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).

Savannah River National Laboratory™

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

We put science to work.™

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

Chemical Composition Measurements of LAWA44 Glass Samples

K. M. Fox

T. B. Edwards

W. T. Riley

November 2016

SRNL-STI-2016-00617, Revision 0

SRNL.DOE.GOV

DISCLAIMER

Printed in the United States of America

Prepared for
U.S. Department of Energy

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

Retention: *Permanent*

Chemical Composition Measurements of LAWA44 Glass Samples

K. M. Fox
T. B. Edwards
W. T. Riley

November 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

____

W. T. Riley, Engineering Process Development Date

TECHNICAL REVIEW:

____

F. C. Johnson, Engineering Process Development, Reviewed per E7 2.60 Date

APPROVAL:

____

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

ACKNOWLEDGEMENTS

The authors thank Courtney Burckhalter, Kim Wyszynski, Beverly Wall, and Mark Reboul at Savannah River National Laboratory for their assistance with the laboratory analyses described in this report. The authors thank Michael Schweiger at the Pacific Northwest National Laboratory for helpful discussions and review of these data and the report. Funding for this work provided by William F. Hamel, Jr., Federal Project Director of the U.S. Department of Energy Office of River Protection Waste Treatment & Immobilization Plant Project through Inter-Entity Work Order M0SRV00101 as managed by Albert A. Kruger is gratefully acknowledged.

EXECUTIVE SUMMARY

In this report, the Savannah River National Laboratory provides chemical analysis results for several samples of a simulated low activity waste glass, LAWA44, provided by the 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 97.9 to 102.6 wt %, indicating acceptable recovery of the glass 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 %. It was noted that the measured B_2O_3 concentrations are somewhat above the targeted values for the study glasses. No obvious trends were observed with regard to the multiple melting steps used to prepare the study glasses, indicating that any potential effects of volatility were below measurable thresholds.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

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

1.0 Introduction

The U.S. Department of Energy (DOE) Office of River Protection (ORP) has requested that the Savannah River National Laboratory (SRNL) provide expert evaluation and experimental work in support of the River Protection Project vitrification technology development. DOE is building the Hanford Tank 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 into borosilicate glass using Joule-heated ceramic melters.

Efforts are being made to increase the loading of Hanford tank wastes in the glass while conforming to processing requirements and product quality regulations. DOE-ORP has requested that 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 enhancing waste glass composition/property models and broadening the compositional regions over which those models are applicable.

In this report, SRNL provides chemical analysis results for several samples of a simulated LAW glass, designated LAWA44, provided by Pacific Northwest National Laboratory (PNNL) as part of an ongoing development task.[2] The objective of the PNNL task is to determine the durability of this glass using EPA Method 1313, which will include test participants at Vanderbilt University and the University of Sheffield. A report on the compositions of similar glasses (referred to as the EPA-series glasses) was issued in March 2016.[3]

2.0 Experimental Procedure

2.1 Glasses Selected for Study

PNNL provided nine LAWA44 glass samples for the analyses described in this report. The identifiers for these glasses are given in Table 2-1.

Table 2-1. Identifiers for the Glasses Included in the Chemical Composition Analyses

Glass ID
LAWA44-BULK-1
LAWA44-BULK-4
LAWA44-RE-1B
LAWA44-RE-3A
LAWA44-RE-3B
LAWA44-RE-5B
LAWA44-RE-7B
LAWA44-RE-9A
LAWA44-RE-9B

A description of the glass preparation methodology was provided by PNNL:

> Twelve kilograms of LAWA44 glass batch was prepared as five individual batches, each blended for 1 hour in a Patterson Kelley V-blender with intensifier bar. The initial melt was performed as a series of smaller melts in an approximately 750 ml platinum/10% rhodium crucible filled with approximately 1.5 kg of batch. The batch was melted for

1 hour at 1150 °C and then poured onto an Inconel® plate. This process was repeated until all 12 kg of glass batch was melted. The glass was then crushed to a fine powder using a jaw crusher with tungsten carbide crushing plates. All 12 kg of the glass powder was added back into the V-blender and mixed for 0.5 hours with the intensifier bar engaged. The glass powder was melted a second time, following the same process used for the initial melt.

Process samples were taken from each glass pour during the second melting step. Glass samples from the first and fourth crucible melts (labeled LAWA-BULK-1 and LAWA-BULK-4) were collected for analysis. After the completion of the second melting step, all of the glass was crushed in a tungsten carbide mill and sieved through -100/+200 stainless steel sieves. Fines remaining after sieving were re-melted for approximately 40 minutes, sampled, and then crushed and sieved again. Melting of fines was repeated nine times until all glass was sieved to the -100/+200 size fraction. Samples of the glass were collected after each of the nine fines melting steps. Samples LAWA44-RE-1B, -3A, -3B, -5B, -7B, -9A, and -9B were selected for chemical composition analysis to determine whether any measurable change in composition took place due to the repeated melt processes.

The final, sieved glass was washed by ultrasonic bath in water until the rinsate lost its cloudiness. The glass was further washed twice by ultrasonic cleaning with absolute ethanol and dried overnight at 90 °C. The approximately 10 kg of clean -100/+200 glass particles were hand mixed in a large plastic bag for 5 minutes in preparation for shipping for durability testing.

Note that as described above, all of the glass samples in this study have the same targeted composition, which is provided in Table 2-2.

Table 2-2. Targeted Composition of LAWA44 Glass

Component	wt %
Al_2O_3	6.20
B_2O_3	8.90
CaO	1.99
Cl	0.65
Cr_2O_3	0.10
F	0.01
Fe_2O_3	6.98
K_2O	0.50
MgO	1.99
MoO_3	0.01
Na_2O	19.99
P_2O_5	0.03
Re_2O_7	0.10
SO_3	0.10
SiO_2	44.53
TiO_2	1.99
ZnO	2.96
ZrO_2	2.99

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

2.2 Compositional Analysis

Chemical analysis was performed under the auspices of an analytical plan[4] on a representative sample of each of the glasses listed in Table 2-1 to allow for comparisons with the targeted composition. Three dissolution techniques, sodium peroxide fusion (PF),[5] lithium metaborate fusion (LM),[6] and potassium hydroxide fusion (KH),[7] were planned for preparing each of the glass samples, in duplicate, for analysis. However, due to insufficient sample amounts, the KH preparation was not performed. A discussion was held with PNNL, resulting in the decision that the KH preparation and analysis for chlorine and fluorine concentrations were not necessary for this study.

Each of the duplicate samples was analyzed twice for each element of interest by Inductively Coupled Plasma – Atomic Emission Spectroscopy (ICP-AES),[8] for a total of four measurements per element per glass. Glass standards were also intermittently measured to assess the performance of the ICP-AES instrument over the course of these analyses. Specifically, several samples of the low-level reference material (LRM)[9] were included as part of the analytical plan. The LRM composition reported as the "Consensus Average" is used as the reference composition of this glass for the purposes of this study.[9] The preparation methods used for each of the reported glass components are listed in Table 2-3.

Table 2-3. Preparation and Measurement Methods Used in Reporting the Concentrations of Each of the Components of the Study Glasses

Analyte	Preparation Method
Al	PF
B	PF
Ca	LM
Cl	Not measured
Cr	LM
F	Not measured
Fe	LM
K	LM
Mg	LM
Mo	LM
Na	LM
P	LM
Re	LM
S	LM
Si	PF
Ti	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, Procedure 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.

3.0 Results and Discussion

3.1 Review and Evaluation of Chemical Composition Measurements

Table A-1 and Table A-2 in Appendix A provide the elemental concentration measurements in wt % for the study glasses as prepared by the LM method. Table A-3 in Appendix A provides the elemental concentration measurements in wt % for the study glasses as prepared by the PF method. Elemental measurements for samples of the LRM standard glass are also provided in the tables of Appendix A. These unprocessed data are provided 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 of the glasses. JMP™ Pro Version 11.2.1 (SAS Institute, Inc.)[10] was used to support these analyses.

3.2 Treatment of Detection Limits

The elemental concentrations in Table A-1 through Table A-3 of Appendix A were converted to oxide concentrations by multiplying the values for each element by the gravimetric factor for the corresponding oxide. 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 review and calculating a sum of oxides for each glass. Those oxides with measured concentrations that were below the associated detection limit (BDL) will be denoted with a less than symbol (<) as the measured compositions are reported.

3.3 Measurements in Analytical Sequence

Exhibit A-1 in Appendix A provides plots of the wt % measurements generated for each sample 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-3 in 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 instruments within and among calibration blocks. A review of these plots did not identify any gross patterns or trends in the analytical process over the course of these measurements.

3.4 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. Some degree of scatter among the B_2O_3, Na_2O, and SiO_2 measurements was noted for the study glasses. These observations were not considered to indicate 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 the study glasses.

3.5 Results for the LRM Standard

Exhibit A-3 in Appendix A provides a comparison of the LRM results to their acceptability limits utilized by SRNL.[8] 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 analyses.

3.6 Measured versus Targeted Compositions

From the discussion of Section 3.4, 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-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 averaged, measured values. Exhibit A-4 in Appendix A provides plots showing the result for each glass for each oxide to allow PNNL to draw comparisons between the measured and targeted values. For example, note that the measured B_2O_3 concentrations are somewhat above the targeted values for the study glasses.

Table A-4 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 97.9 to 102.6 wt %, indicating acceptable recovery of the glass components.[a] Entries in Table A-4 show the relative differences between the measured

[a] As noted earlier, chlorine and fluorine concentrations for the study glasses were not measured.

values and the targeted values for the oxides with targeted values above 5 wt %. The relative differences are shaded if they are 10% or more.[a]

4.0 Summary

In this report, SRNL provides chemical analysis results for several samples of a simulated LAW glass, LAWA44, 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 97.9 to 102.6 wt %, indicating acceptable recovery of the glass 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 %. It was noted that the measured B_2O_3 concentrations are somewhat above the targeted values for the study glasses. No obvious trends were observed with regard to the multiple melting steps used to prepare the study glasses, indicating that any potential effects of volatility were below measurable thresholds.

[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. Fox, K. M. and T. B. Edwards, “Chemical Composition Measurements of the Low Activity Waste (LAW) EPA-Series Glasses,” *U.S. Department of Energy Report SRNL-STI-2016-00095, Revision 0,* Savannah River National Laboratory, Aiken, SC (2016).

4. Edwards, T. B., “An Analytical Plan for Measuring the Chemical Compositions of PNNL LAWA44 Glasses,” *U.S. Department of Energy Memorandum SRNL-L3100-2016-00164,* Savannah River National Laboratory, Aiken, SC (2016).

5. Best, D. R., “Dissolution of Glass, Sludge, and Slurry Samples Using Na_2O_2/NaOH/HCl,” *Manual L29, ITS-0040, Revision 2,* Savannah River National Laboratory, Aiken, SC (2013).

6. Best, D. R., “Lithium Metaborate Fusion Preparation,” *Manual L29, ITS-0071, Revision 3,* Savannah River National Laboratory, Aiken, SC (2015).

7. “Sample Dissolution Using Potassium Hydroxide Fusion,” *Manual L29, ITS-0035, Revision 3,* Savannah River National Laboratory, Aiken, SC (2015).

8. Best, D. R., “Inductively Coupled Plasma-Atomic Emission Spectrometer, Agilent 730 ES,” *Manual L29, Procedure ITS-0079, Revision 5,* Savannah River National Laboratory, Aiken, SC (2014).

9. 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).

10. **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. LM Elemental Measurements of the LAWA44 Study Glasses – Part 1

ID	Block	Sequence	Lab ID	Ca (wt %)	Cr (wt %)	Fe (wt %)	K (wt %)	Mg (wt %)	Mo (wt %)	Na (wt %)
LRM	1	1	LRMLM11	0.333	0.135	0.982	1.20	<0.100	<0.100	15.6
LAWA44-RE-9B	1	2	R04LM21	1.37	0.072	4.58	0.406	1.11	<0.100	14.2
LAWA44-RE-7B	1	3	R09LM21	1.42	0.071	4.72	0.406	1.14	<0.100	14.8
LAWA44-BULK-4	1	4	R05LM11	1.42	0.070	4.71	0.395	1.14	<0.100	14.8
LAWA44-RE-5B	1	5	R08LM21	1.39	0.069	4.65	0.381	1.12	<0.100	14.5
LAWA44-RE-1B	1	6	R06LM21	1.41	0.070	4.68	0.389	1.14	<0.100	14.7
LAWA44-RE-3B	1	7	R07LM11	1.42	0.070	4.71	0.390	1.14	<0.100	14.8
LAWA44-RE-3B	1	8	R07LM21	1.43	0.071	4.73	0.390	1.15	<0.100	14.8
LAWA44-BULK-1	1	9	R02LM11	1.42	0.071	4.71	0.394	1.14	<0.100	14.9
LAWA44-RE-9B	1	10	R04LM11	1.42	0.072	4.71	0.392	1.14	<0.100	14.7
LRM	1	11	LRMLM12	0.329	0.134	0.957	1.16	<0.100	<0.100	15.2
LAWA44-RE-3A	1	12	R03LM11	1.45	0.072	4.80	0.424	1.16	<0.100	15.2
LAWA44-RE-9A	1	13	R01LM11	1.46	0.074	4.83	0.415	1.17	<0.100	15.1
LAWA44-RE-7B	1	14	R09LM11	1.43	0.072	4.76	0.403	1.15	<0.100	14.9
LAWA44-BULK-1	1	15	R02LM21	1.40	0.072	4.64	0.383	1.12	<0.100	14.6
LAWA44-RE-1B	1	16	R06LM11	1.37	0.071	4.60	0.376	1.11	<0.100	14.3
LAWA44-BULK-4	1	17	R05LM21	1.40	0.073	4.65	0.387	1.13	<0.100	14.6
LAWA44-RE-9A	1	18	R01LM21	1.40	0.074	4.67	0.385	1.13	<0.100	14.5
LAWA44-RE-3A	1	19	R03LM21	1.44	0.073	4.78	0.405	1.16	<0.100	15.1
LAWA44-RE-5B	1	20	R08LM11	1.41	0.073	4.70	0.390	1.14	<0.100	14.7
LRM	1	21	LRMLM13	0.334	0.135	0.963	1.18	<0.100	<0.100	15.3
LRM	2	1	LRMLM21	0.335	0.135	0.975	1.20	<0.100	<0.100	15.7
LAWA44-RE-9B	2	2	R04LM12	1.46	0.071	4.82	0.392	1.16	<0.100	15.2
LAWA44-RE-1B	2	3	R06LM22	1.43	0.070	4.74	0.383	1.15	<0.100	15.1
LAWA44-RE-3B	2	4	R07LM22	1.44	0.071	4.78	0.381	1.16	<0.100	15.1
LAWA44-BULK-1	2	5	R02LM22	1.39	0.069	4.64	0.363	1.12	<0.100	14.7
LAWA44-RE-3A	2	6	R03LM12	1.40	0.072	4.66	0.385	1.13	<0.100	14.7
LAWA44-RE-9B	2	7	R04LM22	1.42	0.073	4.70	0.411	1.13	<0.100	14.8
LAWA44-RE-5B	2	8	R08LM22	1.41	0.072	4.69	0.369	1.13	<0.100	14.8
LAWA44-RE-1B	2	9	R06LM12	1.39	0.072	4.64	0.365	1.12	<0.100	14.6
LAWA44-RE-3A	2	10	R03LM22	1.46	0.072	4.83	0.392	1.17	<0.100	15.4
LRM	2	11	LRMLM22	0.338	0.134	0.988	1.24	<0.100	<0.100	15.1
LAWA44-RE-7B	2	12	R09LM12	1.45	0.072	4.80	0.391	1.16	<0.100	15.2
LAWA44-BULK-4	2	13	R05LM22	1.48	0.071	4.88	0.403	1.18	<0.100	15.7

Table A-1. LM Elemental Measurements of the LAWA44 Study Glasses – Part 1 (continued)

ID	Block	Sequence	Lab ID	Ca (wt %)	Cr (wt %)	Fe (wt %)	K (wt %)	Mg (wt %)	Mo (wt %)	Na (wt %)
LAWA44-RE-9A	2	14	R01LM12	1.43	0.072	4.76	0.386	1.14	<0.100	15.0
LAWA44-RE-9A	2	15	R01LM22	1.49	0.071	4.91	0.401	1.19	<0.100	15.6
LAWA44-RE-3B	2	16	R07LM12	1.44	0.071	4.75	0.381	1.15	<0.100	15.1
LAWA44-BULK-1	2	17	R02LM12	1.42	0.070	4.72	0.378	1.14	<0.100	15.0
LAWA44-RE-7B	2	18	R09LM22	1.45	0.070	4.76	0.399	1.15	<0.100	15.1
LAWA44-BULK-4	2	19	R05LM12	1.48	0.068	4.84	0.398	1.17	<0.100	15.5
LAWA44-RE-5B	2	20	R08LM12	1.49	0.068	4.89	0.401	1.18	<0.100	15.6
LRM	2	21	LRMLM23	0.343	0.136	1.00	1.26	<0.100	<0.100	14.8

Table A-2. LM Elemental Measurements of the LAWA44 Study Glasses – Part 2

ID	Block	Sequence	Lab ID	P (wt %)	Re (wt %)	S (wt %)	Ti (wt %)	Zn (wt %)	Zr (wt %)
LRM	1	1	LRMLM11	0.208	<0.100	0.085	<0.100	<0.100	0.684
LAWA44-RE-9B	1	2	R04LM21	<0.100	<0.100	0.038	1.10	2.23	2.00
LAWA44-RE-7B	1	3	R09LM21	<0.100	<0.100	0.038	1.13	2.30	2.09
LAWA44-BULK-4	1	4	R05LM11	<0.100	<0.100	0.043	1.12	2.32	2.05
LAWA44-RE-5B	1	5	R08LM21	<0.100	<0.100	0.043	1.09	2.27	1.83
LAWA44-RE-1B	1	6	R06LM21	<0.100	<0.100	0.044	1.12	2.30	2.08
LAWA44-RE-3B	1	7	R07LM11	<0.100	<0.100	0.043	1.12	2.30	2.08
LAWA44-RE-3B	1	8	R07LM21	<0.100	<0.100	0.042	1.13	2.33	2.10
LAWA44-BULK-1	1	9	R02LM11	<0.100	<0.100	0.044	1.13	2.30	2.09
LAWA44-RE-9B	1	10	R04LM11	<0.100	<0.100	0.041	1.13	2.30	2.09
LRM	1	11	LRMLM12	0.206	<0.100	0.086	<0.100	<0.100	0.682
LAWA44-RE-3A	1	12	R03LM11	<0.100	<0.100	0.042	1.14	2.34	2.05
LAWA44-RE-9A	1	13	R01LM11	<0.100	<0.100	0.043	1.15	2.38	2.13
LAWA44-RE-7B	1	14	R09LM11	<0.100	<0.100	0.039	1.14	2.35	2.11
LAWA44-BULK-1	1	15	R02LM21	<0.100	<0.100	0.044	1.11	2.28	2.04
LAWA44-RE-1B	1	16	R06LM11	<0.100	<0.100	0.044	1.10	2.25	2.04
LAWA44-BULK-4	1	17	R05LM21	<0.100	<0.100	0.046	1.11	2.29	2.05
LAWA44-RE-9A	1	18	R01LM21	<0.100	<0.100	0.041	1.11	2.30	2.07
LAWA44-RE-3A	1	19	R03LM21	<0.100	<0.100	0.044	1.14	2.35	2.11
LAWA44-RE-5B	1	20	R08LM11	<0.100	<0.100	0.040	1.12	2.32	2.04
LRM	1	21	LRMLM13	0.206	<0.100	0.086	<0.100	<0.100	0.687
LRM	2	1	LRMLM21	0.208	<0.100	0.085	<0.100	<0.100	0.686
LAWA44-RE-9B	2	2	R04LM12	<0.100	<0.100	0.042	1.14	2.36	2.12
LAWA44-RE-1B	2	3	R06LM22	<0.100	<0.100	0.047	1.13	2.33	2.09
LAWA44-RE-3B	2	4	R07LM22	<0.100	<0.100	0.045	1.14	2.34	2.11
LAWA44-BULK-1	2	5	R02LM22	<0.100	<0.100	0.044	1.11	2.26	2.03
LAWA44-RE-3A	2	6	R03LM12	<0.100	<0.100	0.046	1.11	2.27	2.00
LAWA44-RE-9B	2	7	R04LM22	<0.100	<0.100	0.042	1.11	2.30	2.05
LAWA44-RE-5B	2	8	R08LM22	<0.100	<0.100	0.047	1.09	2.28	1.85
LAWA44-RE-1B	2	9	R06LM12	<0.100	<0.100	0.047	1.11	2.26	2.05
LAWA44-RE-3A	2	10	R03LM22	<0.100	<0.100	0.044	1.15	2.38	2.14
LRM	2	11	LRMLM22	0.206	<0.100	0.081	<0.100	<0.100	0.689
LAWA44-RE-7B	2	12	R09LM12	<0.100	<0.100	0.045	1.15	2.35	2.12
LAWA44-BULK-4	2	13	R05LM22	<0.100	<0.100	0.047	1.16	2.40	2.15

Table A-2. LM Elemental Measurements of the LAWA44 Study Glasses – Part 2 (continued)

ID	Block	Sequence	Lab ID	P (wt %)	Re (wt %)	S (wt %)	Ti (wt %)	Zn (wt %)	Zr (wt %)
LAWA44-RE-9A	2	14	R01LM12	<0.100	<0.100	0.044	1.13	2.32	2.10
LAWA44-RE-9A	2	15	R01LM22	<0.100	<0.100	0.039	1.17	2.40	2.17
LAWA44-RE-3B	2	16	R07LM12	<0.100	<0.100	0.045	1.13	2.32	2.10
LAWA44-BULK-1	2	17	R02LM12	<0.100	<0.100	0.043	1.13	2.30	2.09
LAWA44-RE-7B	2	18	R09LM22	<0.100	<0.100	0.043	1.14	2.35	2.11
LAWA44-BULK-4	2	19	R05LM12	<0.100	<0.100	0.042	1.15	2.38	2.11
LAWA44-RE-5B	2	20	R08LM12	<0.100	<0.100	0.042	1.16	2.39	2.12
LRM	2	21	LRMLM23	0.209	<0.100	0.086	<0.100	<0.100	0.698

Table A-3. PF Elemental Measurements of the LAWA44 Study Glasses

ID	Block	Sequence	Lab ID	Al (wt %)	B (wt %)	Si (wt %)
LRM	1	1	LRMPF11	5.09	2.90	26.4
LAWA44-BULK-4	1	2	R05PF21	3.31	3.34	23.1
LAWA44-RE-3B	1	3	R07PF11	3.19	3.14	22.3
LAWA44-RE-3B	1	4	R07PF21	3.12	3.03	21.8
LAWA44-RE-9B	1	5	R04PF11	3.23	3.18	22.6
LAWA44-RE-5B	1	6	R08PF11	3.13	2.95	22.0
LAWA44-BULK-1	1	7	R02PF21	3.15	3.10	22.1
LAWA44-RE-9A	1	8	R01PF21	3.25	3.21	22.9
LAWA44-RE-3A	1	9	R03PF11	3.14	3.02	22.1
LAWA44-BULK-1	1	10	R02PF11	3.22	3.17	22.6
LRM	1	11	LRMPF12	4.83	2.63	25.7
LAWA44-RE-5B	1	12	R08PF21	3.26	3.33	22.4
LAWA44-RE-7B	1	13	R09PF11	3.21	3.10	22.1
LAWA44-RE-9B	1	14	R04PF21	3.18	3.07	21.6
LAWA44-RE-3A	1	15	R03PF21	3.20	3.04	21.7
LAWA44-RE-1B	1	16	R06PF21	3.09	2.92	20.7
LAWA44-RE-9A	1	17	R01PF11	3.06	2.76	20.4
LAWA44-BULK-4	1	18	R05PF11	3.12	2.95	20.8
LAWA44-RE-1B	1	19	R06PF11	3.12	2.98	20.7
LAWA44-RE-7B	1	20	R09PF21	3.25	2.98	21.0
LRM	1	21	LRMPF13	4.87	2.52	24.8
LRM	2	1	LRMPF21	5.10	2.91	26.2
LAWA44-RE-3A	2	2	R03PF12	3.31	3.21	23.1
LAWA44-RE-7B	2	3	R09PF22	3.10	2.85	20.7
LAWA44-RE-5B	2	4	R08PF22	2.96	2.72	20.2
LAWA44-RE-3B	2	5	R07PF12	3.03	2.91	20.7
LAWA44-RE-3B	2	6	R07PF22	3.19	3.01	21.9
LAWA44-BULK-4	2	7	R05PF22	3.09	2.91	21.0
LAWA44-RE-1B	2	8	R06PF12	3.03	2.84	20.5
LAWA44-RE-7B	2	9	R09PF12	3.06	2.87	20.7
LAWA44-RE-3A	2	10	R03PF22	2.95	2.67	20.1
LRM	2	11	LRMPF22	4.97	2.60	26.3
LAWA44-RE-9B	2	12	R04PF22	3.08	2.93	21.1
LAWA44-BULK-1	2	13	R02PF12	2.93	2.74	20.0
LAWA44-RE-5B	2	14	R08PF12	2.99	2.76	20.4
LAWA44-RE-1B	2	15	R06PF22	2.98	2.72	20.3
LAWA44-RE-9A	2	16	R01PF22	3.15	2.94	21.5
LAWA44-BULK-4	2	17	R05PF12	3.11	2.91	21.5
LAWA44-RE-9B	2	18	R04PF12	3.16	2.91	21.9
LAWA44-BULK-1	2	19	R02PF22	2.99	2.70	20.5
LAWA44-RE-9A	2	20	R01PF12	3.22	2.98	23.3
LRM	2	21	LRMPF23	4.97	2.51	25.9

Table A-4. 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
LAWA44-BULK-1	Al_2O_3		5.805	6.200	-0.395	-6.4%
LAWA44-BULK-1	B_2O_3		9.426	8.900	0.526	5.9%
LAWA44-BULK-1	CaO		1.969	1.990	-0.021	
LAWA44-BULK-1	Cr_2O_3		0.103	0.100	0.003	
LAWA44-BULK-1	Fe_2O_3		6.687	6.980	-0.293	-4.2%
LAWA44-BULK-1	K_2O		0.457	0.500	-0.043	
LAWA44-BULK-1	MgO		1.874	1.990	-0.116	
LAWA44-BULK-1	MoO_3	<	0.150	0.010	0.140	
LAWA44-BULK-1	Na_2O		19.950	19.990	-0.040	-0.2%
LAWA44-BULK-1	P_2O_5	<	0.229	0.030	0.199	
LAWA44-BULK-1	Re_2O_7	<	0.130	0.100	0.030	
LAWA44-BULK-1	SiO_2		45.567	44.530	1.037	2.3%
LAWA44-BULK-1	SO_3		0.109	0.100	0.009	
LAWA44-BULK-1	TiO_2		1.868	1.990	-0.122	
LAWA44-BULK-1	ZnO		2.844	2.960	-0.116	
LAWA44-BULK-1	ZrO_2		2.786	2.990	-0.204	
LAWA44-BULK-1	Sum		99.957	99.360	0.597	0.6%
LAWA44-BULK-4	Al_2O_3		5.966	6.200	-0.234	-3.8%
LAWA44-BULK-4	B_2O_3		9.748	8.900	0.848	9.5%
LAWA44-BULK-4	CaO		2.022	1.990	0.032	
LAWA44-BULK-4	Cr_2O_3		0.103	0.100	0.003	
LAWA44-BULK-4	Fe_2O_3		6.820	6.980	-0.160	-2.3%
LAWA44-BULK-4	K_2O		0.477	0.500	-0.023	
LAWA44-BULK-4	MgO		1.915	1.990	-0.075	
LAWA44-BULK-4	MoO_3	<	0.150	0.010	0.140	
LAWA44-BULK-4	Na_2O		20.422	19.990	0.432	2.2%
LAWA44-BULK-4	P_2O_5	<	0.229	0.030	0.199	
LAWA44-BULK-4	Re_2O_7	<	0.130	0.100	0.030	
LAWA44-BULK-4	SiO_2		46.209	44.530	1.679	3.8%
LAWA44-BULK-4	SO_3		0.111	0.100	0.011	
LAWA44-BULK-4	TiO_2		1.893	1.990	-0.097	
LAWA44-BULK-4	ZnO		2.922	2.960	-0.038	
LAWA44-BULK-4	ZrO_2		2.823	2.990	-0.167	
LAWA44-BULK-4	Sum		101.941	99.360	2.581	2.6%
LAWA44-RE-1B	Al_2O_3		5.772	6.200	-0.428	-6.9%
LAWA44-RE-1B	B_2O_3		9.225	8.900	0.325	3.7%
LAWA44-RE-1B	CaO		1.959	1.990	-0.031	
LAWA44-RE-1B	Cr_2O_3		0.103	0.100	0.003	
LAWA44-RE-1B	Fe_2O_3		6.670	6.980	-0.310	-4.4%
LAWA44-RE-1B	K_2O		0.456	0.500	-0.044	
LAWA44-RE-1B	MgO		1.874	1.990	-0.116	
LAWA44-RE-1B	MoO_3	<	0.150	0.010	0.140	
LAWA44-RE-1B	Na_2O		19.782	19.990	-0.208	-1.0%
LAWA44-RE-1B	P_2O_5	<	0.229	0.030	0.199	
LAWA44-RE-1B	Re_2O_7	<	0.130	0.100	0.030	
LAWA44-RE-1B	SiO_2		43.963	44.530	-0.567	-1.3%
LAWA44-RE-1B	SO_3		0.114	0.100	0.014	

Table A-4. 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-RE-1B	TiO_2		1.860	1.990	-0.130	
LAWA44-RE-1B	ZnO		2.844	2.960	-0.116	
LAWA44-RE-1B	ZrO_2		2.789	2.990	-0.201	
LAWA44-RE-1B	Sum		97.920	99.360	-1.440	-1.4%
LAWA44-RE-3A	Al_2O_3		5.952	6.200	-0.248	-4.0%
LAWA44-RE-3A	B_2O_3		9.611	8.900	0.711	8.0%
LAWA44-RE-3A	CaO		2.011	1.990	0.021	
LAWA44-RE-3A	Cr_2O_3		0.106	0.100	0.006	
LAWA44-RE-3A	Fe_2O_3		6.816	6.980	-0.164	-2.3%
LAWA44-RE-3A	K_2O		0.484	0.500	-0.016	
LAWA44-RE-3A	MgO		1.915	1.990	-0.075	
LAWA44-RE-3A	MoO_3	<	0.150	0.010	0.140	
LAWA44-RE-3A	Na_2O		20.355	19.990	0.365	1.8%
LAWA44-RE-3A	P_2O_5	<	0.229	0.030	0.199	
LAWA44-RE-3A	Re_2O_7	<	0.130	0.100	0.030	
LAWA44-RE-3A	SiO_2		46.530	44.530	2.000	4.5%
LAWA44-RE-3A	SO_3		0.110	0.100	0.010	
LAWA44-RE-3A	TiO_2		1.893	1.990	-0.097	
LAWA44-RE-3A	ZnO		2.907	2.960	-0.053	
LAWA44-RE-3A	ZrO_2		2.803	2.990	-0.187	
LAWA44-RE-3A	Sum		102.002	99.360	2.642	2.7%
LAWA44-RE-3B	Al_2O_3		5.919	6.200	-0.281	-4.5%
LAWA44-RE-3B	B_2O_3		9.732	8.900	0.832	9.3%
LAWA44-RE-3B	CaO		2.004	1.990	0.014	
LAWA44-RE-3B	Cr_2O_3		0.103	0.100	0.003	
LAWA44-RE-3B	Fe_2O_3		6.780	6.980	-0.200	-2.9%
LAWA44-RE-3B	K_2O		0.464	0.500	-0.036	
LAWA44-RE-3B	MgO		1.907	1.990	-0.083	
LAWA44-RE-3B	MoO_3	<	0.150	0.010	0.140	
LAWA44-RE-3B	Na_2O		20.153	19.990	0.163	0.8%
LAWA44-RE-3B	P_2O_5	<	0.229	0.030	0.199	
LAWA44-RE-3B	Re_2O_7	<	0.130	0.100	0.030	
LAWA44-RE-3B	SiO_2		46.369	44.530	1.839	4.1%
LAWA44-RE-3B	SO_3		0.109	0.100	0.009	
LAWA44-RE-3B	TiO_2		1.885	1.990	-0.105	
LAWA44-RE-3B	ZnO		2.891	2.960	-0.069	
LAWA44-RE-3B	ZrO_2		2.833	2.990	-0.157	
LAWA44-RE-3B	Sum		101.660	99.360	2.300	2.3%
LAWA44-RE-5B	Al_2O_3		5.829	6.200	-0.371	-6.0%
LAWA44-RE-5B	B_2O_3		9.467	8.900	0.567	6.4%
LAWA44-RE-5B	CaO		1.994	1.990	0.004	
LAWA44-RE-5B	Cr_2O_3		0.103	0.100	0.003	
LAWA44-RE-5B	Fe_2O_3		6.766	6.980	-0.214	-3.1%
LAWA44-RE-5B	K_2O		0.464	0.500	-0.036	
LAWA44-RE-5B	MgO		1.895	1.990	-0.095	
LAWA44-RE-5B	MoO_3	<	0.150	0.010	0.140	
LAWA44-RE-5B	Na_2O		20.085	19.990	0.095	0.5%

Table A-4. 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-RE-5B	P_2O_5	<	0.229	0.030	0.199	
LAWA44-RE-5B	Re_2O_7	<	0.130	0.100	0.030	
LAWA44-RE-5B	SiO_2		45.460	44.530	0.930	2.1%
LAWA44-RE-5B	SO_3		0.107	0.100	0.007	
LAWA44-RE-5B	TiO_2		1.860	1.990	-0.130	
LAWA44-RE-5B	ZnO		2.882	2.960	-0.078	
LAWA44-RE-5B	ZrO_2		2.648	2.990	-0.342	
LAWA44-RE-5B	Sum		100.068	99.360	0.708	0.7%
LAWA44-RE-7B	Al_2O_3		5.961	6.200	-0.239	-3.9%
LAWA44-RE-7B	B_2O_3		9.499	8.900	0.599	6.7%
LAWA44-RE-7B	CaO		2.011	1.990	0.021	
LAWA44-RE-7B	Cr_2O_3		0.104	0.100	0.004	
LAWA44-RE-7B	Fe_2O_3		6.805	6.980	-0.175	-2.5%
LAWA44-RE-7B	K_2O		0.482	0.500	-0.018	
LAWA44-RE-7B	MgO		1.907	1.990	-0.083	
LAWA44-RE-7B	MoO_3	<	0.150	0.010	0.140	
LAWA44-RE-7B	Na_2O		20.220	19.990	0.230	1.2%
LAWA44-RE-7B	P_2O_5	<	0.229	0.030	0.199	
LAWA44-RE-7B	Re_2O_7	<	0.130	0.100	0.030	
LAWA44-RE-7B	SiO_2		45.193	44.530	0.663	1.5%
LAWA44-RE-7B	SO_3		0.103	0.100	0.003	
LAWA44-RE-7B	TiO_2		1.902	1.990	-0.088	
LAWA44-RE-7B	ZnO		2.910	2.960	-0.050	
LAWA44-RE-7B	ZrO_2		2.847	2.990	-0.143	
LAWA44-RE-7B	Sum		100.453	99.360	1.093	1.1%
LAWA44-RE-9A	Al_2O_3		5.990	6.200	-0.210	-3.4%
LAWA44-RE-9A	B_2O_3		9.571	8.900	0.671	7.5%
LAWA44-RE-9A	CaO		2.022	1.990	0.032	
LAWA44-RE-9A	Cr_2O_3		0.106	0.100	0.006	
LAWA44-RE-9A	Fe_2O_3		6.852	6.980	-0.128	-1.8%
LAWA44-RE-9A	K_2O		0.478	0.500	-0.022	
LAWA44-RE-9A	MgO		1.919	1.990	-0.071	
LAWA44-RE-9A	MoO_3	<	0.150	0.010	0.140	
LAWA44-RE-9A	Na_2O		20.287	19.990	0.297	1.5%
LAWA44-RE-9A	P_2O_5	<	0.229	0.030	0.199	
LAWA44-RE-9A	Re_2O_7	<	0.130	0.100	0.030	
LAWA44-RE-9A	SiO_2		47.118	44.530	2.588	5.8%
LAWA44-RE-9A	SO_3		0.104	0.100	0.004	
LAWA44-RE-9A	TiO_2		1.902	1.990	-0.088	
LAWA44-RE-9A	ZnO		2.925	2.960	-0.035	
LAWA44-RE-9A	ZrO_2		2.860	2.990	-0.130	
LAWA44-RE-9A	Sum		102.644	99.360	3.284	3.3%
LAWA44-RE-9B	Al_2O_3		5.976	6.200	-0.224	-3.6%
LAWA44-RE-9B	B_2O_3		9.732	8.900	0.832	9.3%
LAWA44-RE-9B	CaO		1.983	1.990	-0.007	
LAWA44-RE-9B	Cr_2O_3		0.105	0.100	0.005	
LAWA44-RE-9B	Fe_2O_3		6.723	6.980	-0.257	-3.7%

Table A-4. 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-RE-9B	K_2O		0.482	0.500	-0.018	
LAWA44-RE-9B	MgO		1.882	1.990	-0.108	
LAWA44-RE-9B	MoO_3	<	0.150	0.010	0.140	
LAWA44-RE-9B	Na_2O		19.849	19.990	-0.141	-0.7%
LAWA44-RE-9B	P_2O_5	<	0.229	0.030	0.199	
LAWA44-RE-9B	Re_2O_7	<	0.130	0.100	0.030	
LAWA44-RE-9B	SiO_2		46.637	44.530	2.107	4.7%
LAWA44-RE-9B	SO_3		0.102	0.100	0.002	
LAWA44-RE-9B	TiO_2		1.868	1.990	-0.122	
LAWA44-RE-9B	ZnO		2.860	2.960	-0.100	
LAWA44-RE-9B	ZrO_2		2.789	2.990	-0.201	
LAWA44-RE-9B	Sum		101.498	99.360	2.138	2.2%
LRM	Al_2O_3		9.394	9.510	-0.116	-1.2%
LRM	B_2O_3		8.624	7.850	0.774	9.9%
LRM	CaO		0.469	0.540	-0.071	
LRM	Cr_2O_3		0.197	0.190	0.007	
LRM	Fe_2O_3		1.398	1.380	0.018	
LRM	K_2O		1.454	1.480	-0.026	
LRM	MgO	<	0.166	0.100	0.066	
LRM	MoO_3	<	0.150	0.000	0.150	
LRM	Na_2O		20.602	20.030	0.572	2.9%
LRM	P_2O_5		0.475	0.540	-0.065	
LRM	Re_2O_7	<	0.130	0.000	0.130	
LRM	SiO_2		55.372	54.200	1.172	2.2%
LRM	SO_3		0.212	0.300	-0.088	
LRM	TiO_2	<	0.167	0.000	0.167	
LRM	ZnO	<	0.124	0.000	0.124	
LRM	ZrO_2		0.929	0.930	-0.001	
LRM	Sum		99.862	97.050	2.812	2.9%

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

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

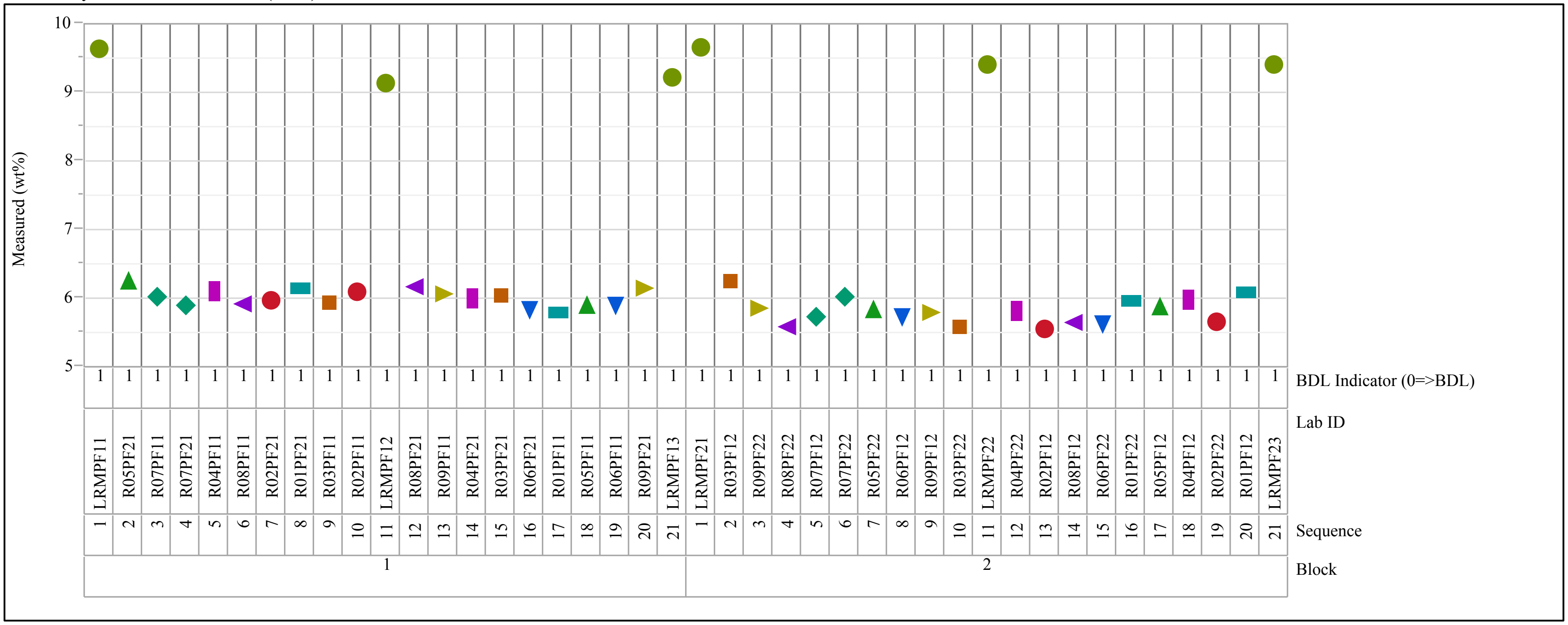


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

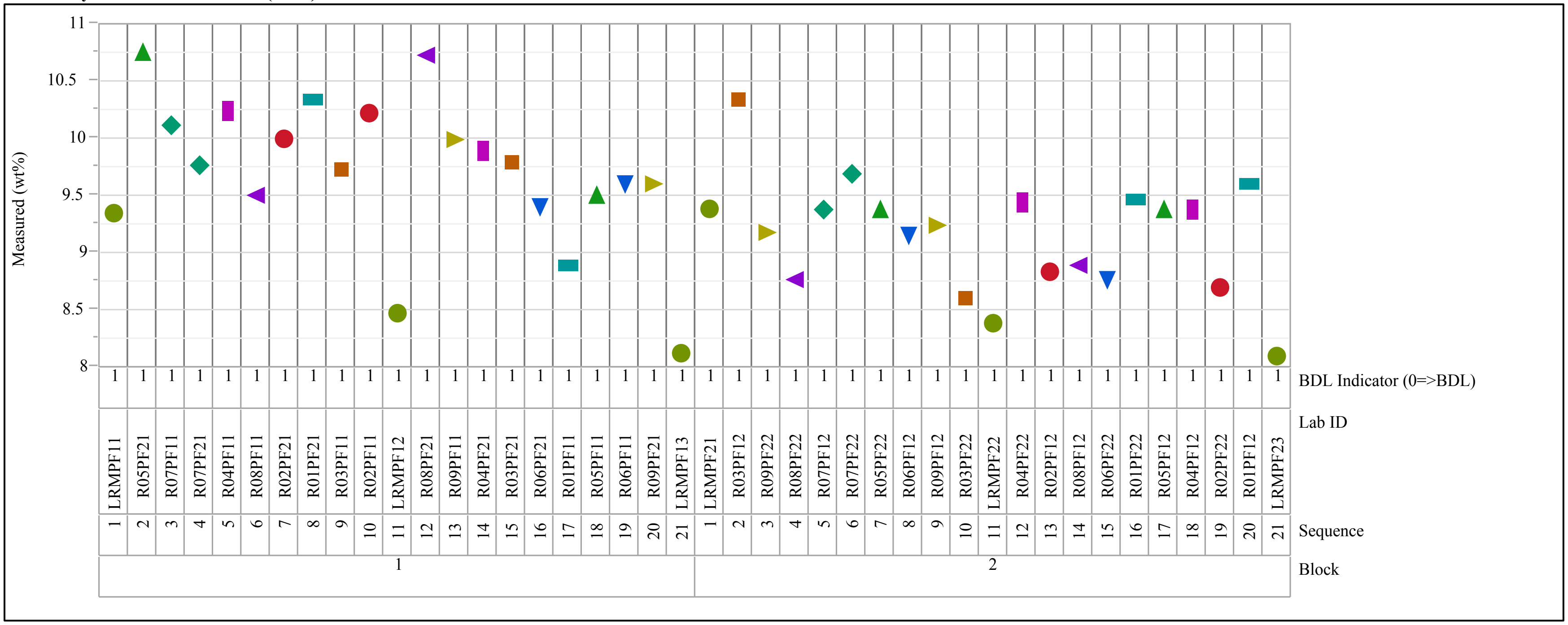


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

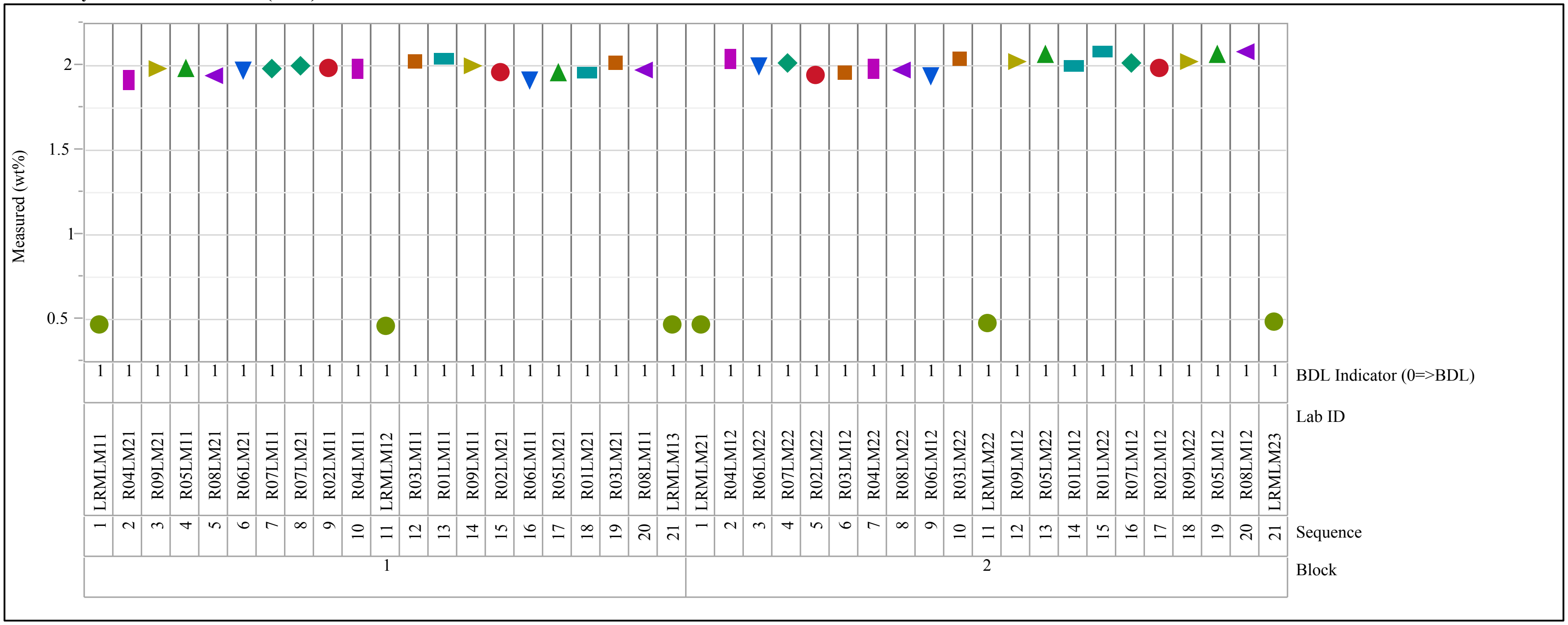


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

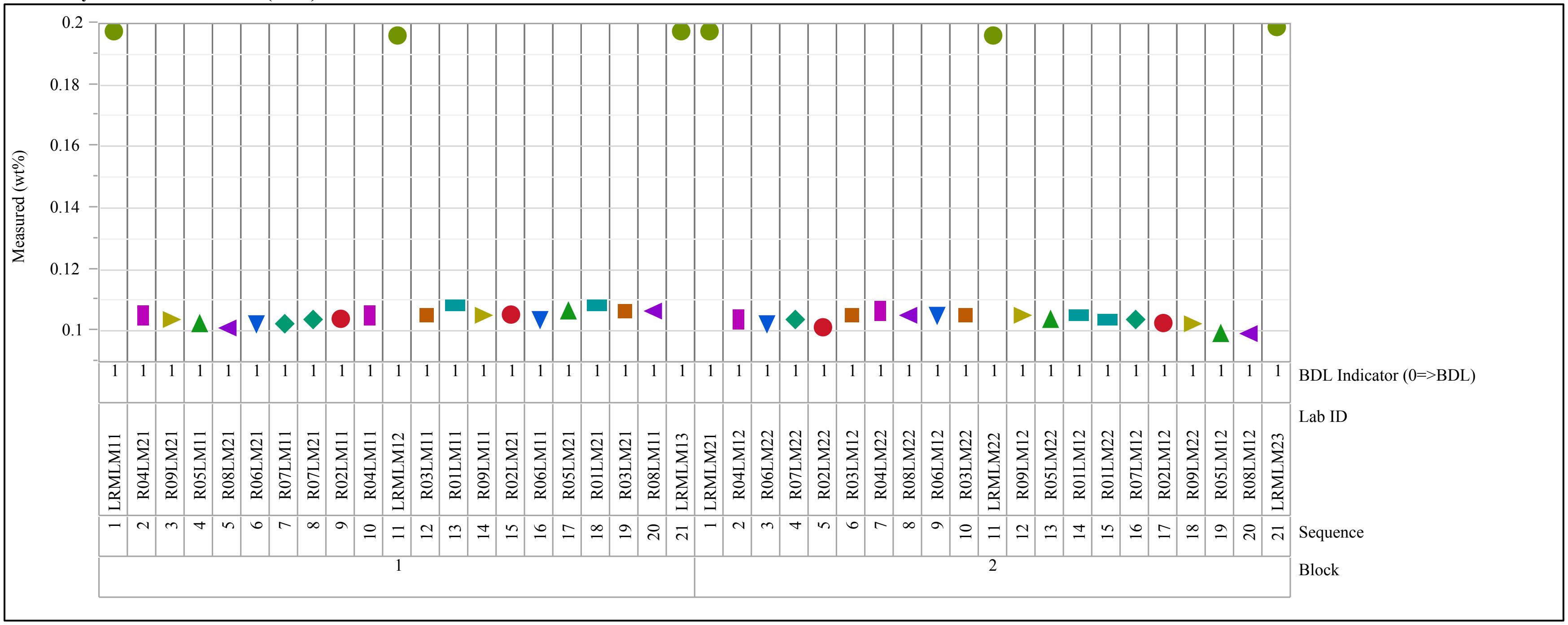


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

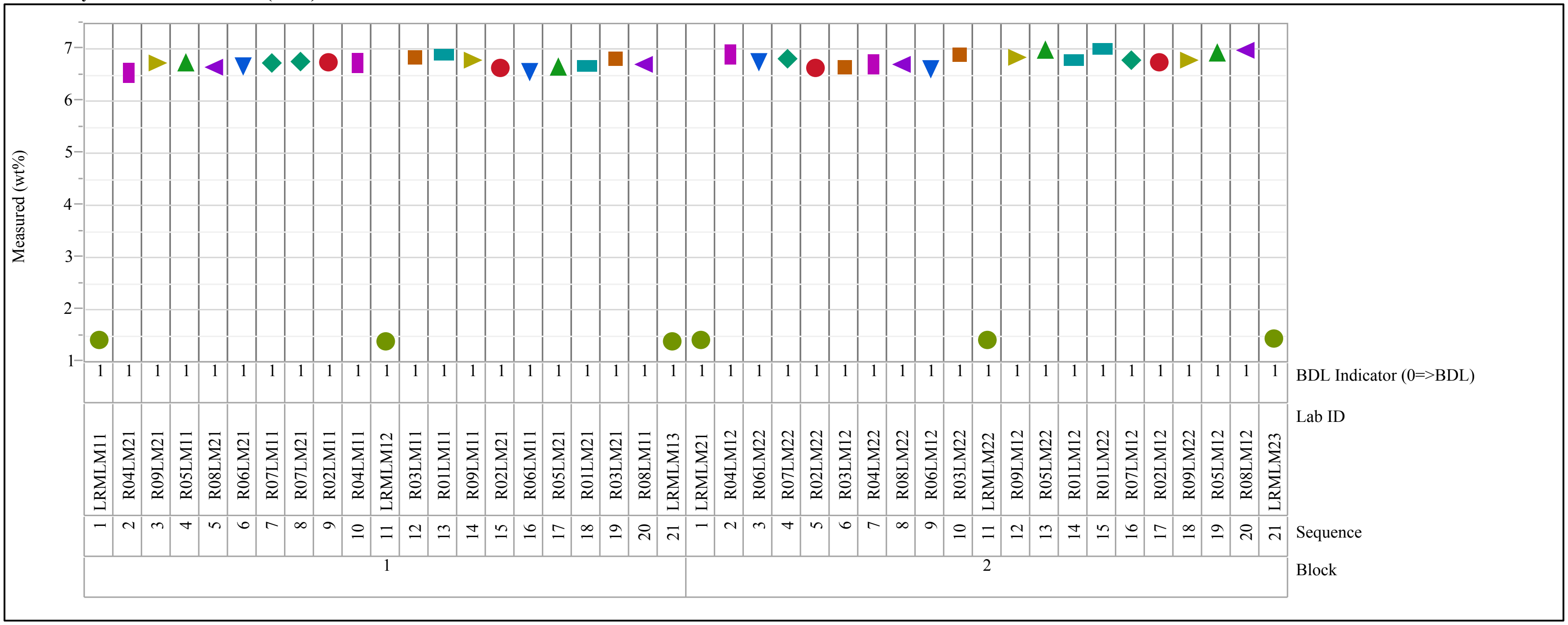


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

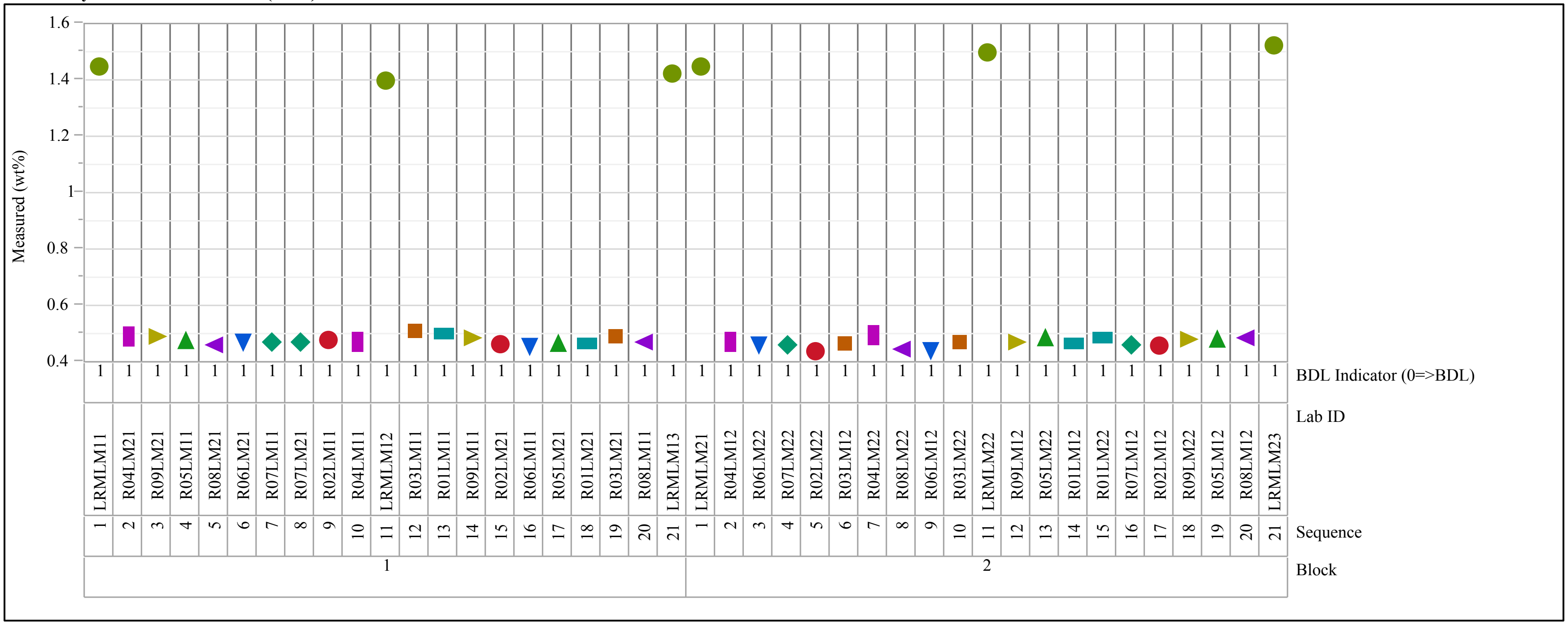


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

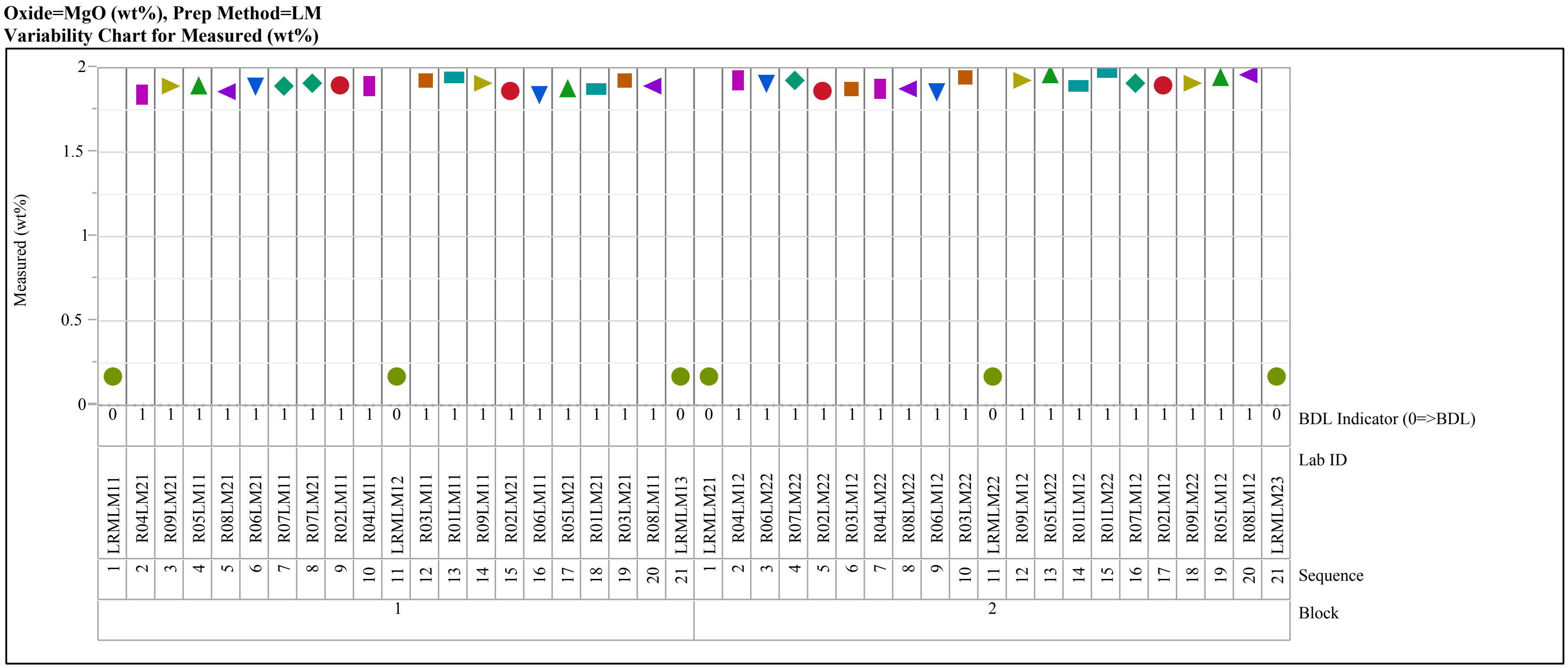


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

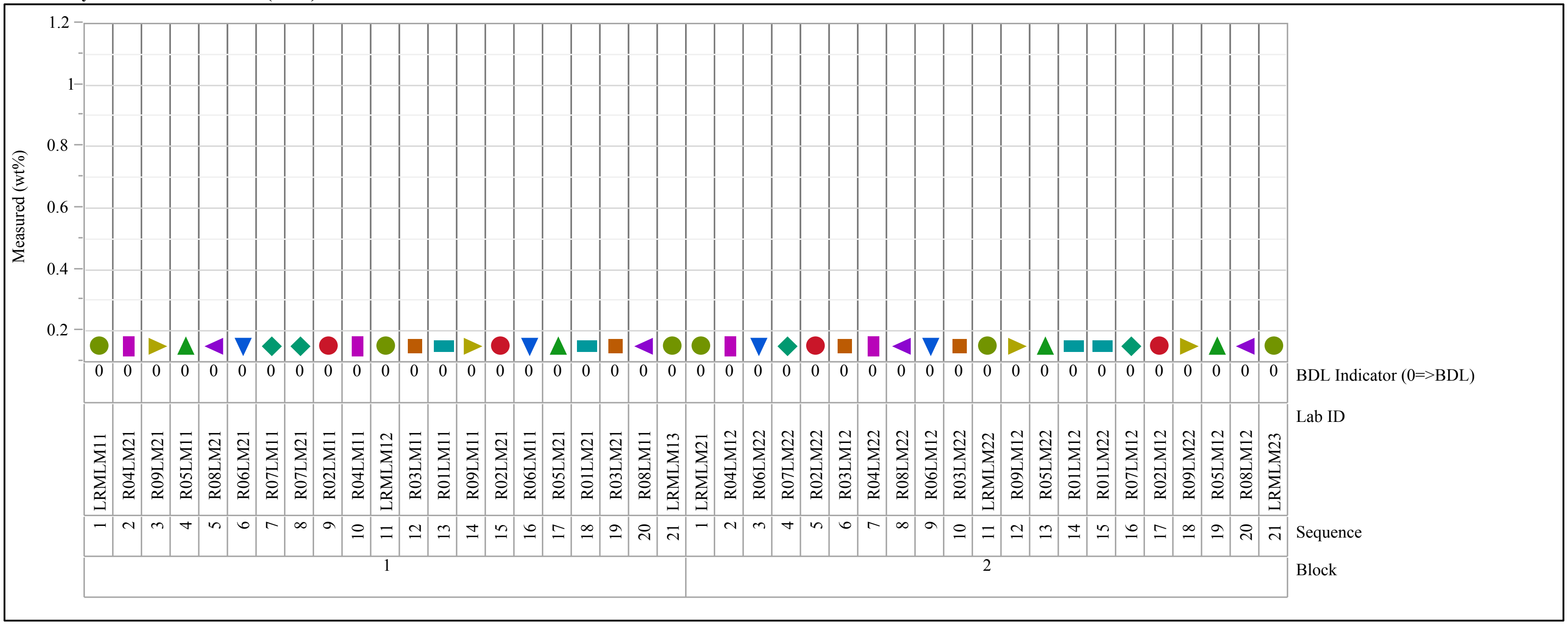


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

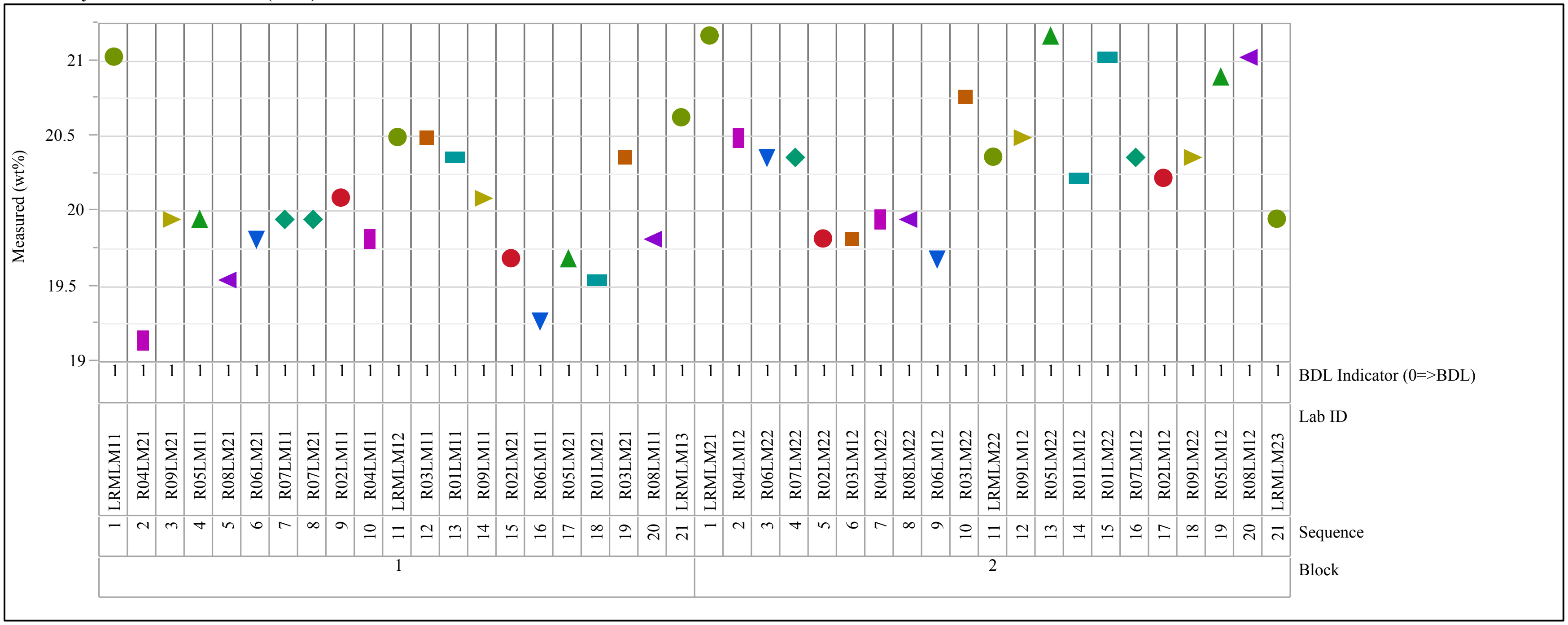


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

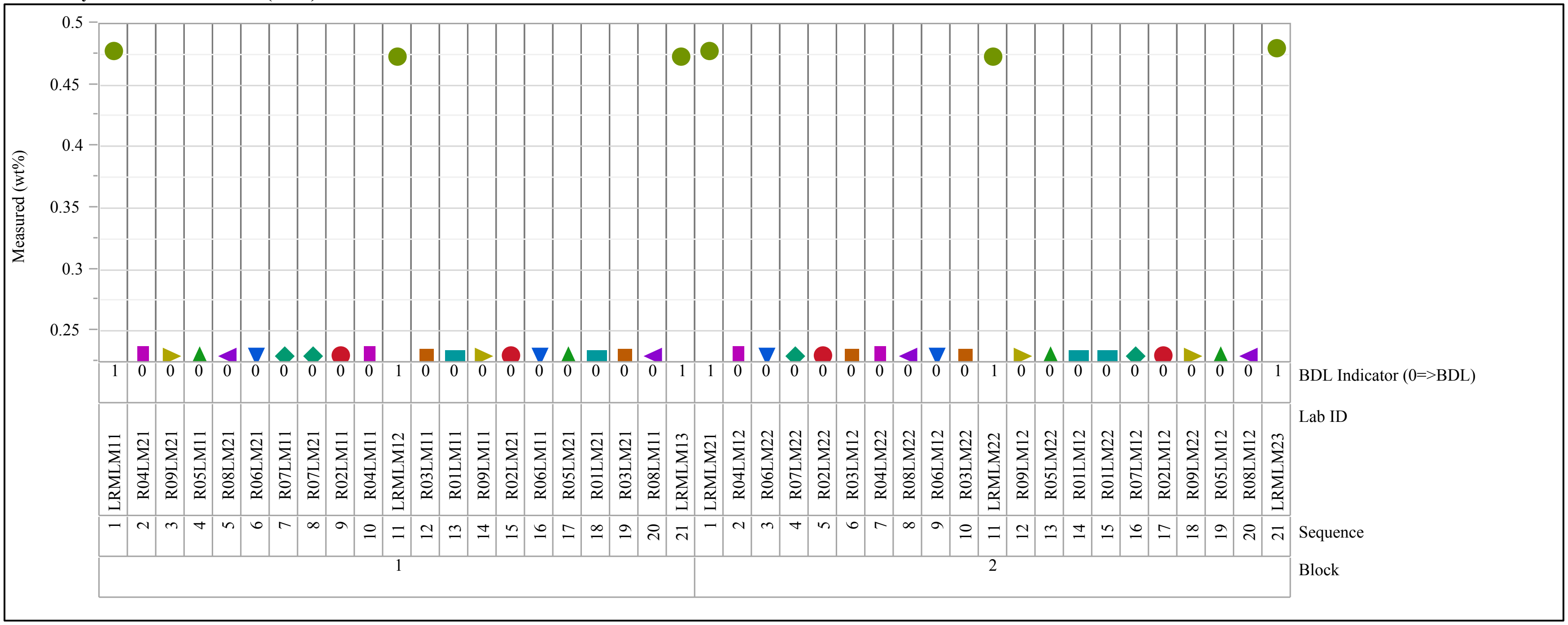


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

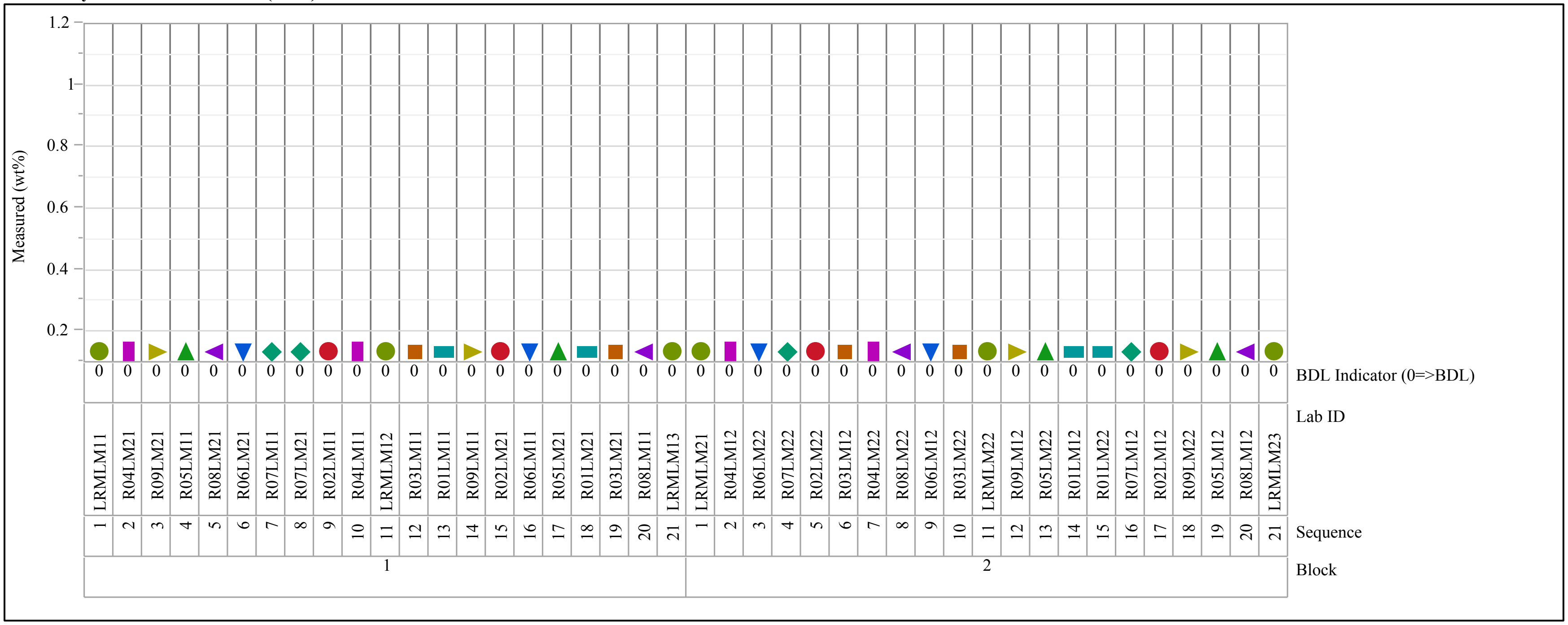


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

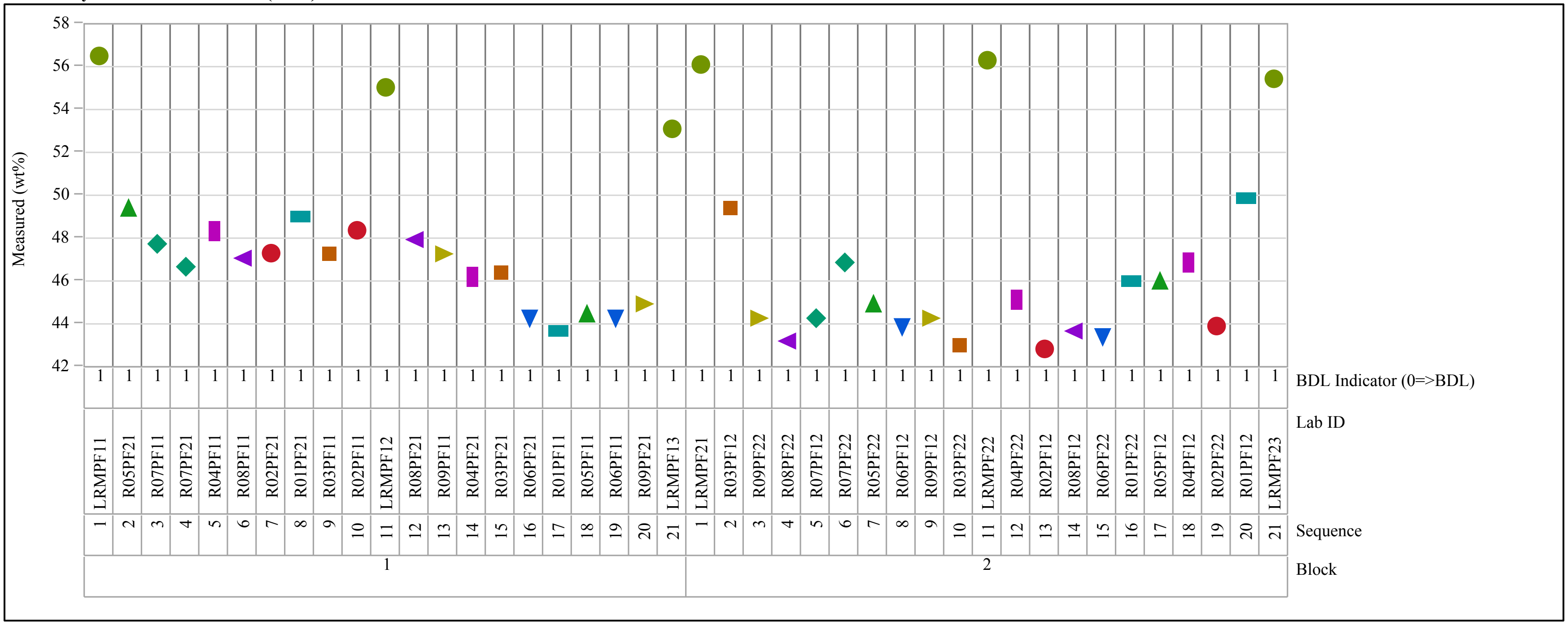


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

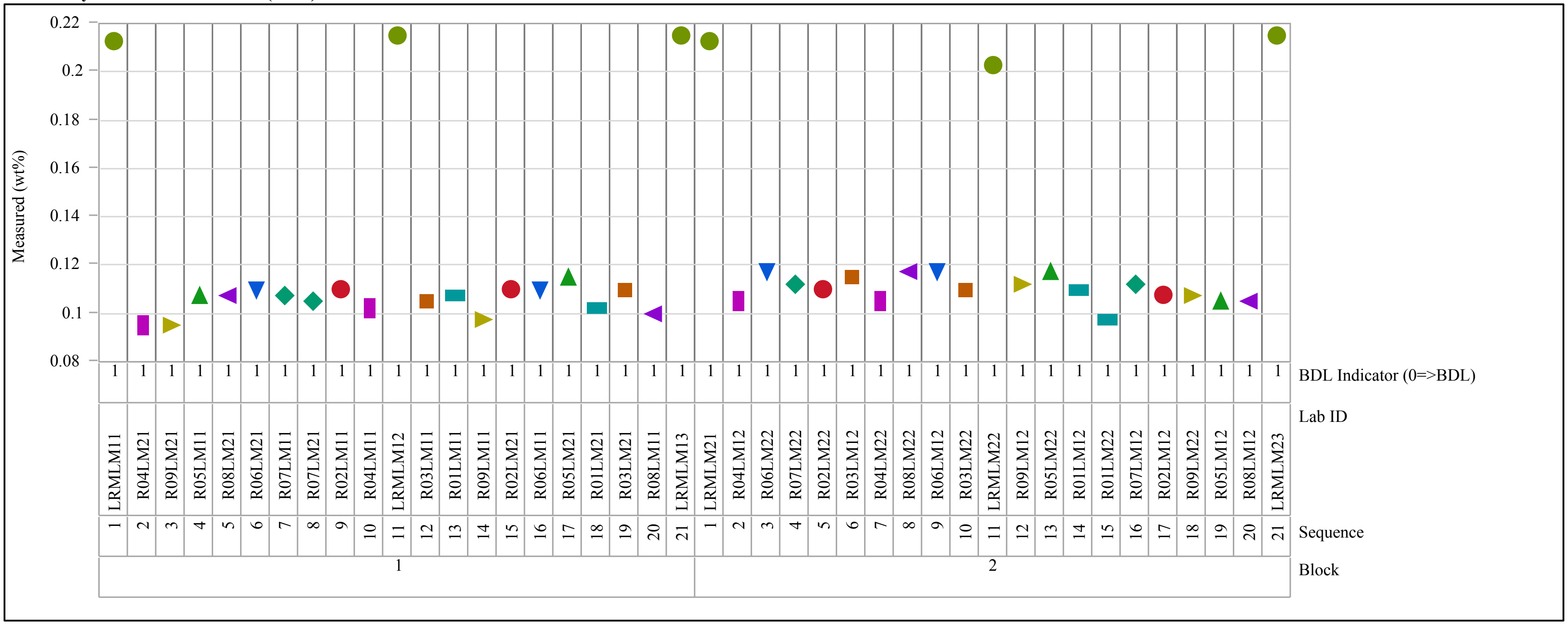


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

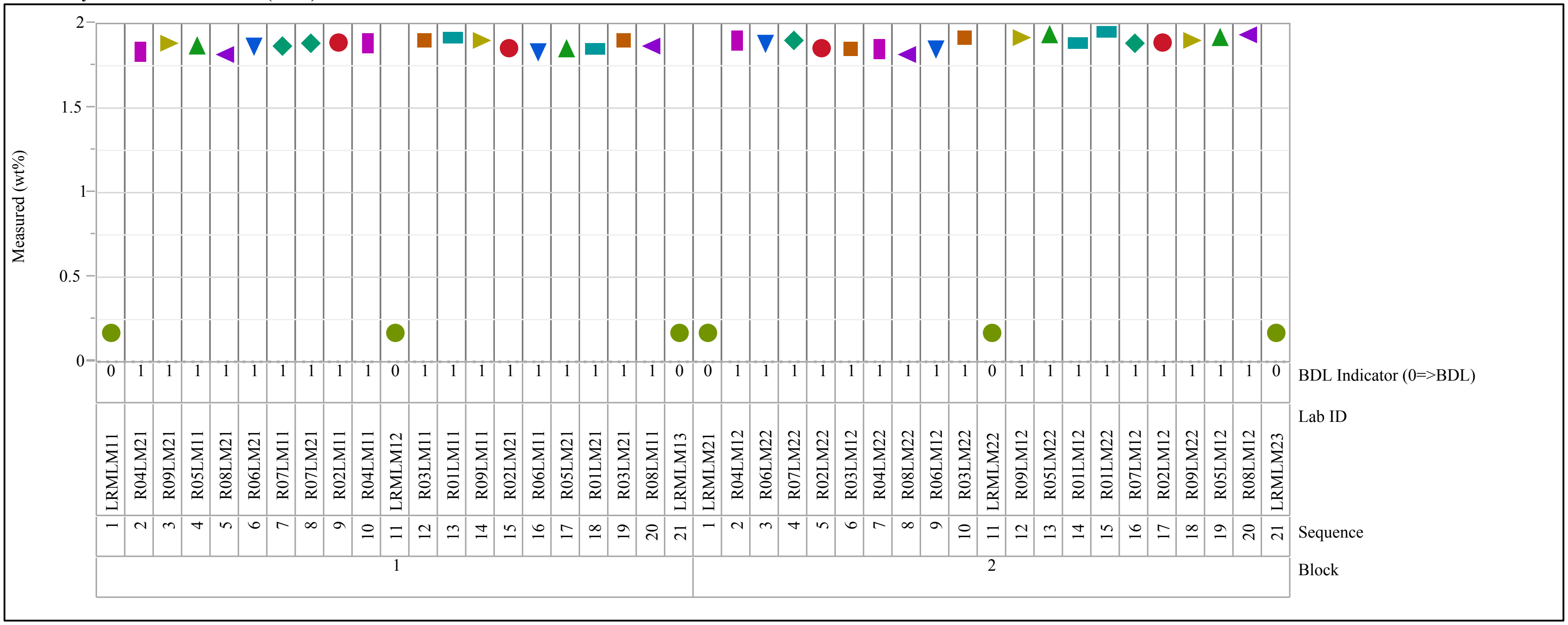


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

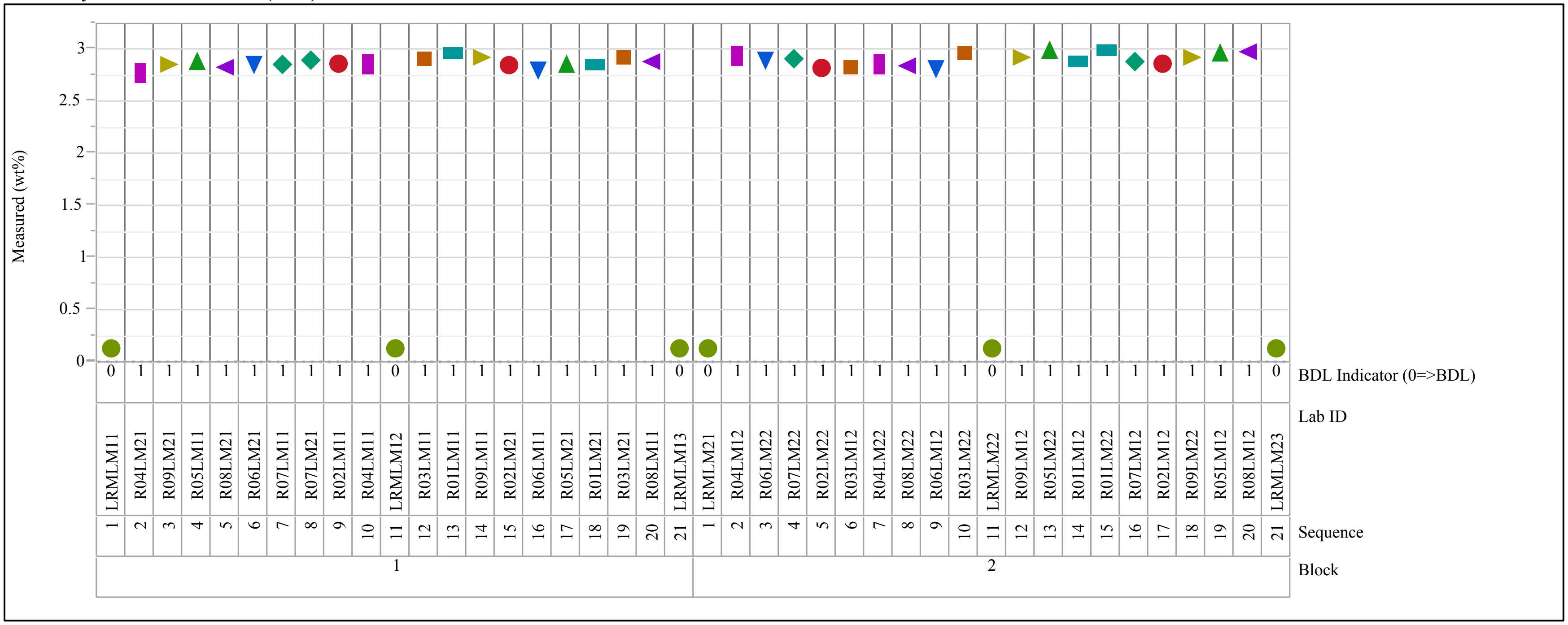


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

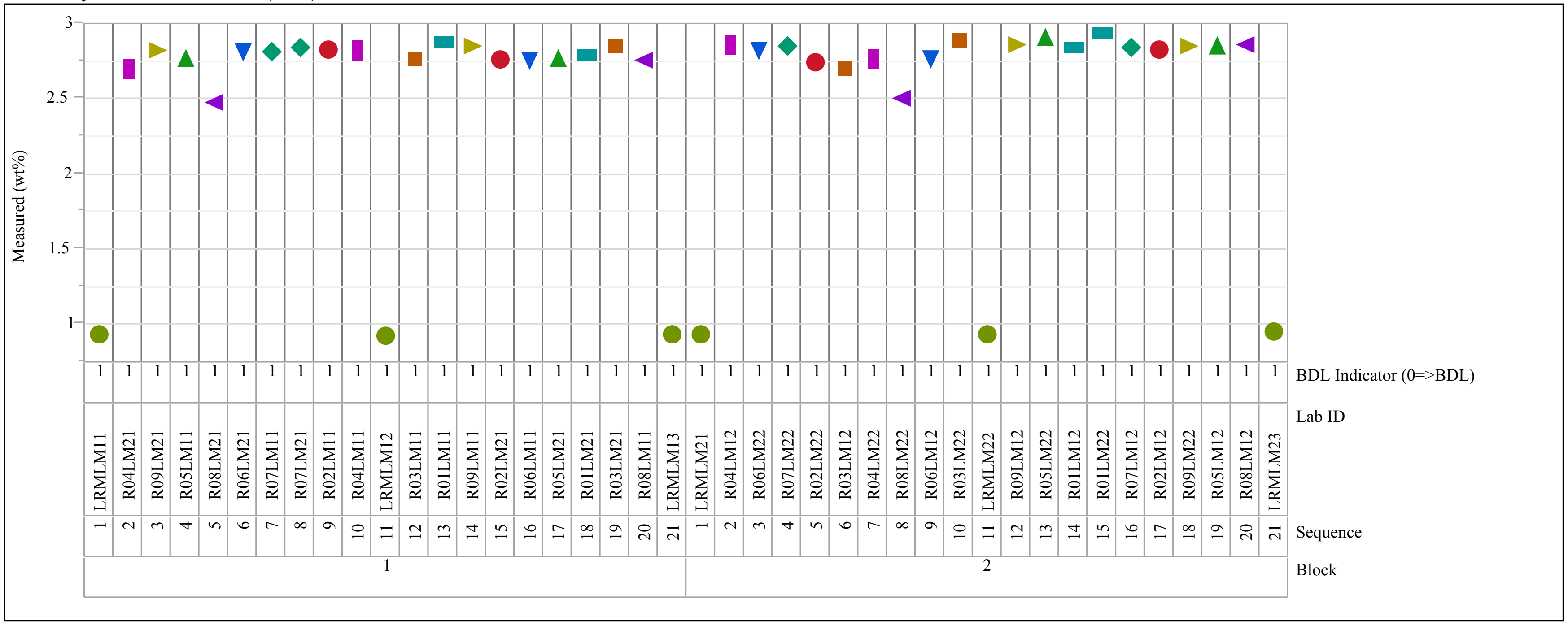


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations

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

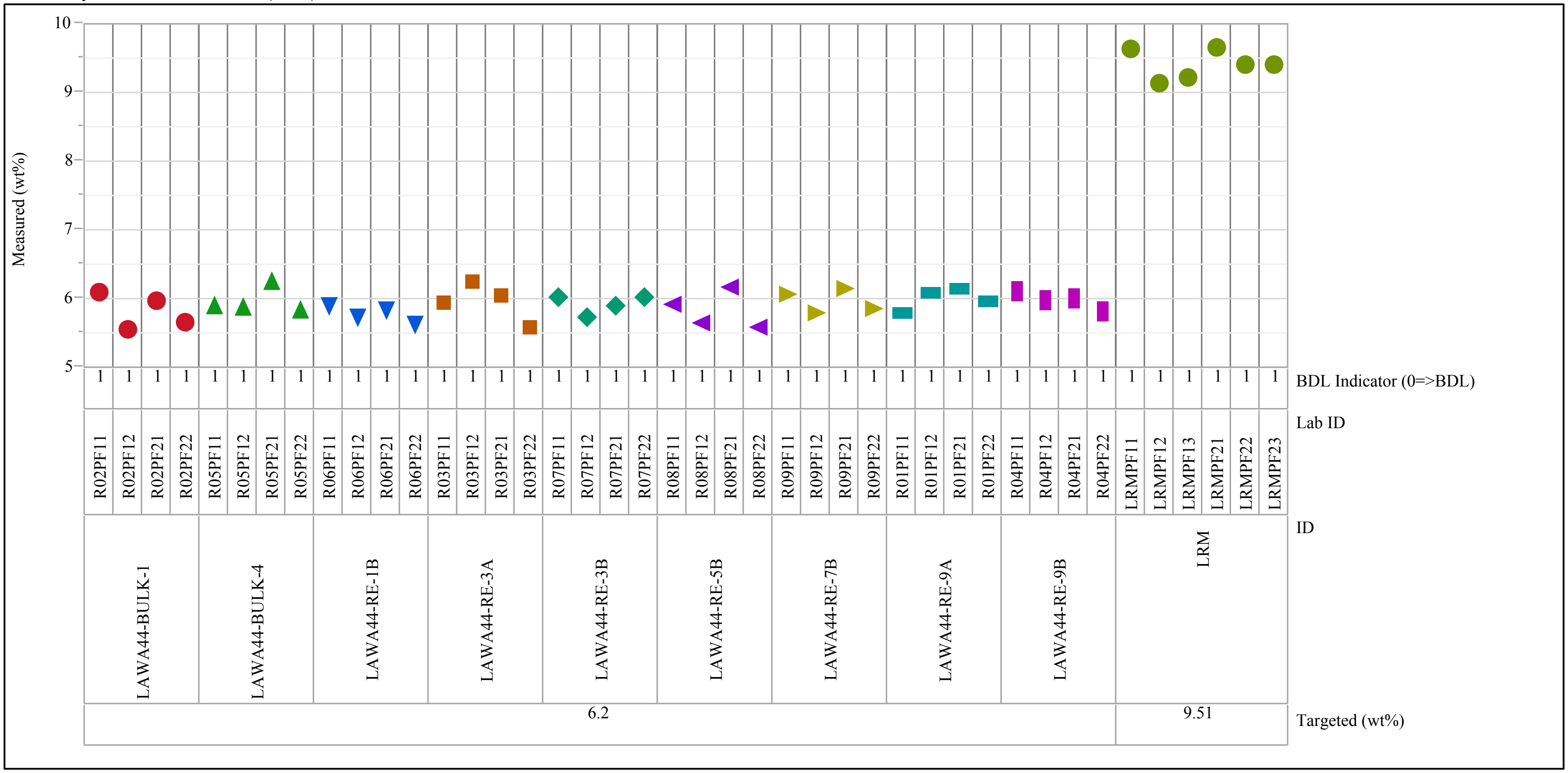


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

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

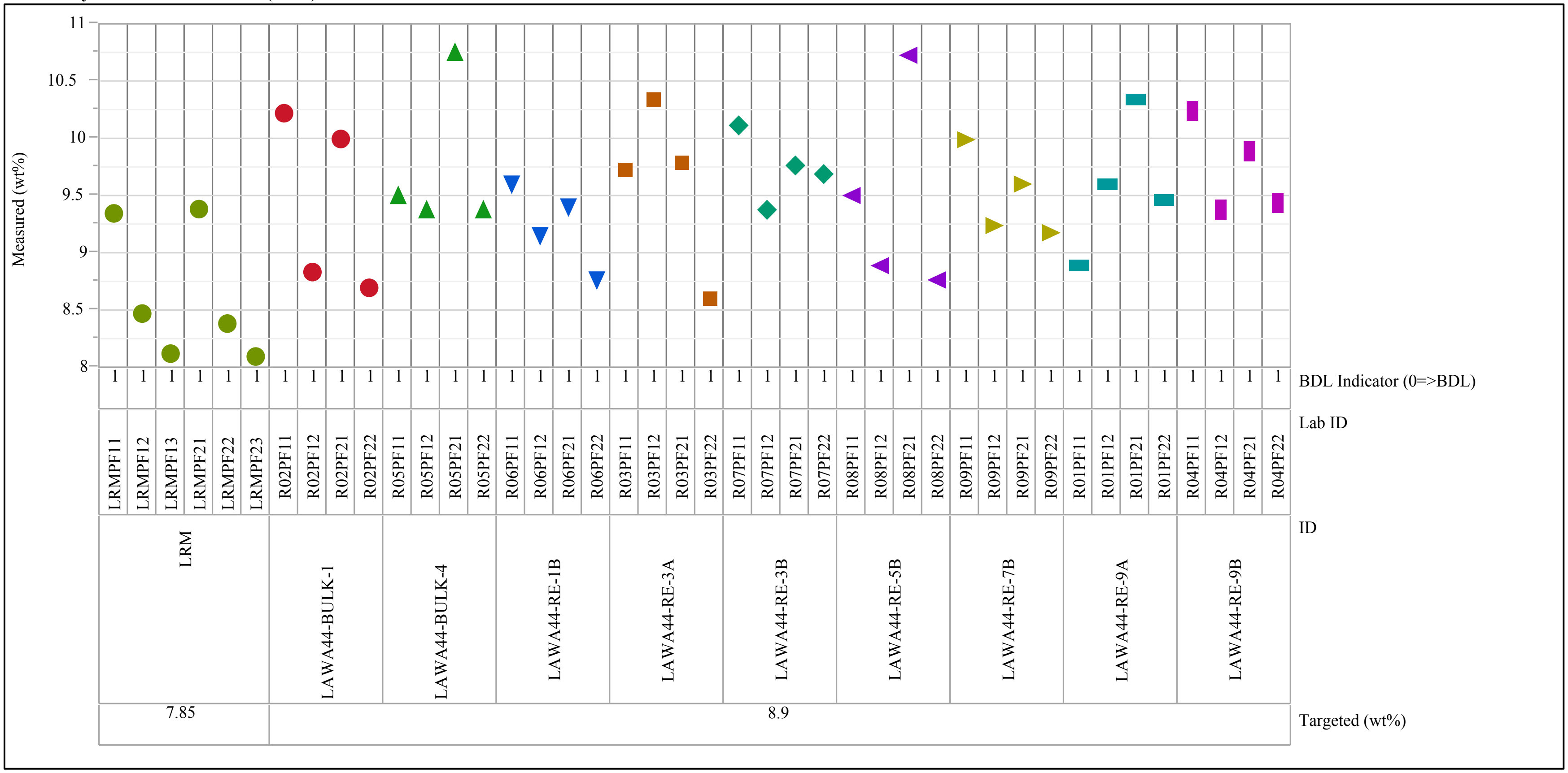


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

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

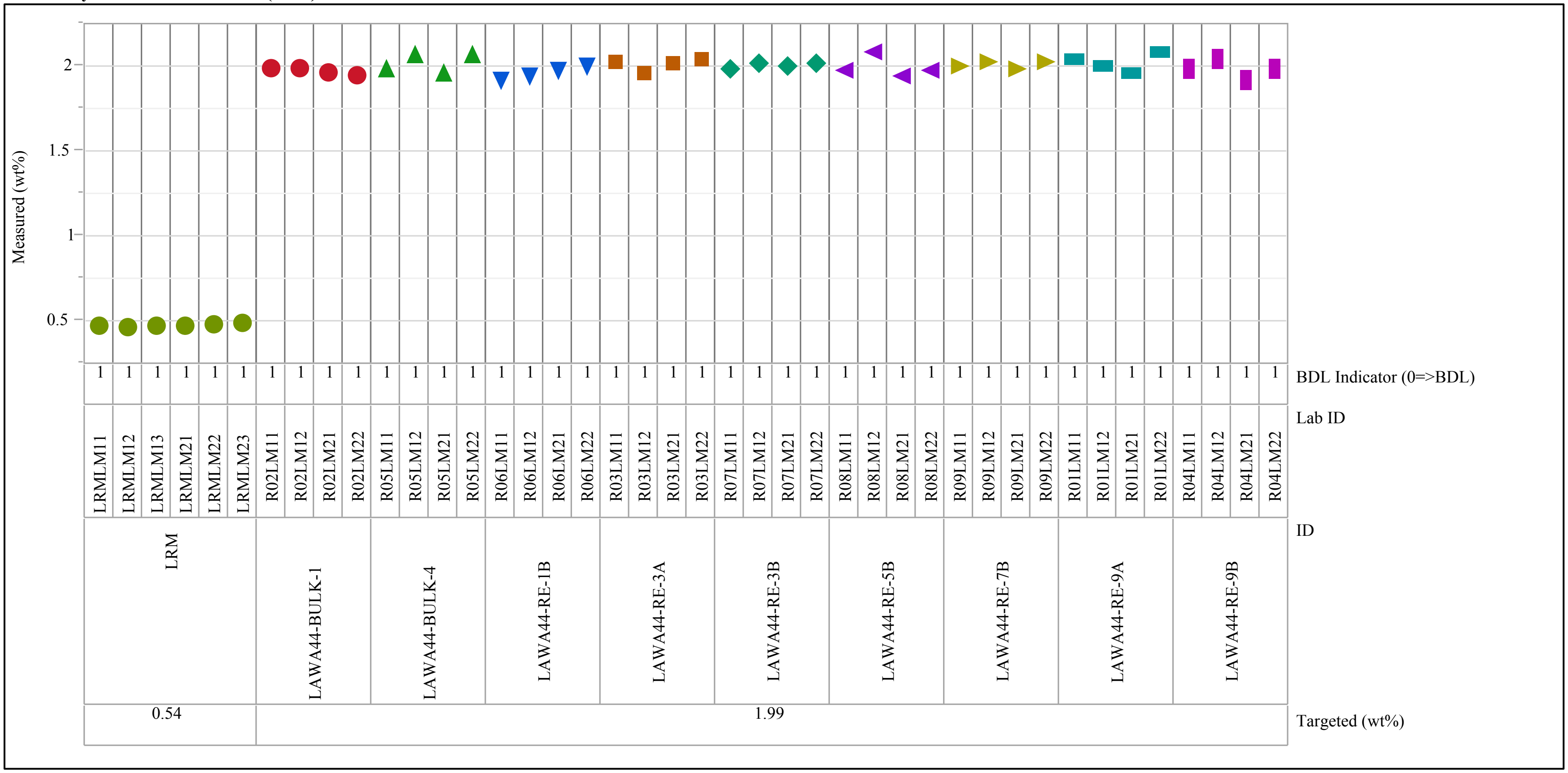


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

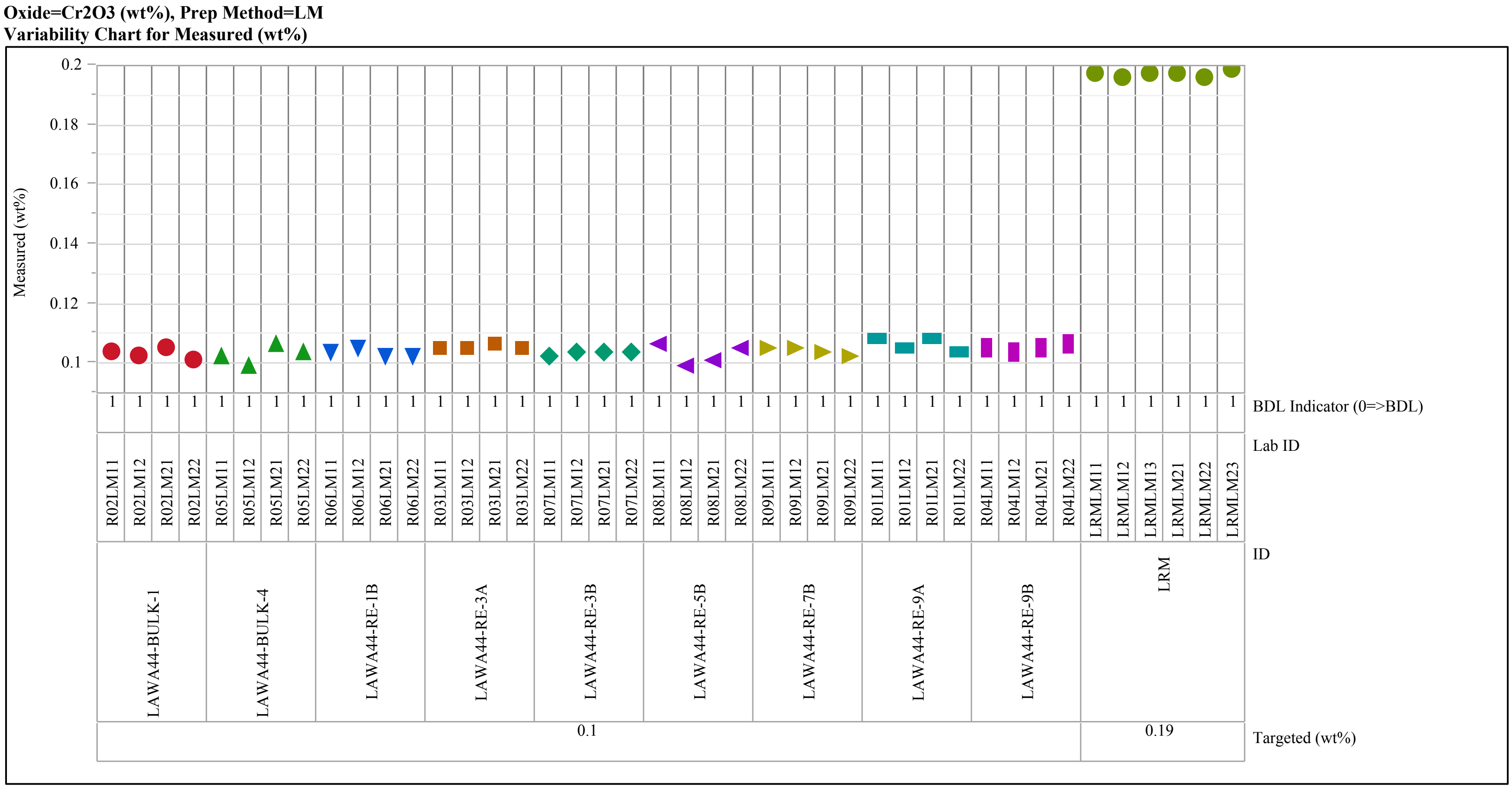


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

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

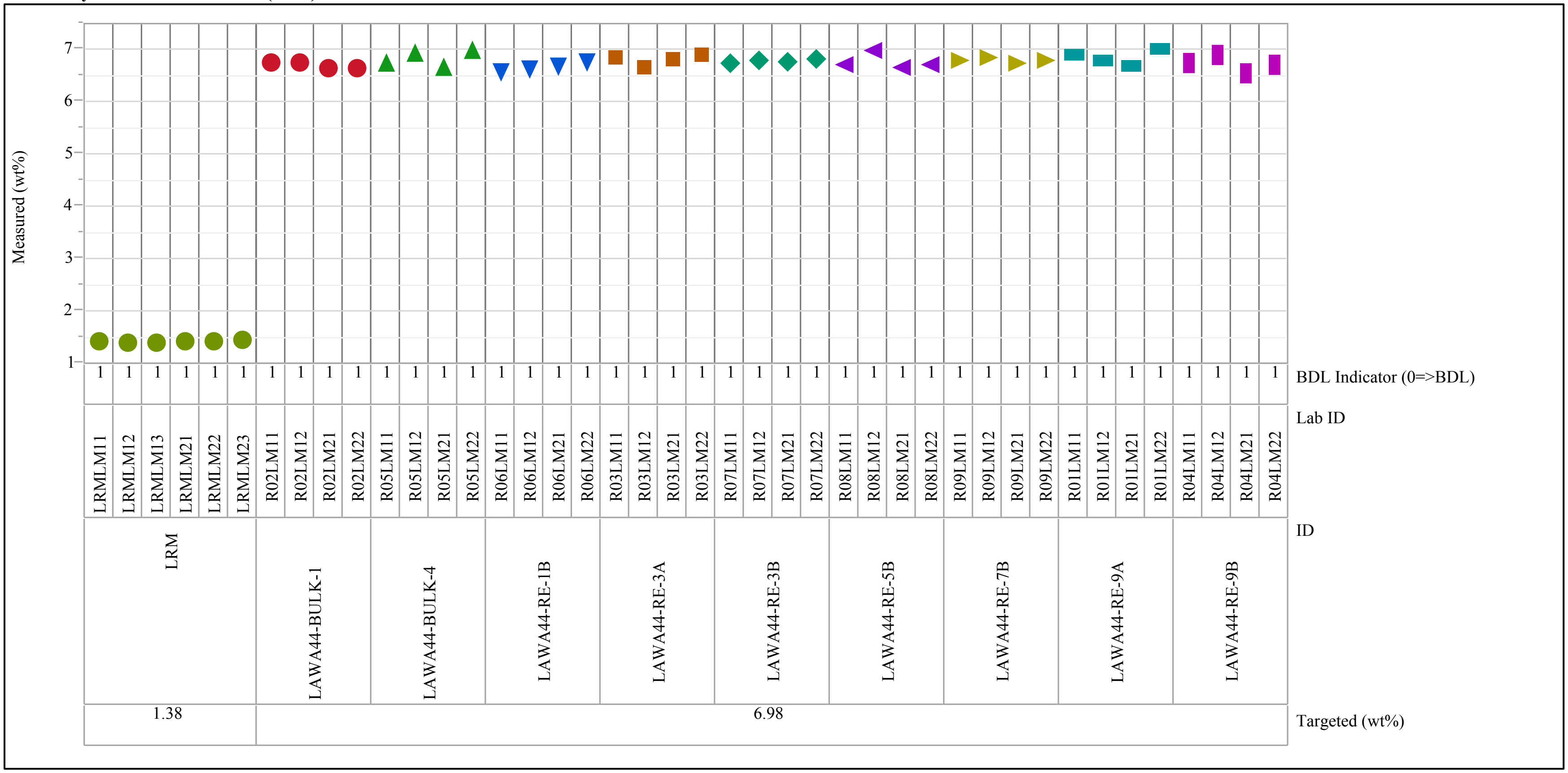


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

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

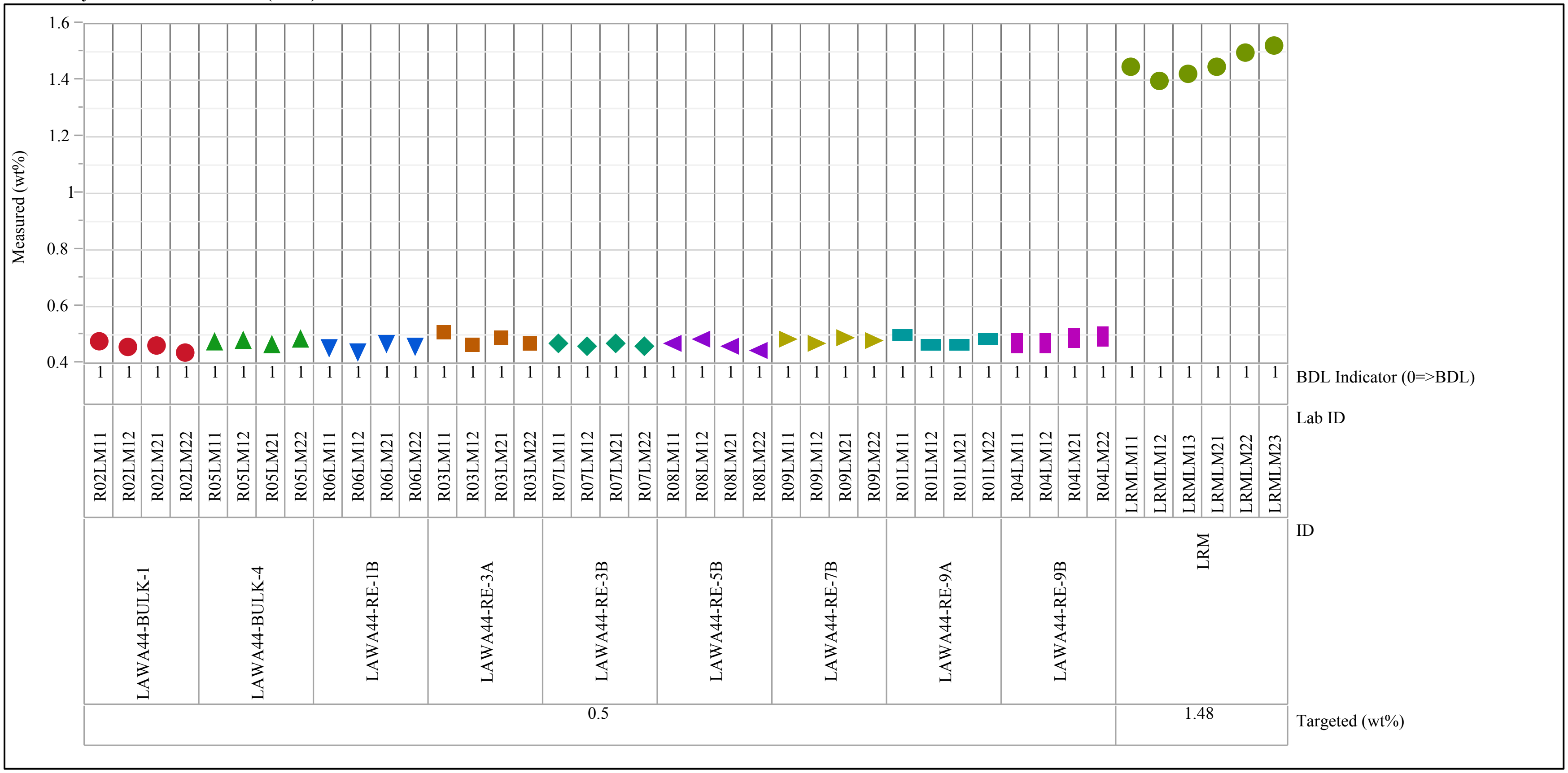


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

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

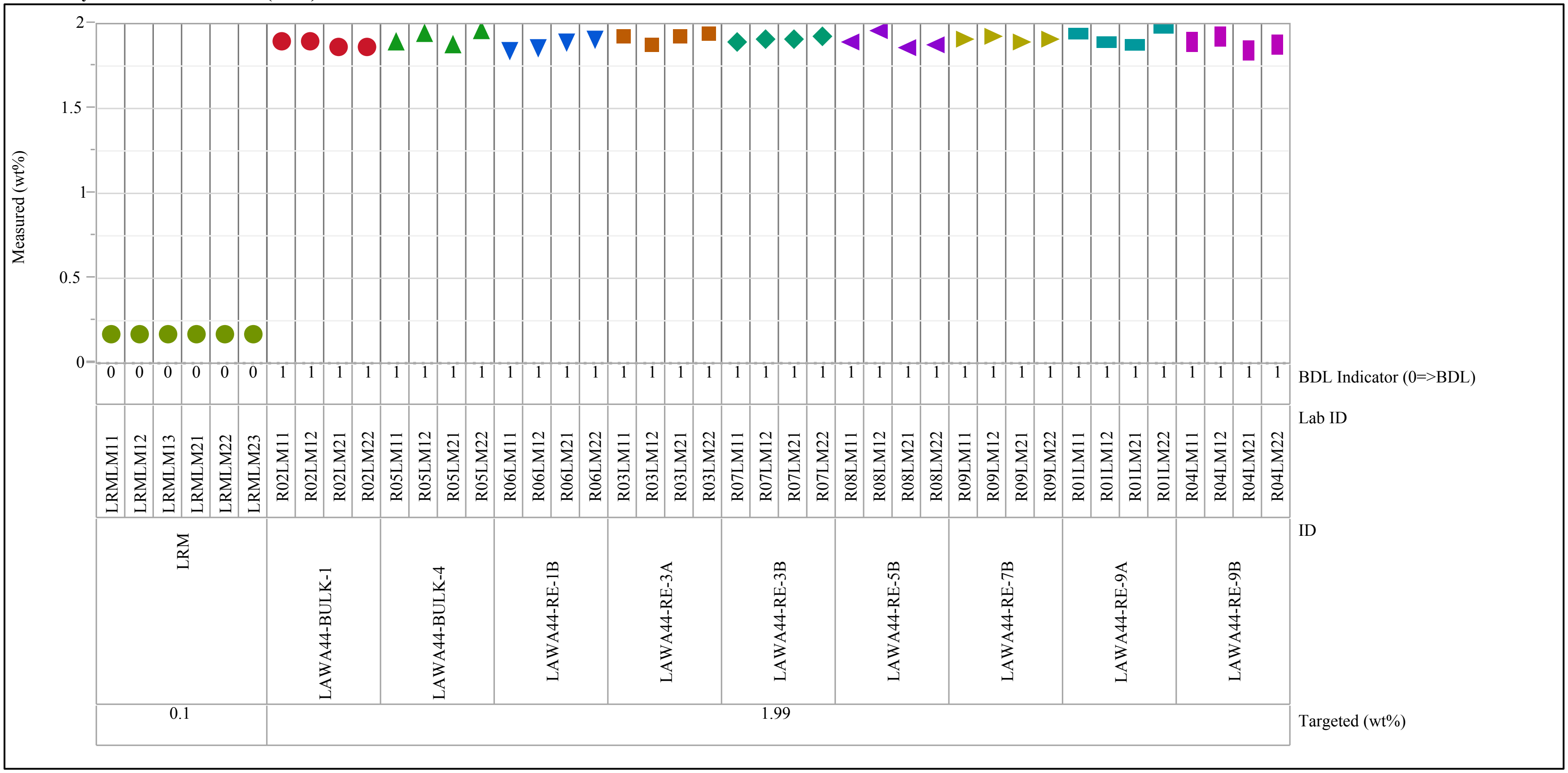


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

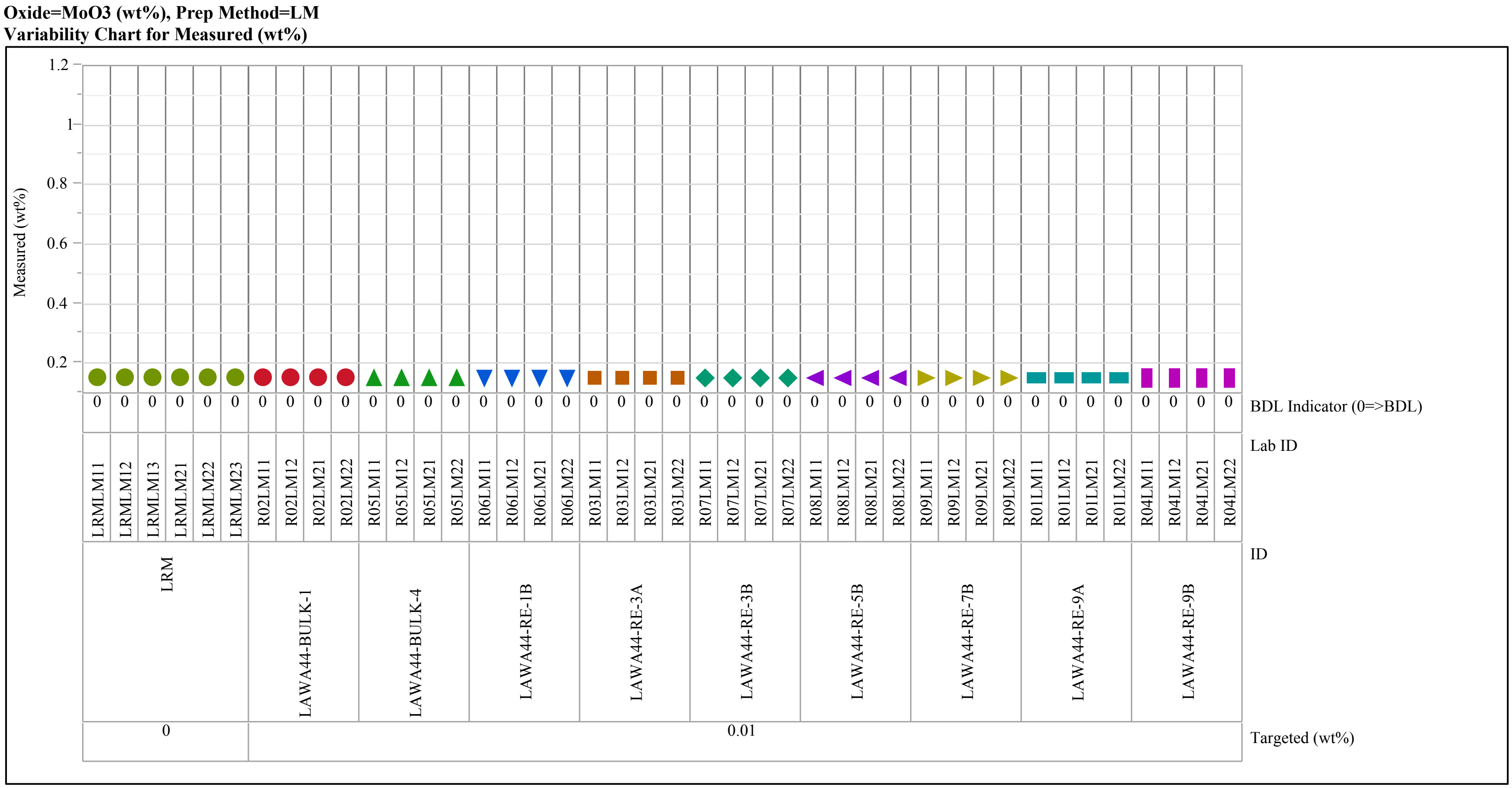


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

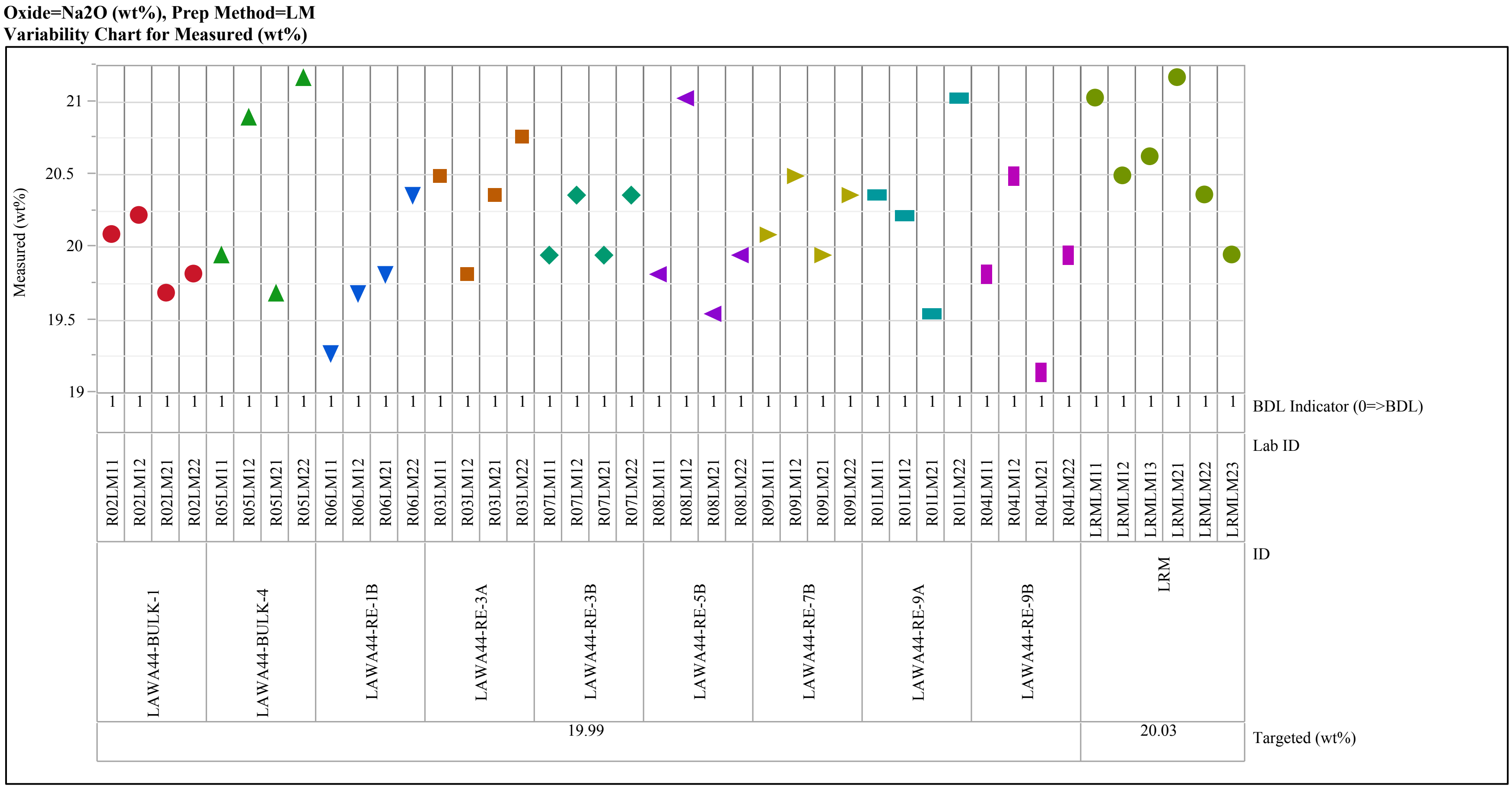


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

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

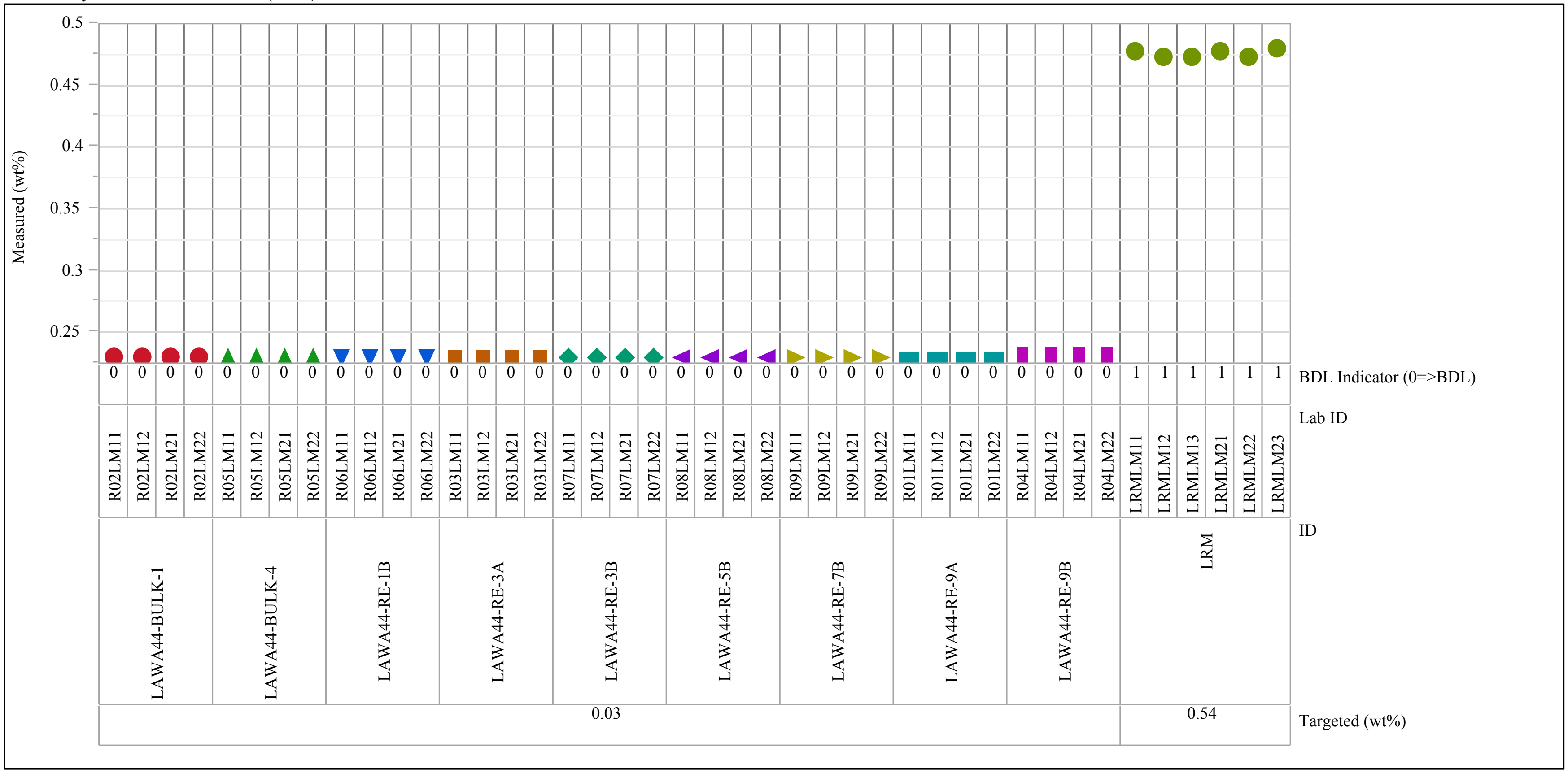


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

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

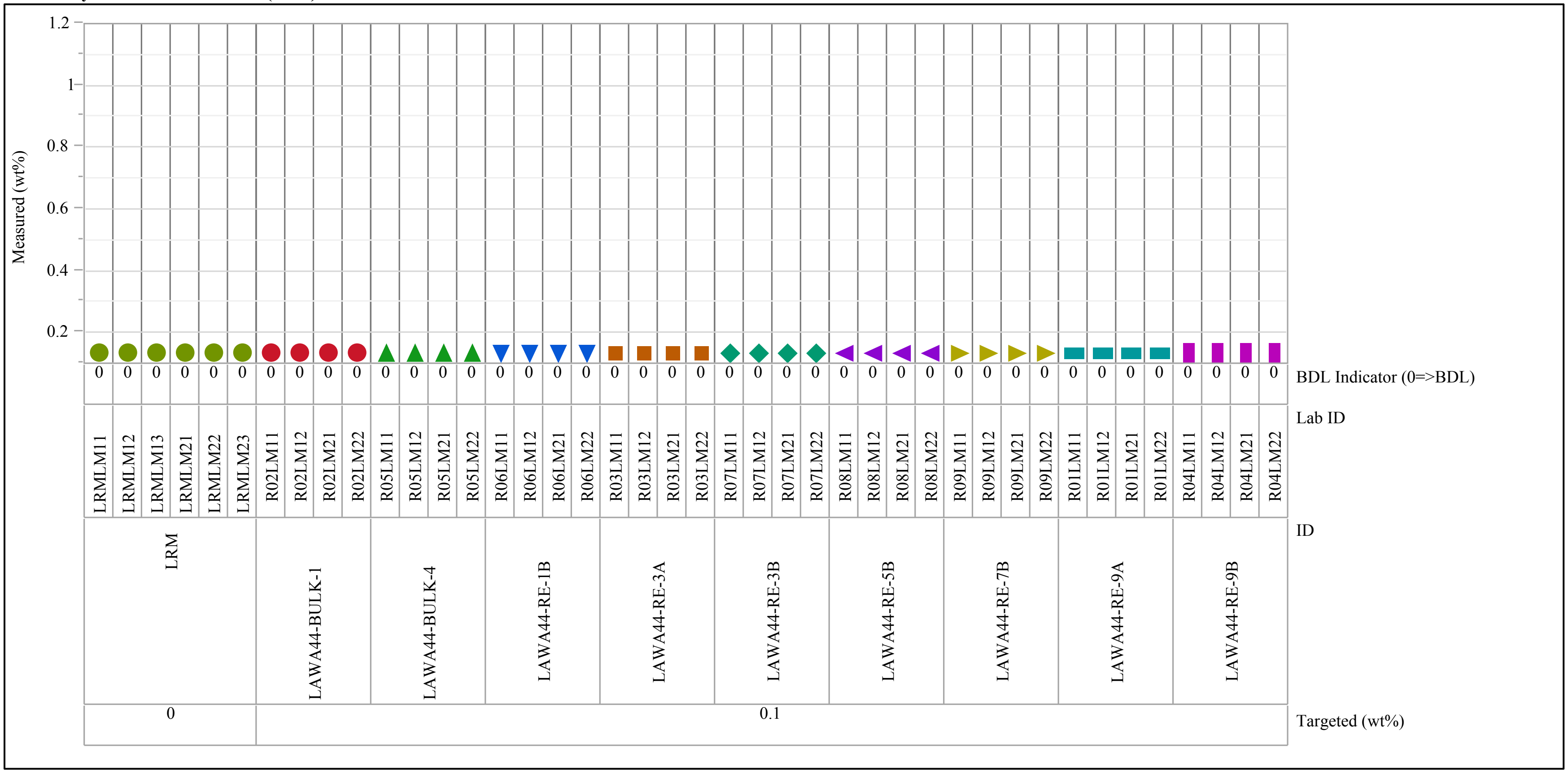


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

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

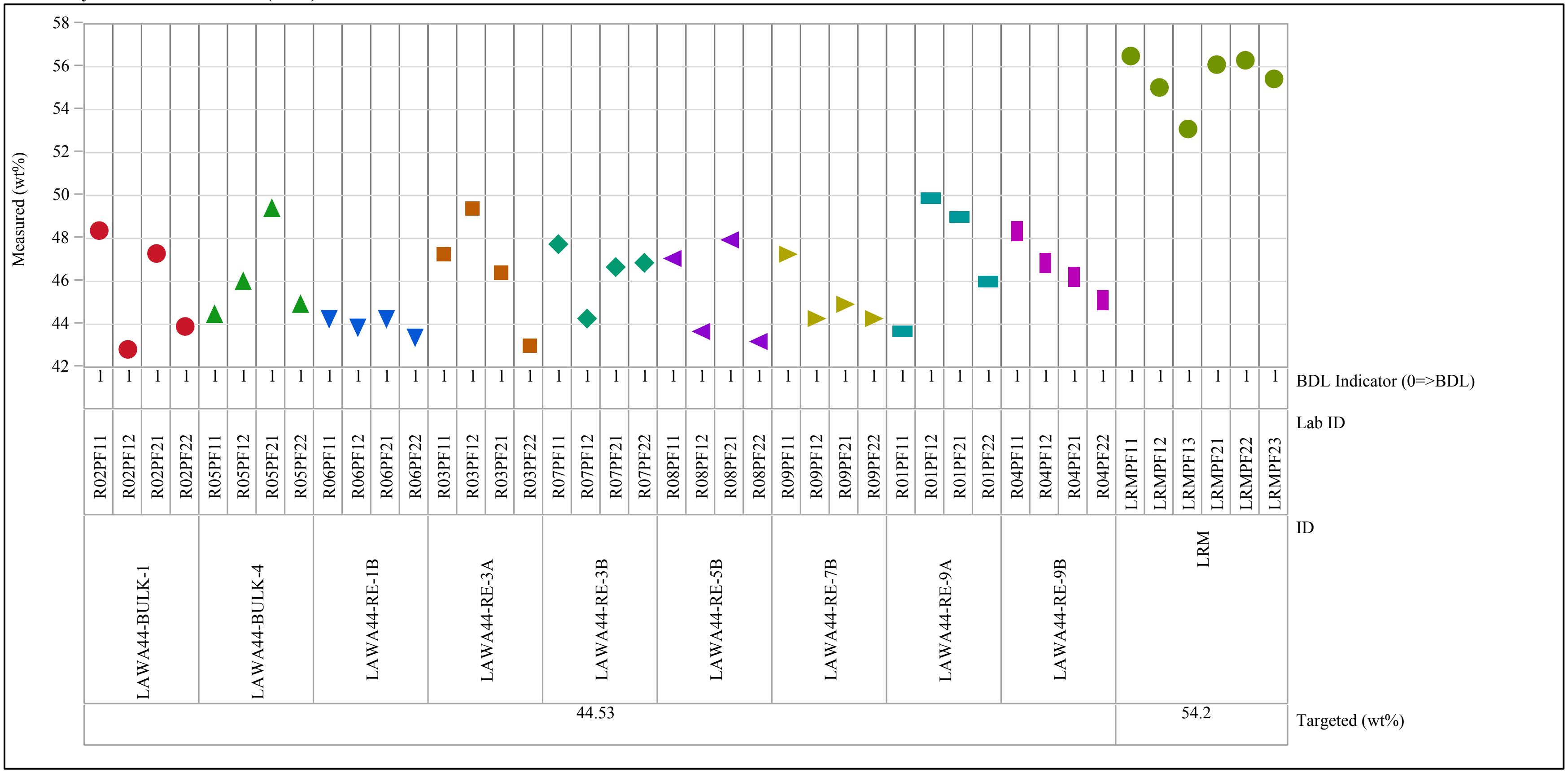


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

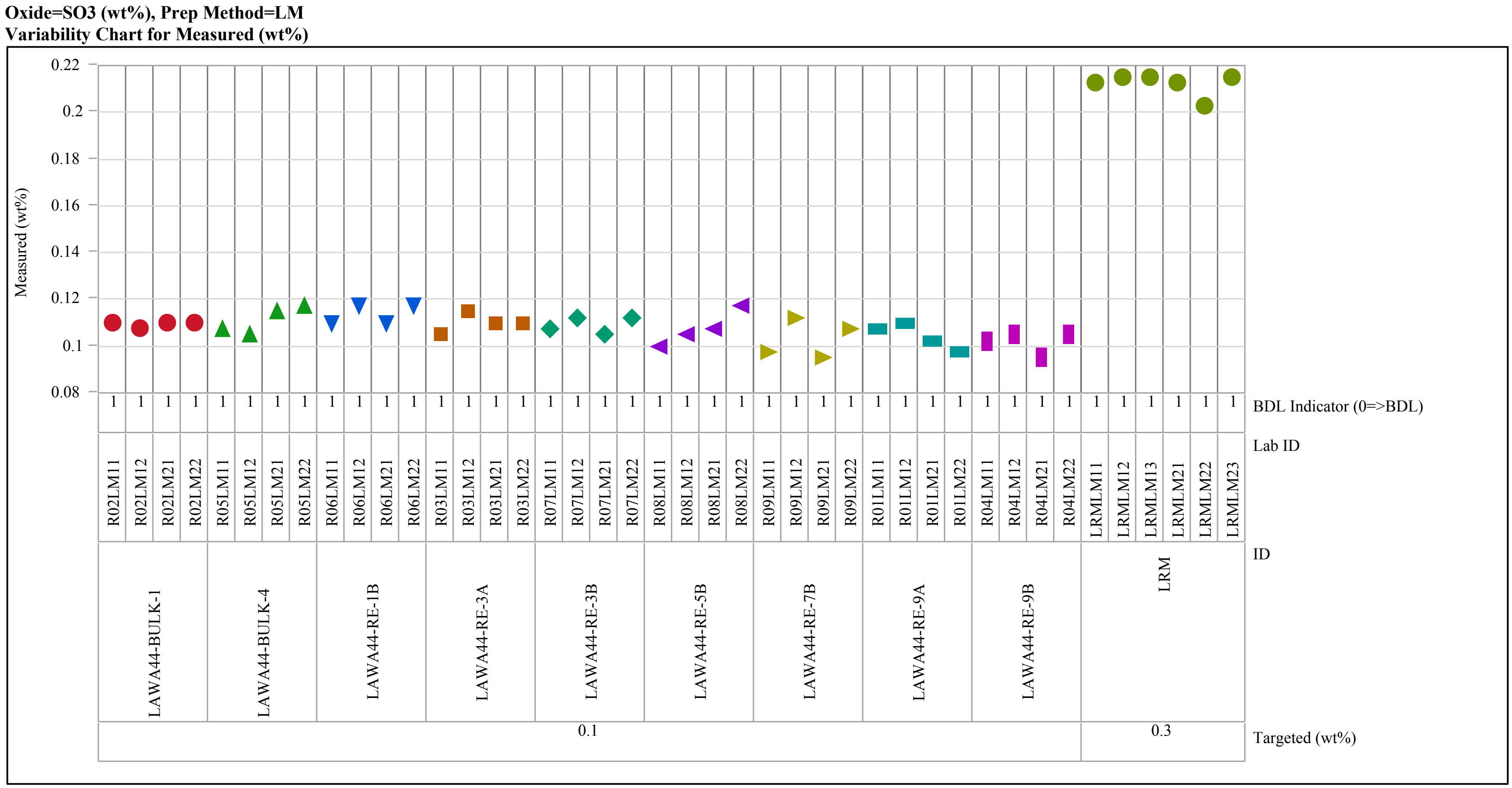


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

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

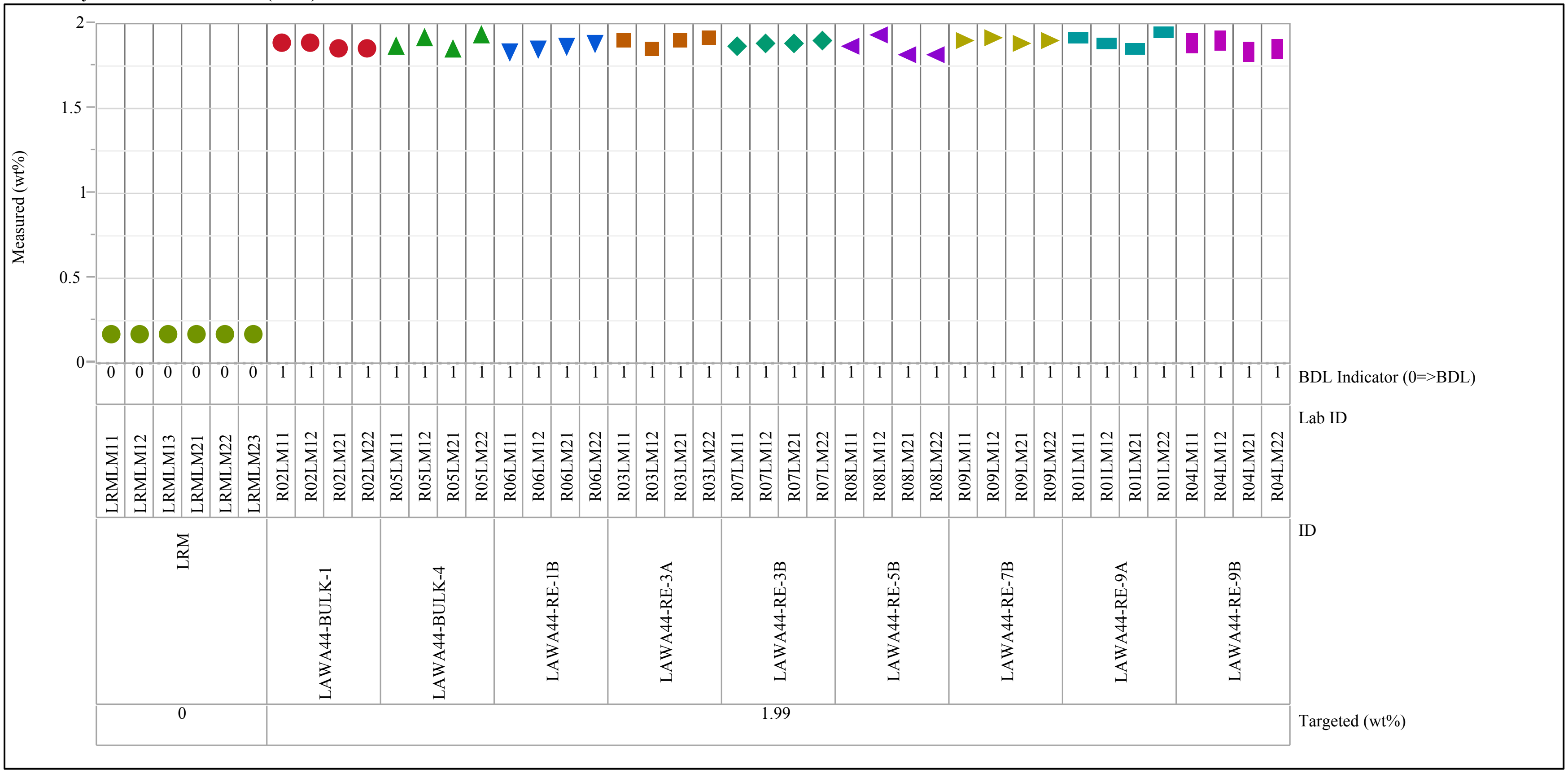


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

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

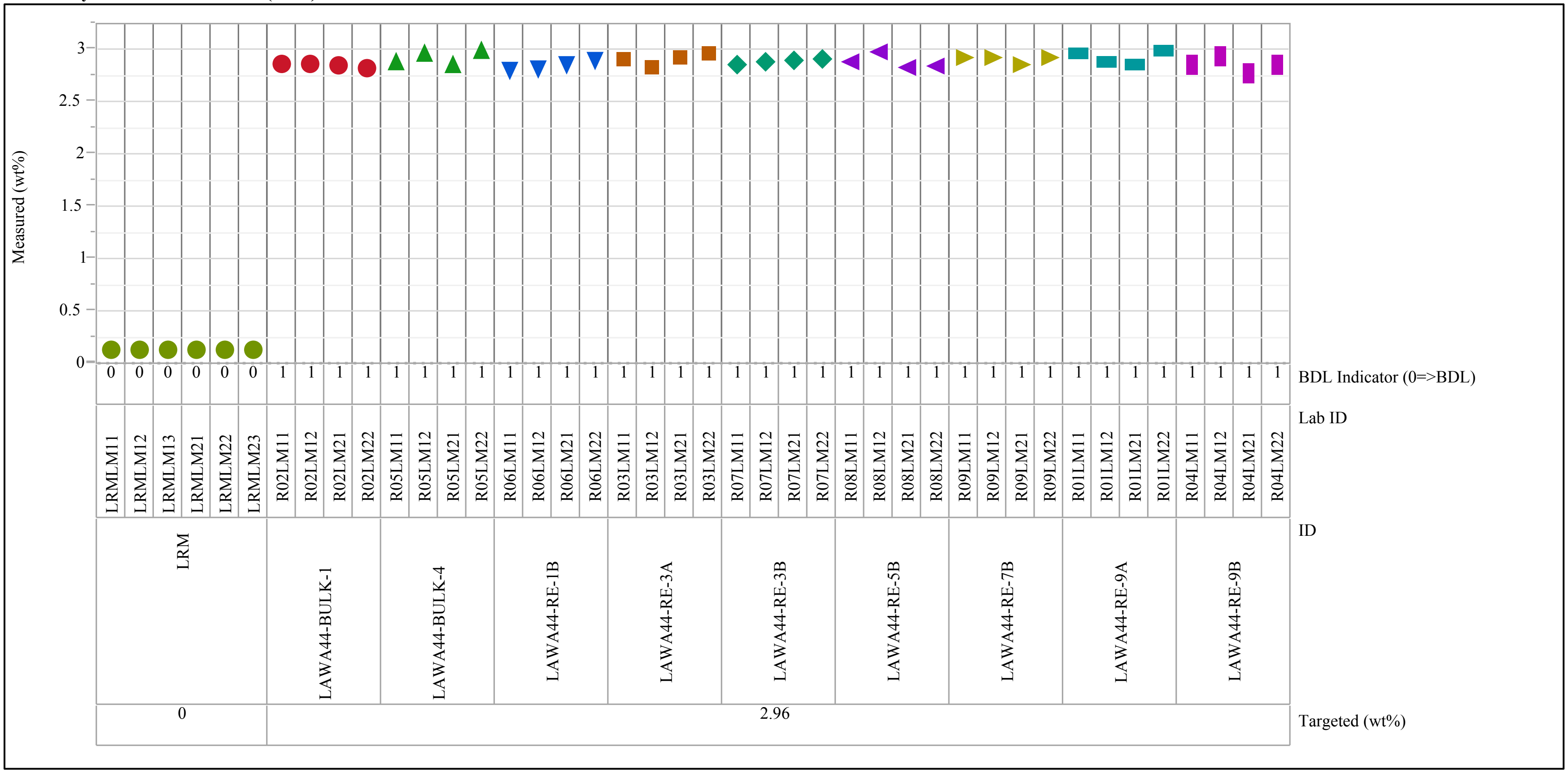


Exhibit A-2. Plots of Oxide Measurements by Glass Identifier Grouped by Targeted Concentrations (continued)

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

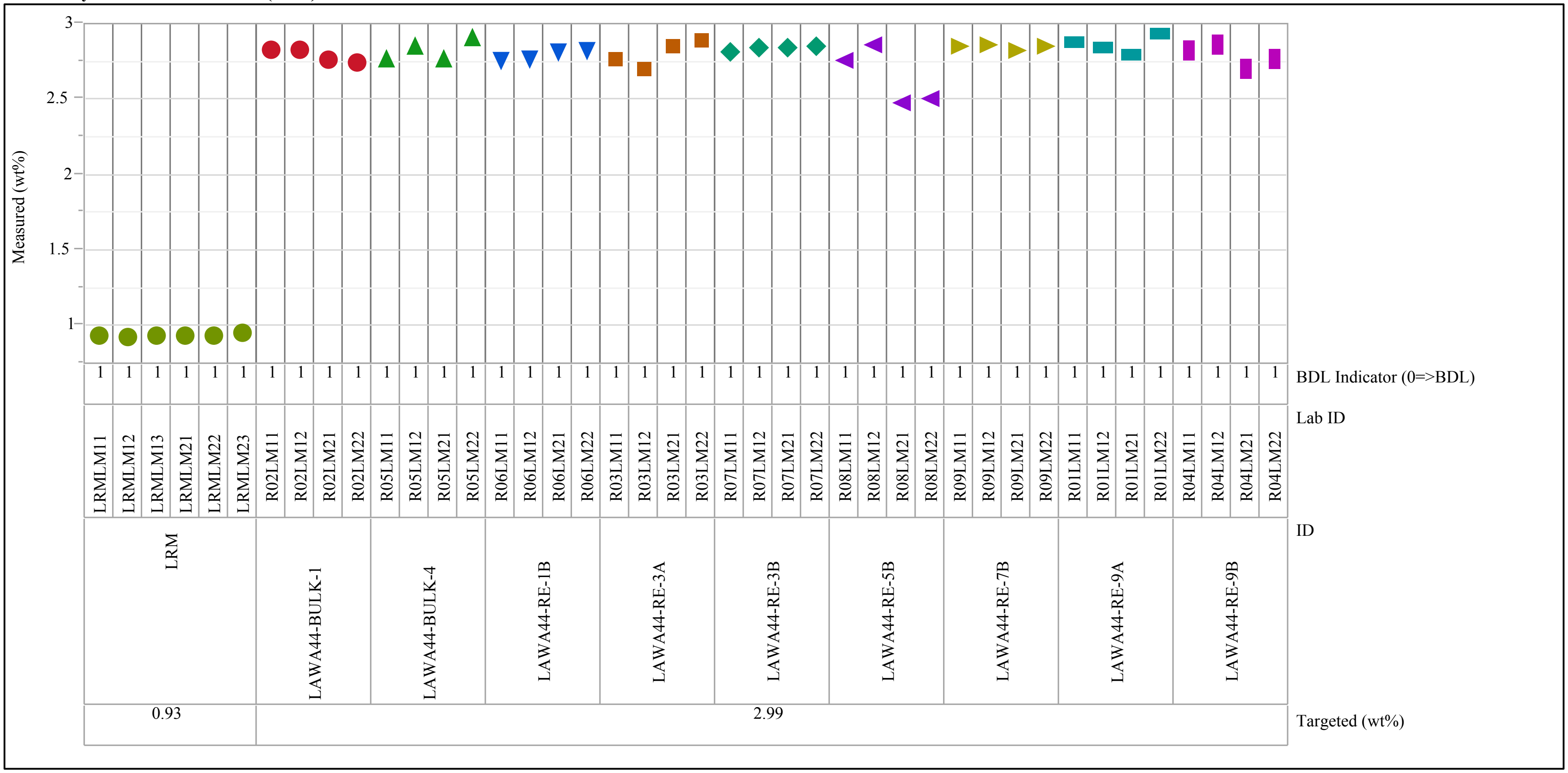
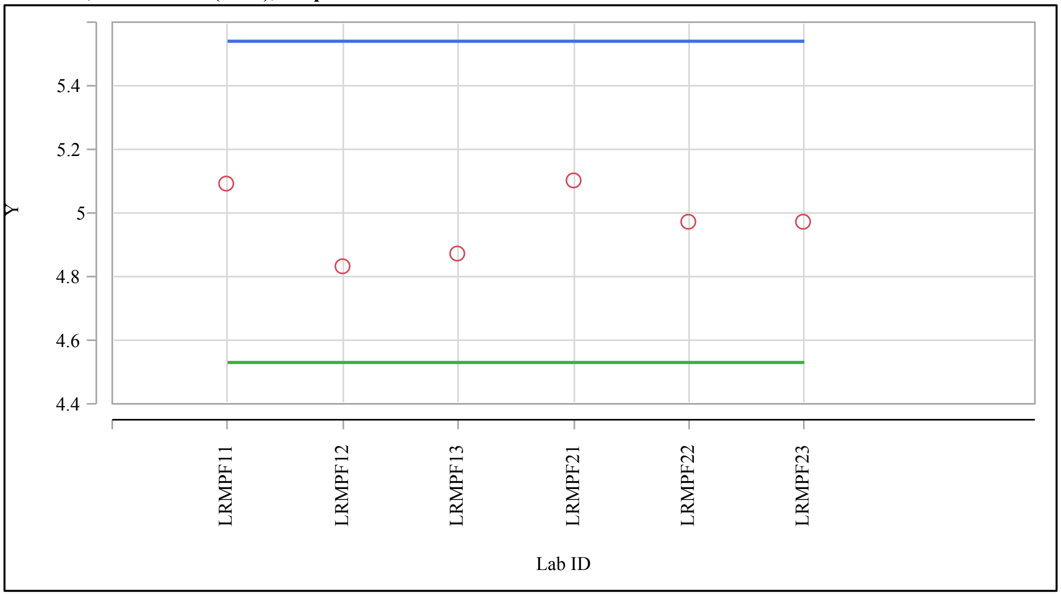
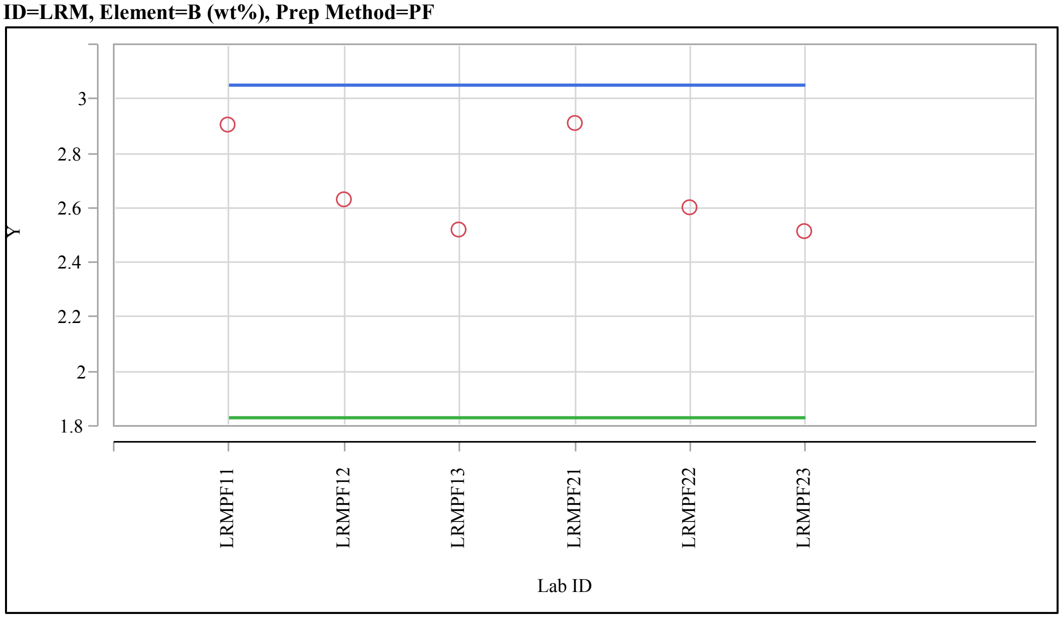


Exhibit A-3. Acceptability Evaluation for Measurements of the LRM Reference Glass

ID=LRM, Element=Al (wt%), Prep Method=PF



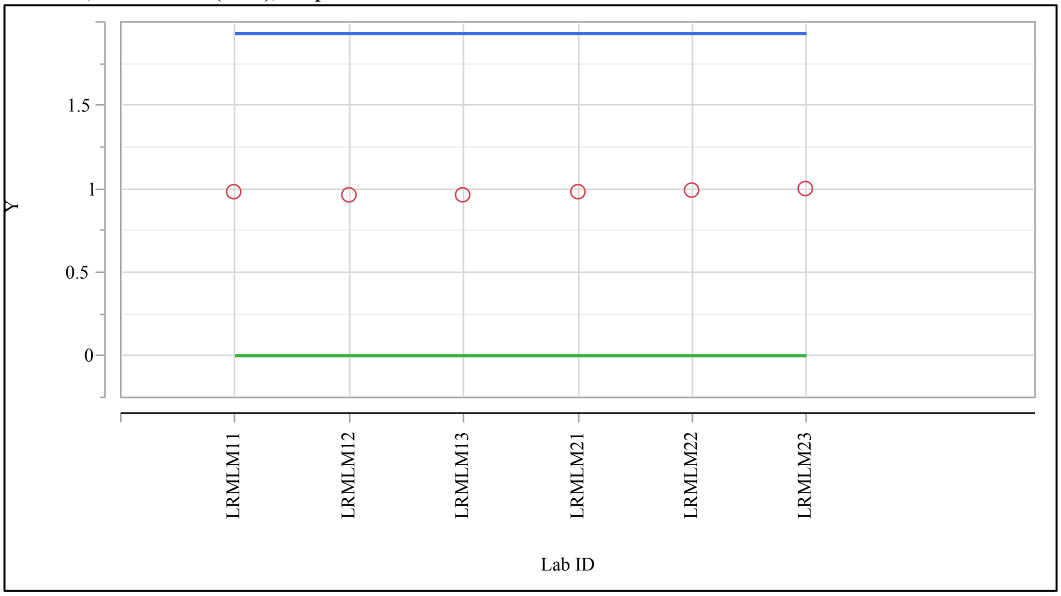
ID=LRM, Element=B (wt%), Prep Method=PF



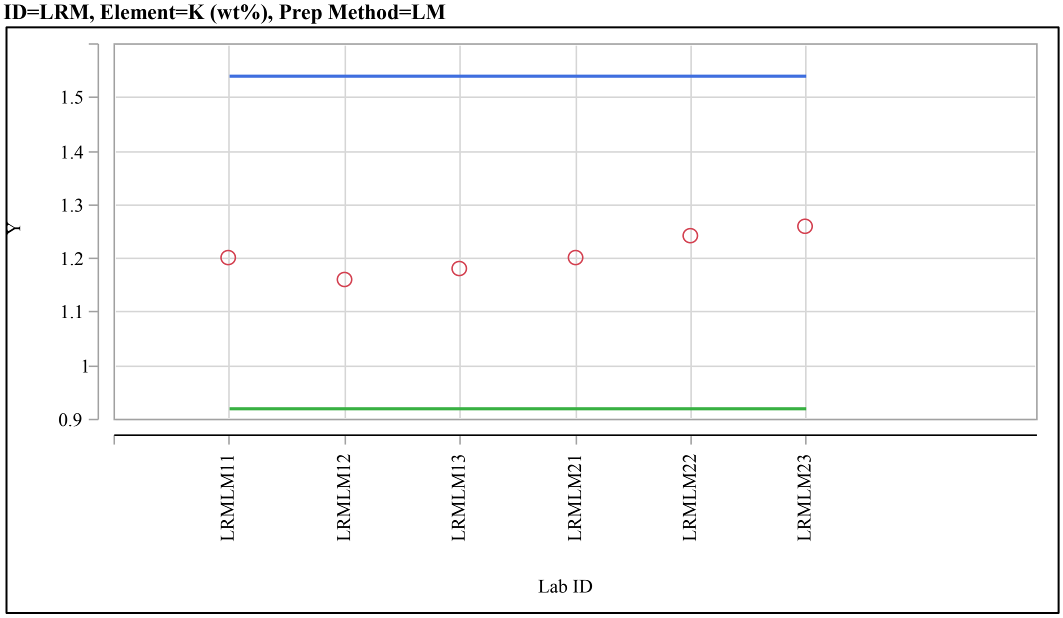
Y ○ Measurement — lower acceptability limit — upper acceptability limit

Exhibit A-3. Acceptability Evaluation for Measurements of the LRM Reference Glass (continued)

ID=LRM, Element=Fe (wt%), Prep Method=LM



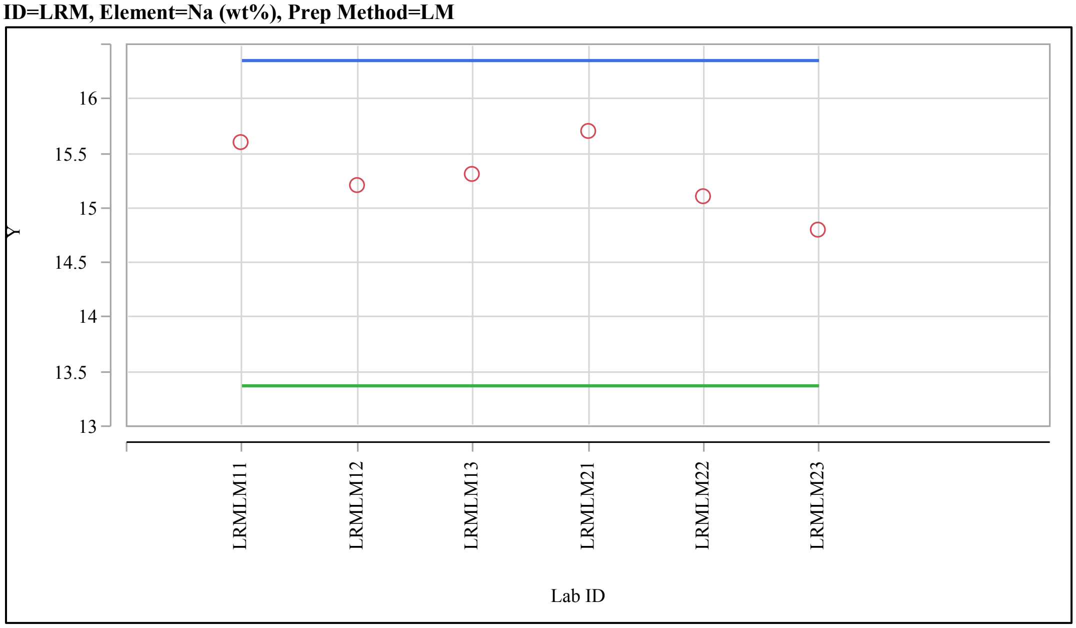
ID=LRM, Element=K (wt%), Prep Method=LM



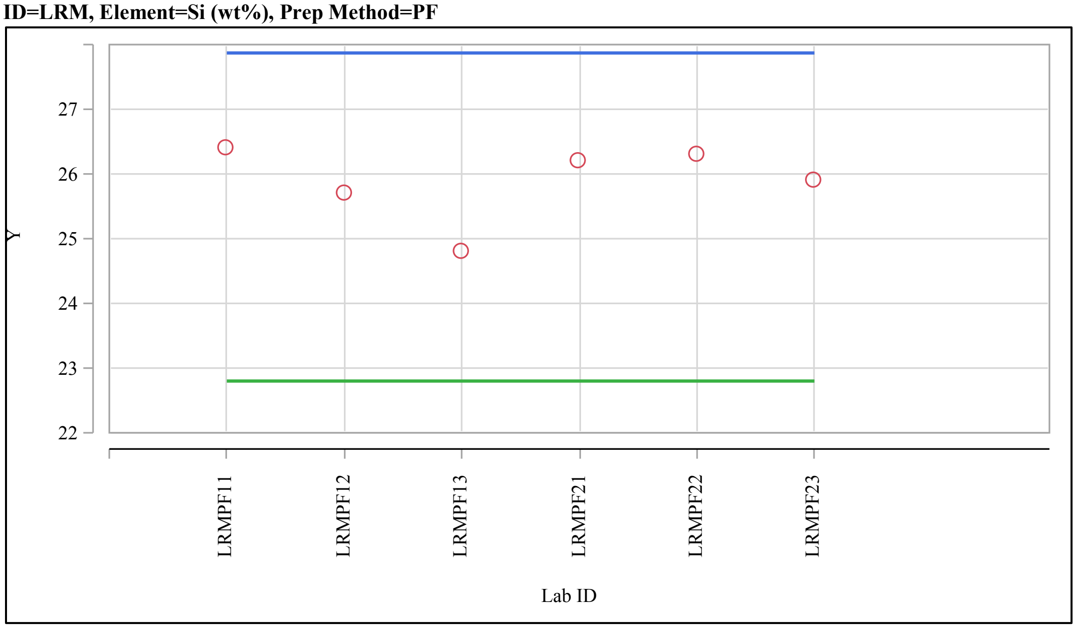
Y ○ Measurement — lower acceptability limit — upper acceptability limit

Exhibit A-3. Acceptability Evaluation for Measurements of the LRM Reference Glass (continued)

ID=LRM, Element=Na (wt%), Prep Method=LM



ID=LRM, Element=Si (wt%), Prep Method=PF



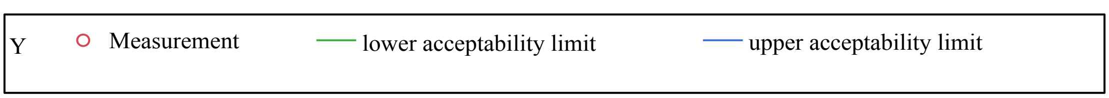


Exhibit A-3. Acceptability Evaluation for Measurements of the LRM Reference Glass (continued)

ID=LRM, Element=Zr (wt%), Prep Method=LM

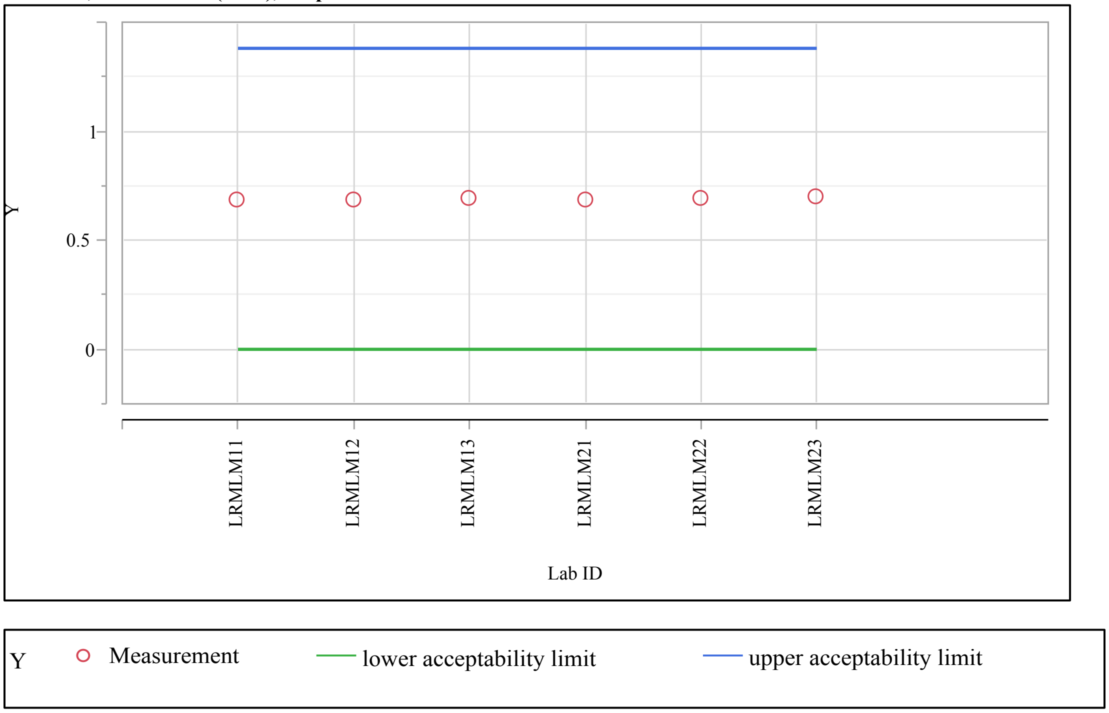
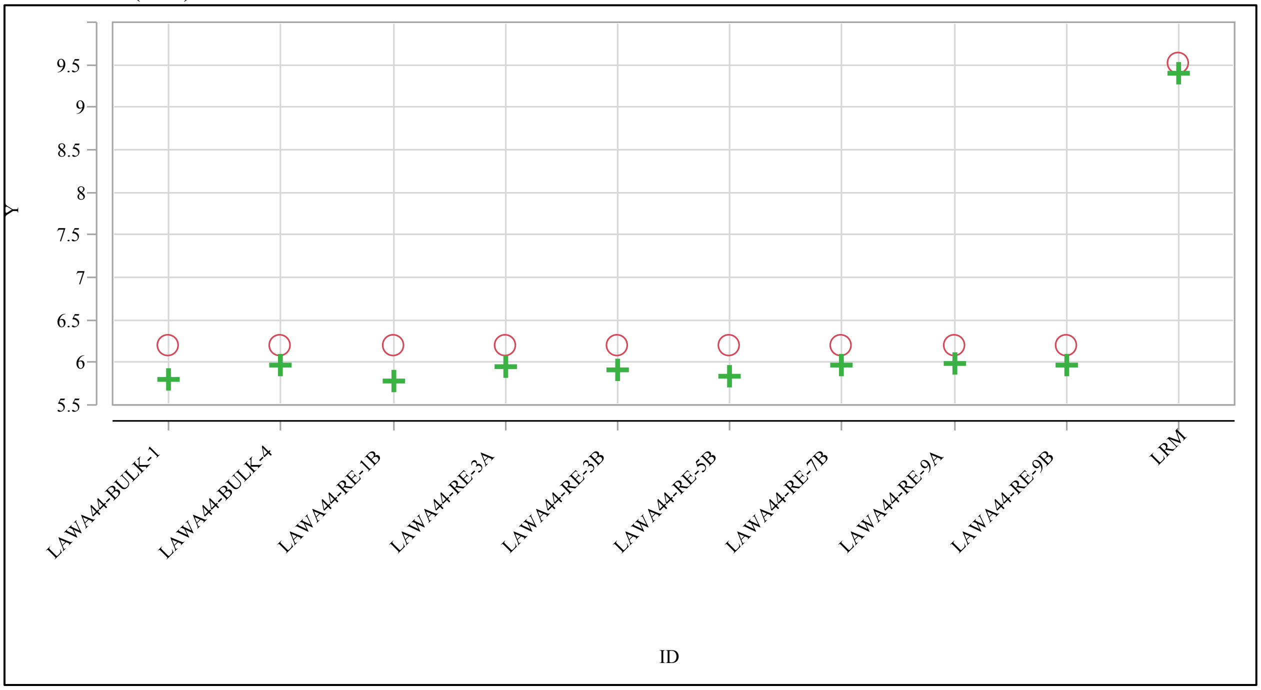


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide

Oxide=Al2O3 (wt%)



Oxide=B2O3 (wt%)

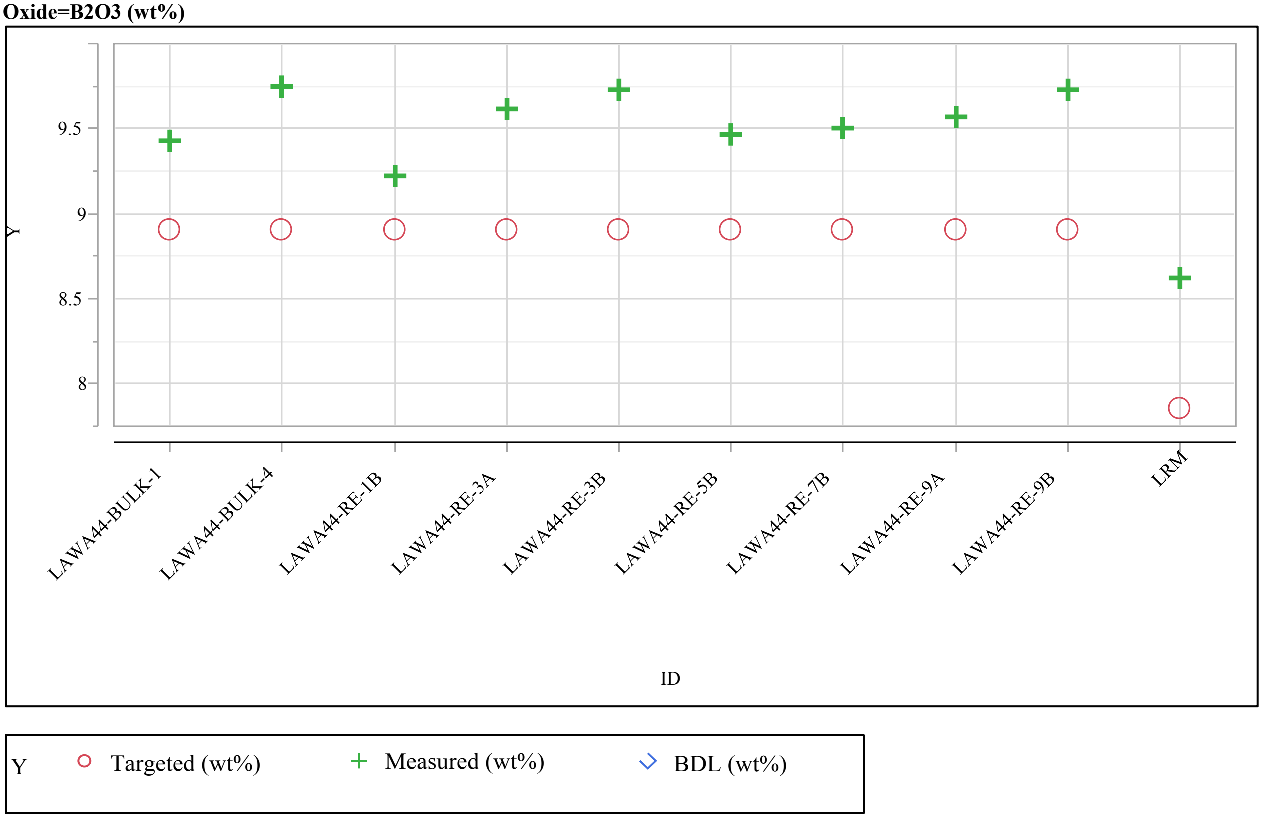
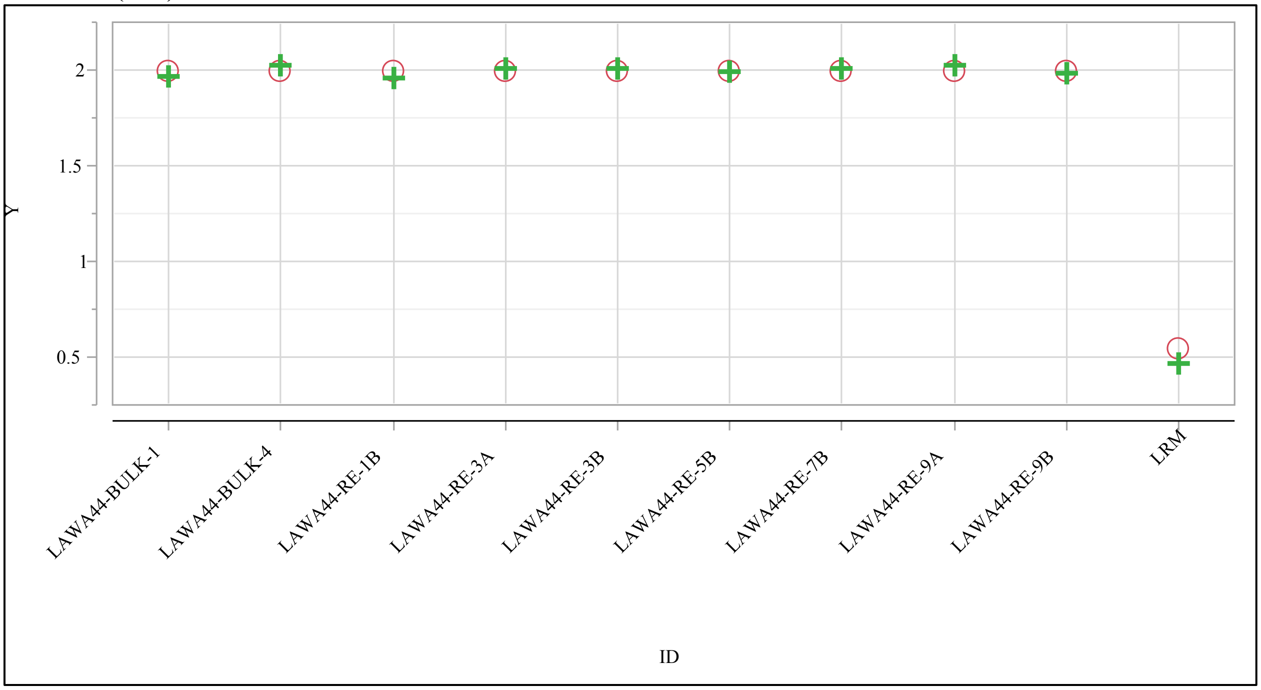
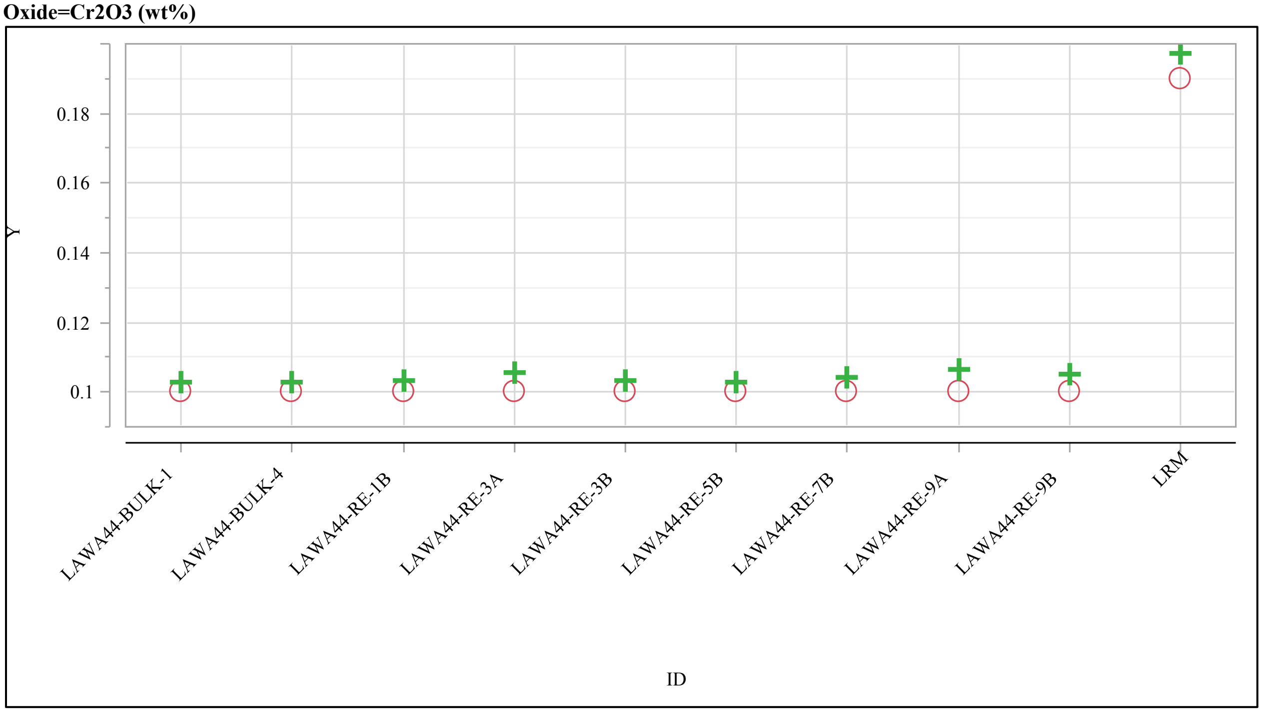


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Oxide=CaO (wt%)



Oxide=Cr2O3 (wt%)



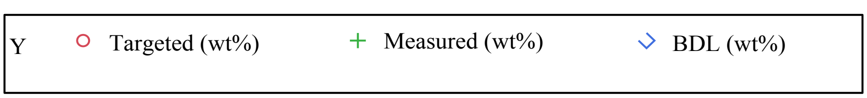
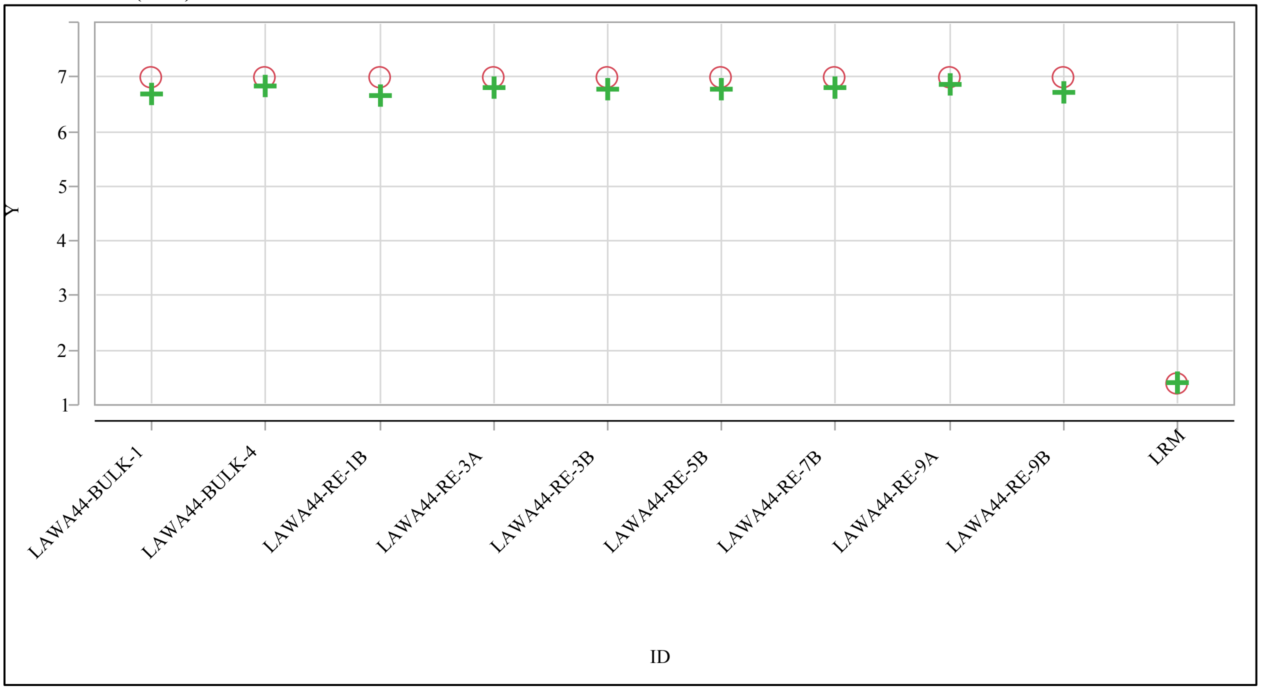
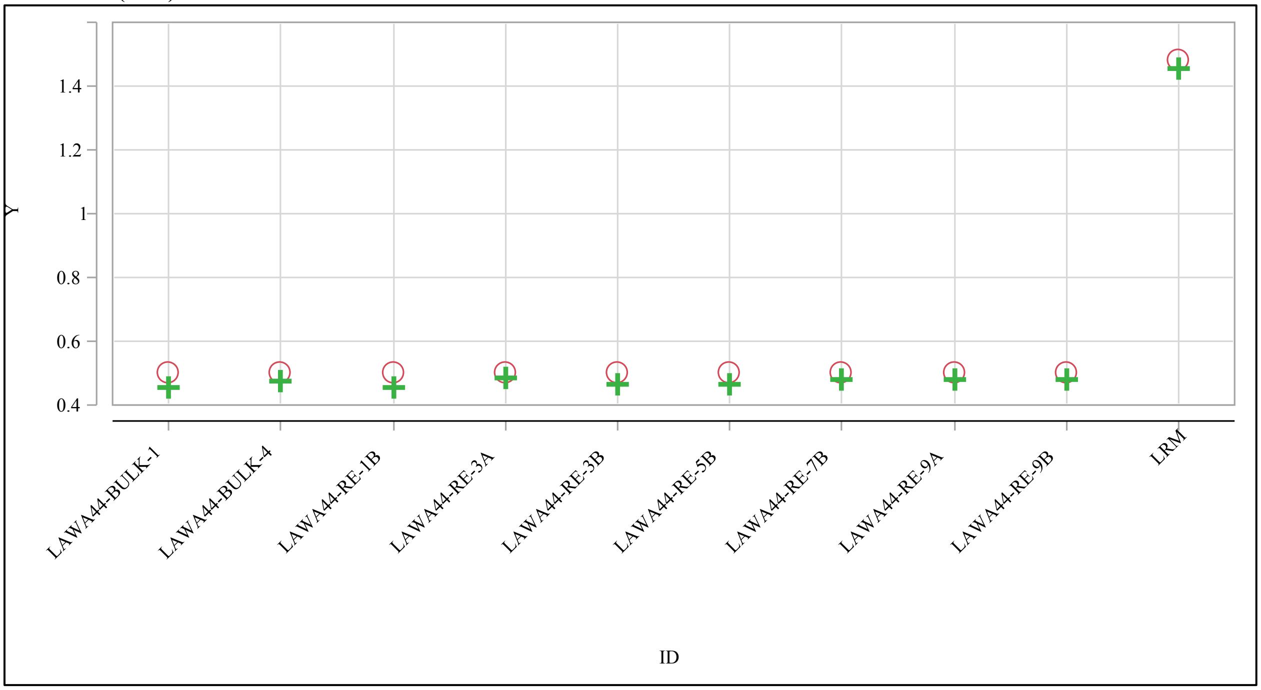


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Oxide=Fe2O3 (wt%)



Oxide=K2O (wt%)



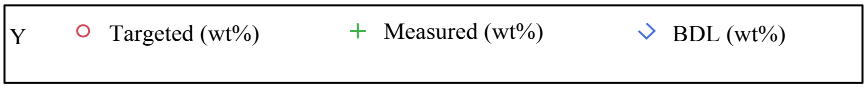
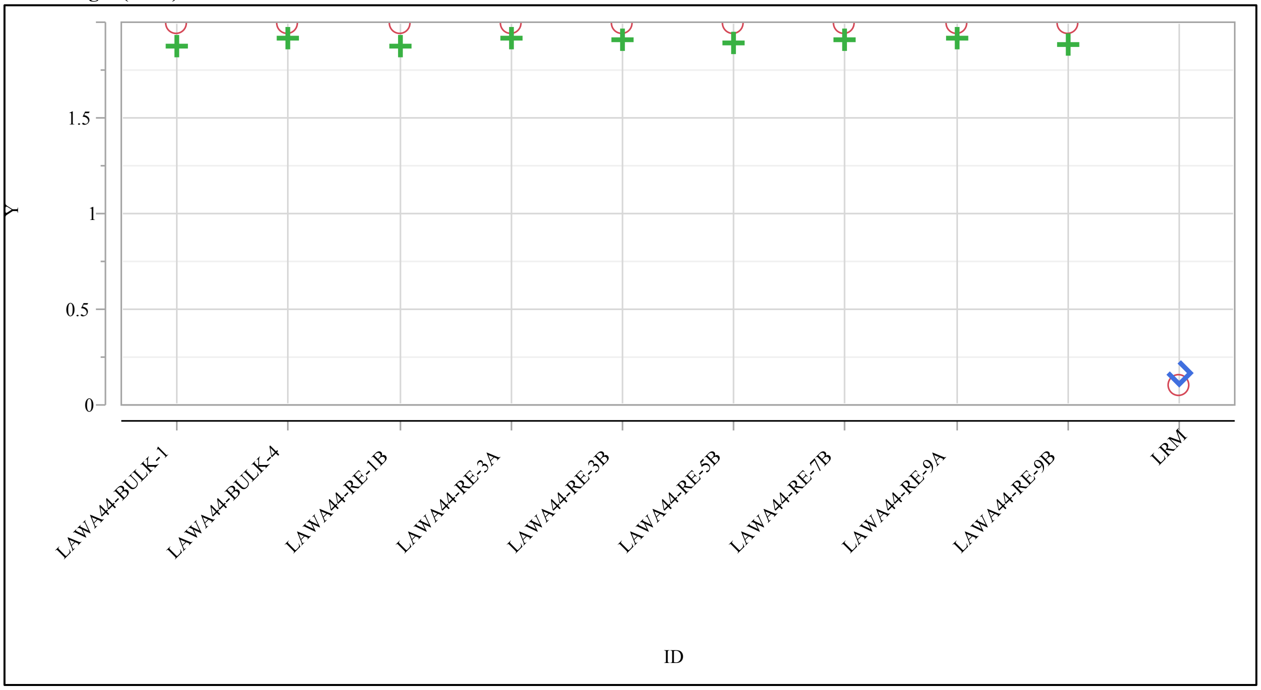
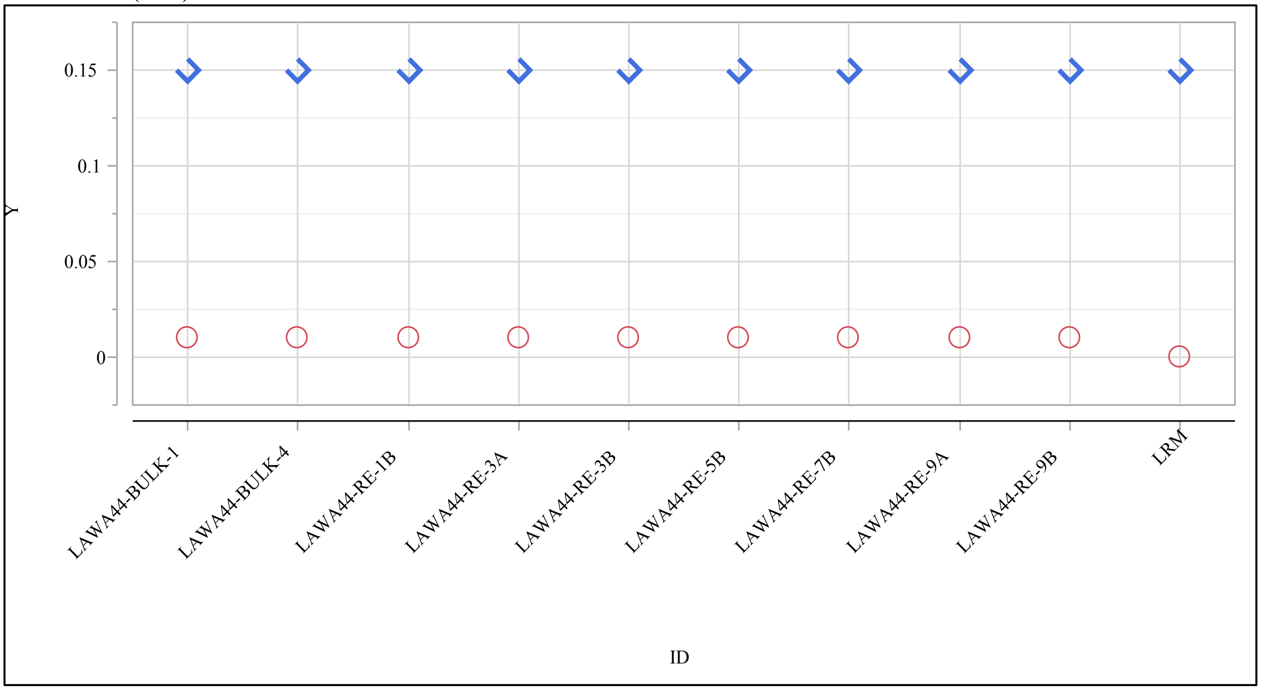


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Oxide=MgO (wt%)



Oxide=MoO3 (wt%)



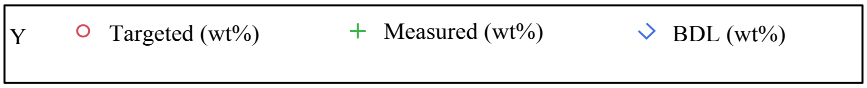
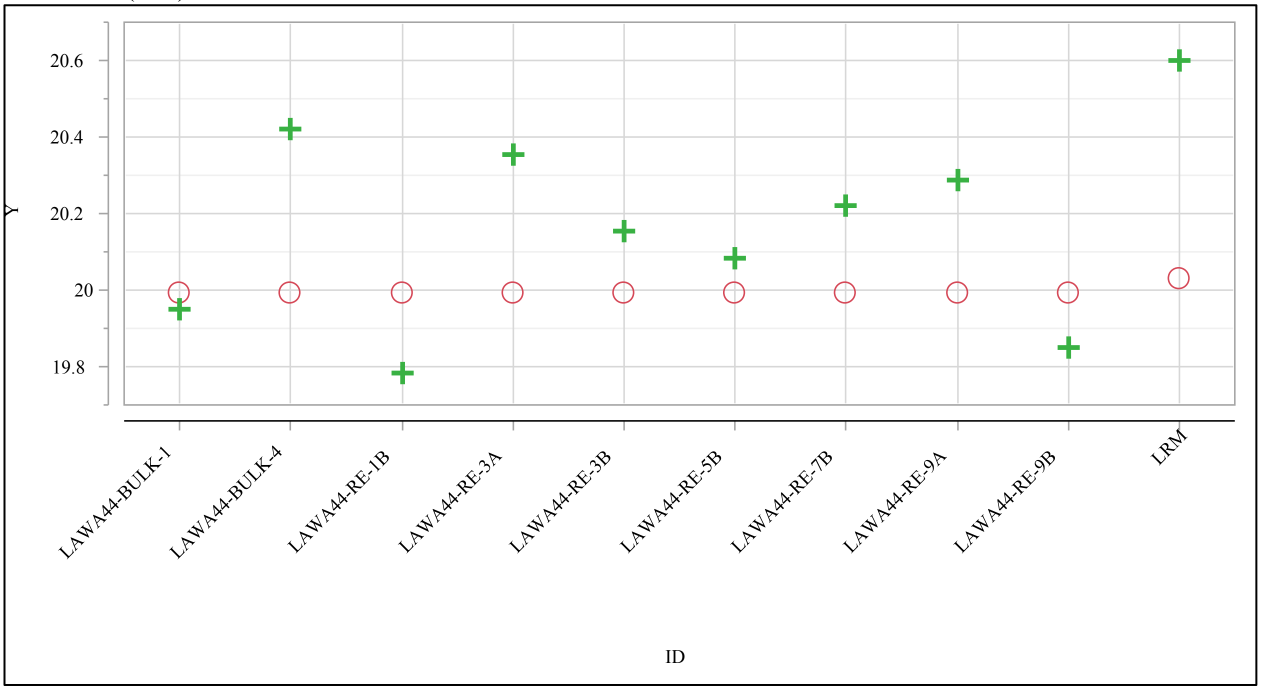


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Oxide=Na2O (wt%)



Oxide=P2O5 (wt%)

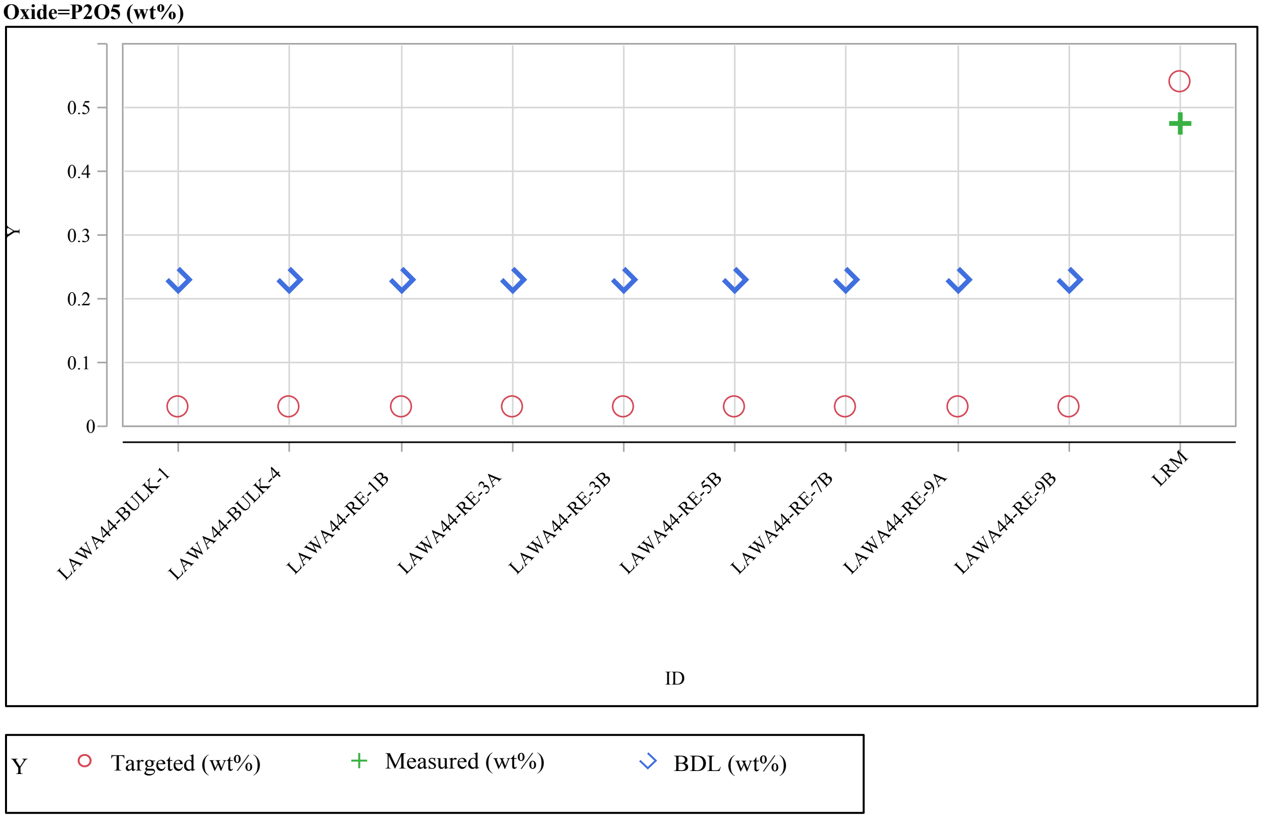
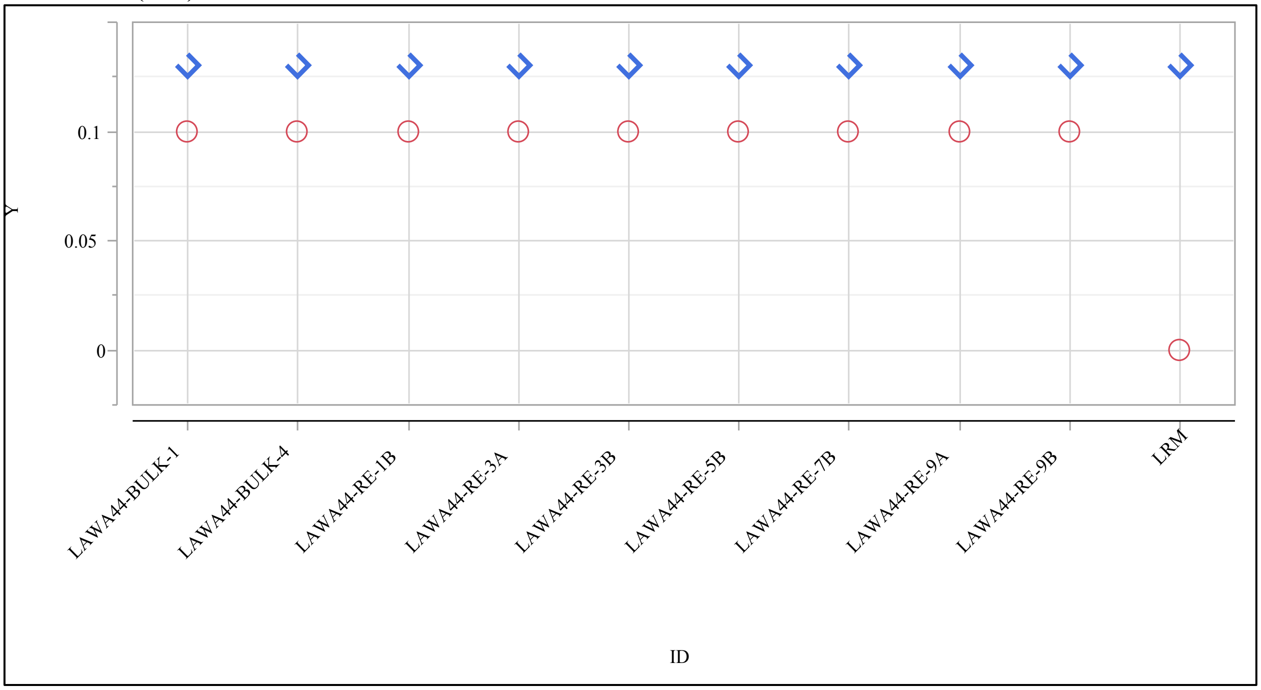
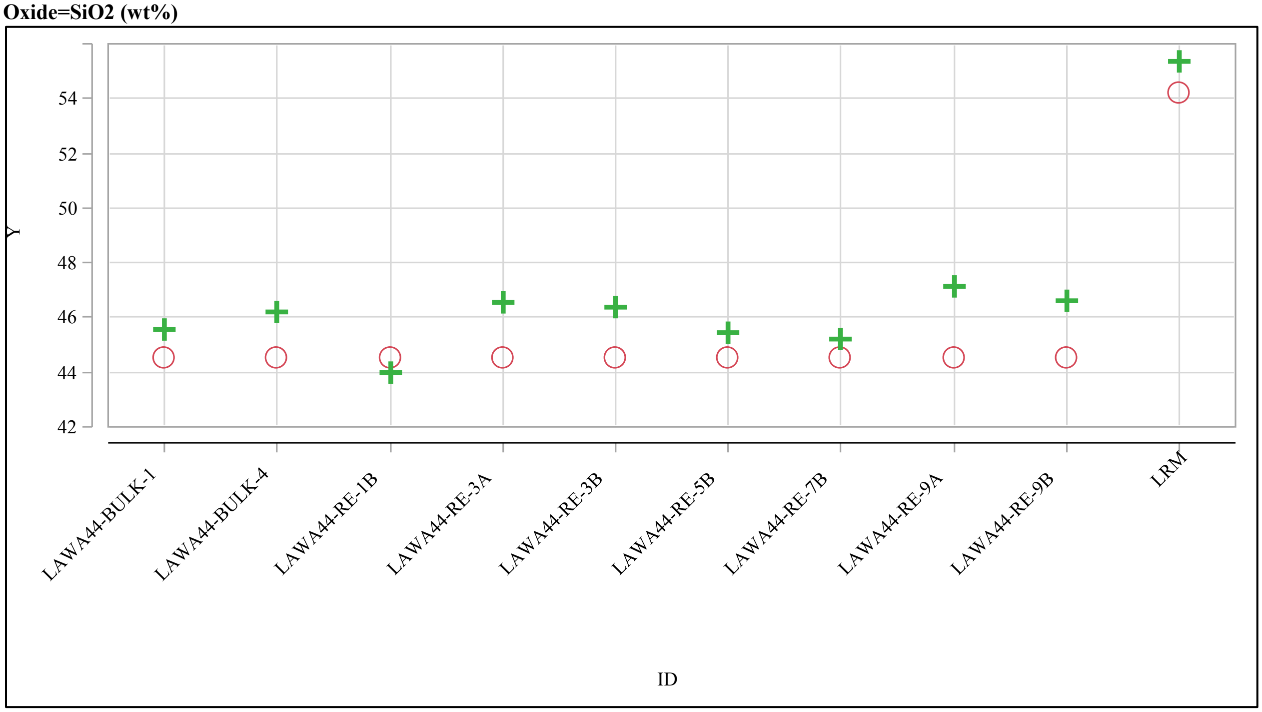


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Oxide=Re2O7 (wt%)



Oxide=SiO2 (wt%)



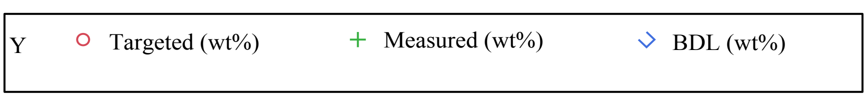
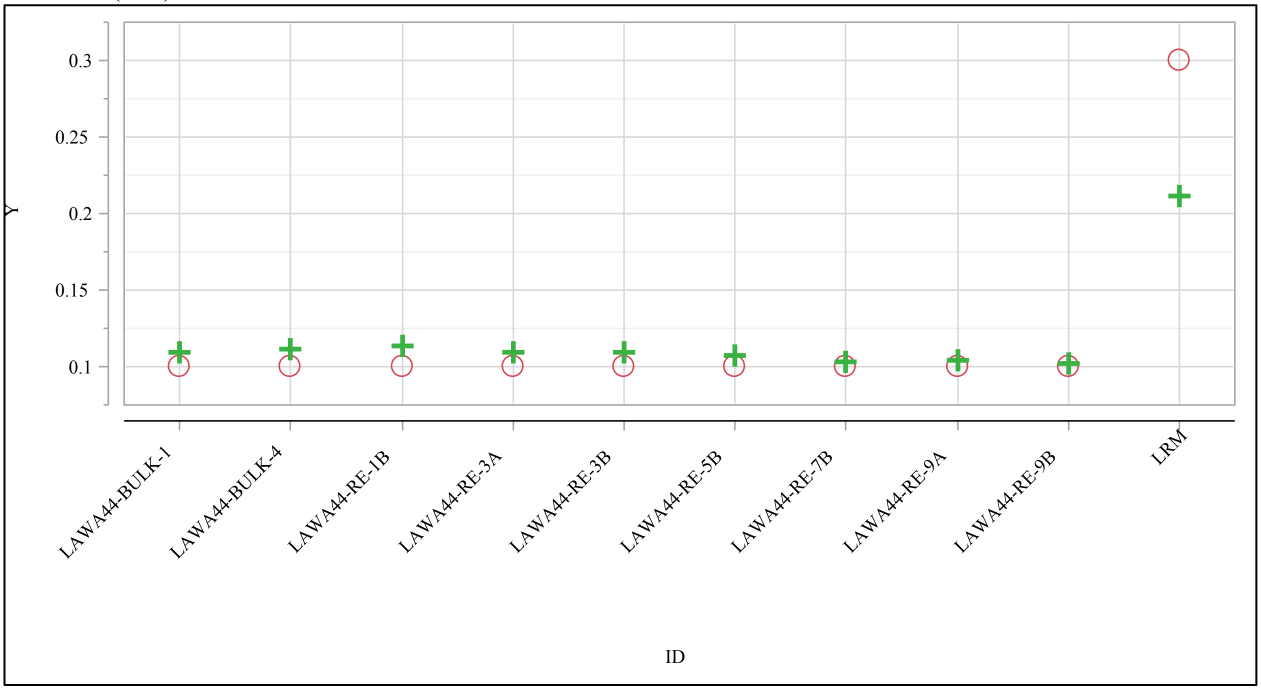
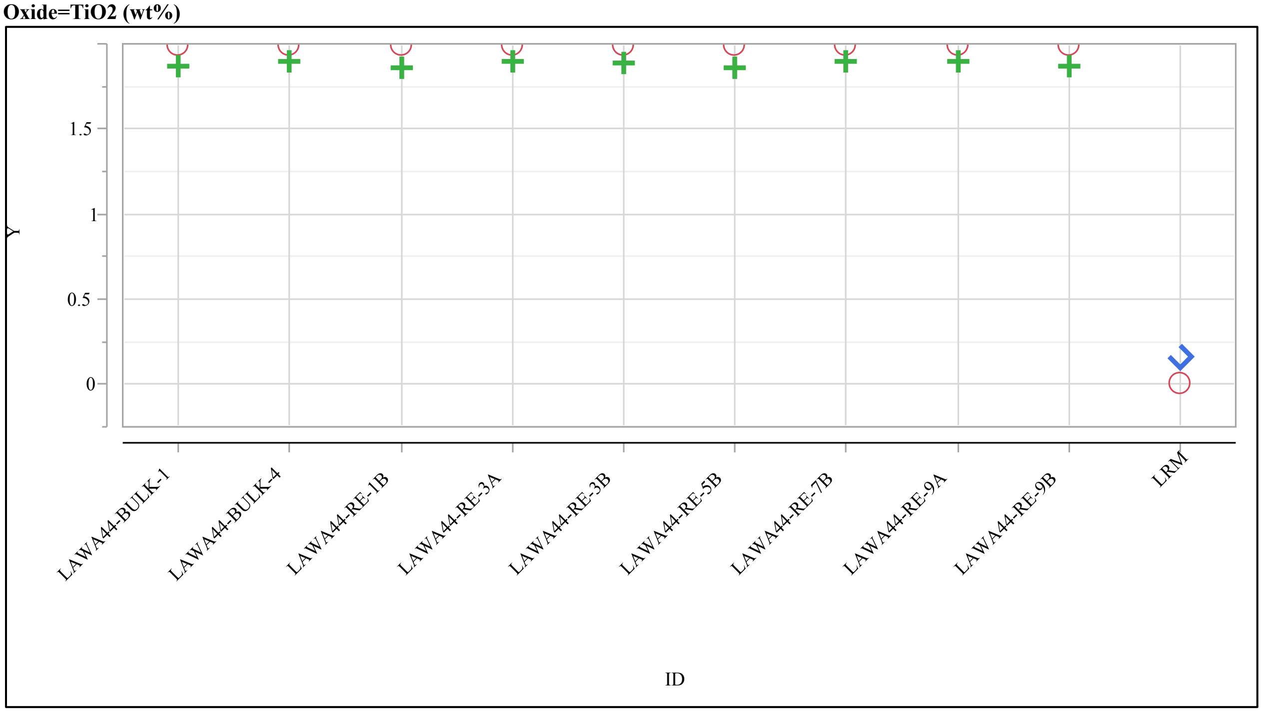


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Oxide=SO3 (wt%)



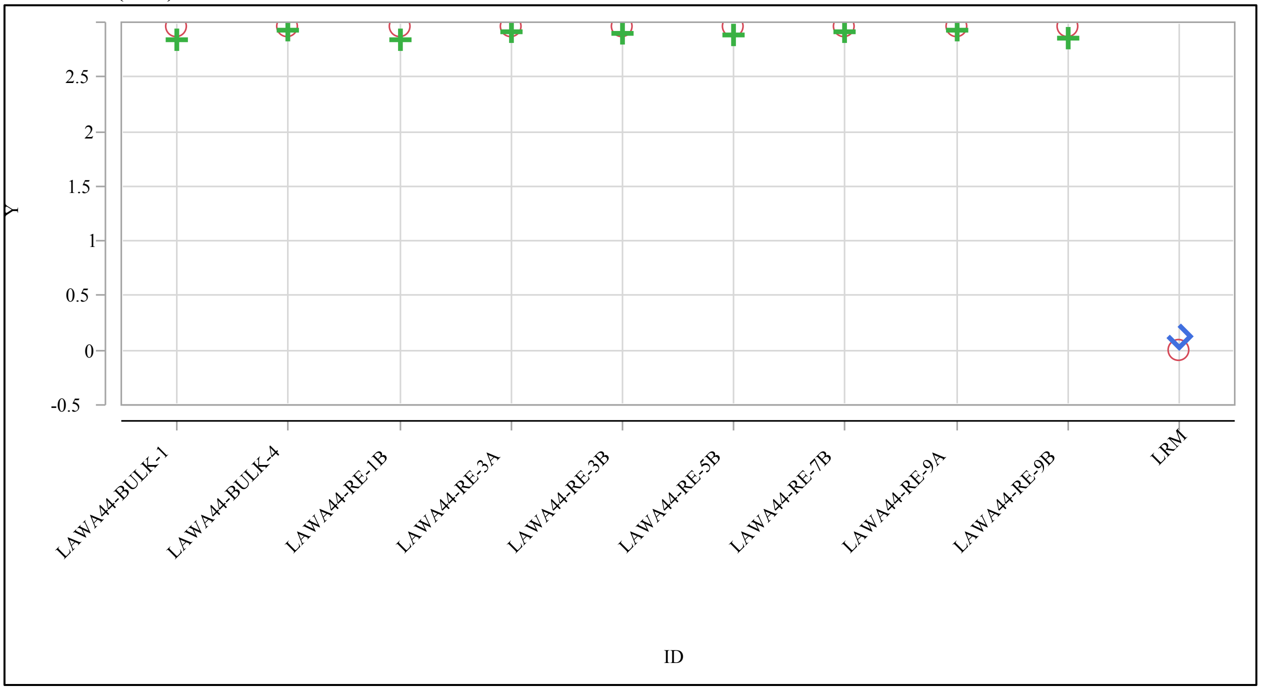
Oxide=TiO2 (wt%)



Y ○ Targeted (wt%) + Measured (wt%) ◇ BDL (wt%)

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

Oxide=ZnO (wt%)



Oxide=ZrO2 (wt%)

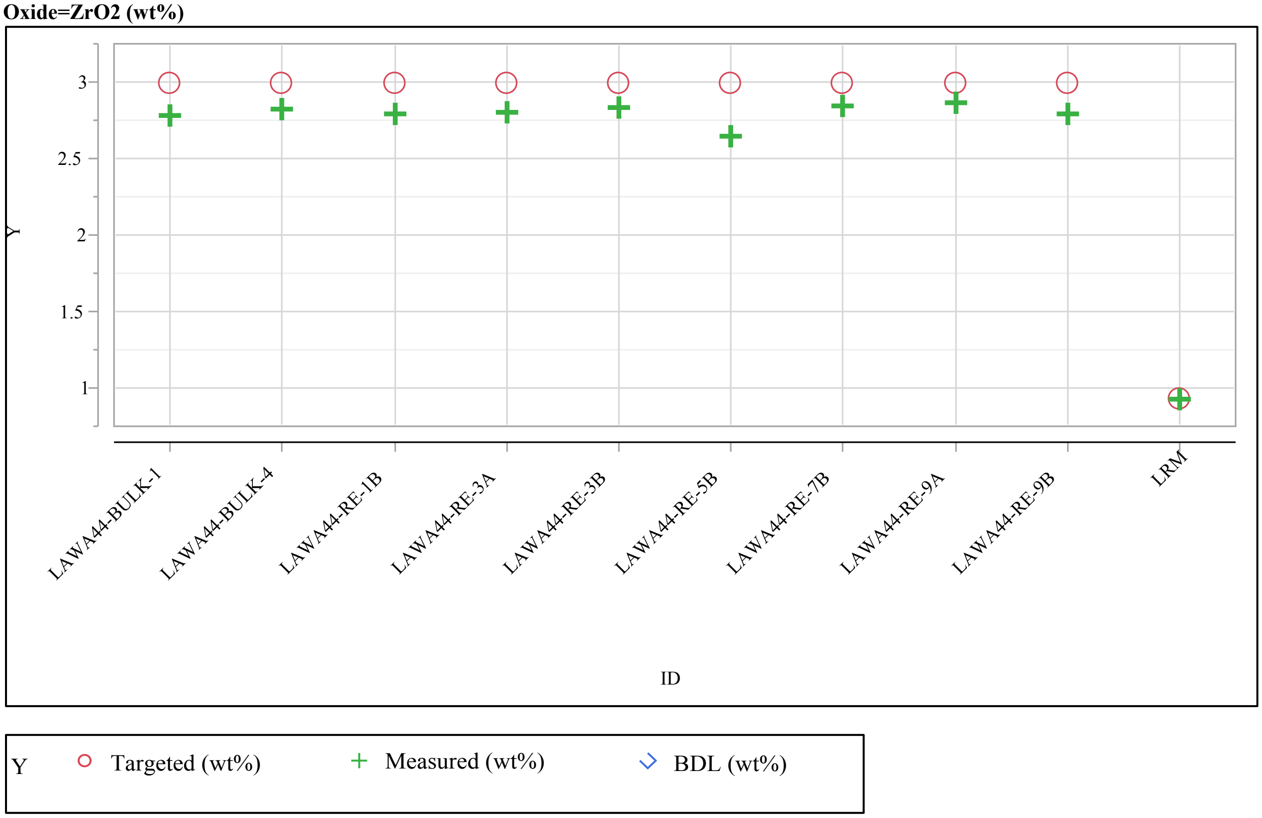
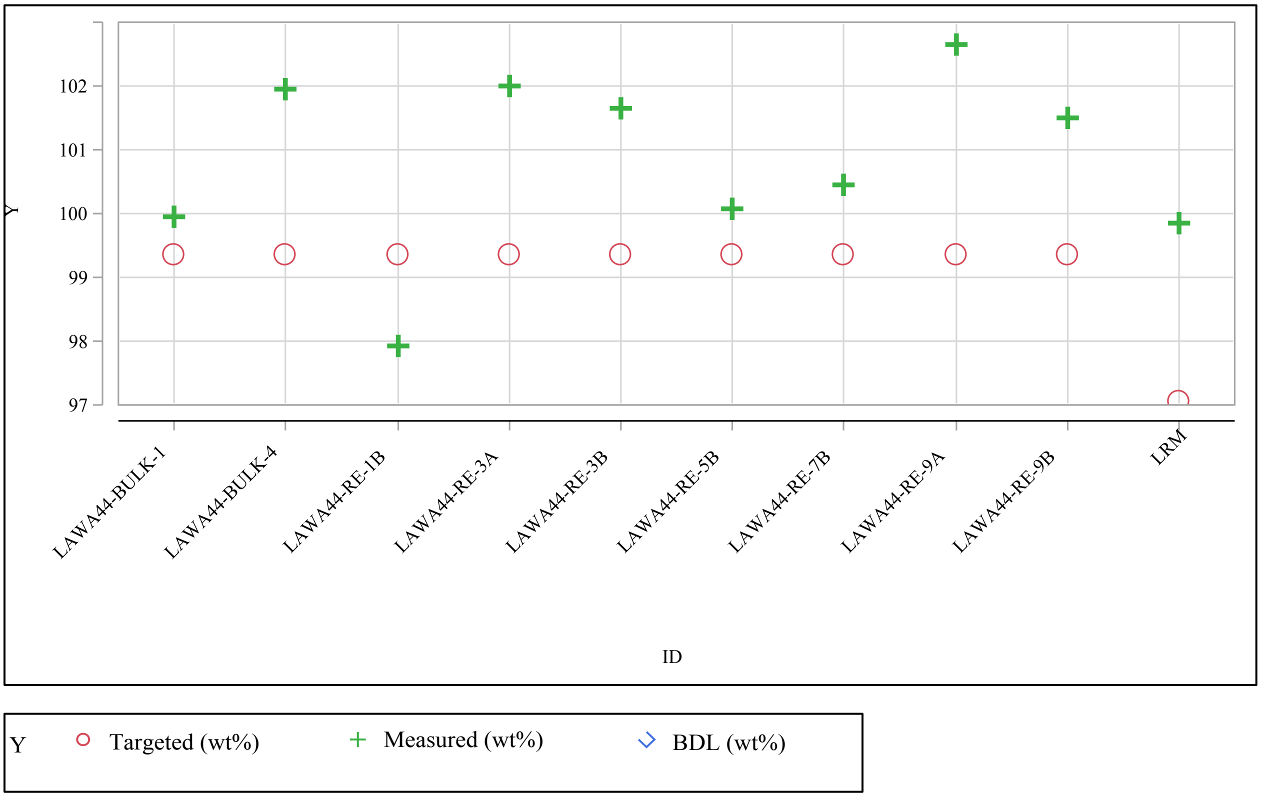


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Oxide=Sum of Oxides



Distribution:

J. W. Amoroso, 999-W
T. B. Brown, 773-A
H. H. Burns, 773-41A
A. D. Cozzi, 999-W
C. L. Crawford, 773-42A
T. B. Edwards, 999-W
S. D. Fink, 773-A
K. M. Fox, 999-W
C. C. Herman, 773-A
E. N. Hoffman, 999-W
J. E. Hyatt, 773-A
C. M. Jantzen, 773-A
T. Jin, PNNL
F. C. Johnson, 999-W
D. S. Kim, PNNL
A. A. Kruger, DOE-ORP
C. S. Lewis, 999-W
J. Matyáš, PNNL
F. M. Pennebaker, 773-42A
R. L. Russell, PNNL
M. J. Schweiger, PNNL
J. D. Vienna, PNNL
W. R. Wilmarth, 773-A
Records Administration (EDWS)