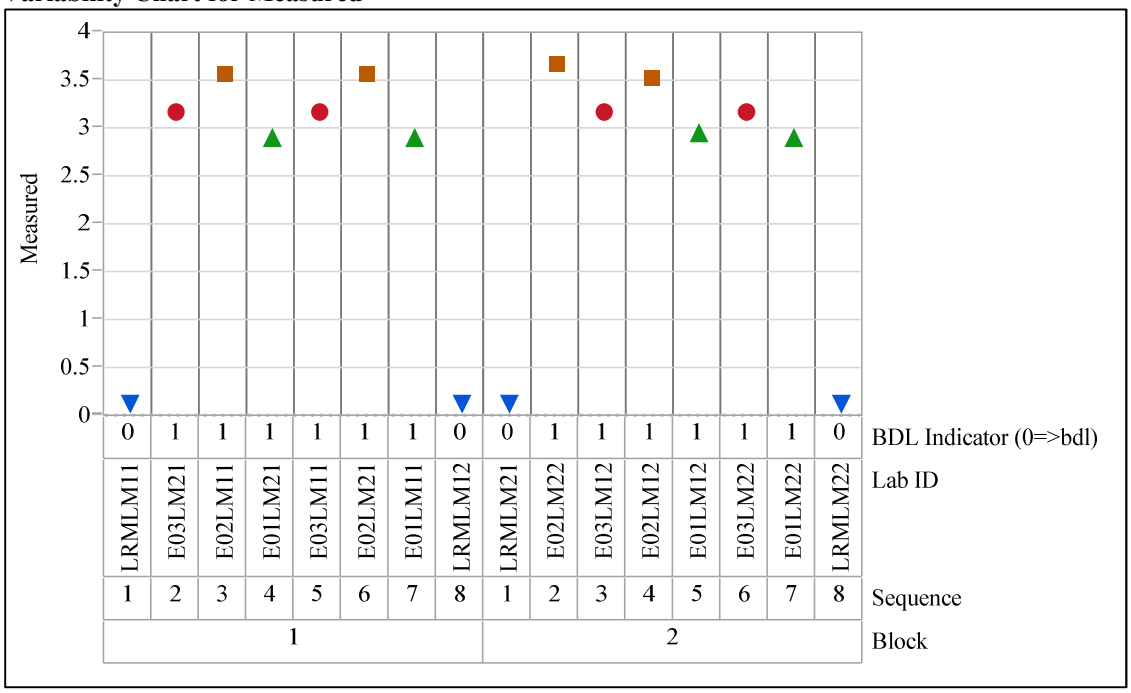


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

Analyte=ZrO2 (wt%), Prep Method=LM
Variability Chart for Measured

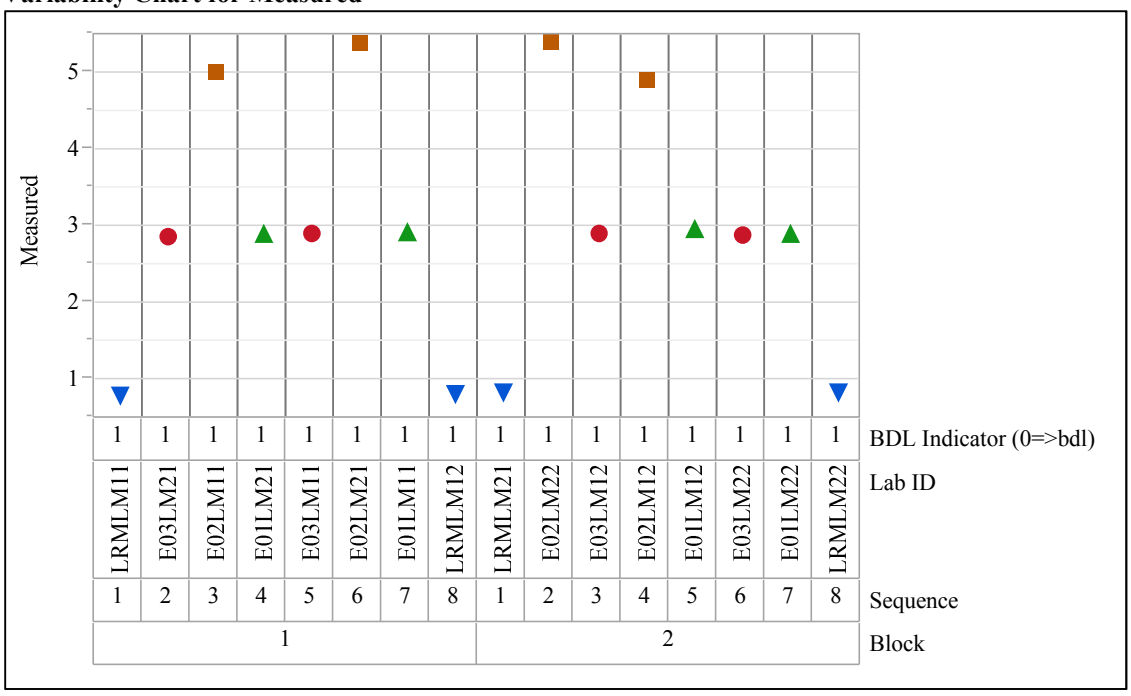


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations

Analyte=Al2O3 (wt%), Prep Method=PF
Variability Chart for Measured

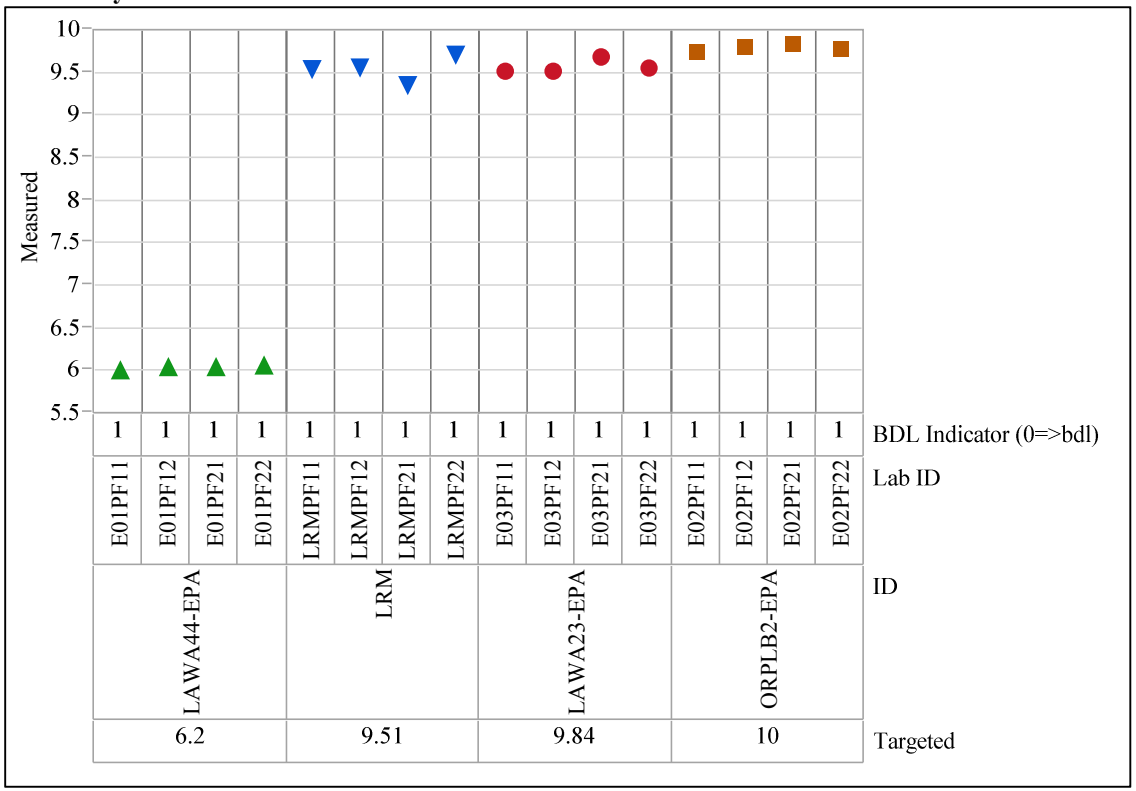


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=B2O3 (wt%), Prep Method=PF
Variability Chart for Measured

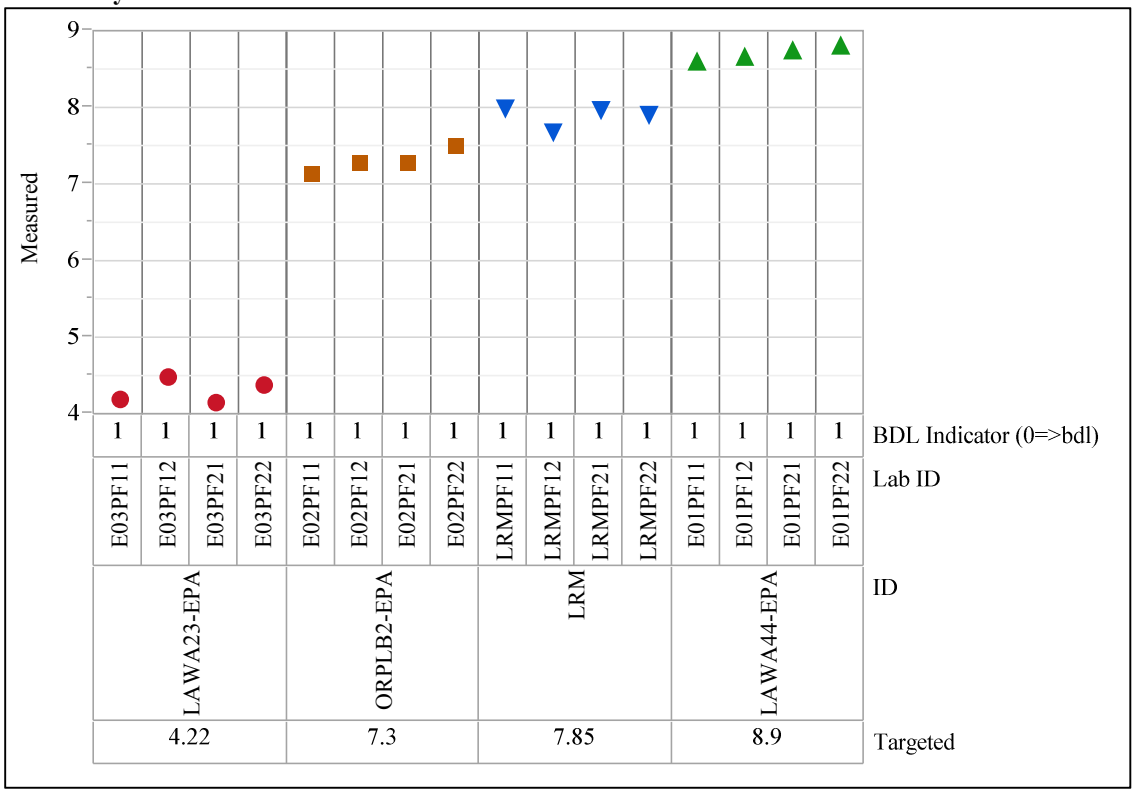


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=CaO (wt%), Prep Method=LM
Variability Chart for Measured

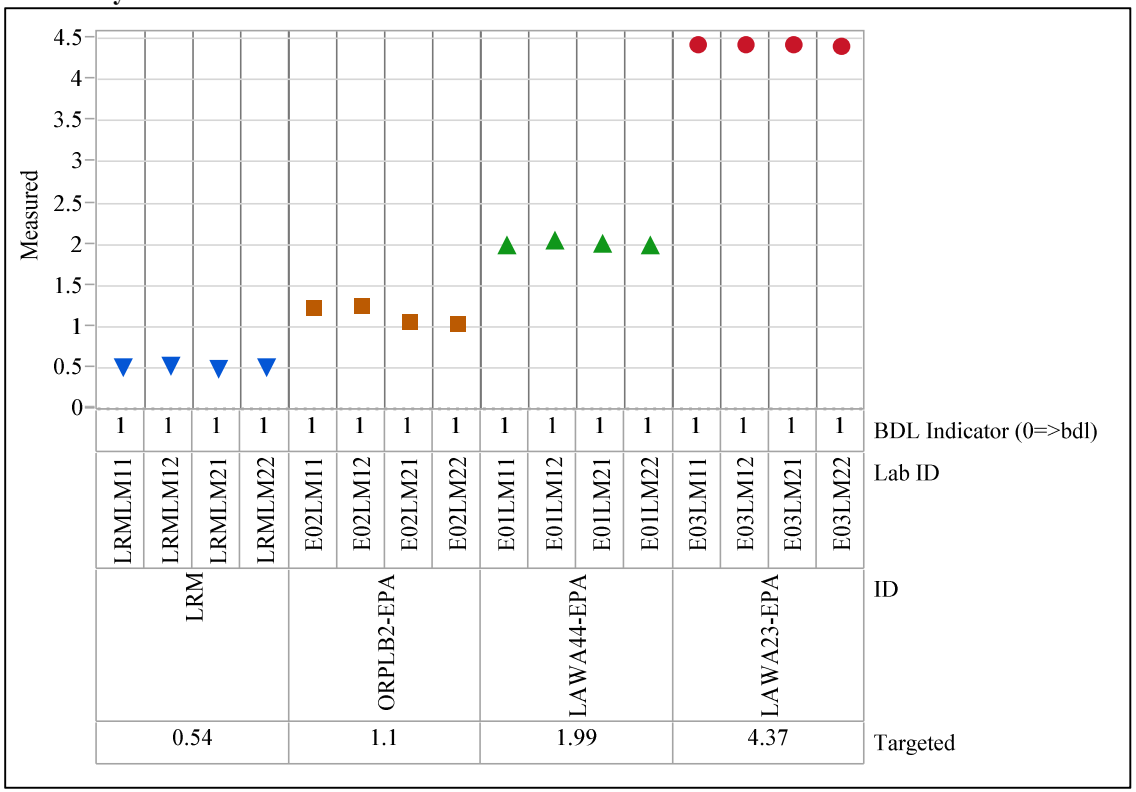


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=Cl (wt%), Prep Method=KH
Variability Chart for Measured

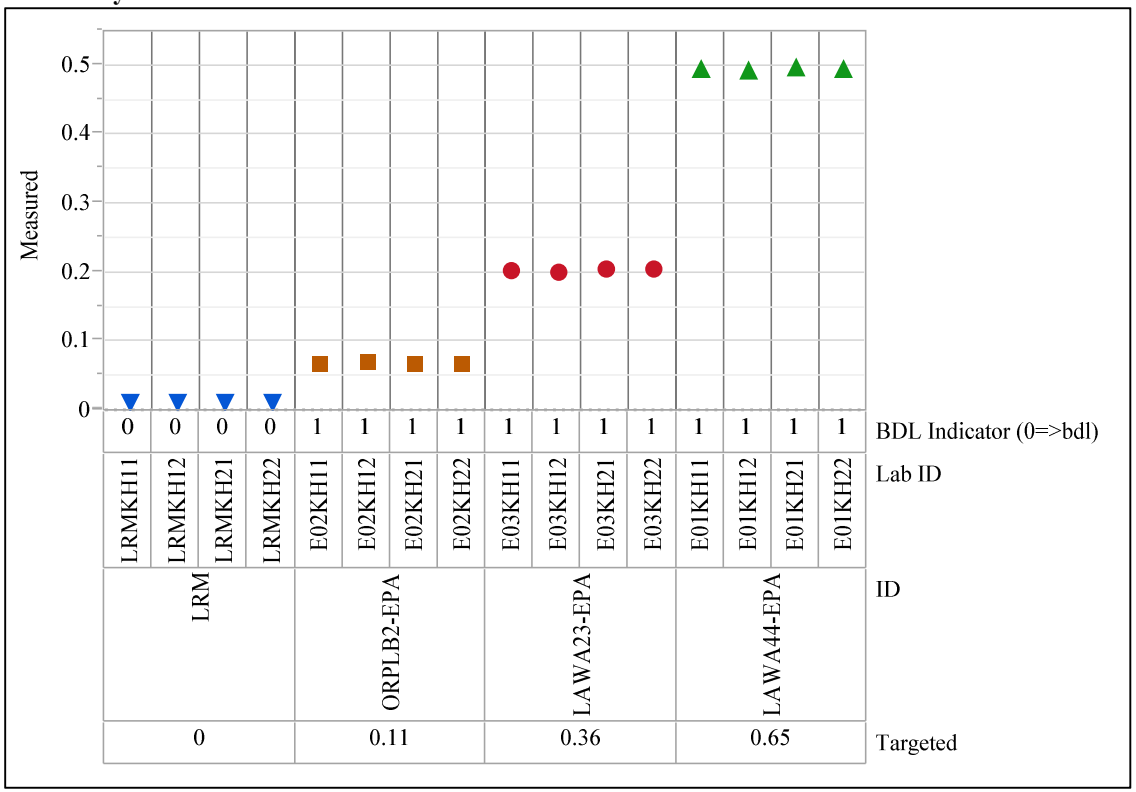


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=Cr2O3 (wt%), Prep Method=LM
Variability Chart for Measured

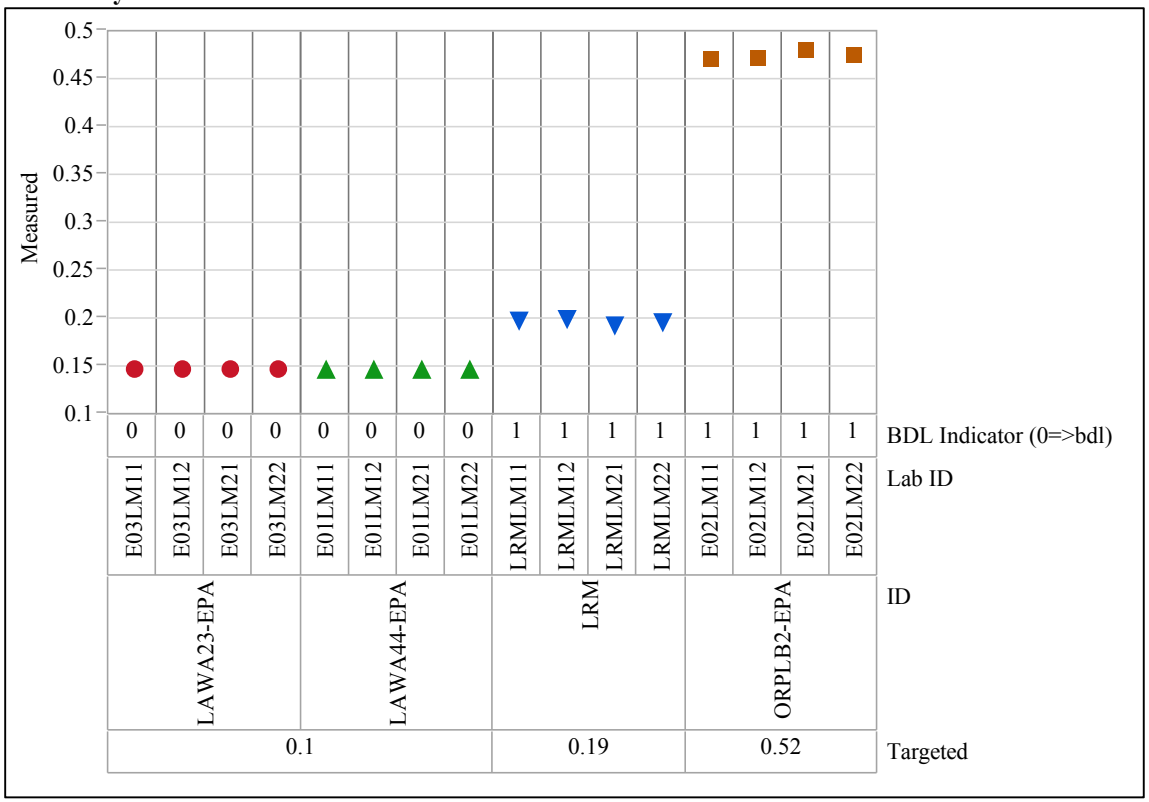


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=Cs2O (wt%), Prep Method=AD
Variability Chart for Measured

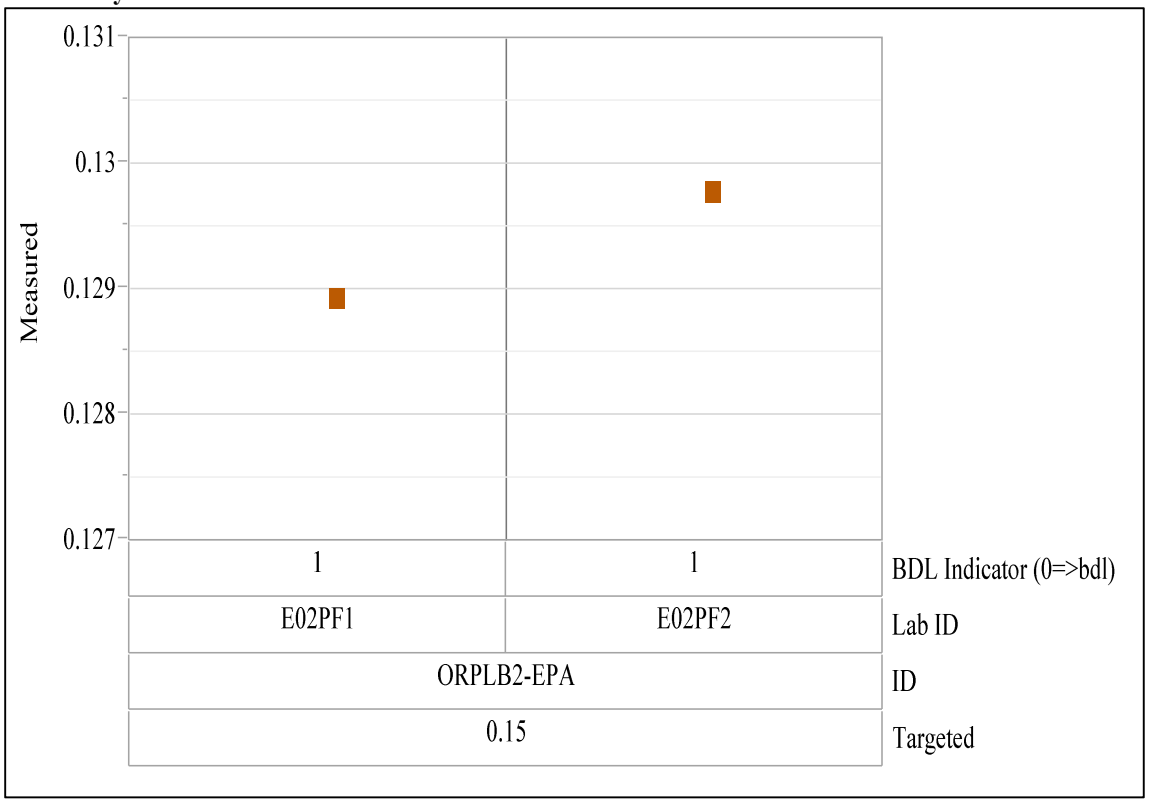


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=F (wt%), Prep Method=KH
Variability Chart for Measured

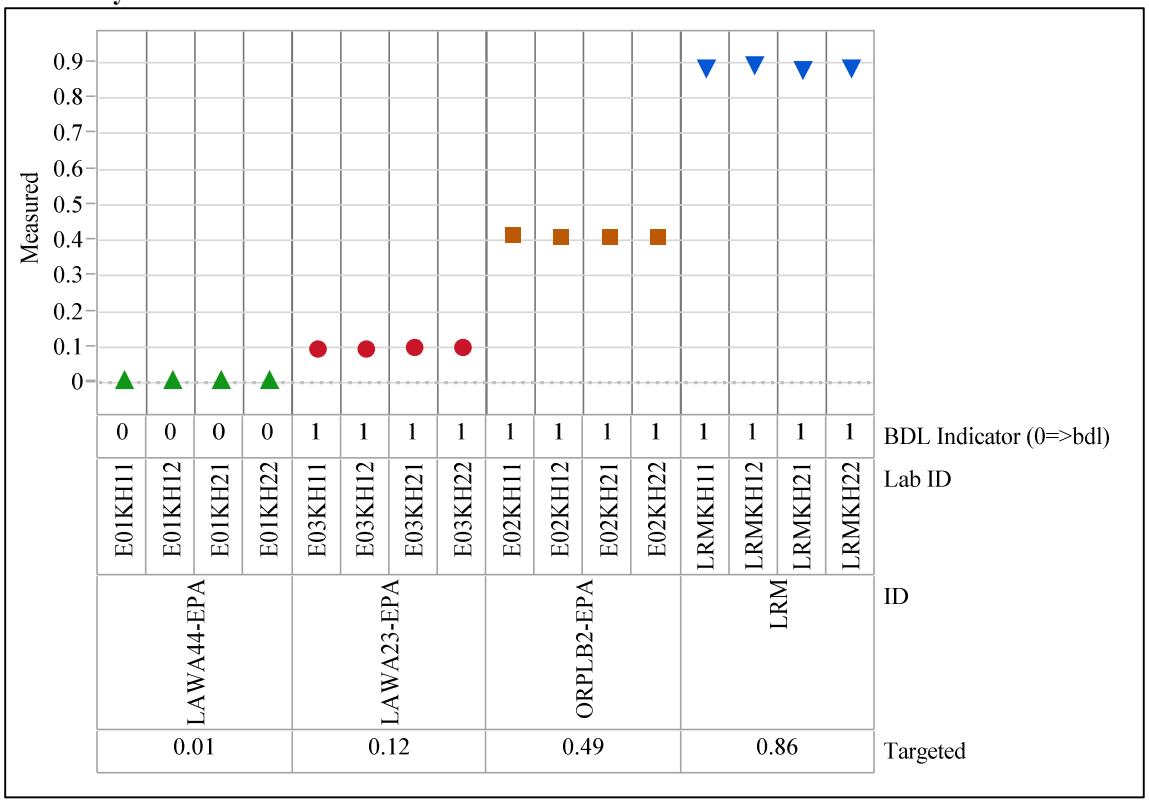


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=Fe2O3 (wt%), Prep Method=LM
Variability Chart for Measured

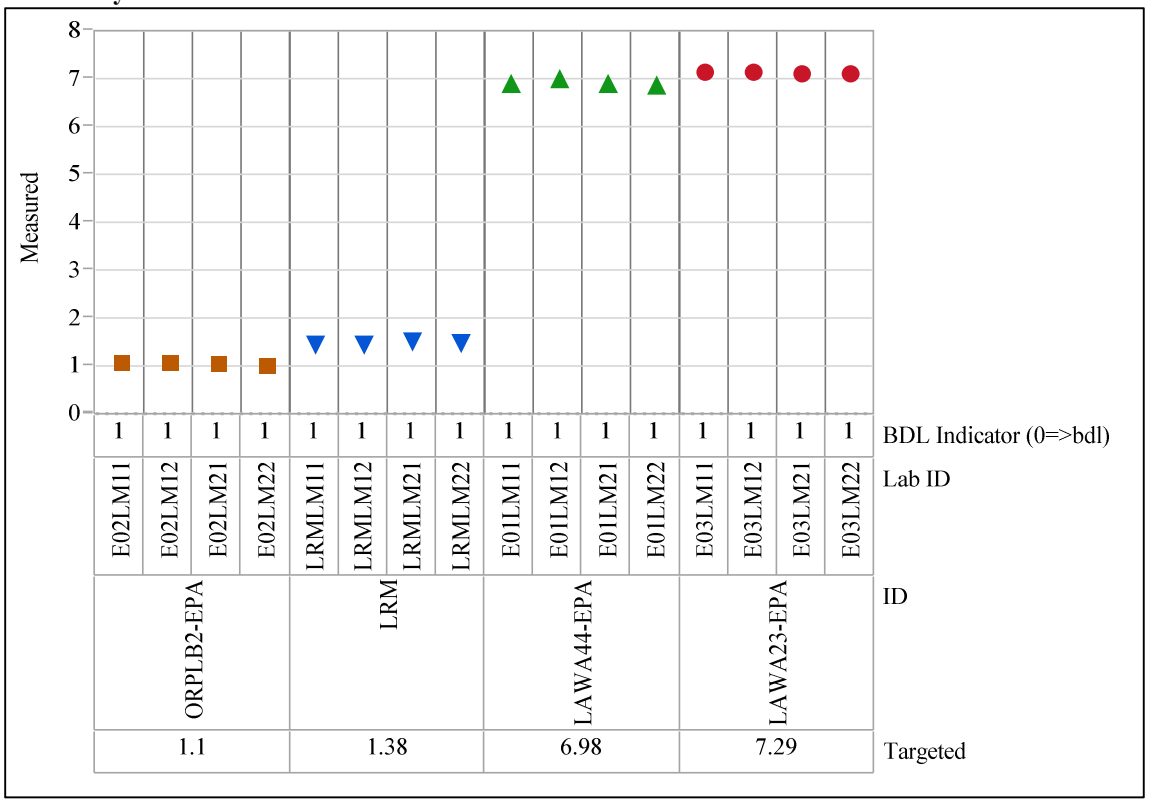


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=Fe2O3 (wt%), Prep Method=PF
Variability Chart for Measured

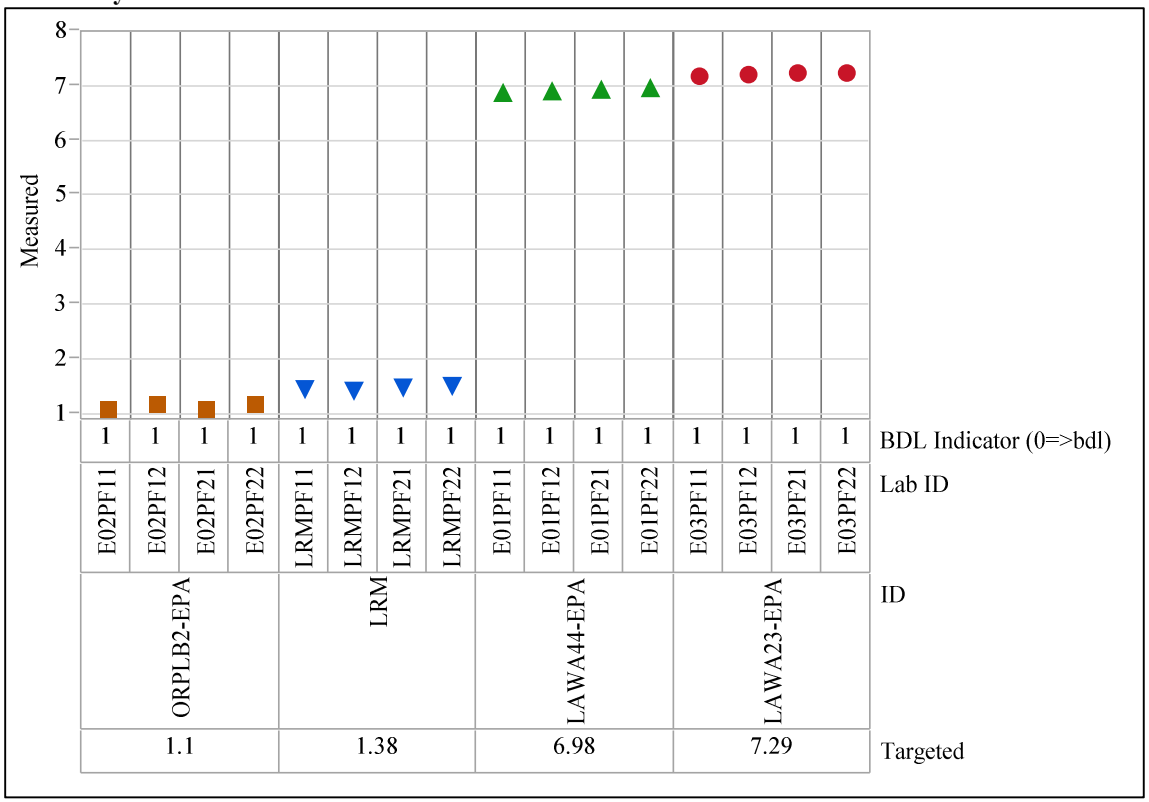


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=K2O (wt%), Prep Method=LM
Variability Chart for Measured

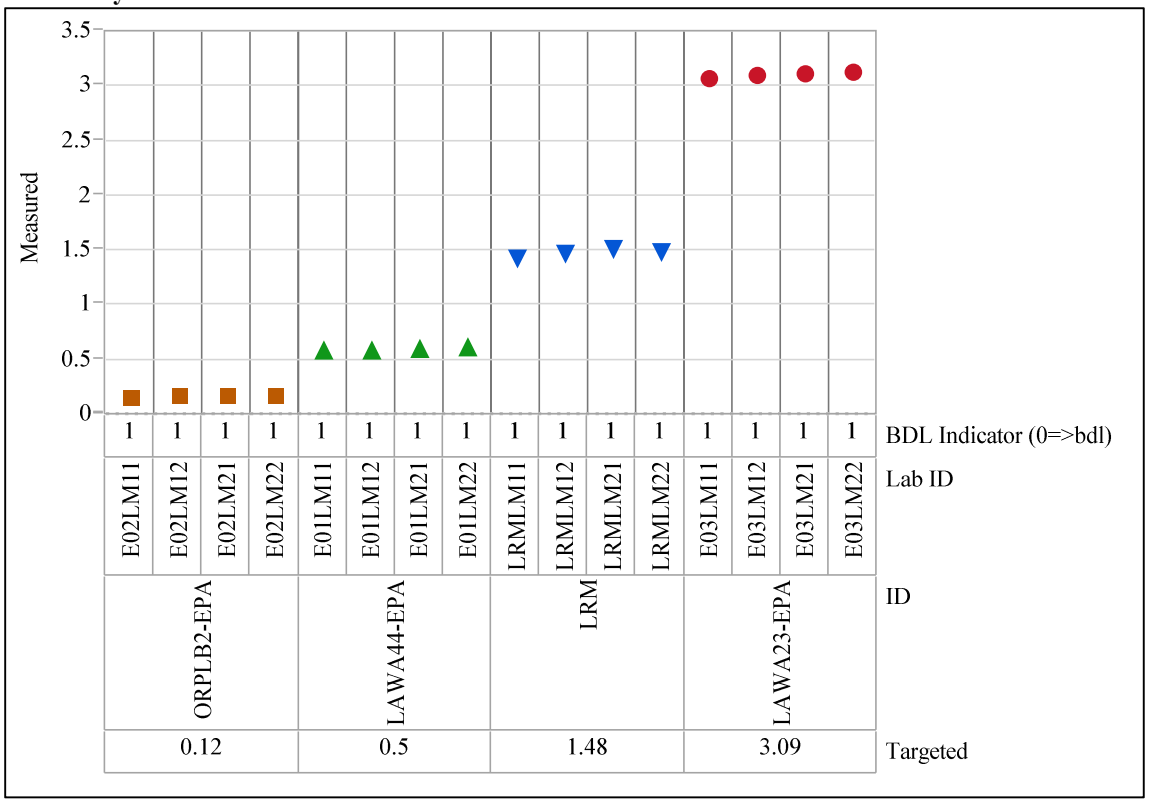


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=Li2O (wt%), Prep Method=PF
Variability Chart for Measured

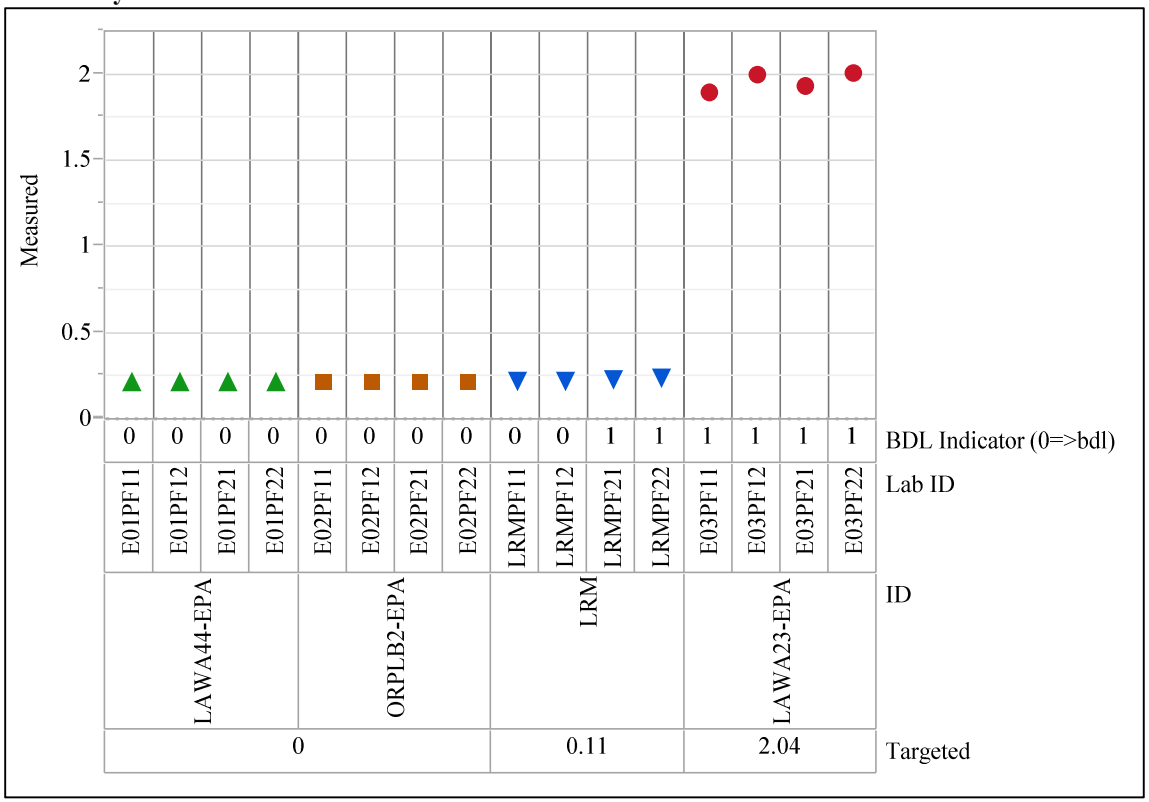


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=MgO (wt%), Prep Method=LM
Variability Chart for Measured

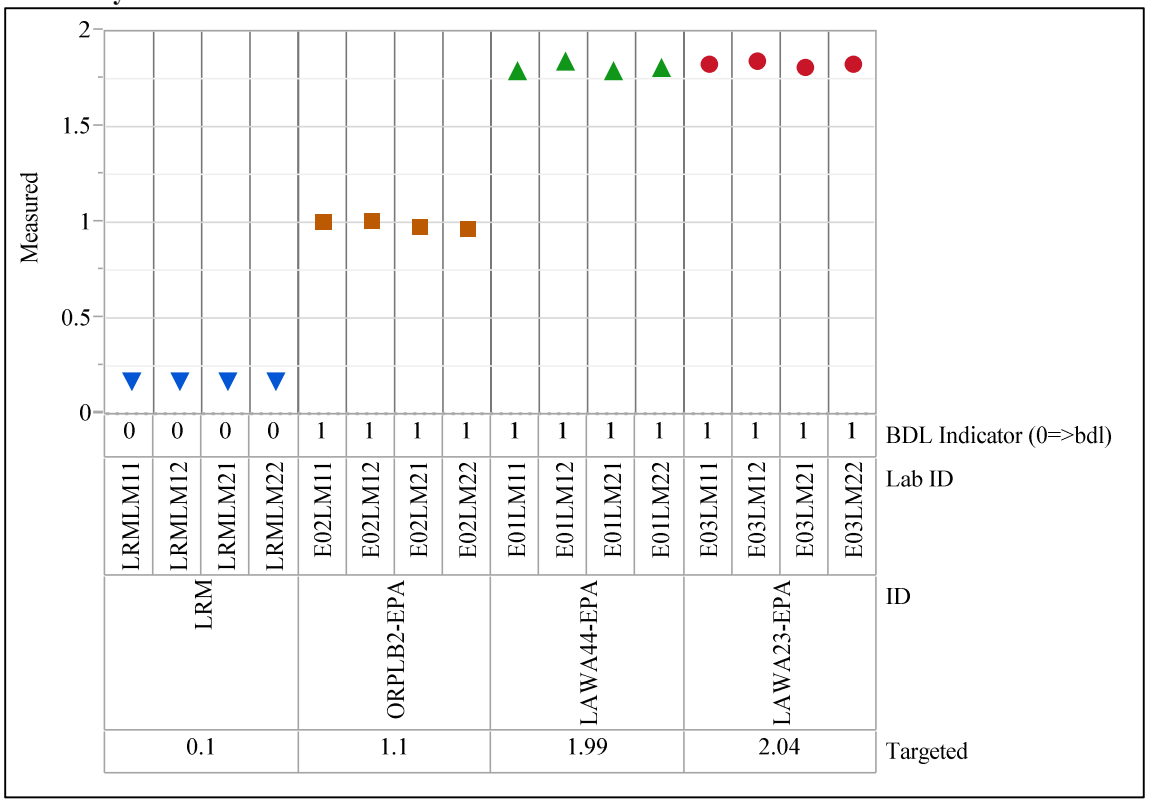


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=MnO2 (wt%), Prep Method=LM
Variability Chart for Measured

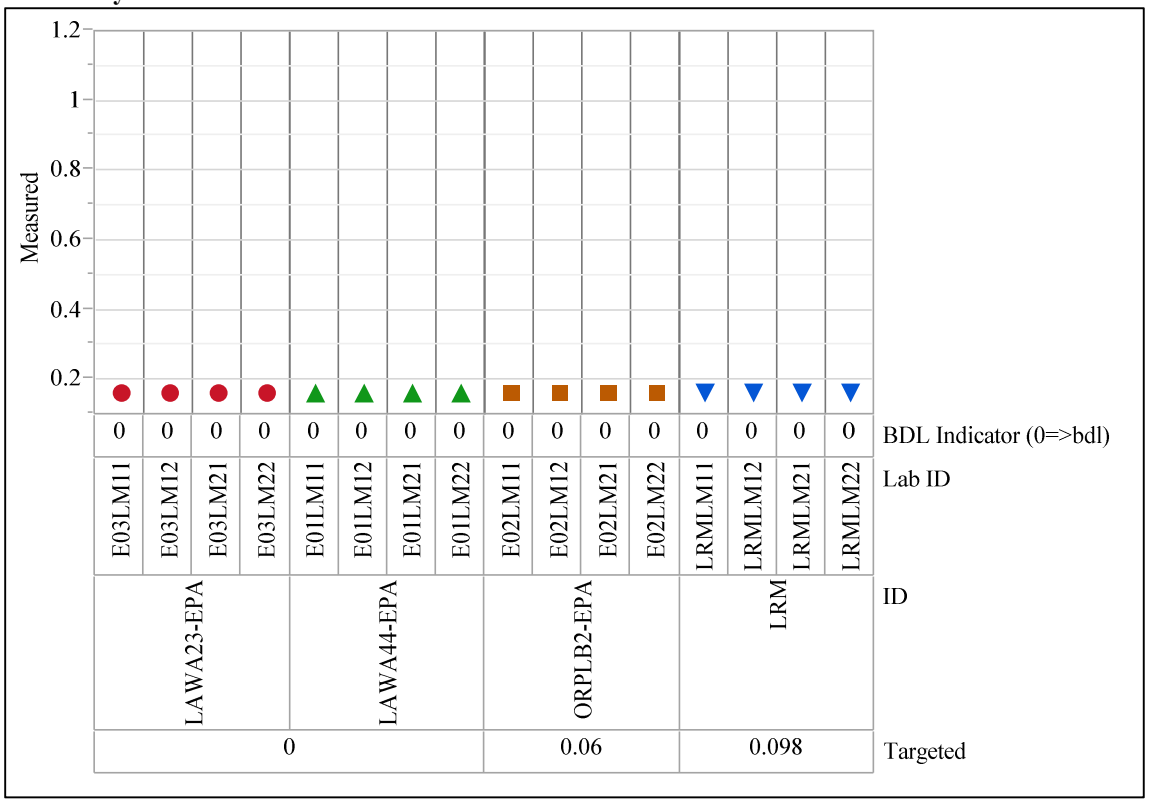


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=MoO3 (wt%), Prep Method=LM
Variability Chart for Measured

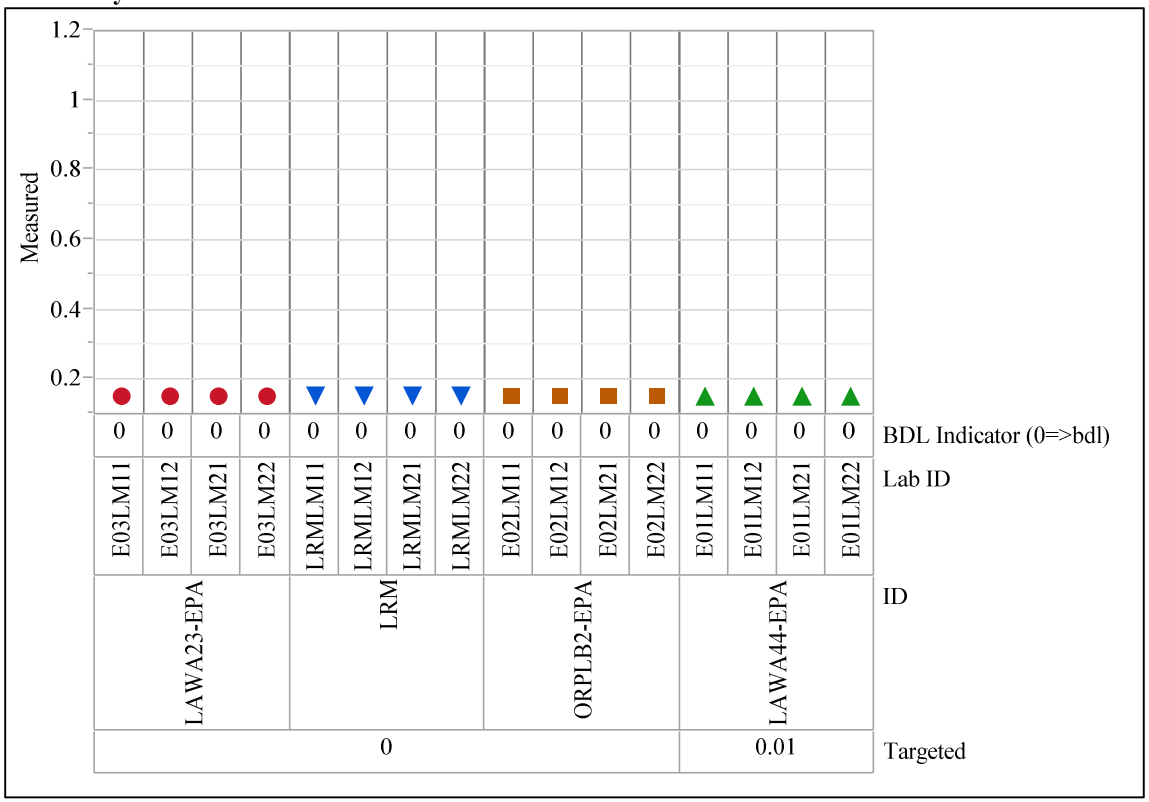


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=Na2O (wt%), Prep Method=LM
Variability Chart for Measured

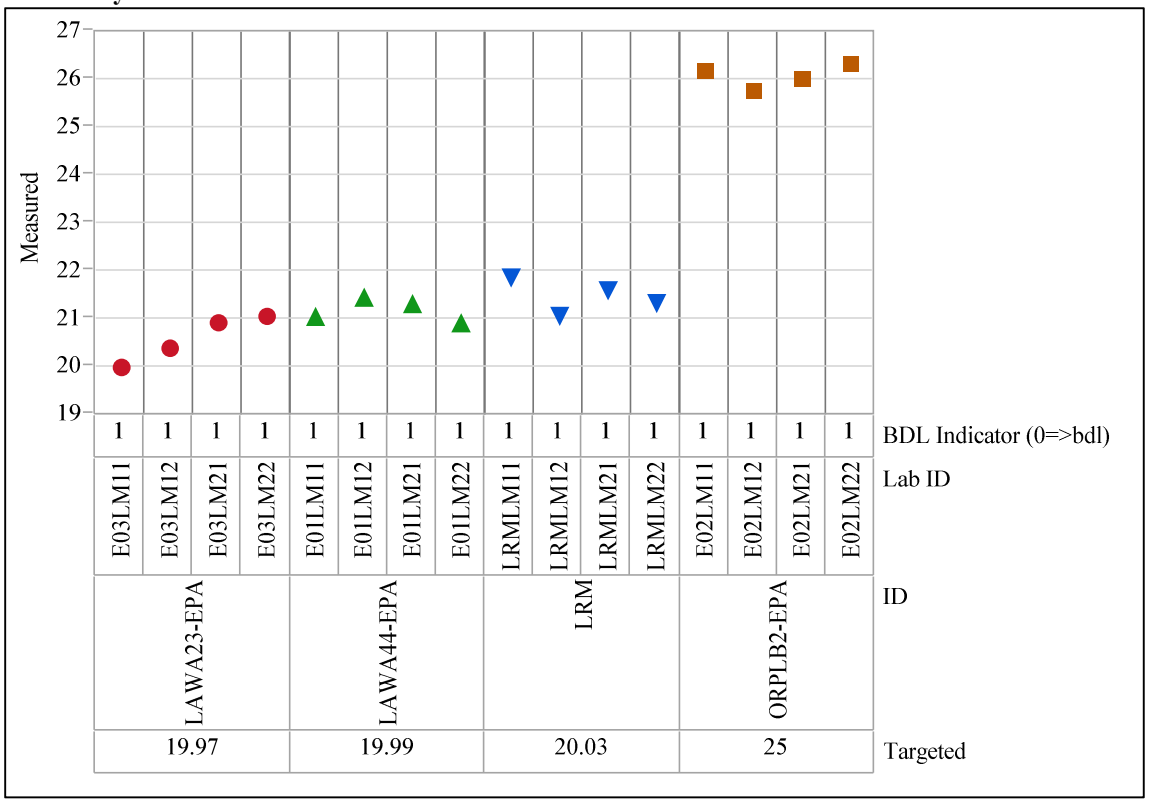


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=NiO (wt%), Prep Method=LM
Variability Chart for Measured

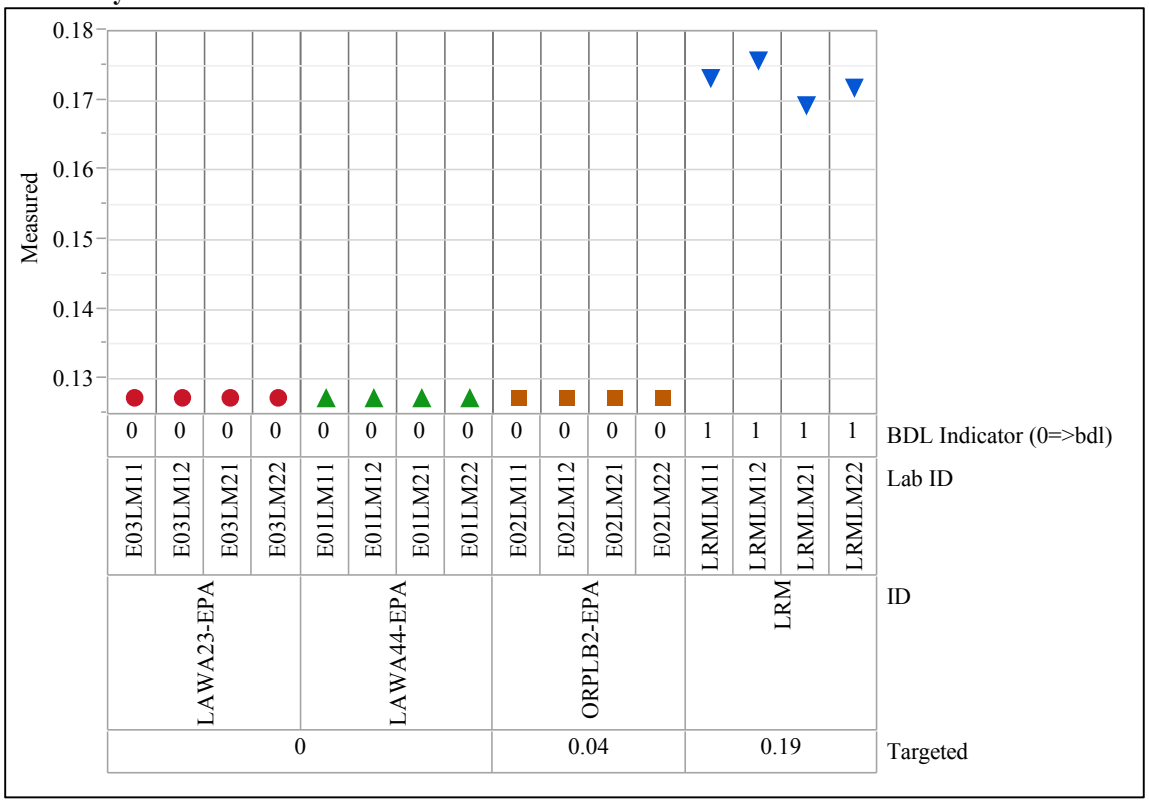


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=P2O5 (wt%), Prep Method=LM
Variability Chart for Measured

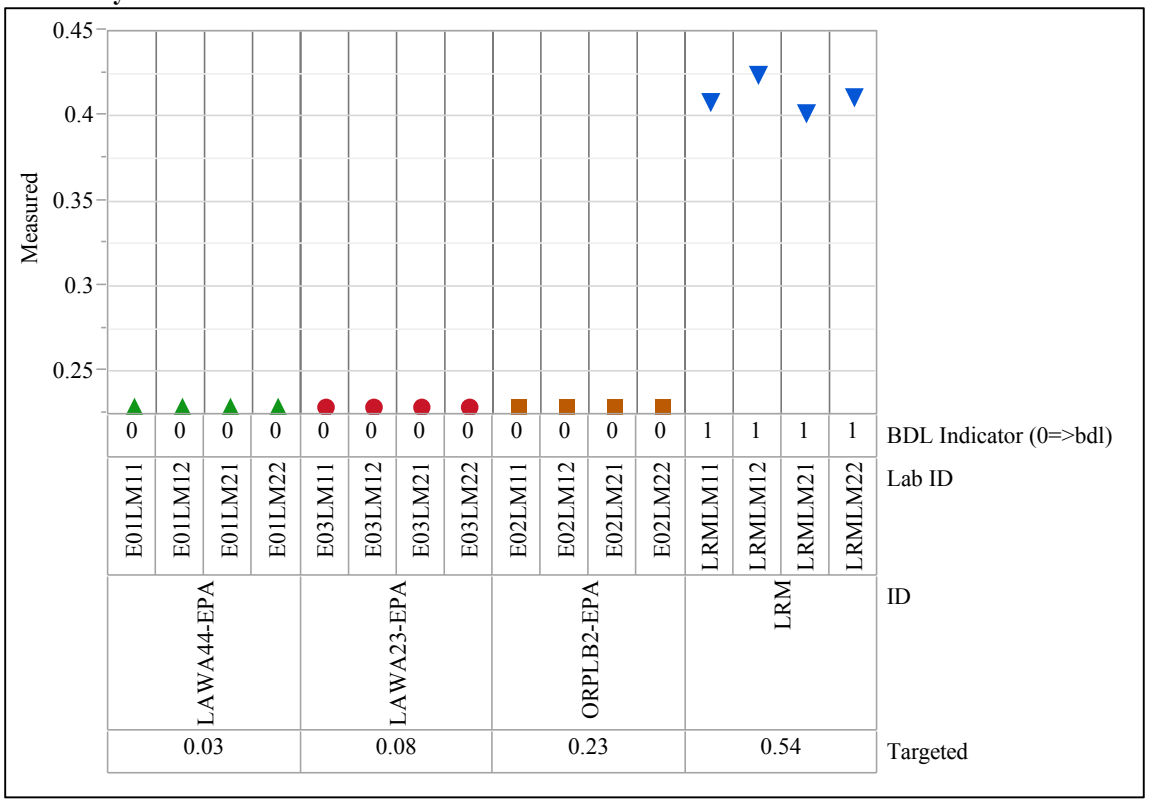


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=Re2O7 (wt%), Prep Method=LM
Variability Chart for Measured

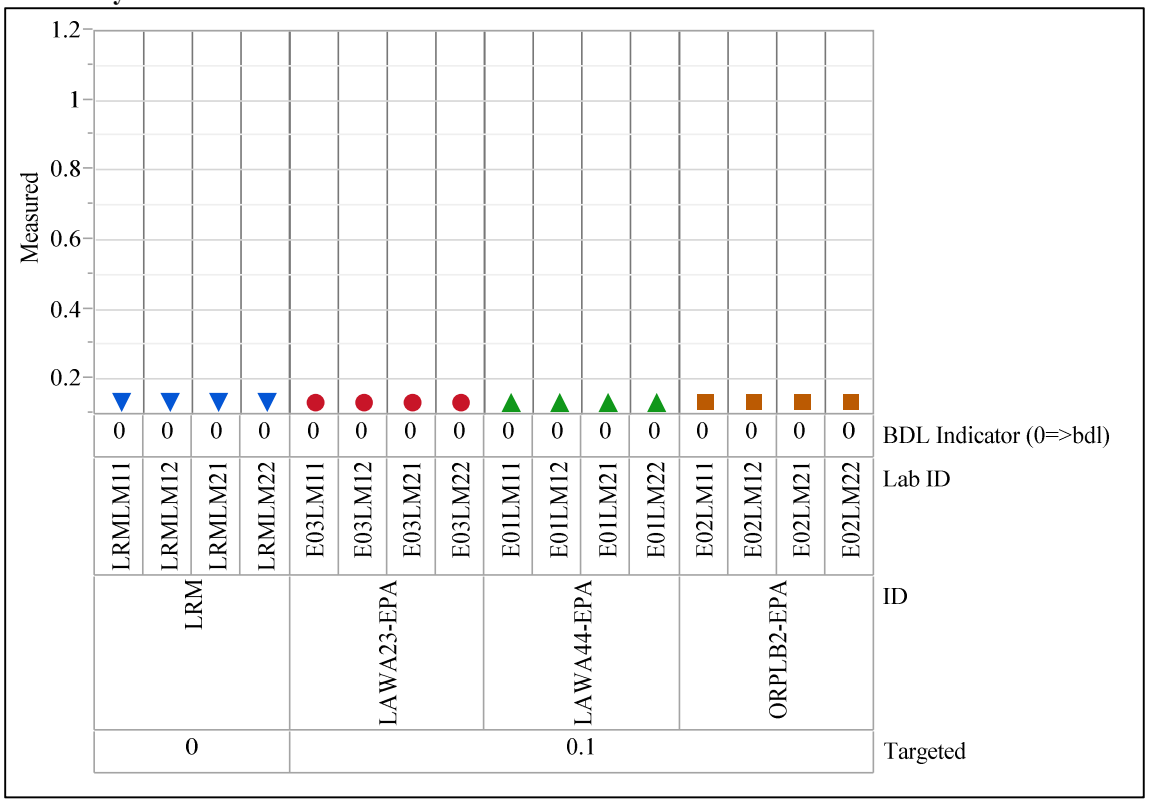


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=SiO2 (wt%), Prep Method=PF
Variability Chart for Measured

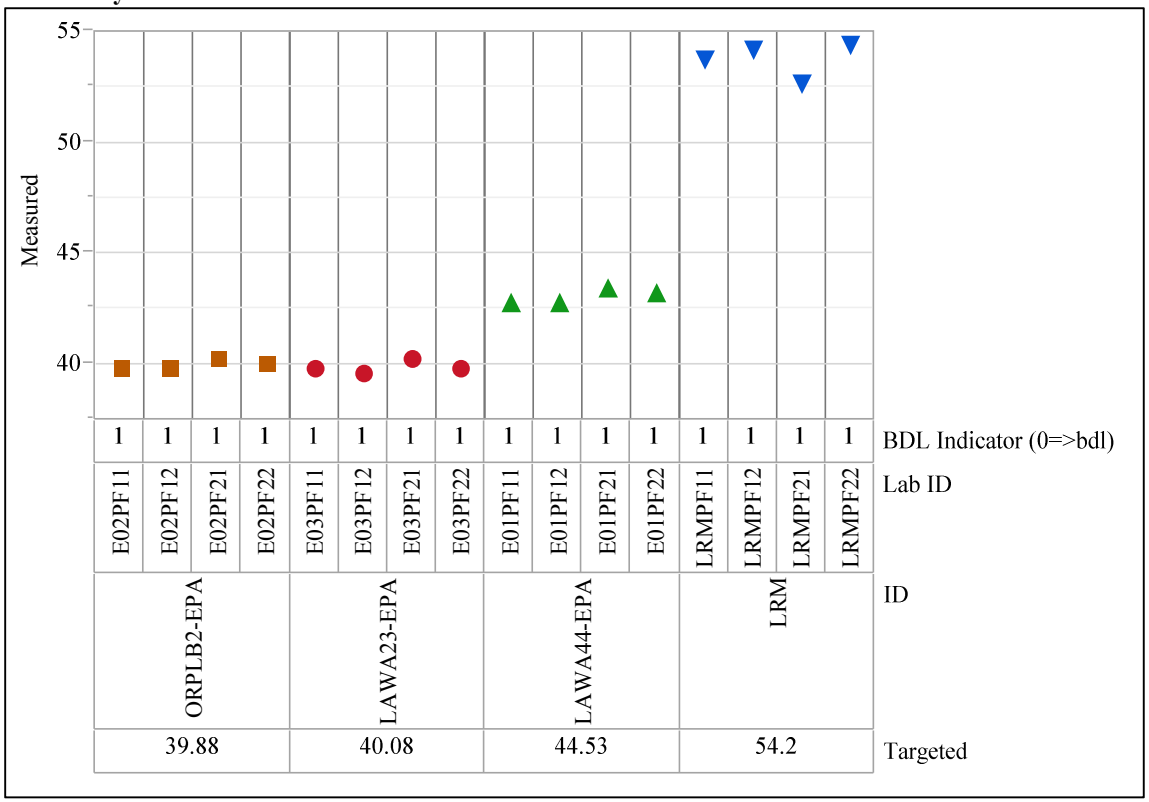


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=SnO2 (wt%), Prep Method=LM
Variability Chart for Measured

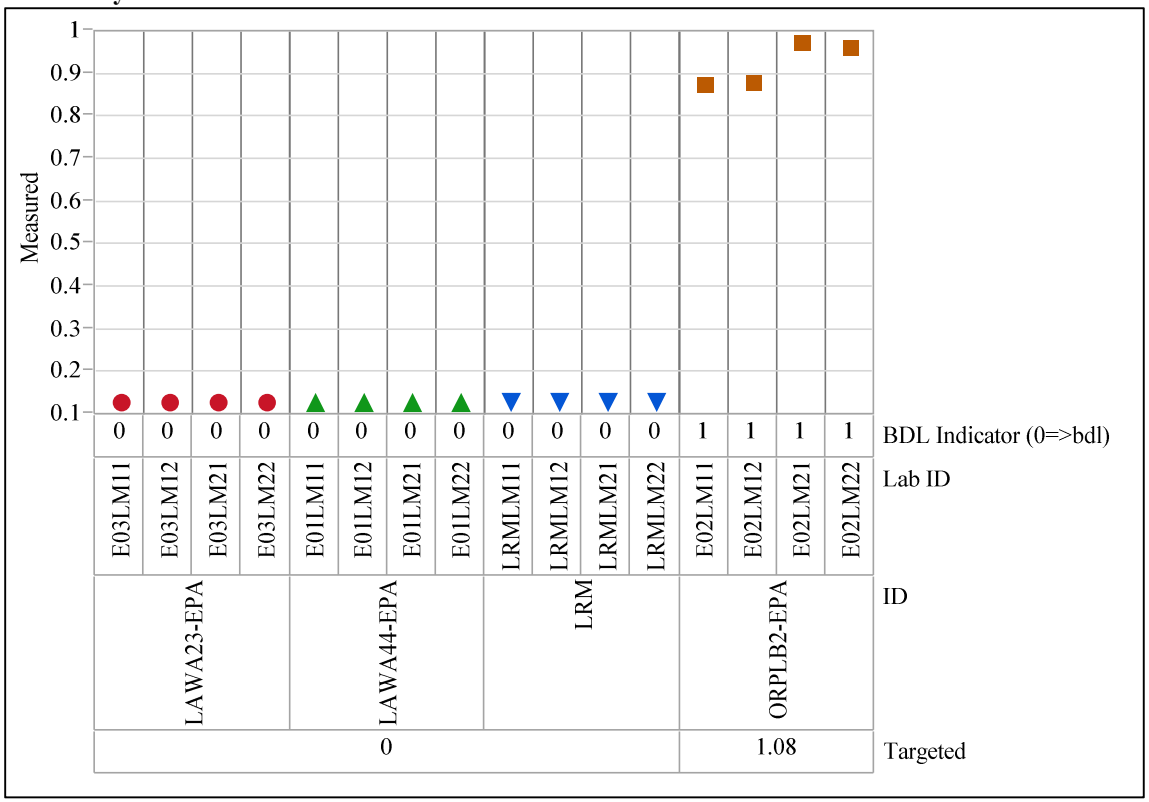


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=SO3 (wt%), Prep Method=LM
Variability Chart for Measured

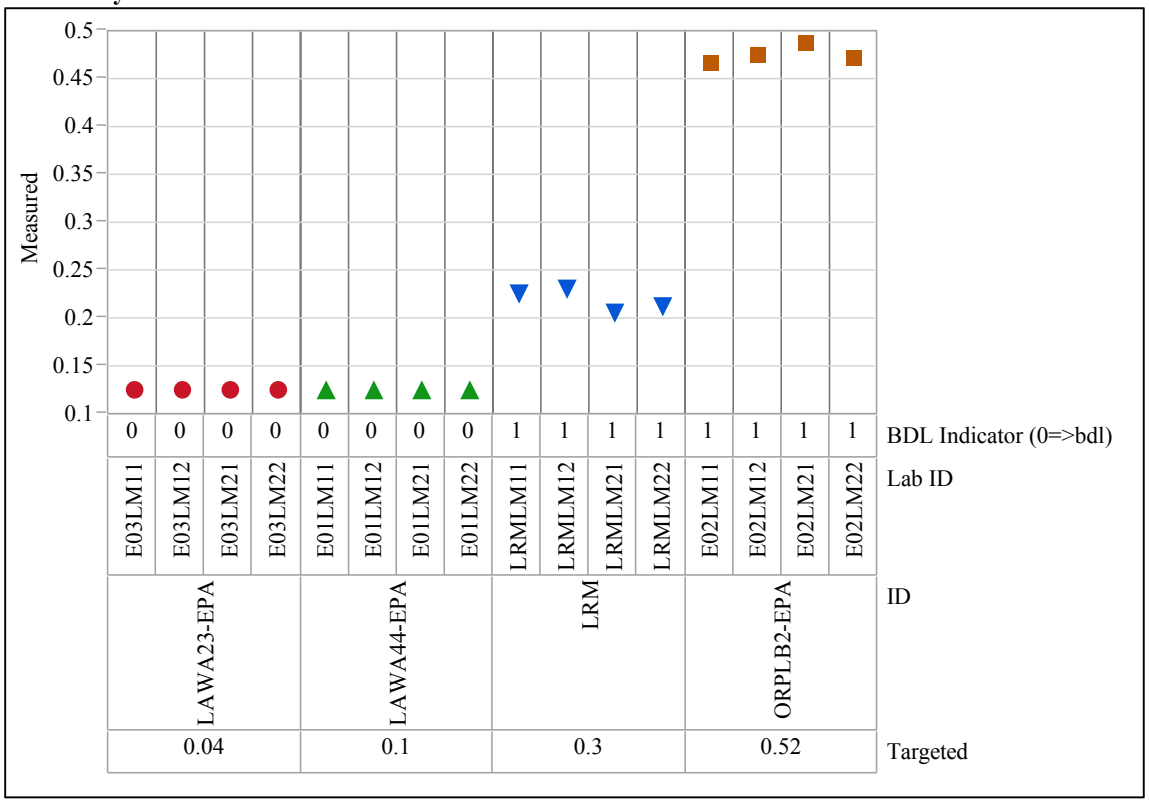


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=TiO2 (wt%), Prep Method=LM
Variability Chart for Measured

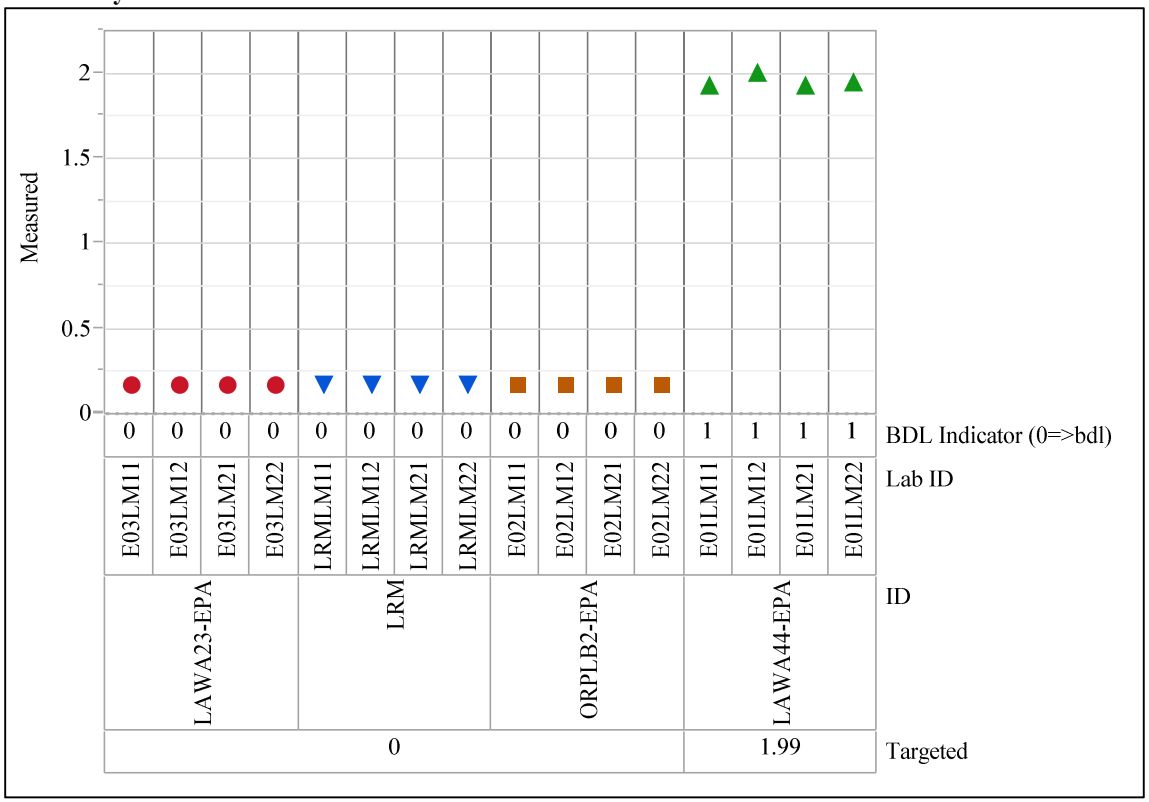


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=V2O5 (wt%), Prep Method=LM
Variability Chart for Measured

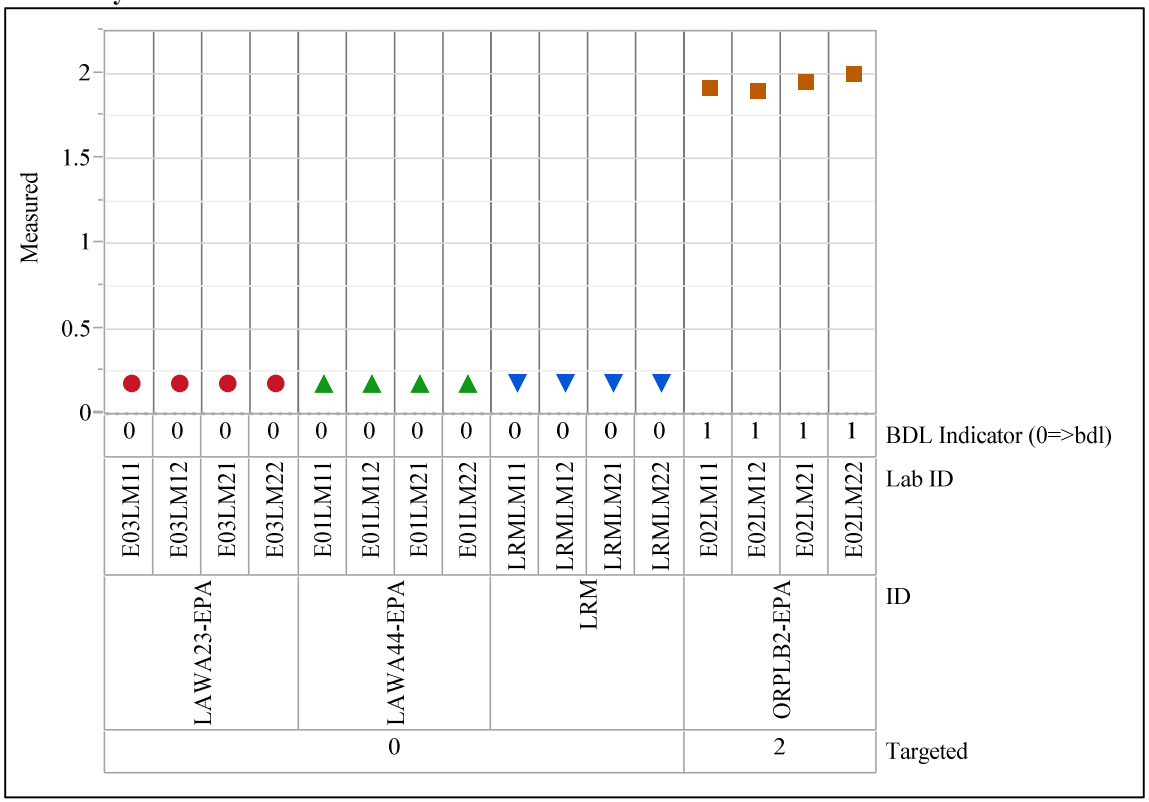


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=ZnO (wt%), Prep Method=LM
Variability Chart for Measured

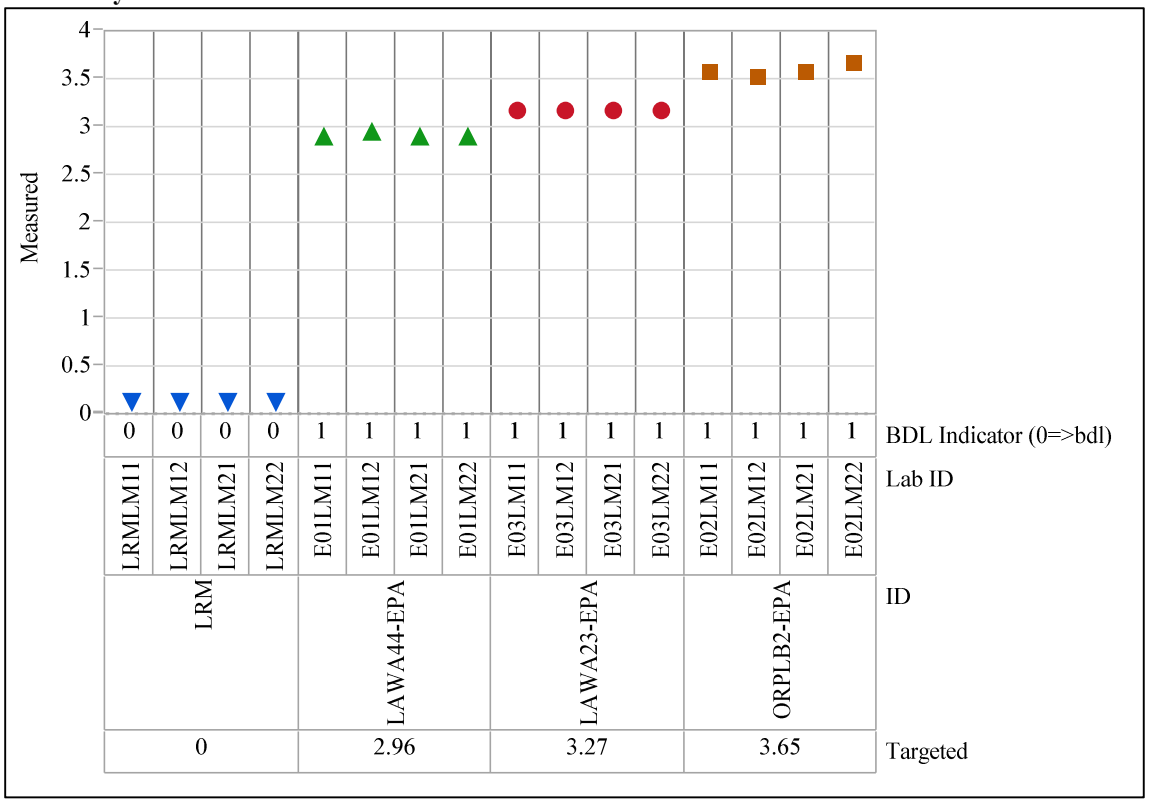


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier by Grouped by Targeted Concentrations (continued)

Analyte=ZrO2 (wt%), Prep Method=LM
Variability Chart for Measured

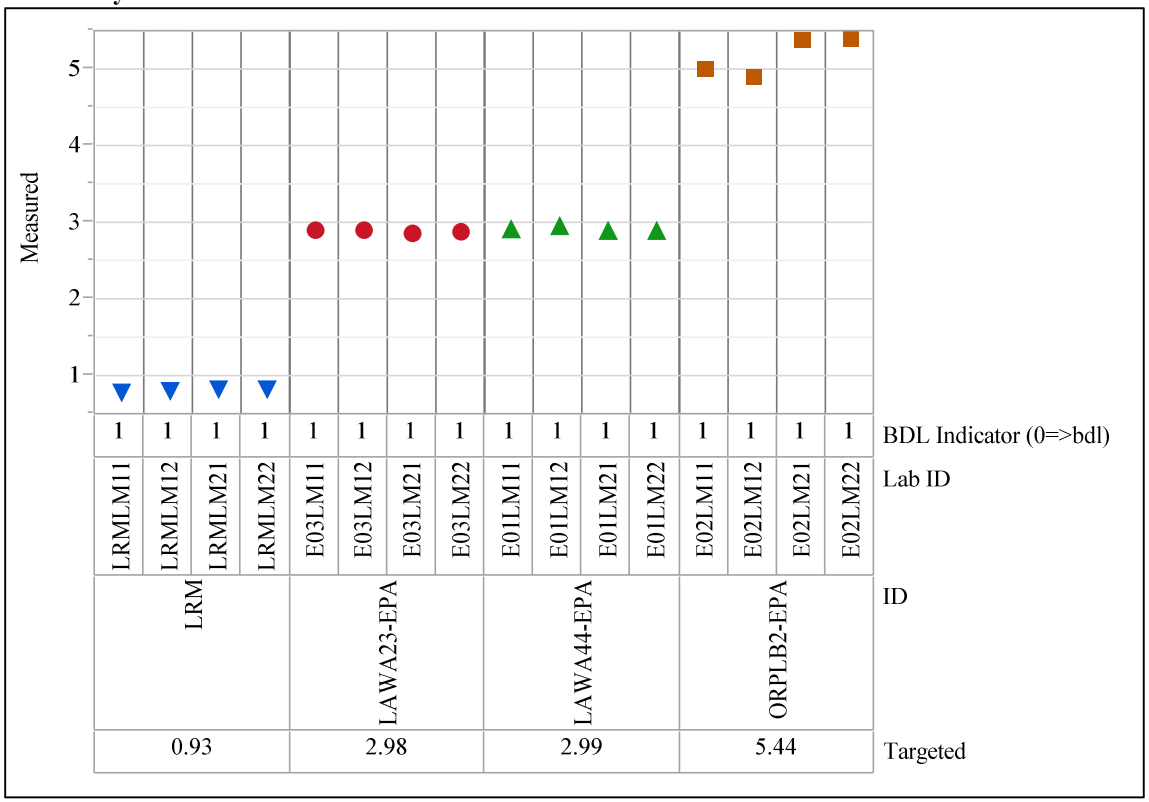
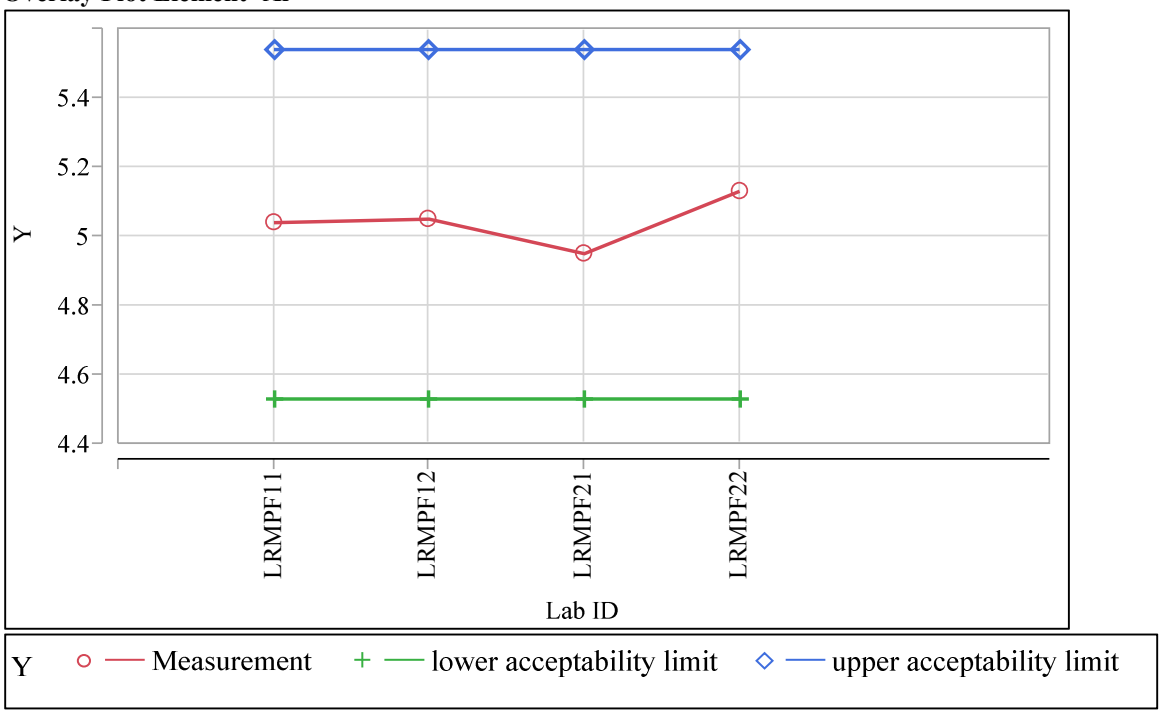
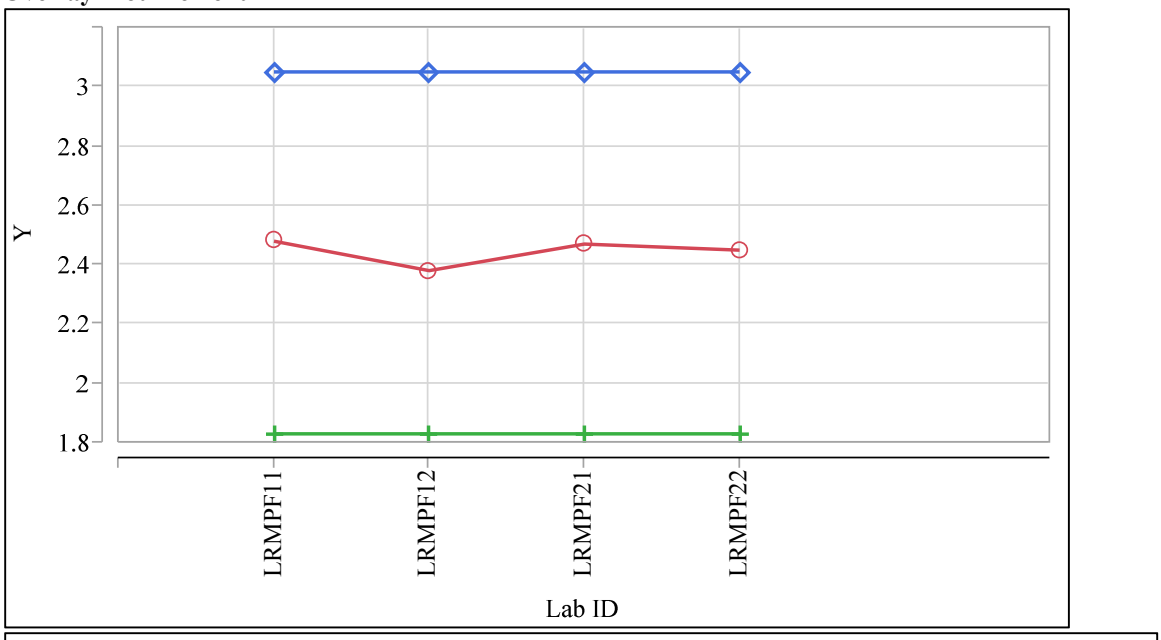


Exhibit A-3. Acceptability Evaluations for Measurements of the LRM Standard Glass

Overlay Plot Element=Al



Overlay Plot Element=B



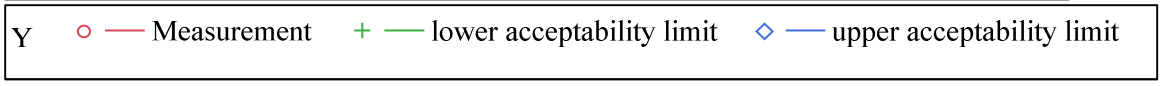
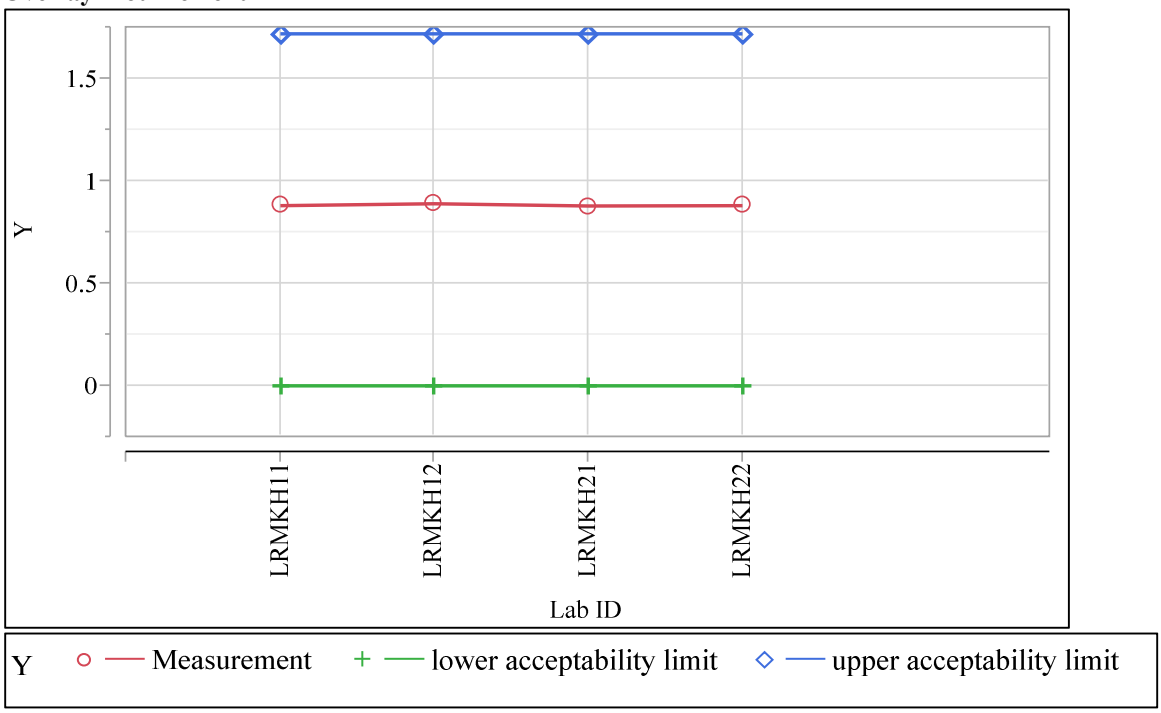
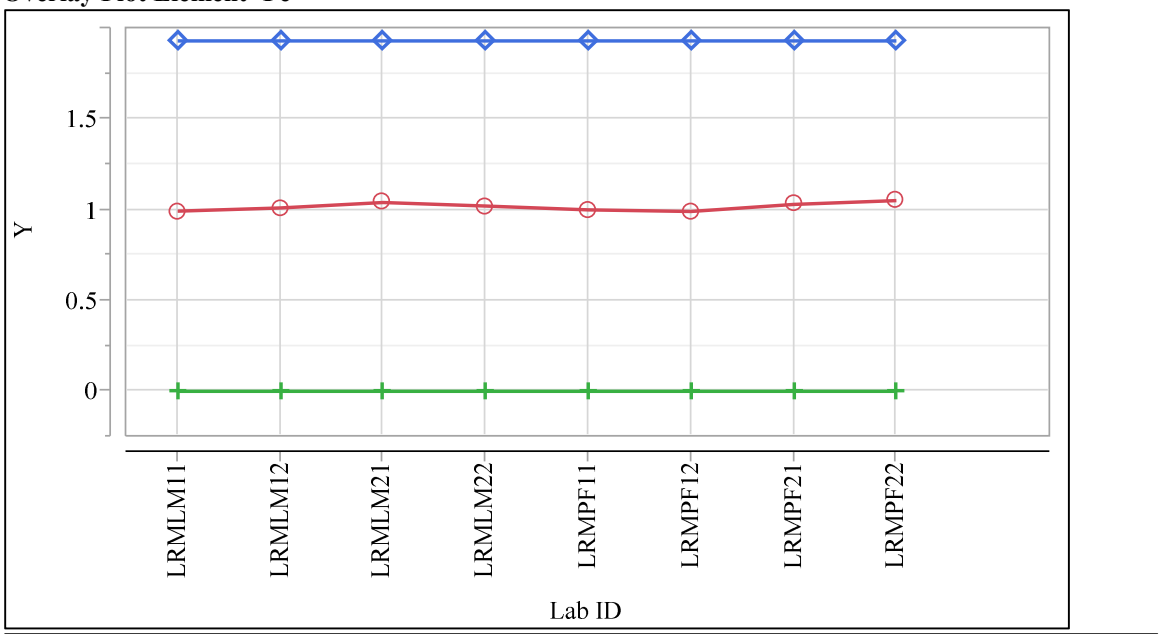


Exhibit A-3. Acceptability Evaluations for Measurements of the LRM Standard Glass (continued)

Overlay Plot Element=F



Overlay Plot Element=Fe



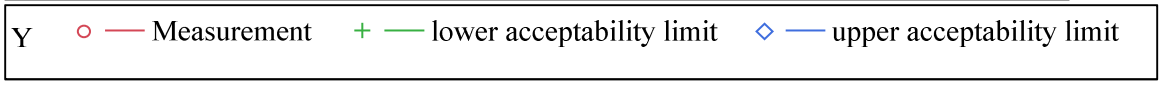
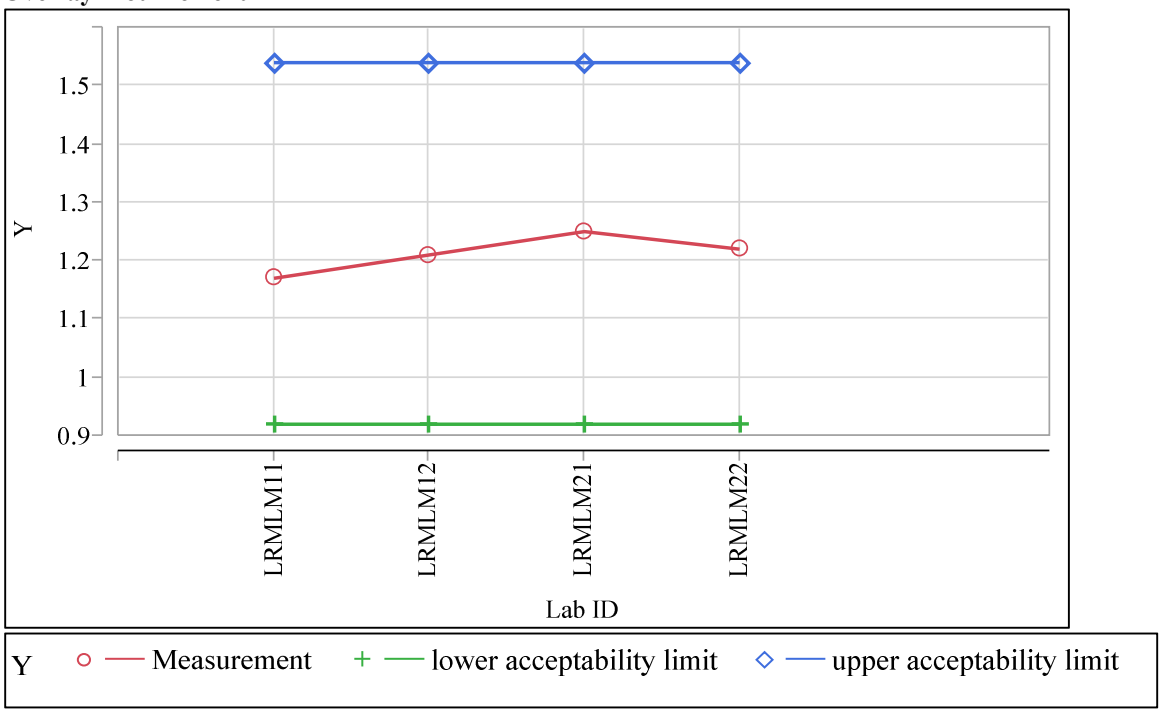
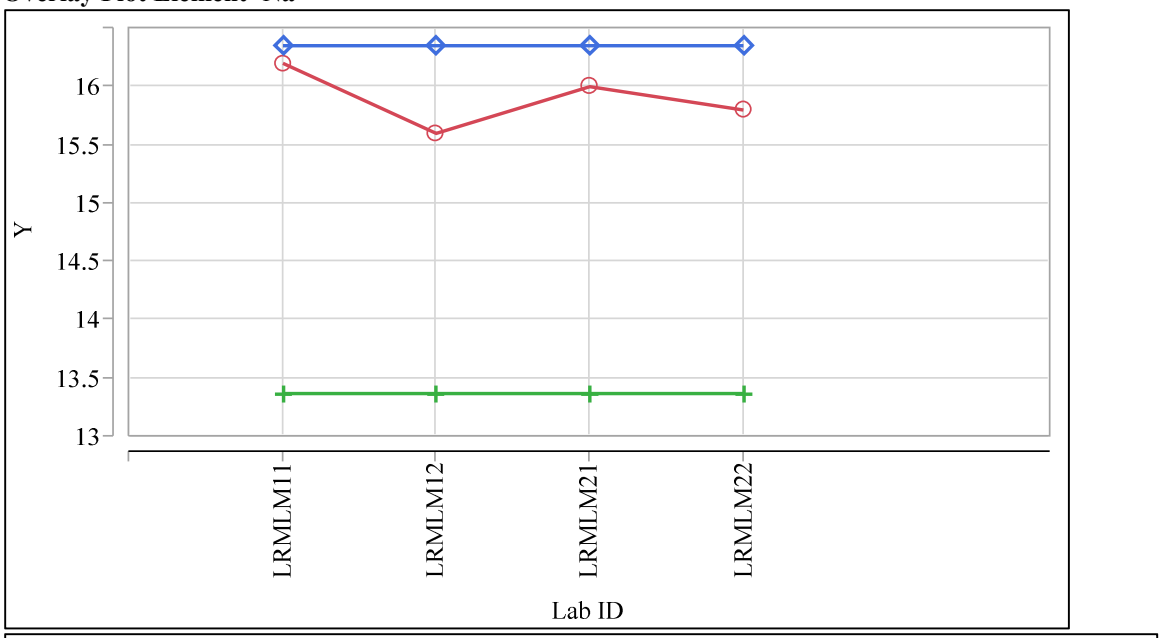


Exhibit A-3. Acceptability Evaluations for Measurements of the LRM Standard Glass (continued)

Overlay Plot Element=K



Overlay Plot Element=Na



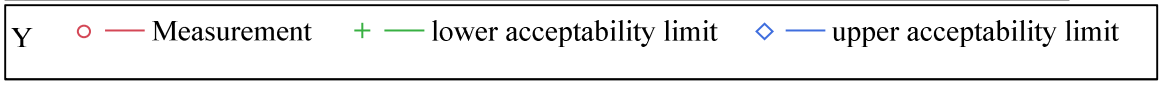
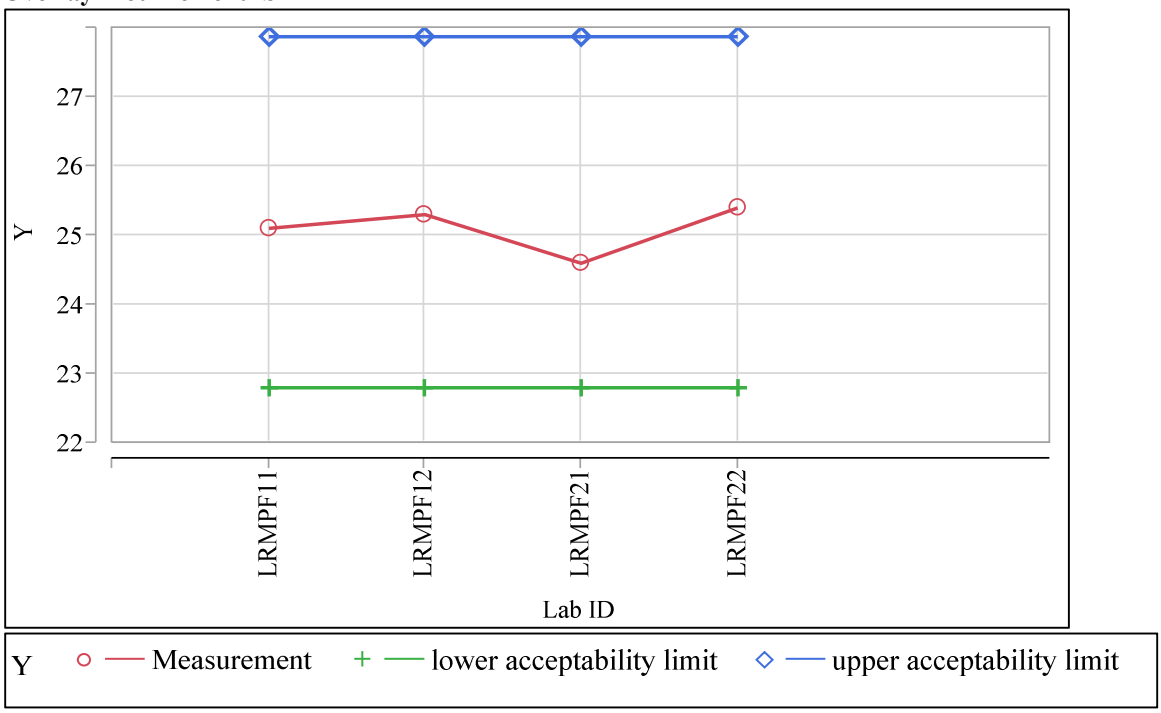
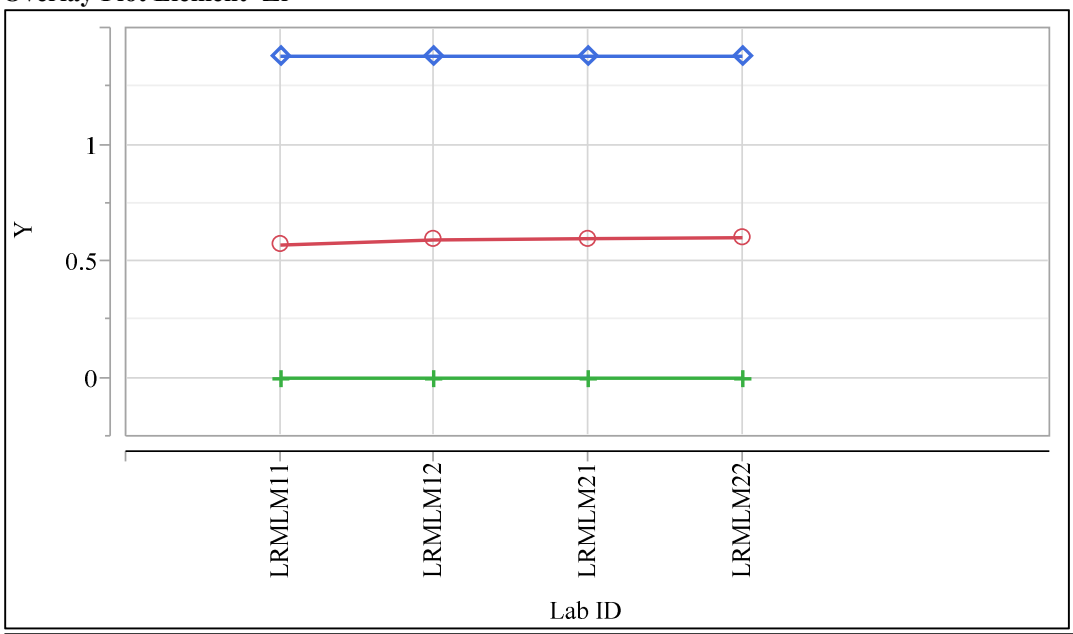


Exhibit A-3. Acceptability Evaluations for Measurements of the LRM Standard Glass (continued)

Overlay Plot Element=Si



Overlay Plot Element=Zr



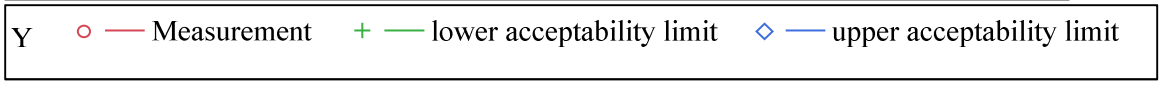
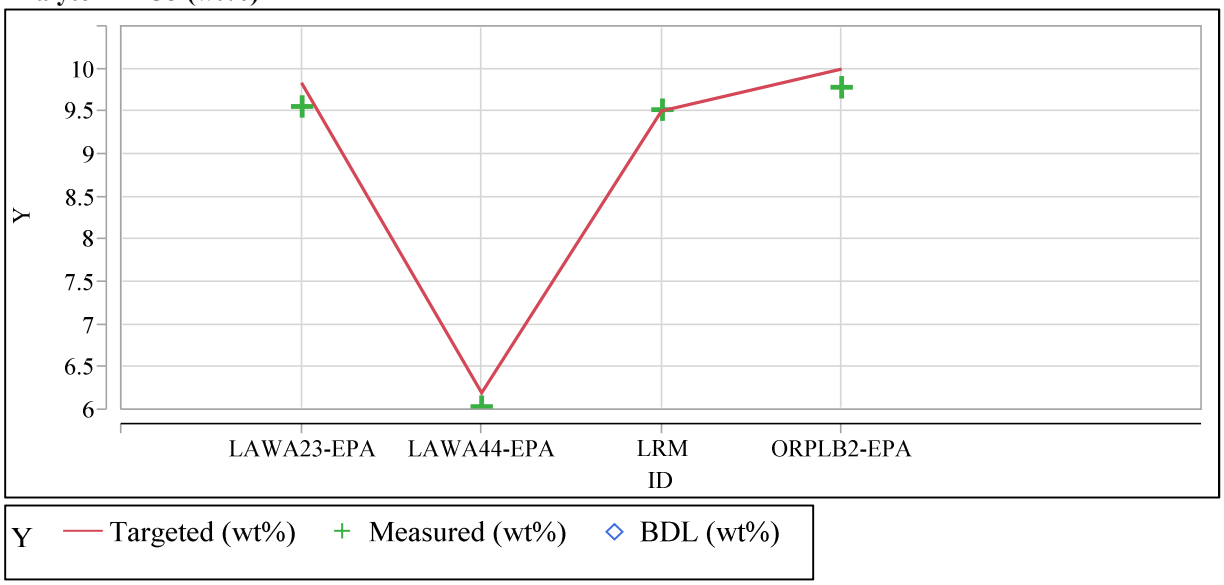
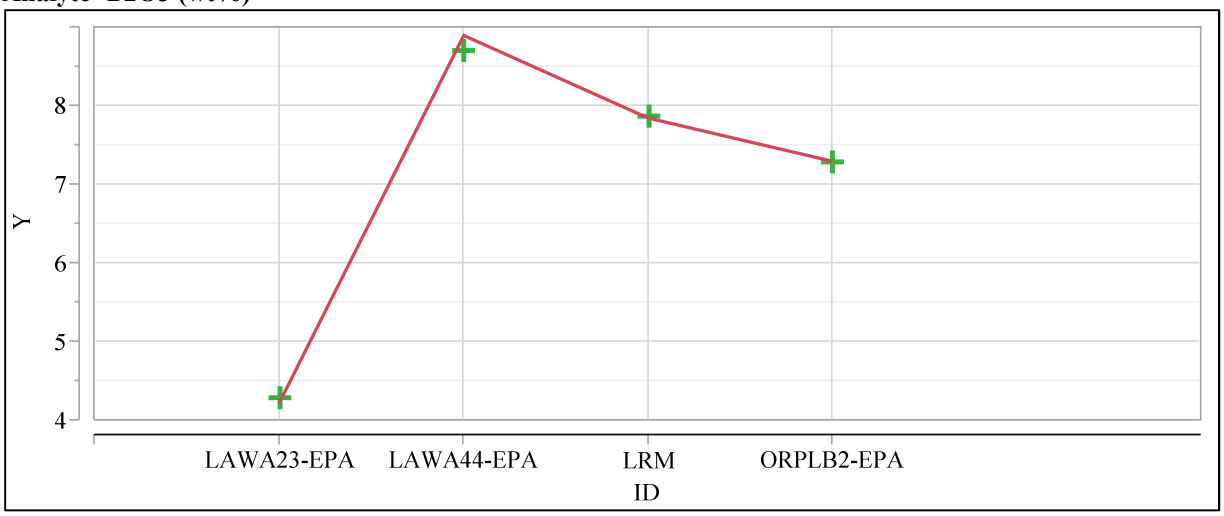


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide

Analyte=Al2O3 (wt%)



Analyte=B2O3 (wt%)



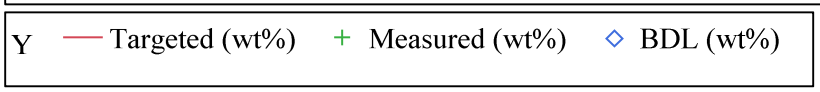
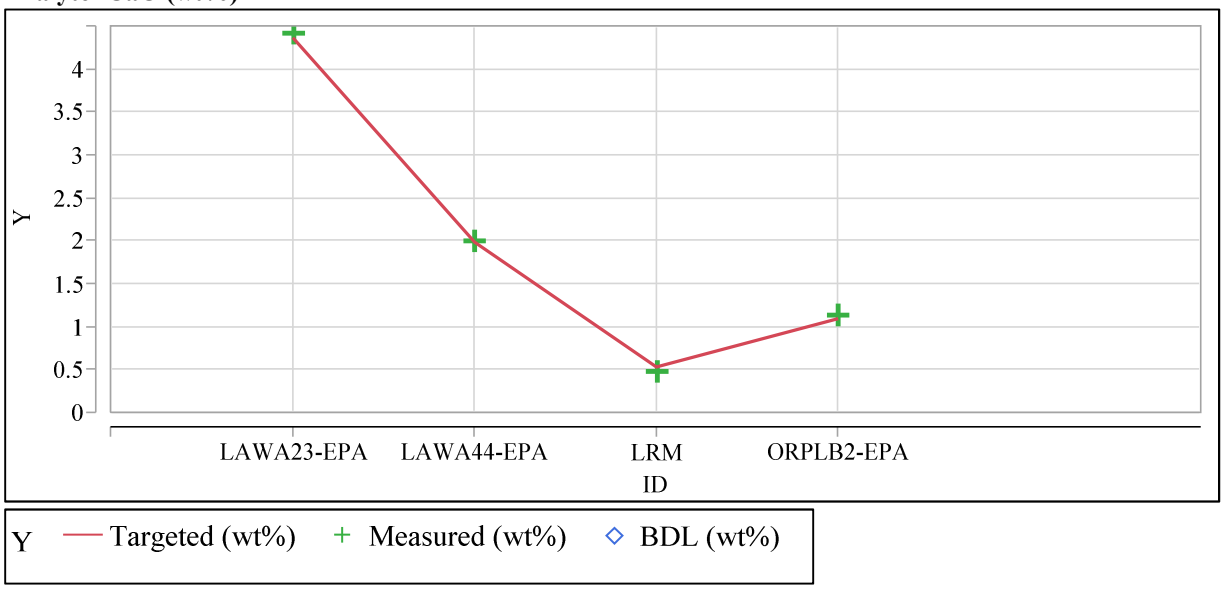


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Analyte=CaO (wt%)



Analyte=Cl (wt%)

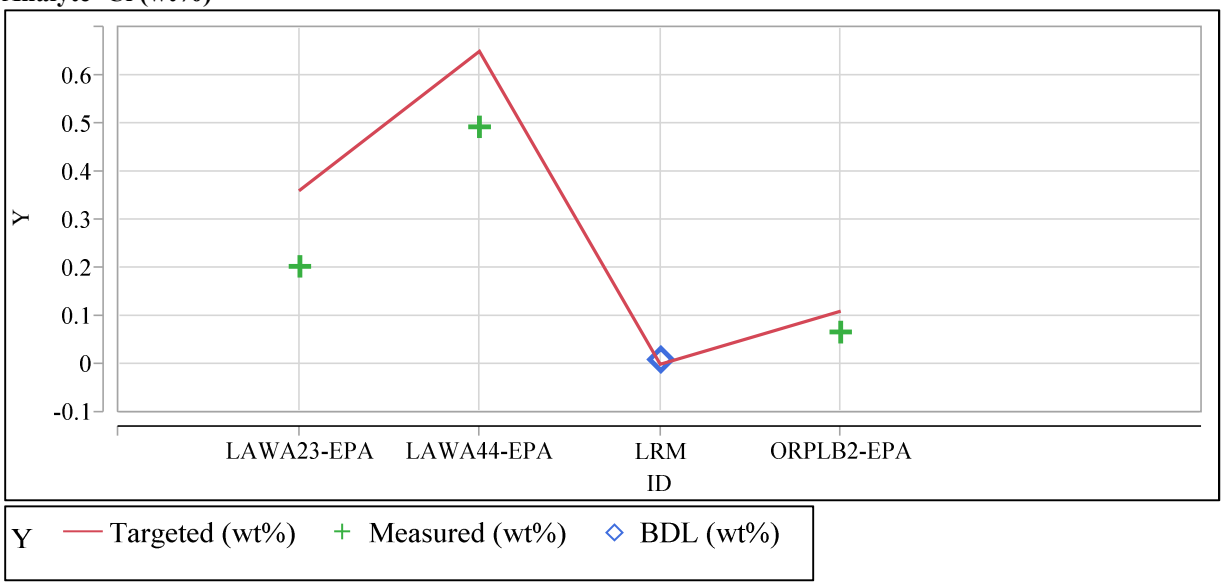
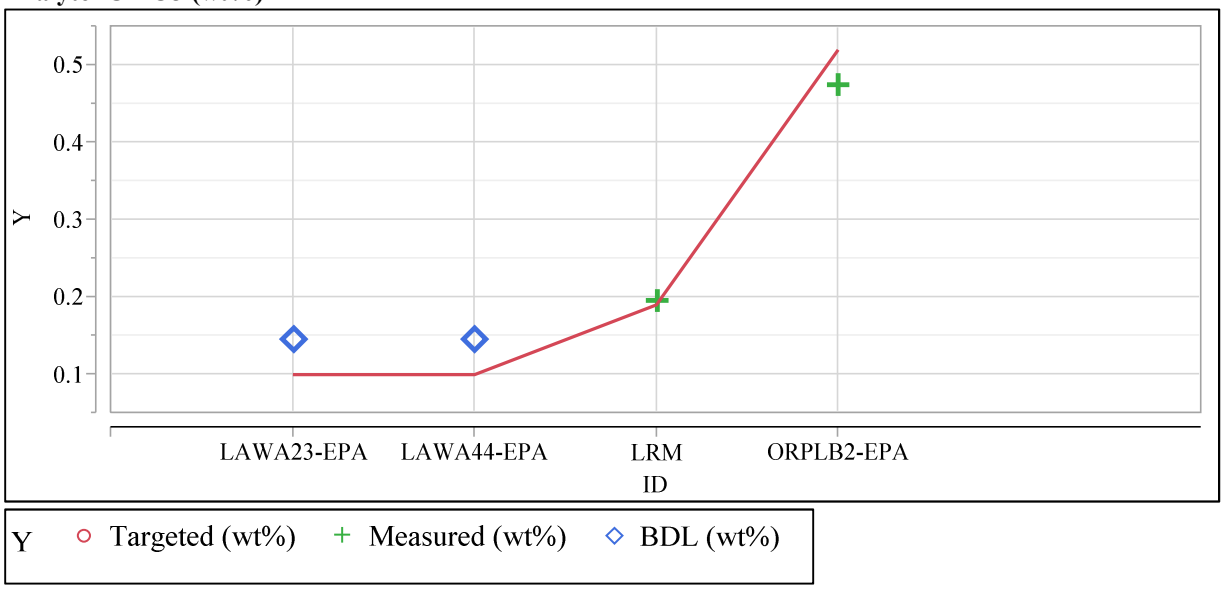


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Analyte=Cr2O3 (wt%)



Analyte=Cs2O (wt%)

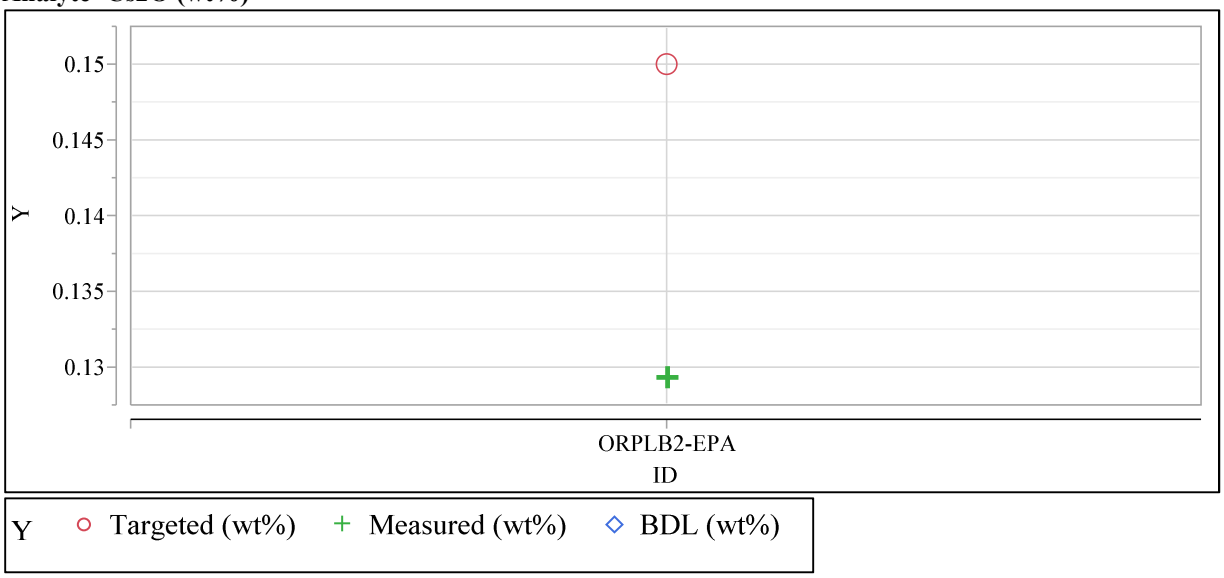
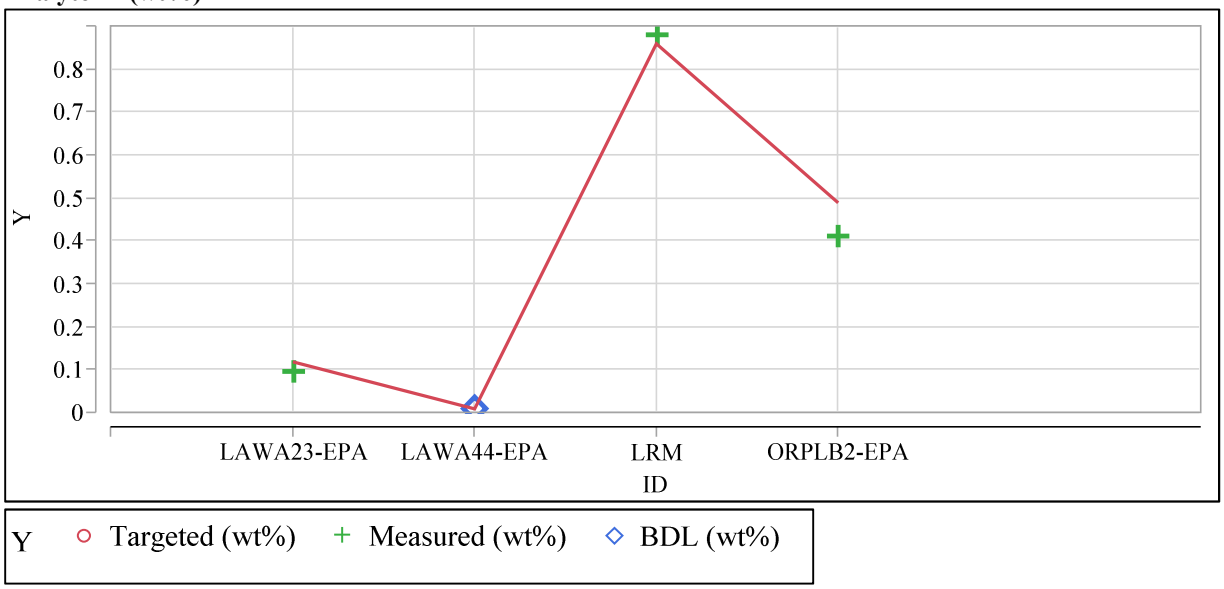
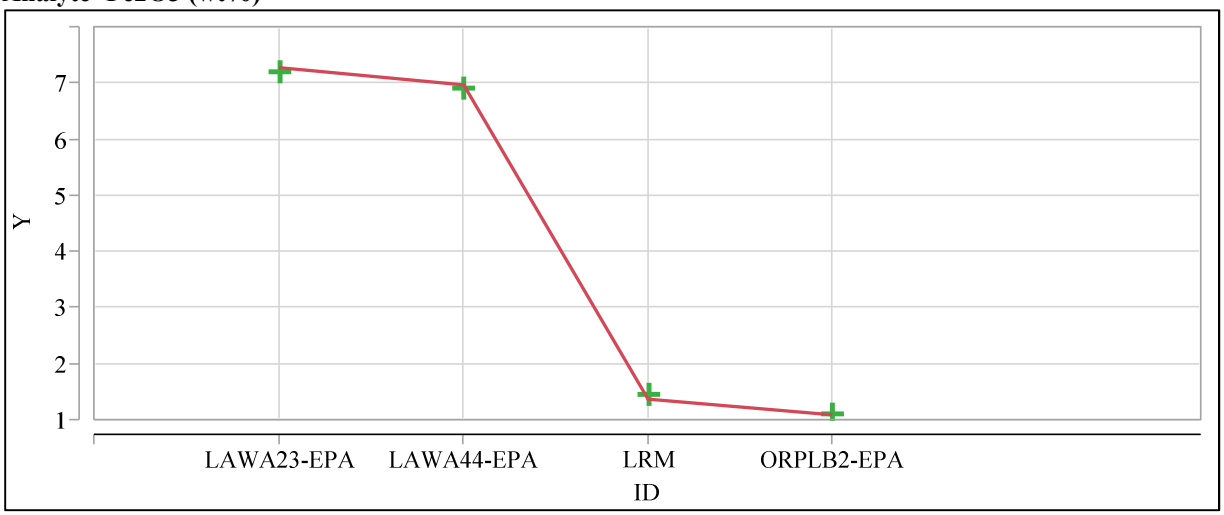


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Analyte=F (wt%)



Analyte=Fe2O3 (wt%)



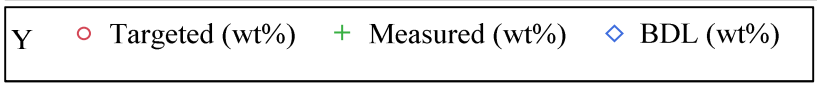
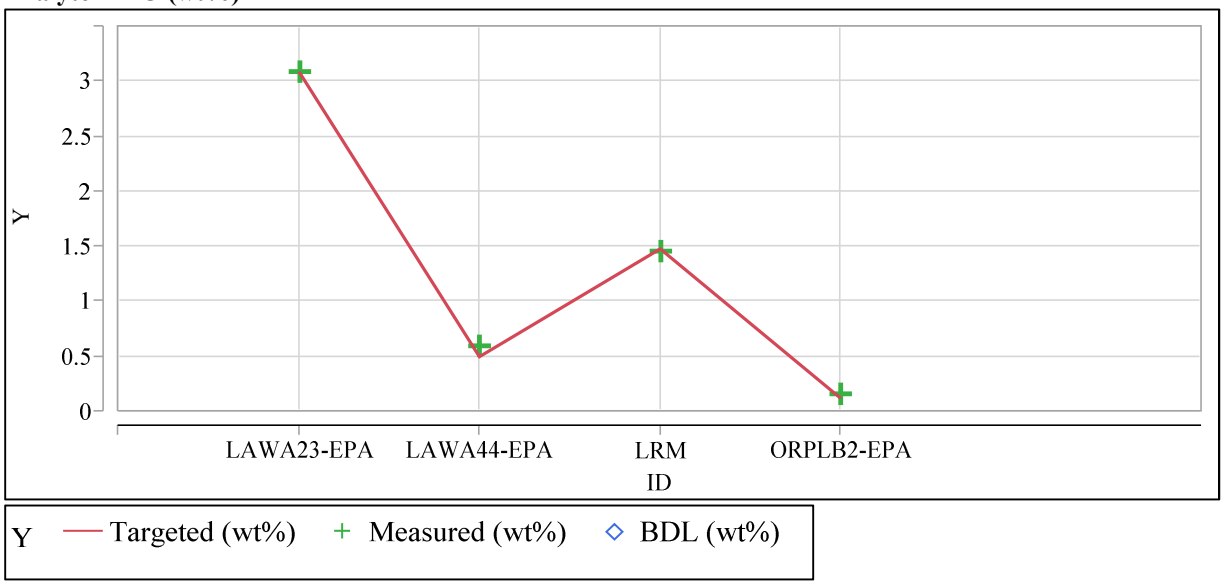


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Analyte=K2O (wt%)



Analyte=Li2O (wt%)

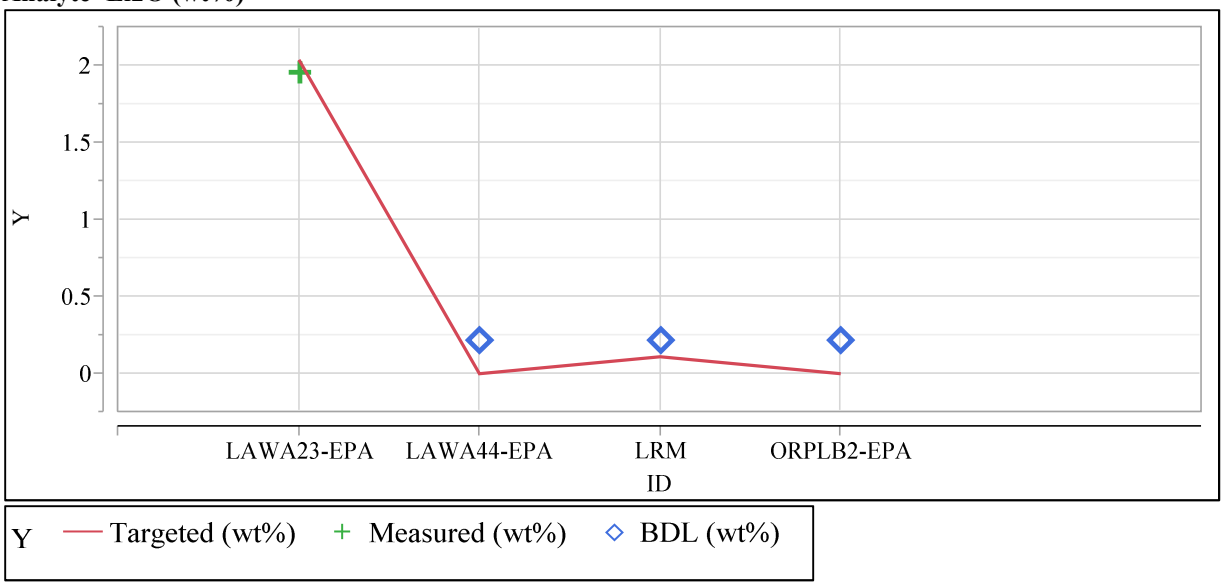
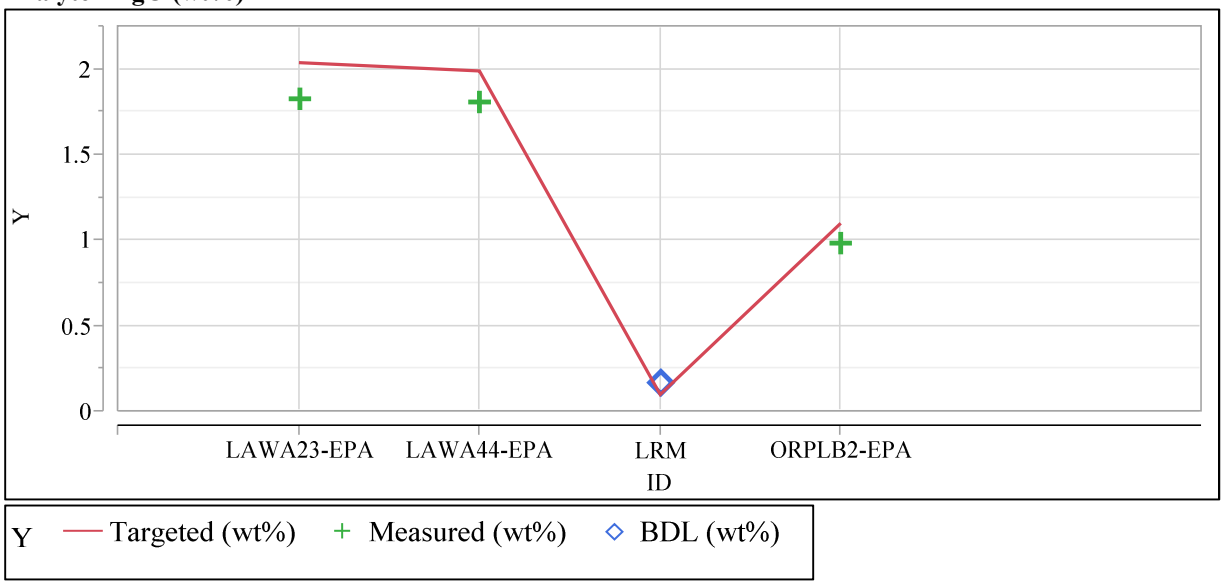


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Analyte=MgO (wt%)



Analyte=MnO2 (wt%)

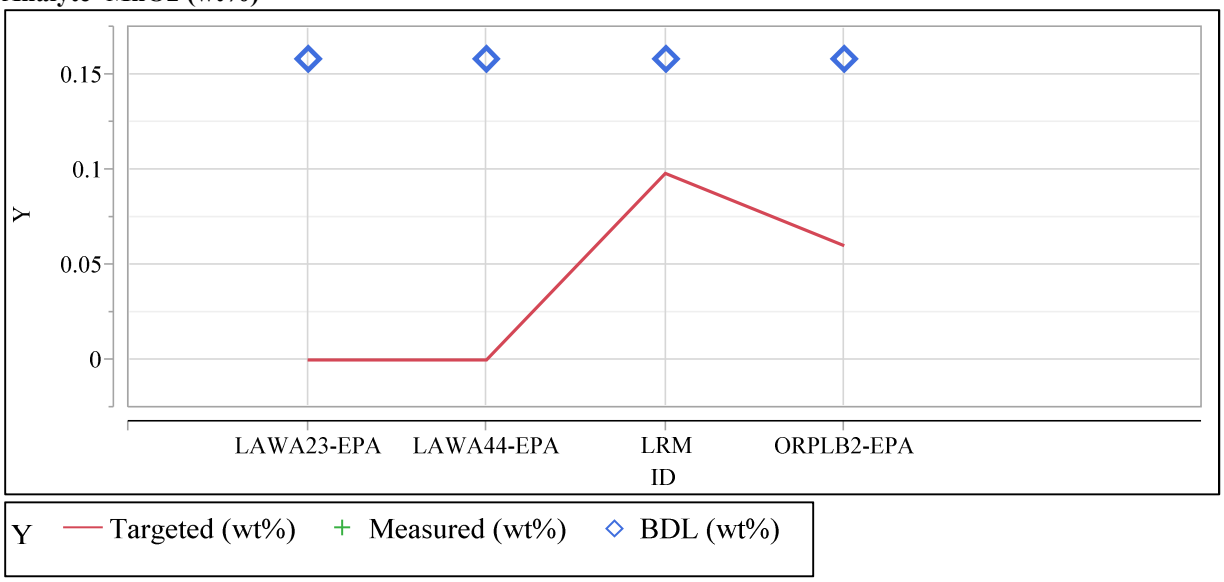
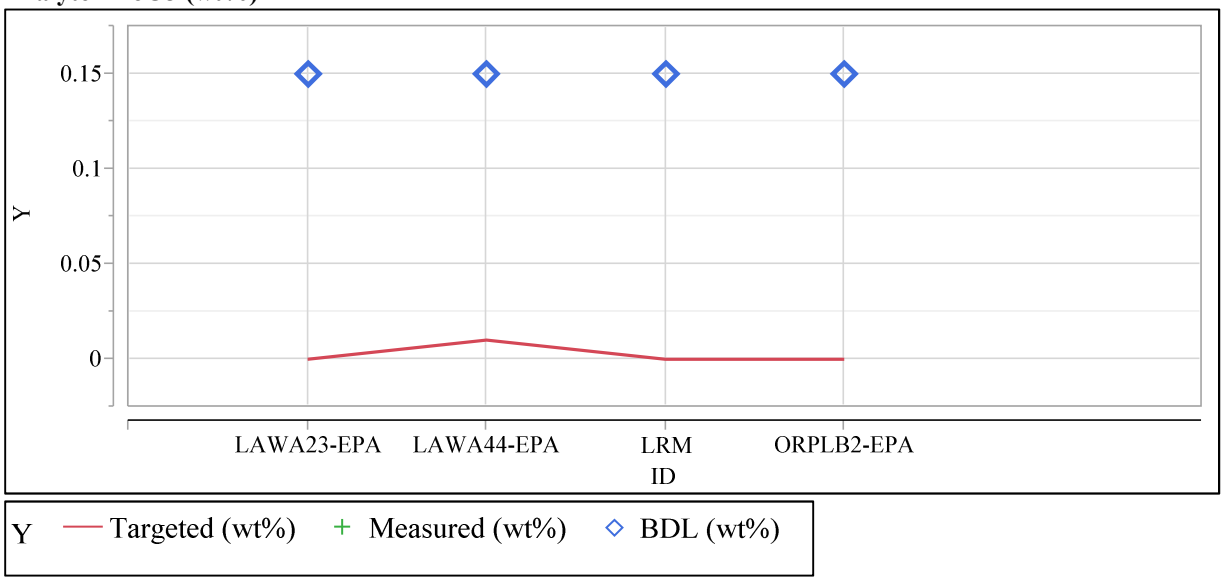


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Analyte=MoO3 (wt%)



Analyte=Na2O (wt%)

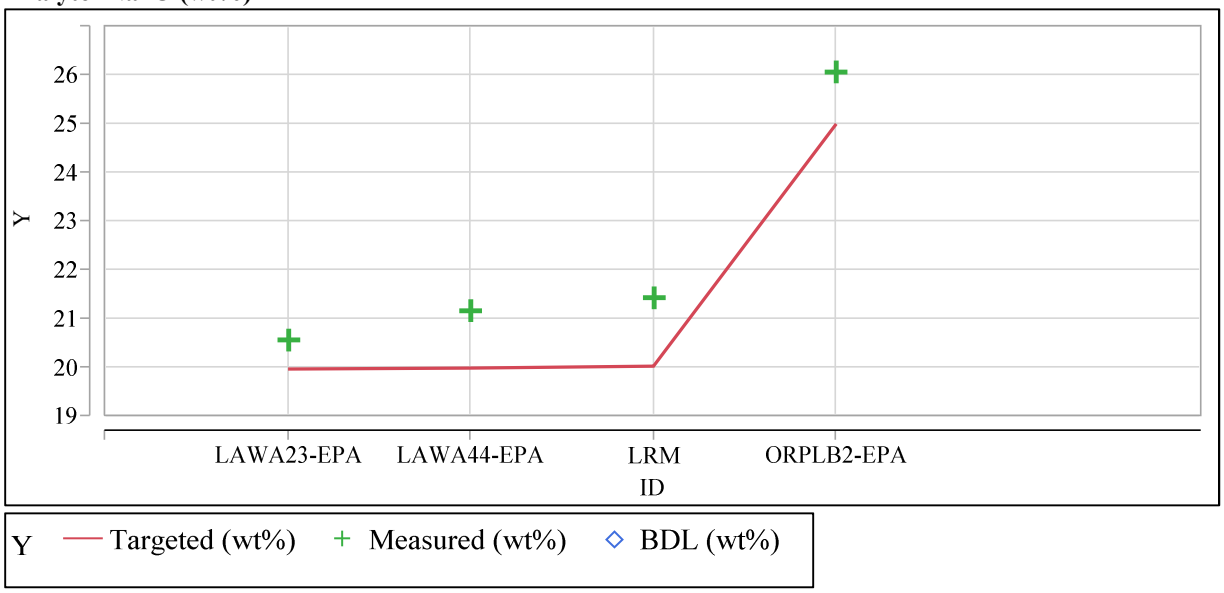
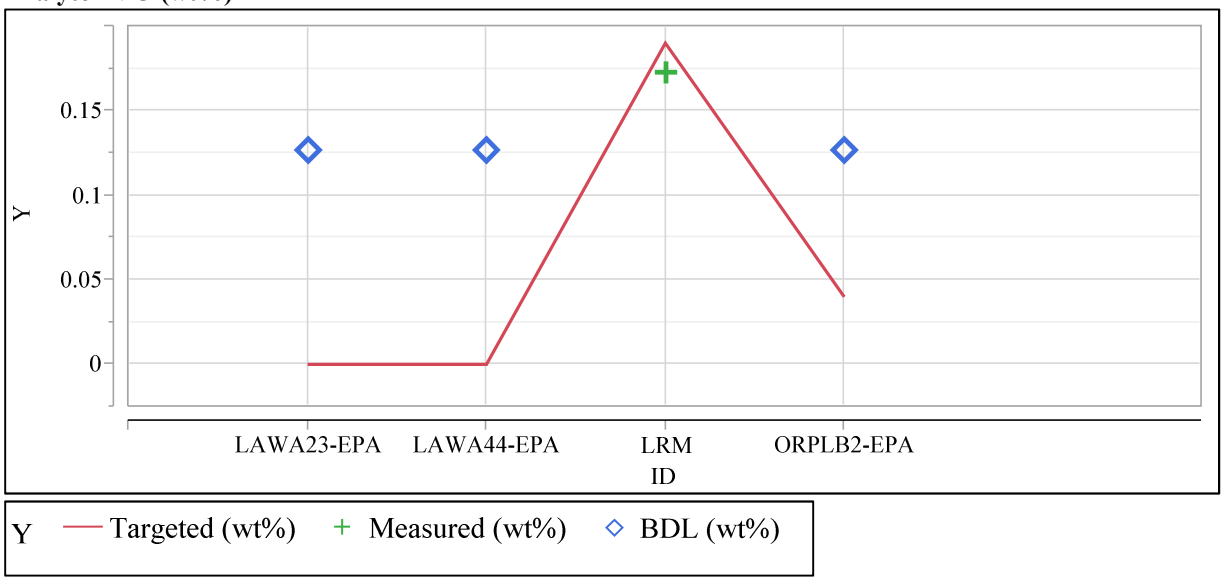


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Analyte=NiO (wt%)



Analyte=P2O5 (wt%)

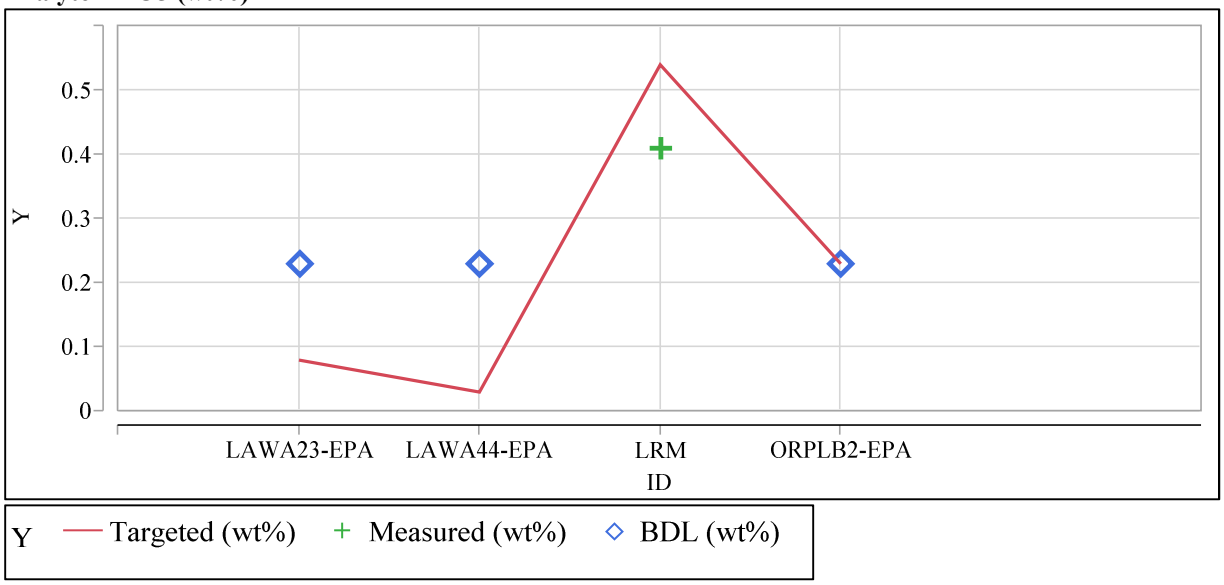
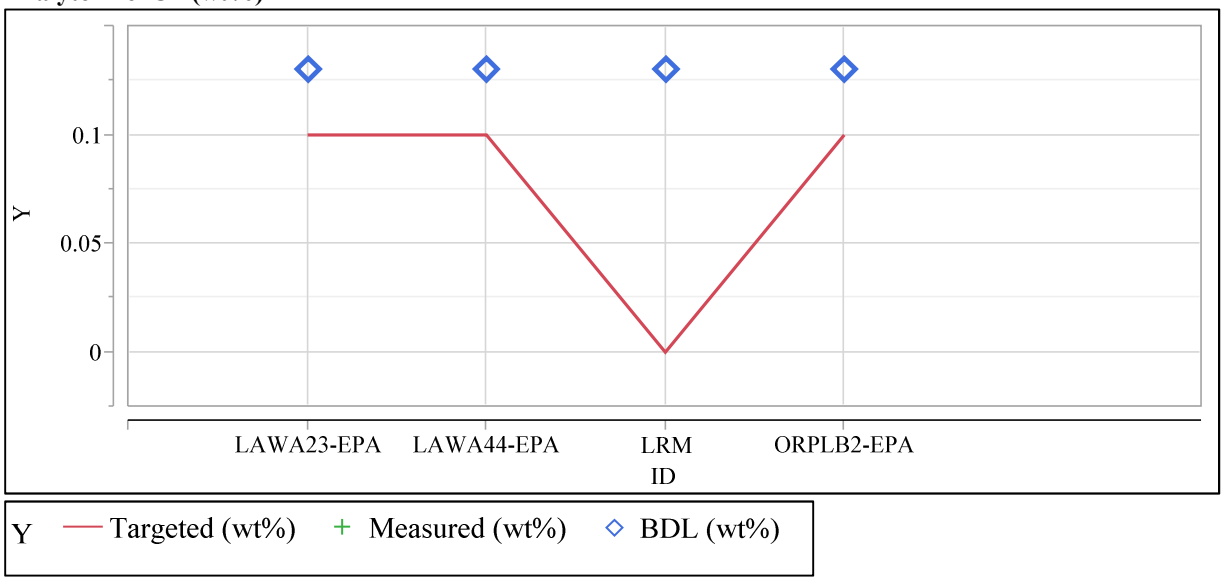
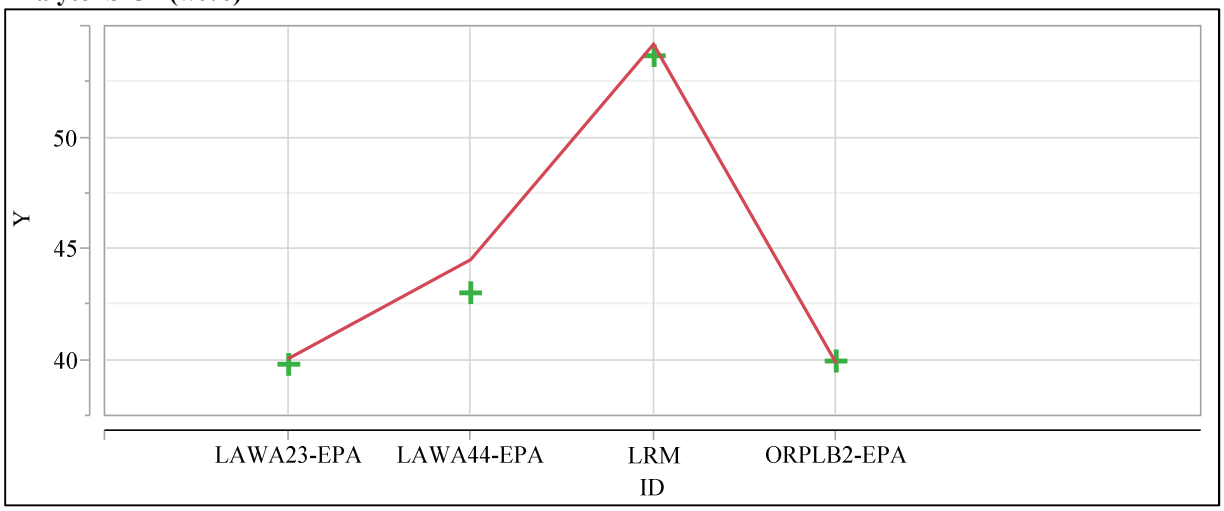


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Analyte=Re2O7 (wt%)



Analyte=SiO2 (wt%)



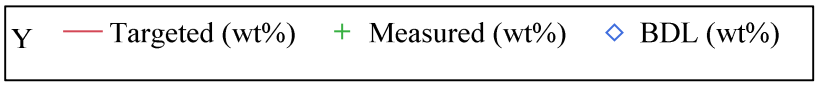
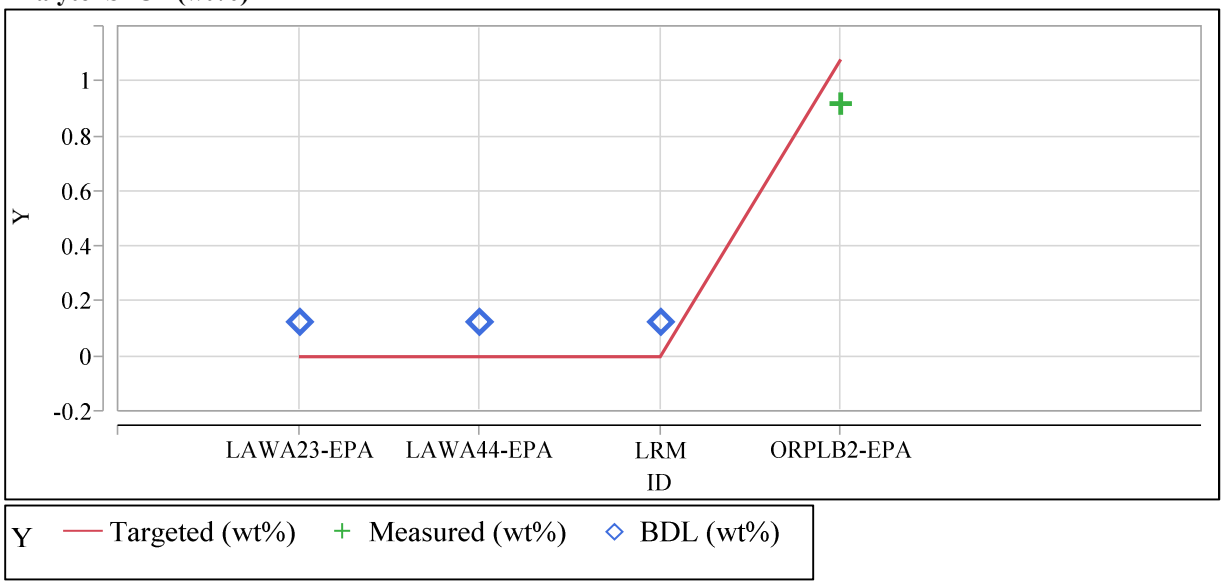
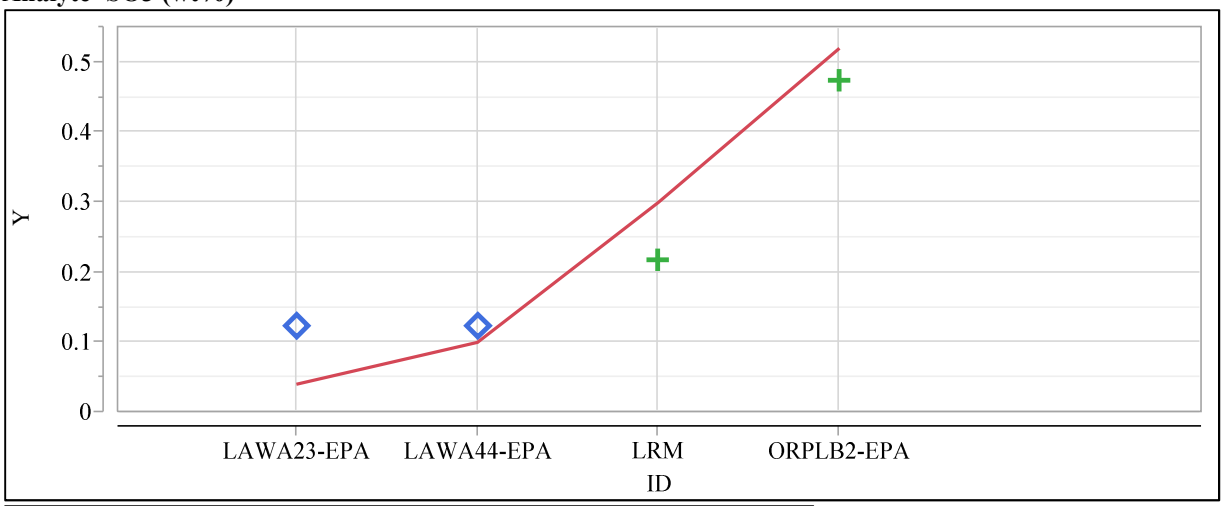


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Analyte=SnO2 (wt%)



Analyte=SO3 (wt%)



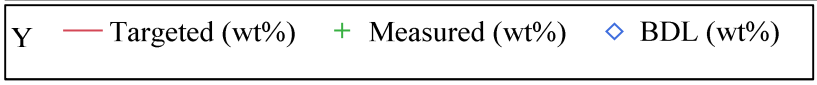
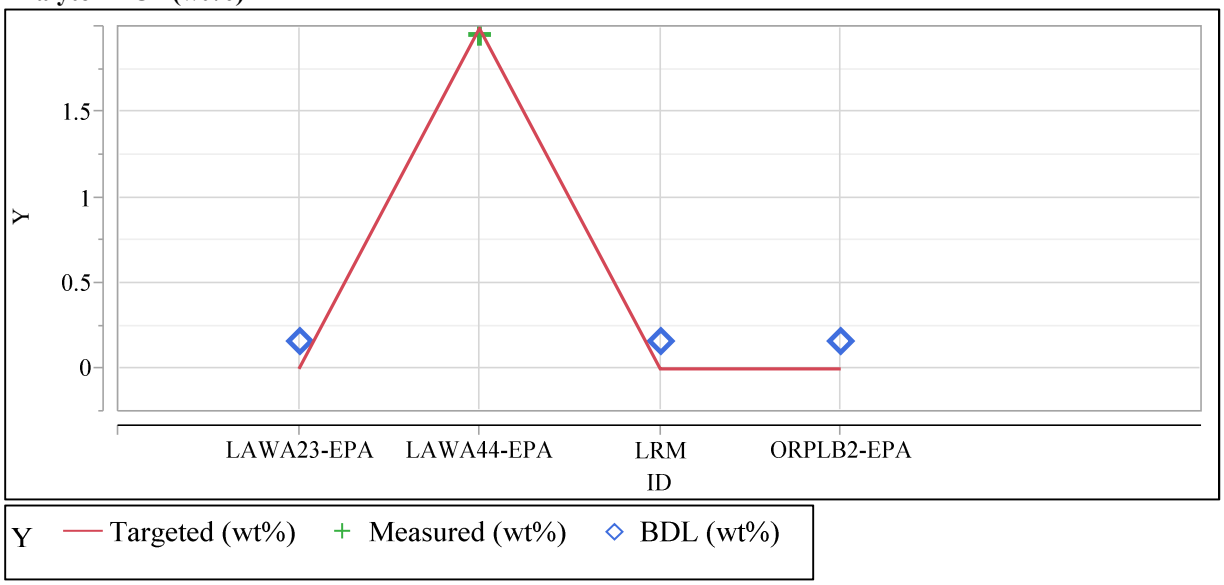


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Analyte=TiO2 (wt%)



Analyte=V2O5 (wt%)

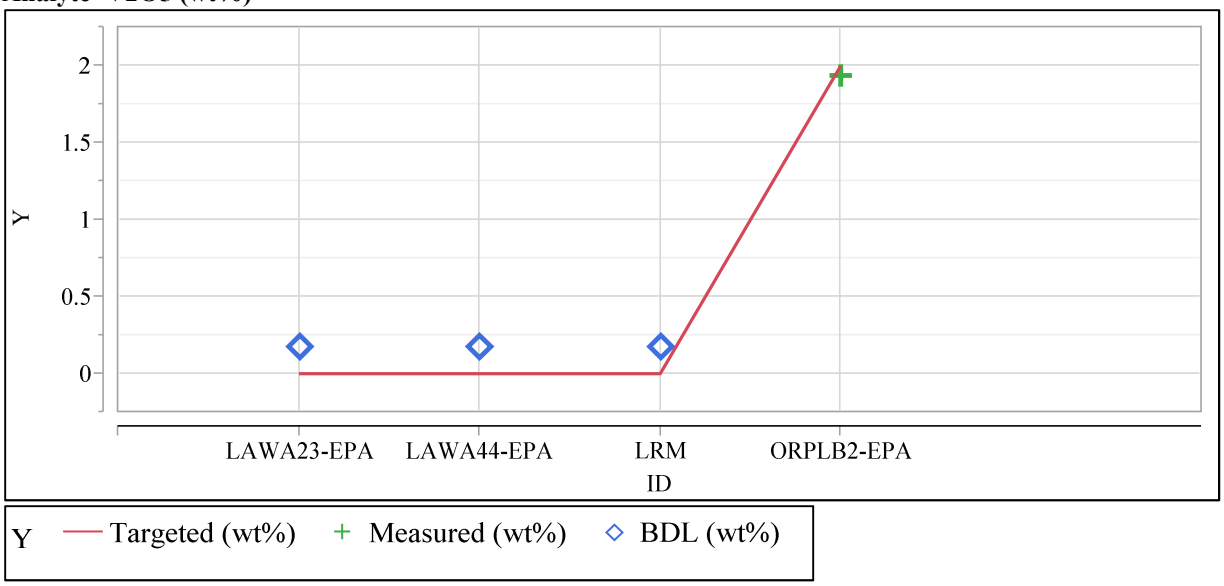
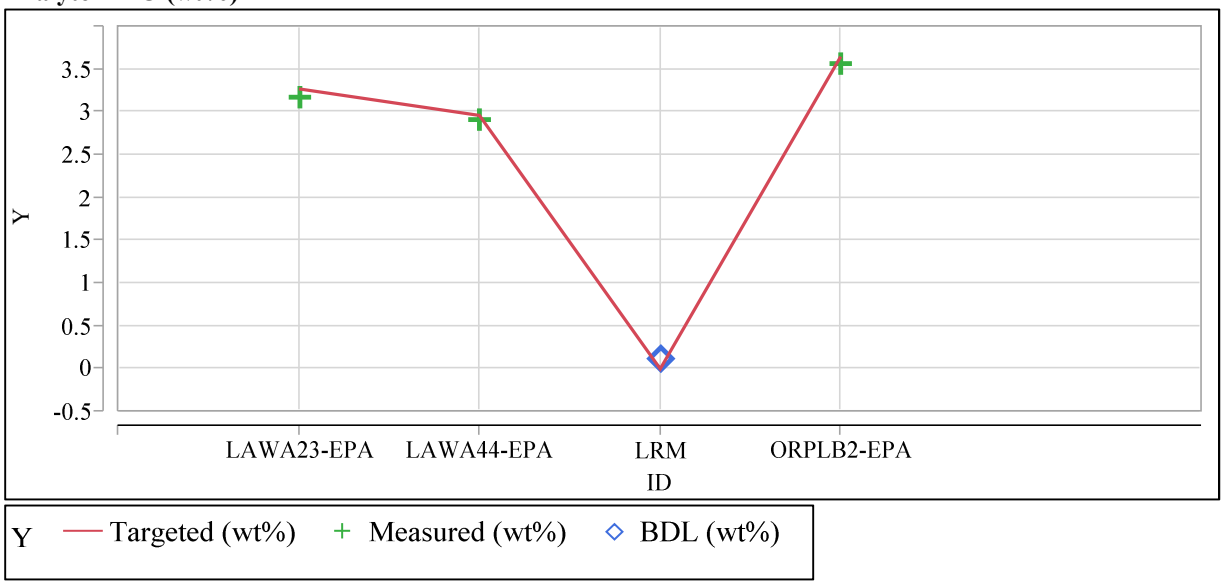
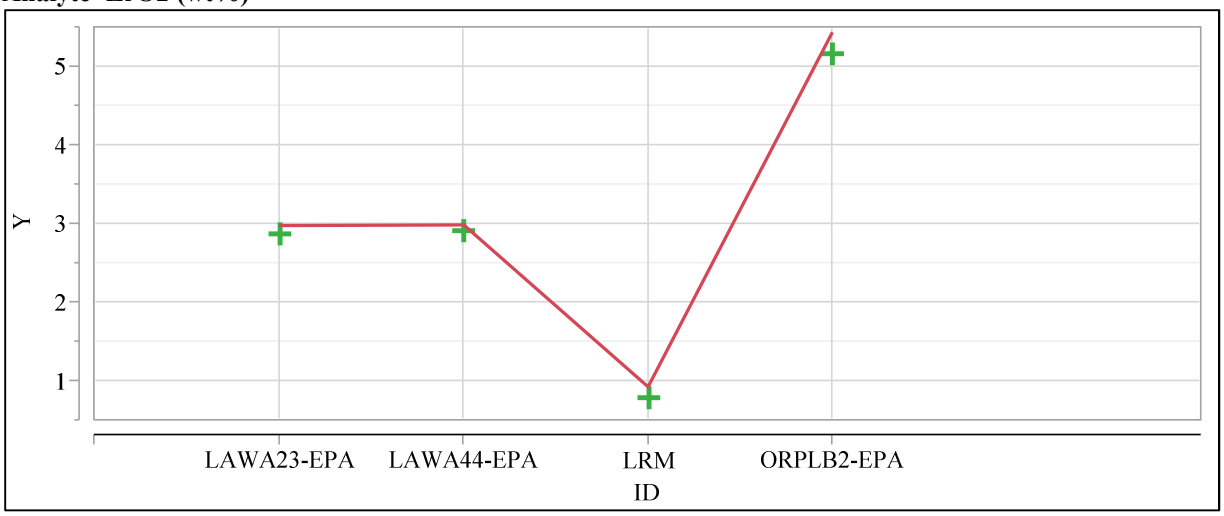


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Analyte=ZnO (wt%)



Analyte=ZrO2 (wt%)



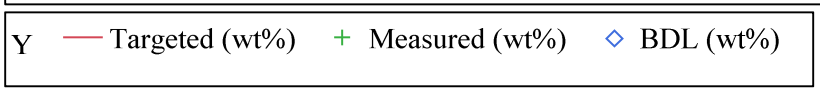
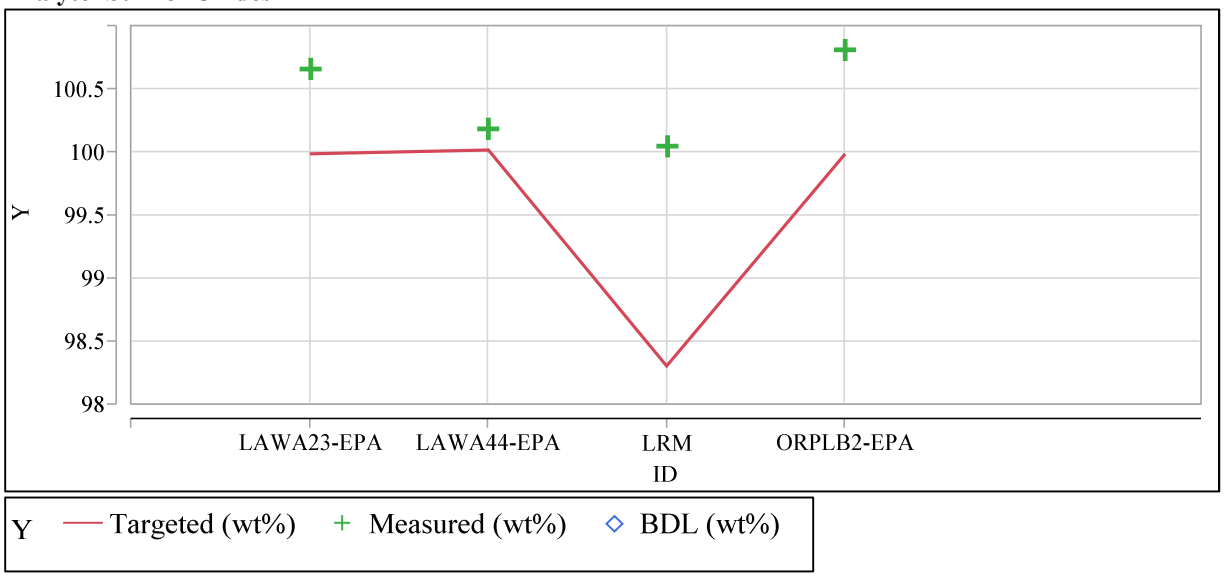


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Analyte=Sum of Oxides



Distribution:

J. W. Amoroso, 999-W
T. B. Brown, 773-A
H. H. Burns, 773-41A
A. S. Choi, 999-W
A. D. Cozzi, 999-W
C. L. Crawford, 773-42A
D. E. Dooley, 999-W
A. P. Fellinger. 773-42A
S. D. Fink, 773-A
K. M. Fox, 999-W
V. Gervasio, PNNL
E. K. Hansen, 999-W
C. C. Herman, 773-A
E. N. Hoffman, 999-W
J. E. Hyatt, 773-A
C. M. Jantzen, 773-A
F. C. Johnson, 999-W
D. S. Kim, PNNL
A. A. Kruger, DOE-ORP
D. J. McCabe, 773-42A
D. L. McClane, 999-W
D. H. Miller, 999-W
D. K. Peeler, PNNL
F. M. Pennebaker, 773-42A
M. R. Poirier, 773-42A
M. J. Schweiger, PNNL
M. E. Stone, 999-W
C. L. Trivelpiece, 999-W
J. D. Vienna, PNNL
B. J. Wiedenman, 773-42A
W. R. Wilmarth, 773-A
Records Administration (EDWS)