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Supplemental Characterization of Hanford LAW Phase 2, Outer Layer Matrix Glasses

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June 2019

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EXECUTIVE SUMMARY

Supplemental chemical composition data are provided for a series of simulated low-activity waste glasses designated as the Phase 2, Outer Layer study. The glasses were selected and fabricated by the Pacific Northwest National Laboratory in support of property/composition model development for operation of the Hanford Tank Waste Treatment and Immobilization Plant. Additional characterization of glasses in this series is described in SRNL-STI-2018-00150, "Sulfur Solubility Testing and Characterization of Hanford LAW Phase 2, Outer Layer Matrix Glasses." The measured concentrations of SO_3 reported here are generally lower than those measured for the earlier versions of these sulfur saturated glasses.

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LIST OF ABBREVIATIONS

BDL	Below Detection Limit
DOE	U.S. Department of Energy
ICP-AES	Inductively Coupled Plasma – Atomic Emission Spectroscopy
HLW	High Level Waste
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] Two of these areas are enhancing waste glass property/composition models and broadening the compositional regions over which those models are applicable.

In this report, SRNL provides chemical analysis for several simulated LAW glasses.[a] These glasses were selected as part of a broader study of the influence of glass composition on chemical durability, sulfur retention, and other properties.[3] The resulting data will be used in the development of improved property/composition models for LAW glass.

2.0 Experimental Procedure

2.1 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. Laboratory data for this study were recorded in the SRNL Electronic Laboratory Notebook system, experiment C3489-00079-25. The glasses provided by PNNL were fabricated following Test Instructions EWG-TI-0056, EWG-TI-0057, and EWG-TI-0060.

2.2 Glasses Selected for Study

Questions regarding the concentration of sulfur in some of the LAW Phase 2, Outer Layer study glasses led to the shipment of an additional series of glasses to SRNL for chemical composition analysis. The glass compositions were selected and fabricated at the Pacific Northwest National Laboratory (PNNL). Identifiers for the glasses are listed in Table 2-1.

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

[a] Characterization of other glasses that are part of the LAW Phase 2 Outer Layer study are described in an earlier report.[2]

Table 2-1. Identifiers for the Glasses Characterized in this Report

Glass Identifier
EWG-LAW-SSM-S-3
LP2-OL-01-3+SO3 4/12/2019
LP2-OL-04-1+SO3 4/12/2019
LP2-OL-05+SO3 4/12/2019
LP2-OL-07-1+SO3 4/12/2019
LP2-OL-09-1+SO3 4/12/2019
LP2-OL-12+SO3 4/12/2019
LP2-OL-14+SO3 4/12/2019
LP2-OL-15+SO3 4/12/2019
LP2-OL-17+SO3 4/12/2019

2.3 Glass Composition Analysis

Chemical analyses were 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 compositions. Two dissolution techniques, sodium peroxide fusion (PF)[5] and lithium metaborate fusion (LM),[6] were used for preparing each of the glass samples, in duplicate, for analysis.

Each of the duplicate samples was analyzed twice for each element of interest by Inductively Coupled Plasma – Atomic Emission Spectroscopy (ICP-AES),[7] 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)[8] 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.[8] The preparation methods used for each of the reported glass components are listed in Table 2-2. Note that anion concentrations (Cl^- and F^-) were not measured in this work since sulfur concentrations were of primary interest and anion measurements would have required separate dissolution and measurement methods.

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

Analyte	Preparation Method
Al	PF
B	PF
Ca	LM
Cr	LM
Fe	PF
K	LM
Li	PF
Mg	LM
Na	LM
Ni	LM
P	PF
S	LM
Si	PF
Sn	PF
V	LM
Zn	LM
Zr	PF

3.0 Results and Discussion

3.1 Review and Evaluation of the Glass Composition Measurements

Table A-1 in Appendix A provides the elemental concentration measurements in weight percent (wt %) for the study glasses as prepared by the LM method. Table A-2 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 included 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.)[9] was used to support these analyses.

3.1.1 Treatment of Detection Limits

The elemental concentrations in Table A-1 and Table A-2 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 measurement 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. This was done for the purposes of data review and calculating a sum of oxides for each glass. Those oxides with one or more concentration measurements that were below the associated detection limit (BDL) 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 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 and Table A-2 in Appendix A, with each plotted point identified by its Lab ID (from the analytical study plan). 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. A calibration shift between the two measurement blocks for SiO_2 was apparent. The instrument check standards were within specification. These calibration effects are typical of ICP-AES analyses and are mitigated by taking the average of the measurements for each analyte.

3.1.3 Composition Measurements by Glass Identifier

Exhibit A-2 in Appendix A provides plots of the oxide concentration measurements grouped by the PNNL ID (including the LRM reference glass) and shows the originally targeted[a] concentrations when available.[b] 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 Al_2O_3, B_2O_3, Na_2O, P_2O_5, SiO_2, and SO_3 measurements was noted for the study glasses. There were no indications of 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.

3.1.4 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.[7] The review is in the form of plots of the measurements arranged by element and preparation method, framed by upper and lower acceptability limits for the concentration of the element in question. The results show that all 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.

3.1.5 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 Table A-1 and Table A-2 in Appendix A) 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 originally targeted values. The following observations are offered from a review of these plots:

- The measured concentrations of Al_2O_3, B_2O_3, CaO, Na_2O, and ZrO_2 are below the targeted values for some of the study glasses.
- The measured concentrations of Cr_2O_3 and K_2O are low for the study glasses, which may be due to partitioning of these components to the excess sulfur phase during preparation.[10]
- The measured P_2O_5 concentrations are low for those glasses that contained phosphorus.
- The measured SiO_2 concentrations are generally above the targeted values, which may be due to the ICP-AES calibration effect identified earlier.

[a] The targeted compositions of the glasses do not reflect the addition of excess sodium sulfate to produce the sulfur saturated melts.
[b] The targeted composition of glass LAW-SSM-S-3 was not provided.

- The measured concentrations of SO_3 are generally lower than those reported for the earlier versions of these glasses.[2]

Table A-3 in Appendix A provides a summary of the average compositions as well as the originally targeted compositions and some associated differences and relative differences. All the measured sums of oxides for the study glasses fall within the interval of about 98.5 to 103.1wt %, indicating acceptable recovery of the glass components.[a] Entries in Table A-3 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 shaded if they are 10% or more.[b] The highlighted cells are consistent with the observations listed above.

4.0 Summary

In this report, SRNL provides chemical analysis for several simulated LAW glasses. These glasses were selected as part of a broader study of the influence of glass composition on chemical durability, sulfur retention, and other properties.[3] The resulting data will be used in the development of improved property/composition models for LAW glass.

Chemical analyses were performed on a representative sample of each of the study glasses to allow for comparisons with the targeted compositions. Sodium peroxide fusion and lithium metaborate fusion were used for preparing each of the glass samples, in duplicate, for analysis. Each of the duplicate samples was analyzed twice for each element of interest by ICP-AES, for a total of four measurements per element per glass. Glass standards were intermittently measured to assess the performance of the analytical instrument over the course of these analyses. There were no issues with measurements of the glass standards.

A review of the individual glass composition measurements identified no analytical issues of concern. Some degree of scatter among the Al_2O_3, B_2O_3, Na_2O, P_2O_5, SiO_2, and SO_3 measurements was noted. There were no indications of an error in preparation or measurement that had to be addressed in treatment of the data. The measured SiO_2 concentrations were generally above the targeted values, which may be due to an ICP-AES calibration effect. The measured concentrations of SO_3 are generally lower than those reported for the earlier versions of these sulfur saturated glasses.[2]

[a] Note again that anions were not measured in this work.

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

5.0 References

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Appendix A Tables and Exhibits Supporting the Chemical Composition Measurements

Table A-1. LM Measurements of the Study Glasses

ID	Block	Sequence	Lab ID	Ca (wt%)	Cr (wt%)	K (wt%)	Mg (wt%)	Na (wt%)	Ni (wt%)	S (wt%)	V (wt%)	Zn (wt%)
LRM	1	1	LRMLM11	0.415	0.150	1.18	<0.100	15.7	0.245	0.102	<0.100	<0.100
EWG-LAW-SSM-S-3	1	2	S-9206LM11	0.715	<0.100	<0.100	0.969	11.7	0.493	<0.0500	<0.100	<0.100
LP2-OL-15+SO3 4/12/2019	1	3	S-9204LM11	7.16	0.256	<0.100	<0.100	15.3	<0.100	0.796	<0.100	2.80
LP2-OL-14+SO3 4/12/2019	1	4	S-9201LM11	4.85	0.226	3.74	<0.100	15.3	<0.100	1.05	2.04	1.59
LP2-OL-14+SO3 4/12/2019	1	5	S-9201LM21	4.98	0.224	3.86	<0.100	15.6	<0.100	1.04	2.14	1.65
EWG-LAW-SSM-S-3	1	6	S-9206LM21	0.731	<0.100	<0.100	0.985	11.9	0.508	<0.0500	<0.100	<0.100
LP2-OL-12+SO3 4/12/2019	1	7	S-9203LM21	5.43	0.248	<0.100	0.753	17.5	<0.100	0.862	<0.100	1.65
LP2-OL-05+SO3 4/12/2019	1	8	S-9207LM21	7.76	0.113	<0.100	<0.100	14.6	<0.100	0.576	<0.100	1.66
LP2-OL-09-1+SO3 4/12/2019	1	9	S-9205LM21	1.37	0.266	<0.100	<0.100	15.3	<0.100	0.449	2.09	1.61
LP2-OL-07-1+SO3 4/12/2019	1	10	S-9200LM11	5.48	0.190	0.114	0.624	14.6	<0.100	0.674	0.548	2.50
LP2-OL-05+SO3 4/12/2019	1	11	S-9207LM11	7.81	0.112	<0.100	<0.100	15.1	<0.100	0.584	<0.100	1.67
LRM	1	12	LRMLM12	0.413	0.150	1.13	<0.100	15.8	0.252	0.0920	<0.100	<0.100
LP2-OL-17+SO3 4/12/2019	1	13	S-9202LM21	3.18	<0.100	3.93	0.785	16.5	<0.100	0.716	2.06	1.65
LP2-OL-04-1+SO3 4/12/2019	1	14	S-9199LM11	5.49	<0.100	3.46	0.784	15.5	<0.100	0.425	<0.100	3.04
LP2-OL-01-3+SO3 4/12/2019	1	15	S-9208LM11	6.20	0.215	<0.100	0.803	15.4	<0.100	0.620	<0.100	1.65
LP2-OL-04-1+SO3 4/12/2019	1	16	S-9199LM21	5.43	<0.100	3.43	0.806	16.1	<0.100	0.433	<0.100	3.01
LP2-OL-15+SO3 4/12/2019	1	17	S-9204LM21	7.25	0.251	<0.100	<0.100	15.5	<0.100	0.846	<0.100	2.89
LP2-OL-17+SO3 4/12/2019	1	18	S-9202LM11	3.21	<0.100	3.76	0.816	16.5	<0.100	0.729	2.06	1.66
LP2-OL-07-1+SO3 4/12/2019	1	19	S-9200LM21	5.36	0.189	0.115	0.626	14.7	<0.100	0.655	0.548	2.43
LP2-OL-12+SO3 4/12/2019	1	20	S-9203LM11	5.26	0.261	<0.100	0.793	17.8	<0.100	0.960	<0.100	1.60
LP2-OL-09-1+SO3 4/12/2019	1	21	S-9205LM11	1.44	0.262	<0.100	<0.100	15.3	<0.100	0.417	2.13	1.68
LP2-OL-01-3+SO3 4/12/2019	1	22	S-9208LM21	6.16	0.215	<0.100	0.790	15.0	<0.100	0.609	<0.100	1.65
LRM	1	23	LRMLM13	0.406	0.149	1.12	<0.100	15.2	0.249	0.0957	<0.100	<0.100
LRM	2	1	LRMLM21	0.415	0.146	1.16	<0.100	15.1	0.239	0.0922	<0.100	<0.100
LP2-OL-17+SO3 4/12/2019	2	2	S-9202LM12	3.26	<0.100	3.78	0.803	16.6	<0.100	0.715	2.07	1.66
LP2-OL-09-1+SO3 4/12/2019	2	3	S-9205LM12	1.41	0.262	<0.100	<0.100	15.5	<0.100	0.446	2.07	1.60
LP2-OL-12+SO3 4/12/2019	2	4	S-9203LM22	5.38	0.263	<0.100	0.796	17.8	<0.100	0.944	<0.100	1.60
LP2-OL-07-1+SO3 4/12/2019	2	5	S-9200LM12	5.36	0.187	0.119	0.631	14.7	<0.100	0.646	0.539	2.40
LP2-OL-05+SO3 4/12/2019	2	6	S-9207LM22	7.68	0.113	<0.100	<0.100	14.3	<0.100	0.578	<0.100	1.60
EWG-LAW-SSM-S-3	2	7	S-9206LM22	0.751	<0.100	<0.100	1.01	11.9	0.520	<0.0500	<0.100	<0.100
LP2-OL-01-3+SO3 4/12/2019	2	8	S-9208LM22	6.00	0.214	<0.100	0.792	15.4	<0.100	0.595	<0.100	1.55
LP2-OL-12+SO3 4/12/2019	2	9	S-9203LM12	5.38	0.258	<0.100	0.789	18.5	<0.100	0.949	<0.100	1.60
LP2-OL-07-1+SO3 4/12/2019	2	10	S-9200LM22	5.48	0.186	0.116	0.624	15.2	<0.100	0.643	0.538	2.44

Table A-1. LM Measurements of the Study Glasses (continued)

ID	Block	Sequence	Lab ID	Ca (wt%)	Cr (wt%)	K (wt%)	Mg (wt%)	Na (wt%)	Ni (wt%)	S (wt%)	V (wt%)	Zn (wt%)
LP2-OL-04-1+SO3 4/12/2019	2	11	S-9199LM22	5.41	0.101	3.26	0.816	16.3	<0.100	0.440	<0.100	2.92
LRM	2	12	LRMLM22	0.421	0.148	1.17	<0.100	15.0	0.235	0.0972	<0.100	<0.100
LP2-OL-01-3+SO3 4/12/2019	2	13	S-9208LM12	6.01	0.214	<0.100	0.795	15.4	<0.100	0.562	<0.100	1.57
LP2-OL-04-1+SO3 4/12/2019	2	14	S-9199LM12	5.38	<0.100	3.27	0.800	15.4	<0.100	0.451	<0.100	2.90
LP2-OL-09-1+SO3 4/12/2019	2	15	S-9205LM22	1.35	0.265	<0.100	<0.100	14.9	<0.100	0.444	2.02	1.55
LP2-OL-14+SO3 4/12/2019	2	16	S-9201LM22	4.95	0.226	3.79	<0.100	15.0	<0.100	1.06	2.13	1.63
LP2-OL-15+SO3 4/12/2019	2	17	S-9204LM22	7.38	0.245	<0.100	<0.100	15.8	<0.100	0.814	<0.100	2.84
LP2-OL-15+SO3 4/12/2019	2	18	S-9204LM12	7.33	0.245	<0.100	<0.100	14.8	<0.100	0.784	<0.100	2.83
LP2-OL-05+SO3 4/12/2019	2	19	S-9207LM12	7.61	0.107	<0.100	<0.100	14.5	<0.100	0.548	<0.100	1.60
LP2-OL-17+SO3 4/12/2019	2	20	S-9202LM22	3.21	<0.100	3.85	0.763	16.6	<0.100	0.701	2.02	1.62
EWG-LAW-SSM-S-3	2	21	S-9206LM12	0.717	<0.100	<0.100	0.969	12.3	0.490	<0.0500	<0.100	<0.100
LP2-OL-14+SO3 4/12/2019	2	22	S-9201LM12	4.86	0.218	3.77	<0.100	15.4	<0.100	1.02	2.08	1.59
LRM	2	23	LRMLM23	0.417	0.141	1.10	<0.100	15.8	0.217	0.0856	<0.100	<0.100

Table A-2. PF Measurements of the Study Glasses

ID	Block	Sequence	Lab ID	Al (wt%)	B (wt%)	Fe (wt%)	Li (wt%)	P (wt%)	Si (wt%)	Sn (wt%)	Zr (wt%)
LRM	1	1	LRMPF11	5.19	2.53	0.981	<0.100	0.186	27.6	<0.100	0.563
LP2-OL-05+SO3 4/12/2019	1	2	S-9207PF21	6.69	1.98	1.06	<0.100	0.434	21.2	<0.100	1.62
LP2-OL-12+SO3 4/12/2019	1	3	S-9203PF11	3.00	4.08	1.01	<0.100	0.483	17.6	<0.100	1.32
LP2-OL-15+SO3 4/12/2019	1	4	S-9204PF11	3.03	4.16	1.01	<0.100	<0.100	18.8	2.52	1.50
LP2-OL-15+SO3 4/12/2019	1	5	S-9204PF21	2.99	4.12	1.02	<0.100	<0.100	18.8	2.61	1.48
LP2-OL-01-3+SO3 4/12/2019	1	6	S-9208PF21	3.06	1.82	<0.100	<0.100	<0.100	24.4	<0.100	3.97
LP2-OL-05+SO3 4/12/2019	1	7	S-9207PF11	6.39	1.86	1.03	<0.100	0.284	20.3	<0.100	1.41
LP2-OL-09-1+SO3 4/12/2019	1	8	S-9205PF11	6.34	4.20	<0.100	<0.100	<0.100	20.3	1.10	1.74
LP2-OL-17+SO3 4/12/2019	1	9	S-9202PF21	3.14	1.88	1.04	<0.100	0.547	18.5	2.71	1.57
EWG-LAW-SSM-S-3	1	10	S-9206PF21	1.85	3.44	6.18	1.94	<0.100	24.5	<0.100	0.207
LP2-OL-04-1+SO3 4/12/2019	1	11	S-9199PF21	5.36	1.80	1.03	<0.100	<0.100	18.0	<0.100	4.00
LRM	1	12	LRMPF12	4.99	2.35	0.942	<0.100	0.179	27.7	<0.100	0.613
LP2-OL-14+SO3 4/12/2019	1	13	S-9201PF11	3.10	4.12	<0.100	<0.100	<0.100	18.7	<0.100	1.50
LP2-OL-01-3+SO3 4/12/2019	1	14	S-9208PF11	2.96	1.76	<0.100	<0.100	<0.100	24.6	<0.100	3.82
LP2-OL-17+SO3 4/12/2019	1	15	S-9202PF11	3.03	1.76	1.00	<0.100	0.460	19.1	2.53	1.51
LP2-OL-12+SO3 4/12/2019	1	16	S-9203PF21	2.92	4.04	0.978	<0.100	0.527	18.1	<0.100	1.45
LP2-OL-07-1+SO3 4/12/2019	1	17	S-9200PF11	5.13	3.62	0.673	<0.100	<0.100	19.8	<0.100	1.77
LP2-OL-07-1+SO3 4/12/2019	1	18	S-9200PF21	5.08	3.55	0.657	<0.100	<0.100	20.2	<0.100	1.76
LP2-OL-09-1+SO3 4/12/2019	1	19	S-9205PF21	5.99	3.84	<0.100	<0.100	<0.100	21.3	1.04	1.64
EWG-LAW-SSM-S-3	1	20	S-9206PF11	1.82	3.30	5.97	1.87	<0.100	25.6	<0.100	0.207
LP2-OL-14+SO3 4/12/2019	1	21	S-9201PF21	2.93	3.89	<0.100	<0.100	<0.100	18.9	<0.100	1.45
LP2-OL-04-1+SO3 4/12/2019	1	22	S-9199PF11	5.24	1.72	0.991	<0.100	<0.100	18.2	<0.100	3.93
LRM	1	23	LRMPF13	5.07	2.39	0.956	<0.100	0.141	27.1	<0.100	0.628
LRM	2	1	LRMPF21	4.94	2.30	0.961	<0.100	0.204	25.9	<0.100	0.563
LP2-OL-17+SO3 4/12/2019	2	2	S-9202PF22	3.01	1.72	1.02	<0.100	0.544	18.5	2.50	1.49
LP2-OL-14+SO3 4/12/2019	2	3	S-9201PF22	2.98	3.98	<0.100	<0.100	0.140	16.6	<0.100	1.50
LP2-OL-12+SO3 4/12/2019	2	4	S-9203PF12	2.92	3.89	1.00	<0.100	0.519	17.0	<0.100	1.32
EWG-LAW-SSM-S-3	2	5	S-9206PF22	1.82	3.26	5.94	1.88	<0.100	24.3	<0.100	0.254
LP2-OL-15+SO3 4/12/2019	2	6	S-9204PF22	3.09	4.31	1.08	<0.100	0.101	18.2	2.66	1.55
EWG-LAW-SSM-S-3	2	7	S-9206PF12	1.88	3.51	6.23	1.96	<0.100	24.5	<0.100	0.271
LP2-OL-09-1+SO3 4/12/2019	2	8	S-9205PF12	6.31	4.25	<0.100	<0.100	0.131	19.7	1.15	1.77
LP2-OL-09-1+SO3 4/12/2019	2	9	S-9205PF22	6.25	4.14	<0.100	<0.100	0.124	19.1	1.14	1.76
LP2-OL-17+SO3 4/12/2019	2	10	S-9202PF12	3.08	1.81	1.06	<0.100	0.534	17.4	2.64	1.58

Table A-2. PF Measurements of the Study Glasses (continued)

ID	Block	Sequence	Lab ID	Al (wt%)	B (wt%)	Fe (wt%)	Li (wt%)	P (wt%)	Si (wt%)	Sn (wt%)	Zr (wt%)
LP2-OL-12+SO3 4/12/2019	2	11	S-9203PF22	2.99	4.09	1.04	<0.100	0.571	16.6	<0.100	1.50
LRM	2	12	LRMPF22	4.99	2.32	0.977	<0.100	0.198	25.8	<0.100	0.617
LP2-OL-15+SO3 4/12/2019	2	13	S-9204PF12	3.00	4.05	1.03	<0.100	<0.100	17.7	2.54	1.50
LP2-OL-14+SO3 4/12/2019	2	14	S-9201PF12	3.01	3.94	<0.100	<0.100	0.138	16.9	<0.100	1.51
LP2-OL-01-3+SO3 4/12/2019	2	15	S-9208PF12	2.93	1.71	<0.100	<0.100	0.107	21.8	<0.100	3.81
LP2-OL-07-1+SO3 4/12/2019	2	16	S-9200PF12	5.24	3.80	0.740	<0.100	0.128	18.5	<0.100	1.88
LP2-OL-05+SO3 4/12/2019	2	17	S-9207PF12	6.52	1.95	1.09	<0.100	0.277	19.3	<0.100	1.42
LP2-OL-04-1+SO3 4/12/2019	2	18	S-9199PF12	5.46	1.85	1.08	<0.100	<0.100	17.4	<0.100	4.14
LP2-OL-04-1+SO3 4/12/2019	2	19	S-9199PF22	5.37	1.79	1.06	<0.100	0.107	17.6	<0.100	4.08
LP2-OL-05+SO3 4/12/2019	2	20	S-9207PF22	6.43	1.83	1.06	<0.100	0.461	19.8	<0.100	1.66
LP2-OL-07-1+SO3 4/12/2019	2	21	S-9200PF22	5.04	3.47	0.698	<0.100	0.172	18.7	<0.100	1.79
LP2-OL-01-3+SO3 4/12/2019	2	22	S-9208PF22	3.02	1.76	<0.100	<0.100	<0.100	23.2	<0.100	3.95
LRM	2	23	LRMPF23	4.95	2.30	0.973	<0.100	0.219	26.2	<0.100	0.665

Table A-3. Comparison of Measured and Targeted Compositions of the Study Glasses

Glass ID	Oxide	BDL (<)	Measured (wt %)	Targeted (wt %)	Difference of Measured versus Targeted	% Difference of Measured versus Targeted
EWG-LAW-SSM-S-3	Al_2O_3		3.481		3.481	
EWG-LAW-SSM-S-3	B_2O_3		10.875		10.875	
EWG-LAW-SSM-S-3	CaO		1.019		1.019	
EWG-LAW-SSM-S-3	Cr_2O_3	<	0.146		0.146	
EWG-LAW-SSM-S-3	Fe_2O_3		8.693		8.693	
EWG-LAW-SSM-S-3	K_2O	<	0.120		0.120	
EWG-LAW-SSM-S-3	Li_2O		4.117		4.117	
EWG-LAW-SSM-S-3	MgO		1.631		1.631	
EWG-LAW-SSM-S-3	Na_2O		16.109		16.109	
EWG-LAW-SSM-S-3	NiO		0.640		0.640	
EWG-LAW-SSM-S-3	P_2O_5	<	0.229		0.229	
EWG-LAW-SSM-S-3	SiO_2		52.894		52.894	
EWG-LAW-SSM-S-3	SnO_2	<	0.127		0.127	
EWG-LAW-SSM-S-3	SO_3	<	0.125		0.125	
EWG-LAW-SSM-S-3	V_2O_5	<	0.179		0.179	
EWG-LAW-SSM-S-3	ZnO	<	0.124		0.124	
EWG-LAW-SSM-S-3	ZrO_2		0.317		0.317	
EWG-LAW-SSM-S-3	Sum		100.827		100.827	
LP2-OL-01-3+SO3 4/12/2019	Al_2O_3		5.654	6.001	-0.347	-5.8%
LP2-OL-01-3+SO3 4/12/2019	B_2O_3		5.675	5.999	-0.324	-5.4%
LP2-OL-01-3+SO3 4/12/2019	CaO		8.525	9.091	-0.566	-6.2%
LP2-OL-01-3+SO3 4/12/2019	Cr_2O_3		0.314	0.601	-0.287	
LP2-OL-01-3+SO3 4/12/2019	Fe_2O_3	<	0.143	0.000	0.143	
LP2-OL-01-3+SO3 4/12/2019	K_2O	<	0.120	0.000	0.120	
LP2-OL-01-3+SO3 4/12/2019	Li_2O	<	0.215		0.215	
LP2-OL-01-3+SO3 4/12/2019	MgO		1.318	1.350	-0.032	
LP2-OL-01-3+SO3 4/12/2019	Na_2O		20.624	21.000	-0.376	-1.8%
LP2-OL-01-3+SO3 4/12/2019	NiO	<	0.127	0.000	0.127	
LP2-OL-01-3+SO3 4/12/2019	P_2O_5	<	0.233	0.204	0.029	
LP2-OL-01-3+SO3 4/12/2019	SiO_2		50.274	46.998	3.275	7.0%
LP2-OL-01-3+SO3 4/12/2019	SnO_2	<	0.127	0.000	0.127	
LP2-OL-01-3+SO3 4/12/2019	SO_3		1.489		1.489	
LP2-OL-01-3+SO3 4/12/2019	V_2O_5	<	0.179	0.000	0.179	
LP2-OL-01-3+SO3 4/12/2019	ZnO		1.998	2.000	-0.002	
LP2-OL-01-3+SO3 4/12/2019	ZrO_2		5.251	6.500	-1.249	-19.2%
LP2-OL-01-3+SO3 4/12/2019	Sum		102.267	99.744	2.523	2.5%
LP2-OL-04-1+SO3 4/12/2019	Al_2O_3		10.123	10.500	-0.377	-3.6%
LP2-OL-04-1+SO3 4/12/2019	B_2O_3		5.764	5.999	-0.235	-3.9%
LP2-OL-04-1+SO3 4/12/2019	CaO		7.594	7.840	-0.246	-3.1%
LP2-OL-04-1+SO3 4/12/2019	Cr_2O_3	<	0.147	0.601	-0.454	
LP2-OL-04-1+SO3 4/12/2019	Fe_2O_3		1.487	1.500	-0.013	
LP2-OL-04-1+SO3 4/12/2019	K_2O		4.041	5.750	-1.708	-29.7%
LP2-OL-04-1+SO3 4/12/2019	Li_2O	<	0.215		0.215	
LP2-OL-04-1+SO3 4/12/2019	MgO		1.329	1.350	-0.021	
LP2-OL-04-1+SO3 4/12/2019	Na_2O		21.332	21.000	0.332	1.6%
LP2-OL-04-1+SO3 4/12/2019	NiO	<	0.127	0.000	0.127	
LP2-OL-04-1+SO3 4/12/2019	P_2O_5	<	0.233	0.204	0.029	
LP2-OL-04-1+SO3 4/12/2019	SiO_2		38.080	34.898	3.181	9.1%
LP2-OL-04-1+SO3 4/12/2019	SnO_2	<	0.127	0.000	0.127	
LP2-OL-04-1+SO3 4/12/2019	SO_3		1.092		1.092	

Table A-3. Comparison of Measured and Targeted Compositions of the Study Glasses (continued)

Glass ID	Oxide	BDL (<)	Measured (wt %)	Targeted (wt %)	Difference of Measured versus Targeted	% Difference of Measured versus Targeted
LP2-OL-04-1+SO3 4/12/2019	V_2O_5	<	0.179	0.000	0.179	
LP2-OL-04-1+SO3 4/12/2019	ZnO		3.694	3.600	0.094	
LP2-OL-04-1+SO3 4/12/2019	ZrO_2		5.454	6.500	-1.046	-16.1%
LP2-OL-04-1+SO3 4/12/2019	Sum		101.017	99.741	1.276	1.3%
LP2-OL-05+SO3 4/12/2019	Al_2O_3		12.296	12.501	-0.205	-1.6%
LP2-OL-05+SO3 4/12/2019	B_2O_3		6.134	5.999	0.135	2.3%
LP2-OL-05+SO3 4/12/2019	CaO		10.795	11.001	-0.206	-1.9%
LP2-OL-05+SO3 4/12/2019	Cr_2O_3		0.163	0.300	-0.137	
LP2-OL-05+SO3 4/12/2019	Fe_2O_3		1.515	1.500	0.016	
LP2-OL-05+SO3 4/12/2019	K_2O	<	0.120	0.000	0.120	
LP2-OL-05+SO3 4/12/2019	Li_2O	<	0.215		0.215	
LP2-OL-05+SO3 4/12/2019	MgO	<	0.166	0.000	0.166	
LP2-OL-05+SO3 4/12/2019	Na_2O		19.715	21.000	-1.286	-6.1%
LP2-OL-05+SO3 4/12/2019	NiO	<	0.127	0.000	0.127	
LP2-OL-05+SO3 4/12/2019	P_2O_5		0.834	1.515	-0.681	
LP2-OL-05+SO3 4/12/2019	SiO_2		43.107	39.079	4.028	10.3%
LP2-OL-05+SO3 4/12/2019	SnO_2	<	0.127	0.000	0.127	
LP2-OL-05+SO3 4/12/2019	SO_3		1.427		1.427	
LP2-OL-05+SO3 4/12/2019	V_2O_5	<	0.179	0.000	0.179	
LP2-OL-05+SO3 4/12/2019	ZnO		2.032	2.000	0.032	
LP2-OL-05+SO3 4/12/2019	ZrO_2		2.063	2.950	-0.887	
LP2-OL-05+SO3 4/12/2019	Sum		101.015	97.844	3.171	3.2%
LP2-OL-07-1+SO3 4/12/2019	Al_2O_3		9.679	10.150	-0.471	-4.6%
LP2-OL-07-1+SO3 4/12/2019	B_2O_3		11.624	12.039	-0.415	-3.5%
LP2-OL-07-1+SO3 4/12/2019	CaO		7.584	8.010	-0.427	-5.3%
LP2-OL-07-1+SO3 4/12/2019	Cr_2O_3		0.275	0.500	-0.225	
LP2-OL-07-1+SO3 4/12/2019	Fe_2O_3		0.989	0.999	-0.010	
LP2-OL-07-1+SO3 4/12/2019	K_2O		0.140	0.160	-0.020	
LP2-OL-07-1+SO3 4/12/2019	Li_2O	<	0.215		0.215	
LP2-OL-07-1+SO3 4/12/2019	MgO		1.039	1.000	0.039	
LP2-OL-07-1+SO3 4/12/2019	Na_2O		19.950	20.980	-1.030	-4.9%
LP2-OL-07-1+SO3 4/12/2019	NiO	<	0.127	0.039	0.088	
LP2-OL-07-1+SO3 4/12/2019	P_2O_5	<	0.286	0.291	-0.005	
LP2-OL-07-1+SO3 4/12/2019	SiO_2		41.288	37.140	4.148	11.2%
LP2-OL-07-1+SO3 4/12/2019	SnO_2	<	0.127	0.000	0.127	
LP2-OL-07-1+SO3 4/12/2019	SO_3		1.634		1.634	
LP2-OL-07-1+SO3 4/12/2019	V_2O_5		0.970	1.000	-0.030	
LP2-OL-07-1+SO3 4/12/2019	ZnO		3.040	3.000	0.040	
LP2-OL-07-1+SO3 4/12/2019	ZrO_2		2.431	3.000	-0.569	
LP2-OL-07-1+SO3 4/12/2019	Sum		101.400	98.310	3.089	3.1%
LP2-OL-09-1+SO3 4/12/2019	Al_2O_3		11.757	12.501	-0.744	-5.9%
LP2-OL-09-1+SO3 4/12/2019	B_2O_3		13.226	13.749	-0.523	-3.8%
LP2-OL-09-1+SO3 4/12/2019	CaO		1.948	1.999	-0.051	
LP2-OL-09-1+SO3 4/12/2019	Cr_2O_3		0.385	0.601	-0.215	
LP2-OL-09-1+SO3 4/12/2019	Fe_2O_3	<	0.143	0.000	0.143	
LP2-OL-09-1+SO3 4/12/2019	K_2O	<	0.120	0.000	0.120	
LP2-OL-09-1+SO3 4/12/2019	Li_2O	<	0.215		0.215	
LP2-OL-09-1+SO3 4/12/2019	MgO	<	0.166	0.000	0.166	
LP2-OL-09-1+SO3 4/12/2019	Na_2O		20.557	21.000	-0.443	-2.1%
LP2-OL-09-1+SO3 4/12/2019	NiO	<	0.127	0.000	0.127	

Table A-3. Comparison of Measured and Targeted Compositions of the Study Glasses (continued)

Glass ID	Oxide	BDL (<)	Measured (wt %)	Targeted (wt %)	Difference of Measured versus Targeted	% Difference of Measured versus Targeted
LP2-OL-09-1+SO3 4/12/2019	P_2O_5	<	0.261	0.204	0.057	
LP2-OL-09-1+SO3 4/12/2019	SiO_2		43.000	39.190	3.810	9.7%
LP2-OL-09-1+SO3 4/12/2019	SnO_2		1.406	1.550	-0.144	
LP2-OL-09-1+SO3 4/12/2019	SO_3		1.096		1.096	
LP2-OL-09-1+SO3 4/12/2019	V_2O_5		3.709	4.001	-0.292	
LP2-OL-09-1+SO3 4/12/2019	ZnO		2.004	2.000	0.004	
LP2-OL-09-1+SO3 4/12/2019	ZrO_2		2.334	2.950	-0.617	
LP2-OL-09-1+SO3 4/12/2019	Sum		102.455	99.746	2.709	2.7%
LP2-OL-12+SO3 4/12/2019	Al_2O_3		5.588	6.001	-0.413	-6.9%
LP2-OL-12+SO3 4/12/2019	B_2O_3		12.960	13.749	-0.789	-5.7%
LP2-OL-12+SO3 4/12/2019	CaO		7.503	7.991	-0.488	-6.1%
LP2-OL-12+SO3 4/12/2019	Cr_2O_3		0.376	0.601	-0.224	
LP2-OL-12+SO3 4/12/2019	Fe_2O_3		1.440	1.500	-0.060	
LP2-OL-12+SO3 4/12/2019	K_2O	<	0.120	0.000	0.120	
LP2-OL-12+SO3 4/12/2019	Li_2O	<	0.215		0.215	
LP2-OL-12+SO3 4/12/2019	MgO		1.298	1.350	-0.052	
LP2-OL-12+SO3 4/12/2019	Na_2O		24.129	25.942	-1.813	-7.0%
LP2-OL-12+SO3 4/12/2019	NiO	<	0.127	0.000	0.127	
LP2-OL-12+SO3 4/12/2019	P_2O_5		1.203	1.515	-0.312	
LP2-OL-12+SO3 4/12/2019	SiO_2		37.063	35.127	1.936	5.5%
LP2-OL-12+SO3 4/12/2019	SnO_2	<	0.127	0.000	0.127	
LP2-OL-12+SO3 4/12/2019	SO_3		2.319		2.319	
LP2-OL-12+SO3 4/12/2019	V_2O_5	<	0.179	0.000	0.179	
LP2-OL-12+SO3 4/12/2019	ZnO		2.007	2.000	0.007	
LP2-OL-12+SO3 4/12/2019	ZrO_2		1.888	2.950	-1.062	
LP2-OL-12+SO3 4/12/2019	Sum		98.544	98.726	-0.182	-0.2%
LP2-OL-14+SO3 4/12/2019	Al_2O_3		5.678	6.001	-0.323	-5.4%
LP2-OL-14+SO3 4/12/2019	B_2O_3		12.823	13.749	-0.926	-6.7%
LP2-OL-14+SO3 4/12/2019	CaO		6.870	7.171	-0.301	-4.2%
LP2-OL-14+SO3 4/12/2019	Cr_2O_3		0.327	0.601	-0.274	
LP2-OL-14+SO3 4/12/2019	Fe_2O_3	<	0.143	0.000	0.143	
LP2-OL-14+SO3 4/12/2019	K_2O		4.565	5.750	-1.184	-20.6%
LP2-OL-14+SO3 4/12/2019	Li_2O	<	0.215		0.215	
LP2-OL-14+SO3 4/12/2019	MgO	<	0.166	0.000	0.166	
LP2-OL-14+SO3 4/12/2019	Na_2O		20.658	21.000	-0.342	-1.6%
LP2-OL-14+SO3 4/12/2019	NiO	<	0.127	0.000	0.127	
LP2-OL-14+SO3 4/12/2019	P_2O_5	<	0.274	0.204	0.070	
LP2-OL-14+SO3 4/12/2019	SiO_2		38.026	34.898	3.128	9.0%
LP2-OL-14+SO3 4/12/2019	SnO_2	<	0.127	0.000	0.127	
LP2-OL-14+SO3 4/12/2019	SO_3		2.603		2.603	
LP2-OL-14+SO3 4/12/2019	V_2O_5		3.744	4.001	-0.256	
LP2-OL-14+SO3 4/12/2019	ZnO		2.010	2.000	0.010	
LP2-OL-14+SO3 4/12/2019	ZrO_2		2.013	2.950	-0.937	
LP2-OL-14+SO3 4/12/2019	Sum		100.370	98.325	2.045	2.1%
LP2-OL-15+SO3 4/12/2019	Al_2O_3		5.720	6.001	-0.281	-4.7%
LP2-OL-15+SO3 4/12/2019	B_2O_3		13.395	13.749	-0.354	-2.6%
LP2-OL-15+SO3 4/12/2019	CaO		10.186	11.001	-0.814	-7.4%
LP2-OL-15+SO3 4/12/2019	Cr_2O_3		0.364	0.601	-0.236	
LP2-OL-15+SO3 4/12/2019	Fe_2O_3		1.480	1.500	-0.020	
LP2-OL-15+SO3 4/12/2019	K_2O	<	0.120	0.000	0.120	

Table A-3. Comparison of Measured and Targeted Compositions of the Study Glasses (continued)

Glass ID	Oxide	BDL (<)	Measured (wt %)	Targeted (wt %)	Difference of Measured versus Targeted	% Difference of Measured versus Targeted
LP2-OL-15+SO3 4/12/2019	Li_2O	<	0.215		0.215	
LP2-OL-15+SO3 4/12/2019	MgO	<	0.166	0.000	0.166	
LP2-OL-15+SO3 4/12/2019	Na_2O		20.692	21.000	-0.309	-1.5%
LP2-OL-15+SO3 4/12/2019	NiO	<	0.127	0.000	0.127	
LP2-OL-15+SO3 4/12/2019	P_2O_5	<	0.230	0.204	0.026	
LP2-OL-15+SO3 4/12/2019	SiO_2		39.310	35.639	3.671	10.3%
LP2-OL-15+SO3 4/12/2019	SnO_2		3.279	3.500	-0.222	
LP2-OL-15+SO3 4/12/2019	SO_3		2.022		2.022	
LP2-OL-15+SO3 4/12/2019	V_2O_5	<	0.179	0.000	0.179	
LP2-OL-15+SO3 4/12/2019	ZnO		3.535	3.600	-0.065	
LP2-OL-15+SO3 4/12/2019	ZrO_2		2.036	2.950	-0.914	
LP2-OL-15+SO3 4/12/2019	Sum		103.057	99.744	3.312	3.3%
LP2-OL-17+SO3 4/12/2019	Al_2O_3		5.791	6.001	-0.210	-3.5%
LP2-OL-17+SO3 4/12/2019	B_2O_3		5.772	5.999	-0.227	-3.8%
LP2-OL-17+SO3 4/12/2019	CaO		4.498	4.550	-0.052	
LP2-OL-17+SO3 4/12/2019	Cr_2O_3	<	0.146	0.300	-0.153	
LP2-OL-17+SO3 4/12/2019	Fe_2O_3		1.473	1.500	-0.027	
LP2-OL-17+SO3 4/12/2019	K_2O		4.614	5.750	-1.136	-19.8%
LP2-OL-17+SO3 4/12/2019	Li_2O	<	0.215		0.215	
LP2-OL-17+SO3 4/12/2019	MgO		1.313	1.350	-0.037	
LP2-OL-17+SO3 4/12/2019	Na_2O		22.309	22.206	0.104	0.5%
LP2-OL-17+SO3 4/12/2019	NiO	<	0.127	0.000	0.127	
LP2-OL-17+SO3 4/12/2019	P_2O_5		1.194	1.515	-0.320	
LP2-OL-17+SO3 4/12/2019	SiO_2		39.310	37.104	2.206	5.9%
LP2-OL-17+SO3 4/12/2019	SnO_2		3.295	3.500	-0.206	
LP2-OL-17+SO3 4/12/2019	SO_3		1.786		1.786	
LP2-OL-17+SO3 4/12/2019	V_2O_5		3.664	4.001	-0.337	
LP2-OL-17+SO3 4/12/2019	ZnO		2.051	2.000	0.050	
LP2-OL-17+SO3 4/12/2019	ZrO_2		2.077	2.950	-0.873	
LP2-OL-17+SO3 4/12/2019	Sum		99.635	98.724	0.911	0.9%
LRM	Al_2O_3		9.488	9.510	-0.022	-0.2%
LRM	B_2O_3		7.615	7.850	-0.235	-3.0%
LRM	CaO		0.580	0.540	0.040	
LRM	Cr_2O_3		0.215	0.190	0.025	
LRM	Fe_2O_3		1.380	1.380	0.000	
LRM	K_2O		1.377	1.480	-0.103	
LRM	Li_2O	<	0.215	0.110	0.105	
LRM	MgO	<	0.166	0.100	0.066	
LRM	Na_2O		20.804	20.030	0.774	3.9%
LRM	NiO		0.305	0.190	0.115	
LRM	P_2O_5		0.430	0.540	-0.110	
LRM	SiO_2		57.155	54.200	2.955	5.5%
LRM	SnO_2	<	0.127	0.000	0.127	
LRM	SO_3		0.235	0.300	-0.065	
LRM	V_2O_5	<	0.179	0.000	0.179	
LRM	ZnO	<	0.124	0.000	0.124	
LRM	ZrO_2		0.822	0.930	-0.108	
LRM	Sum		101.218	97.350	3.868	4.0%

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

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

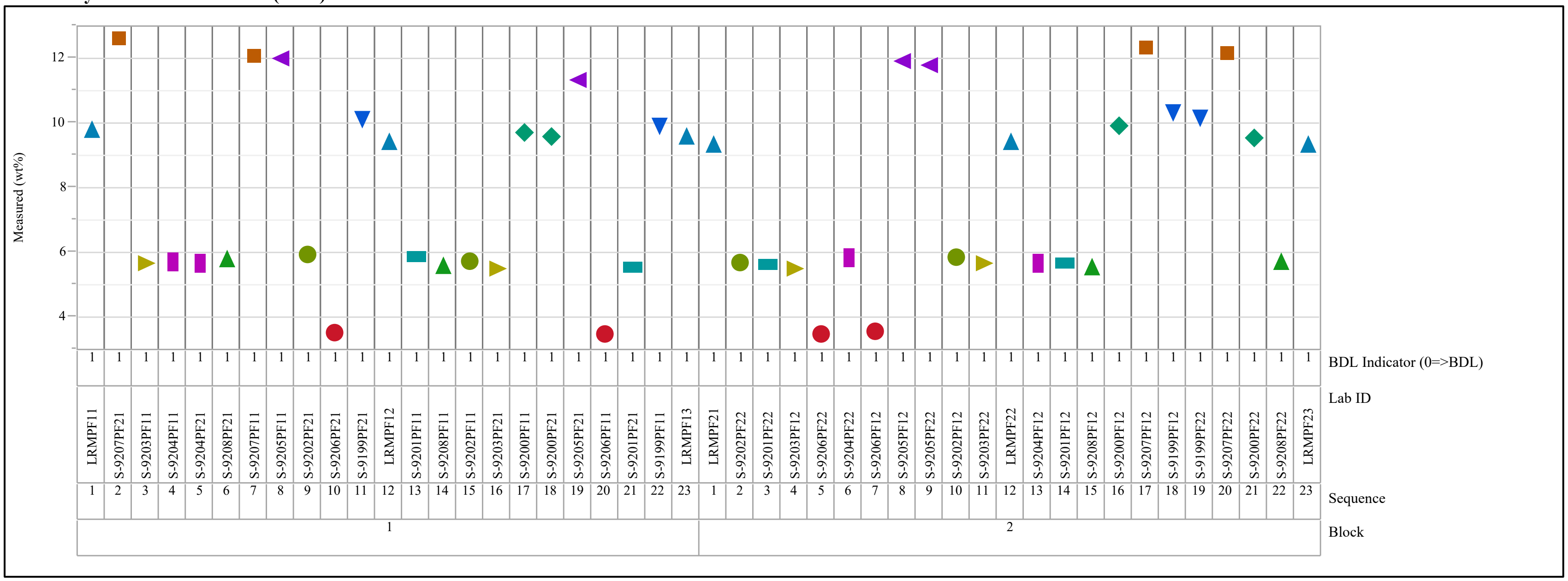


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

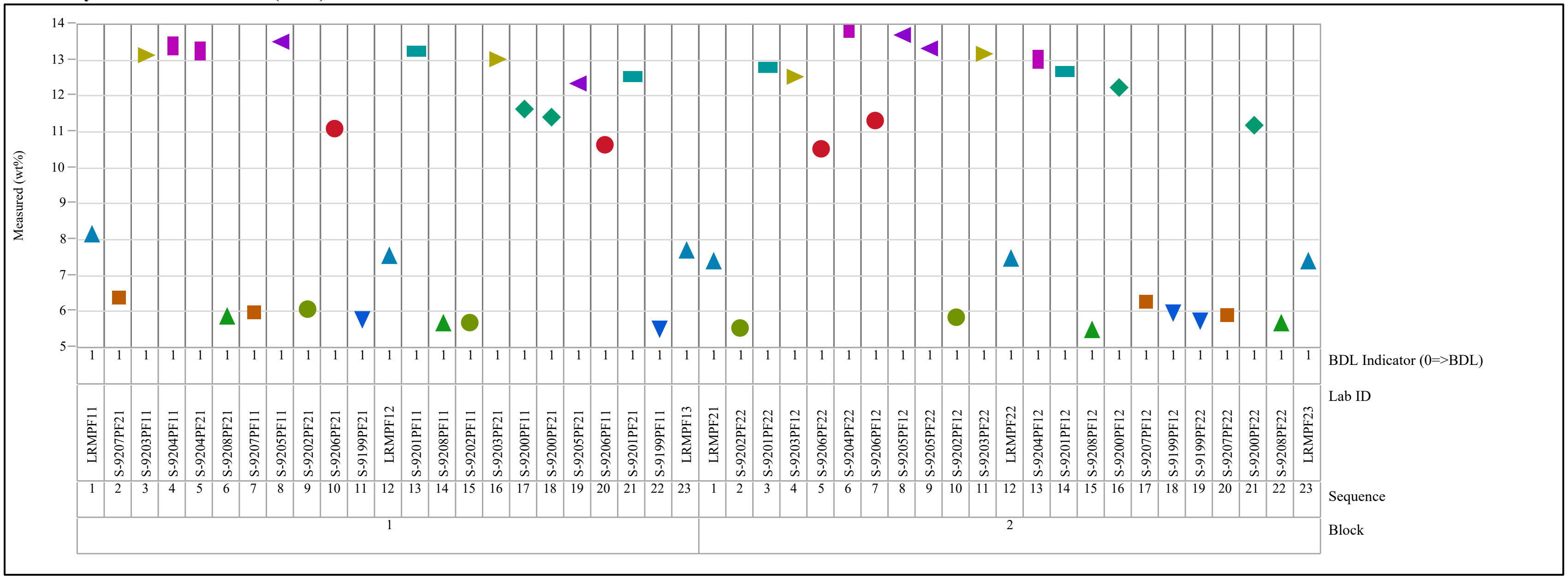


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

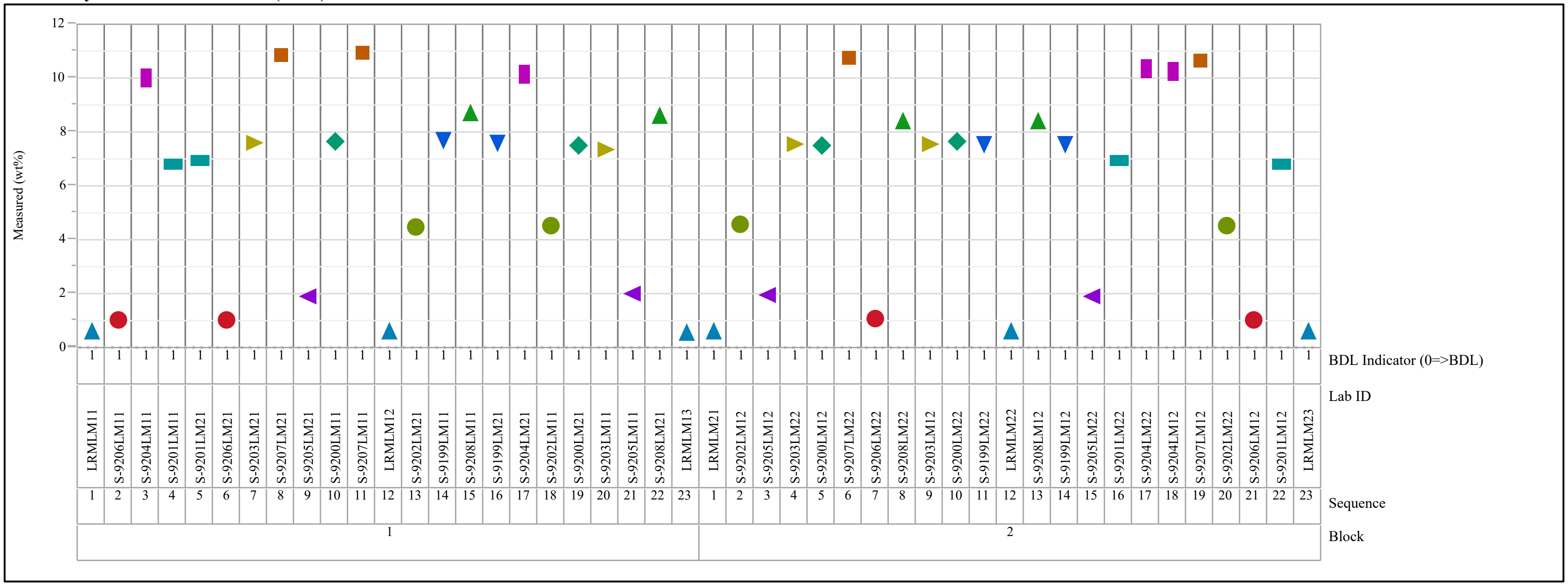


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

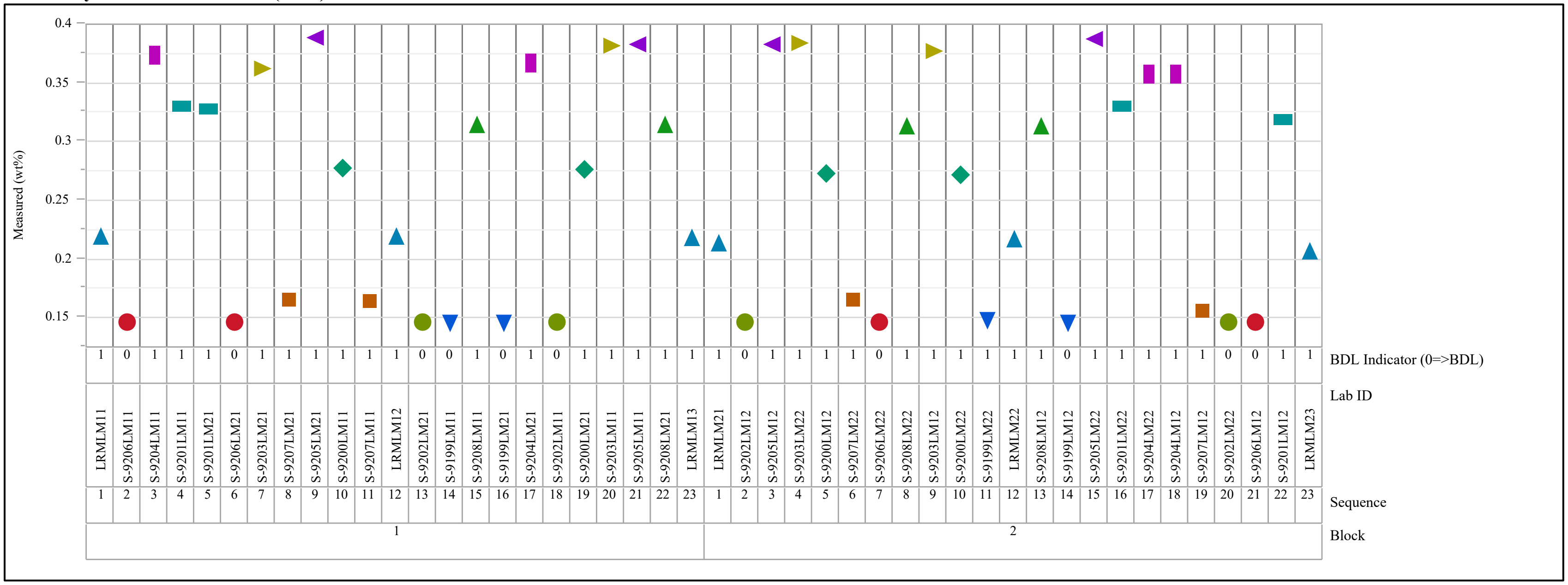


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

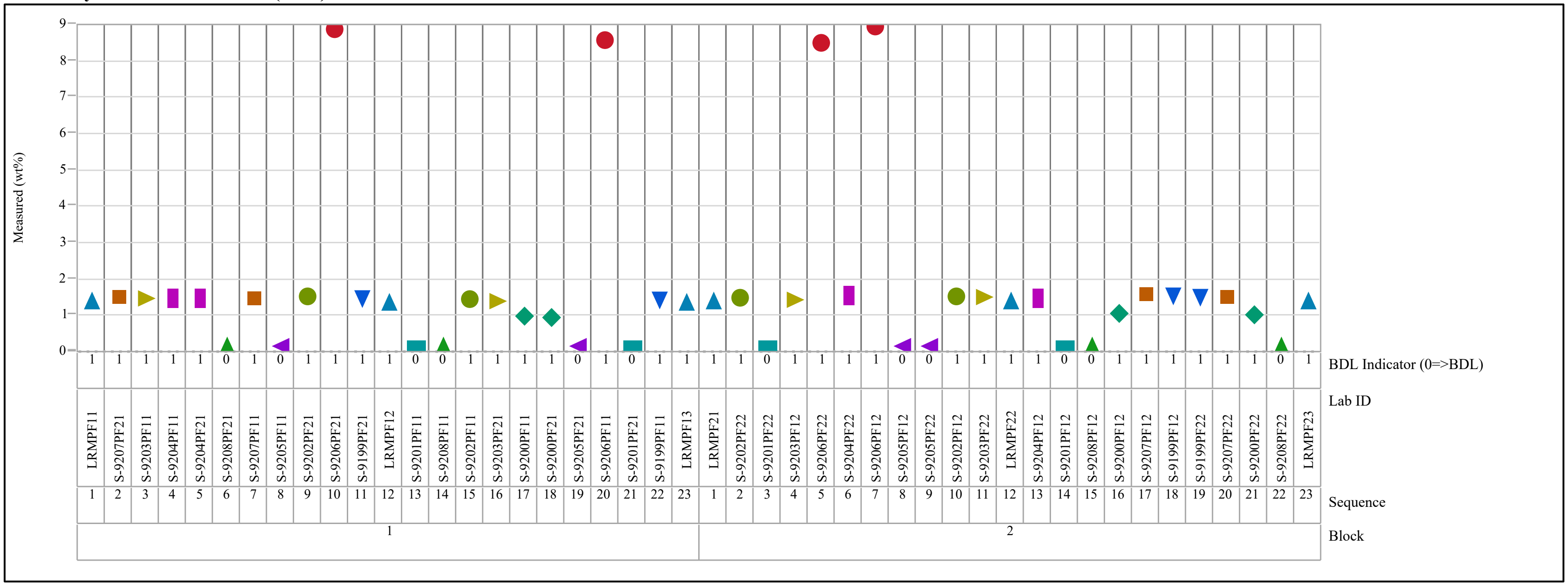


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

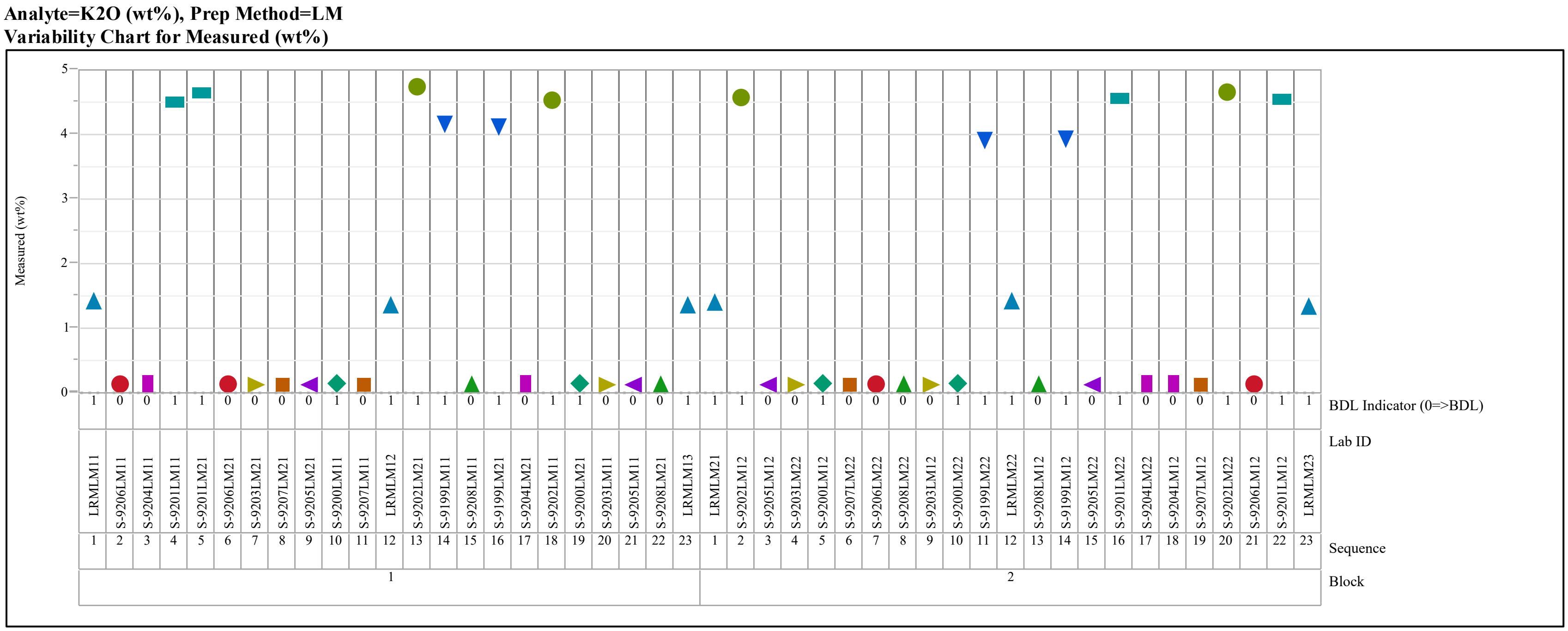


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

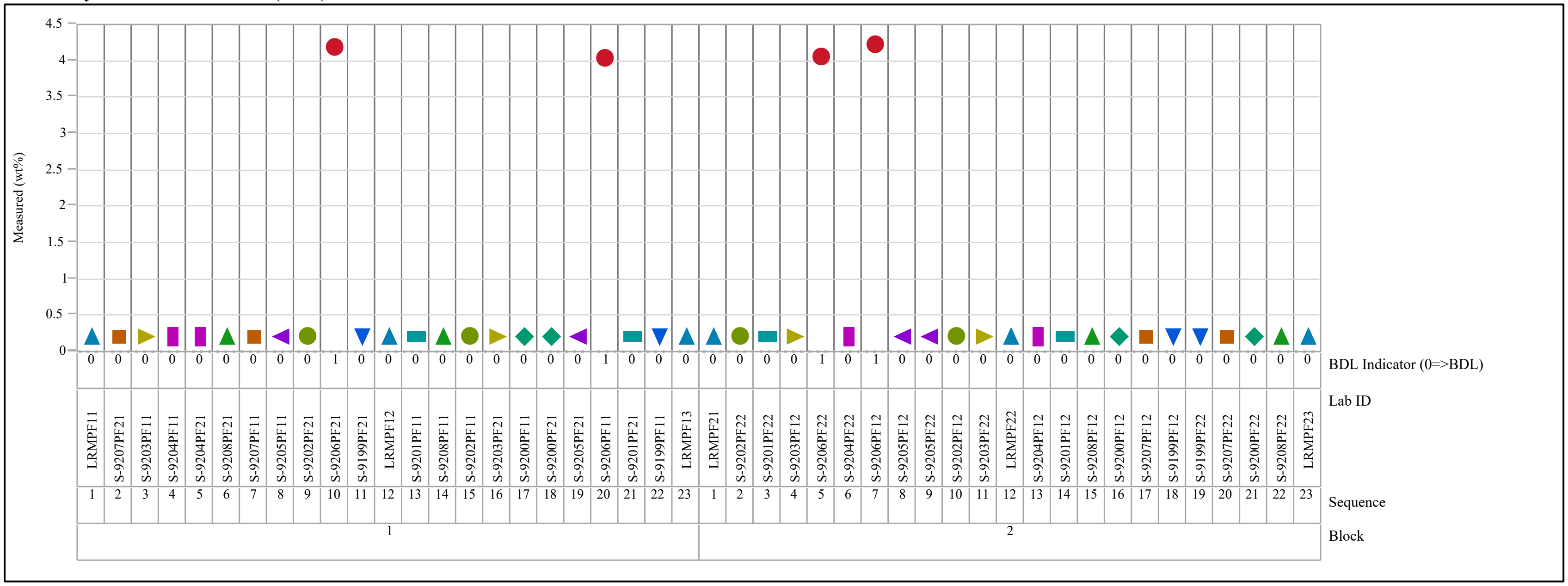


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

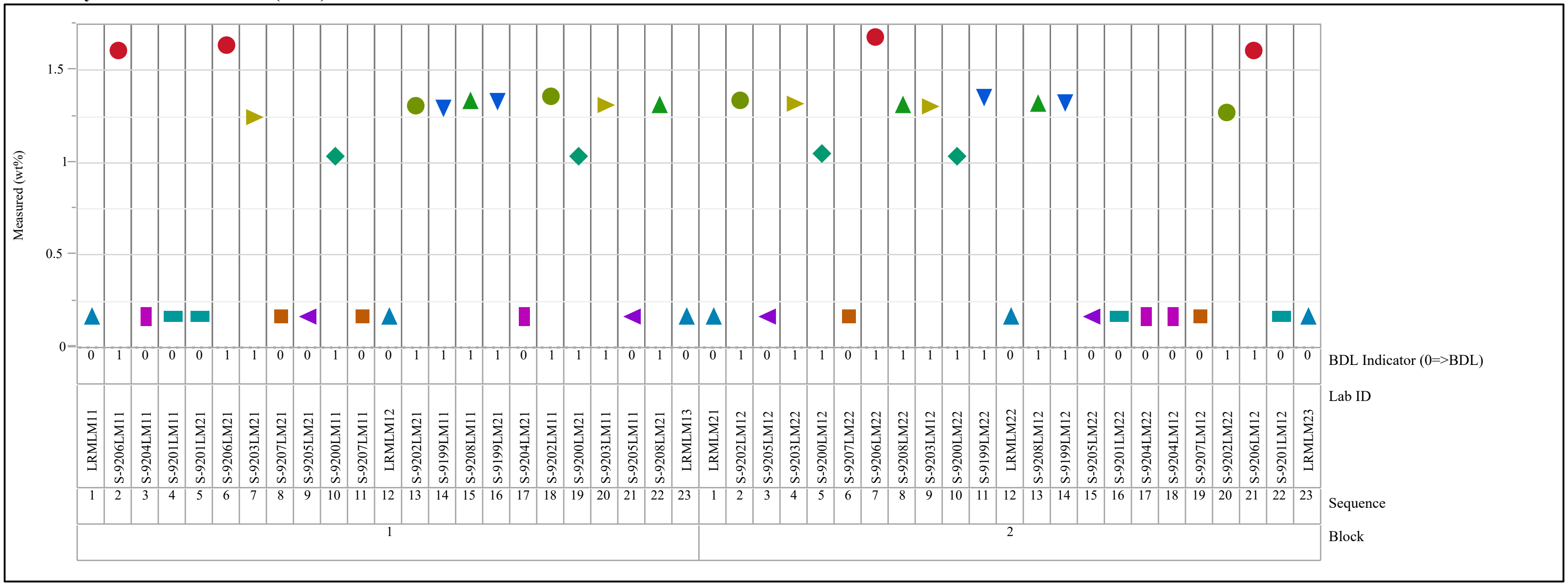


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

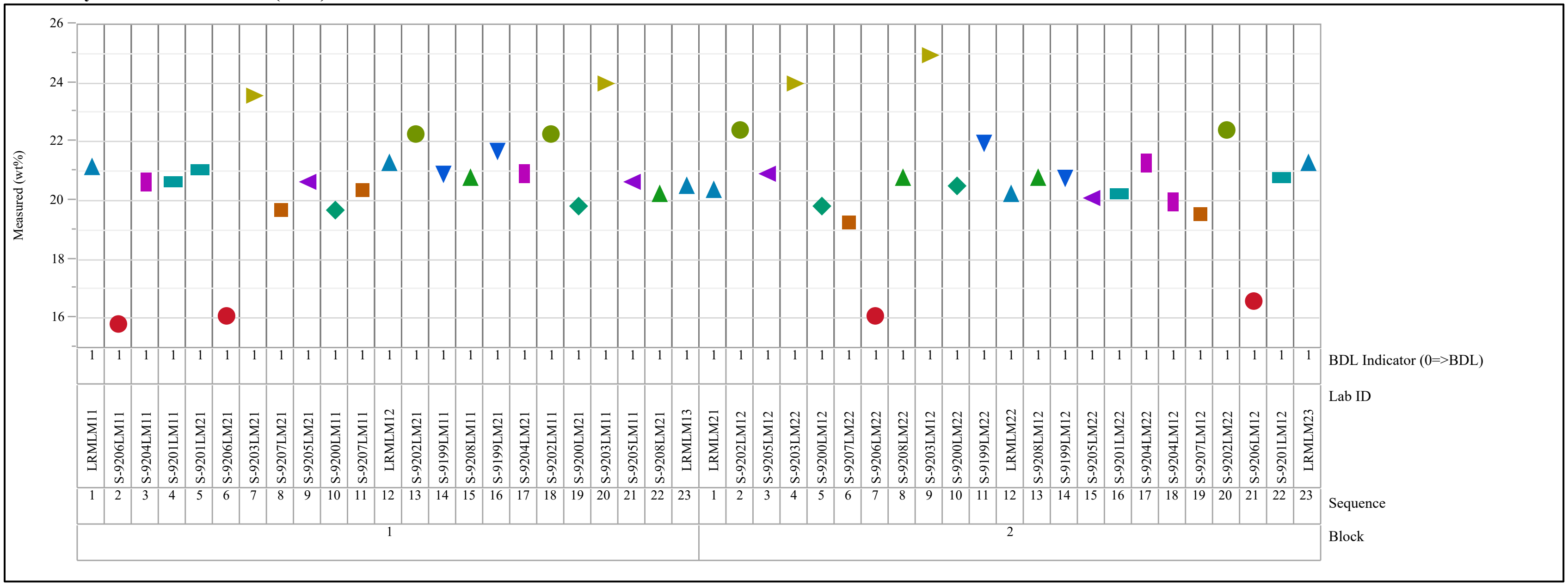


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

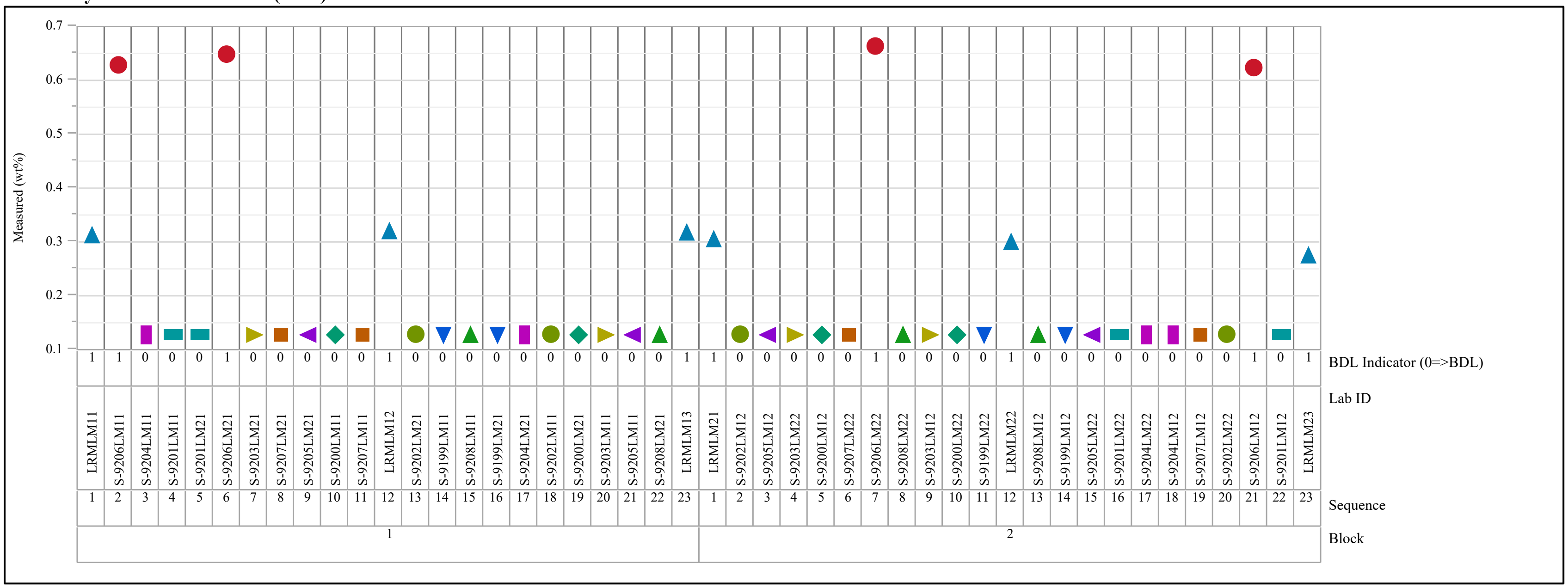


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

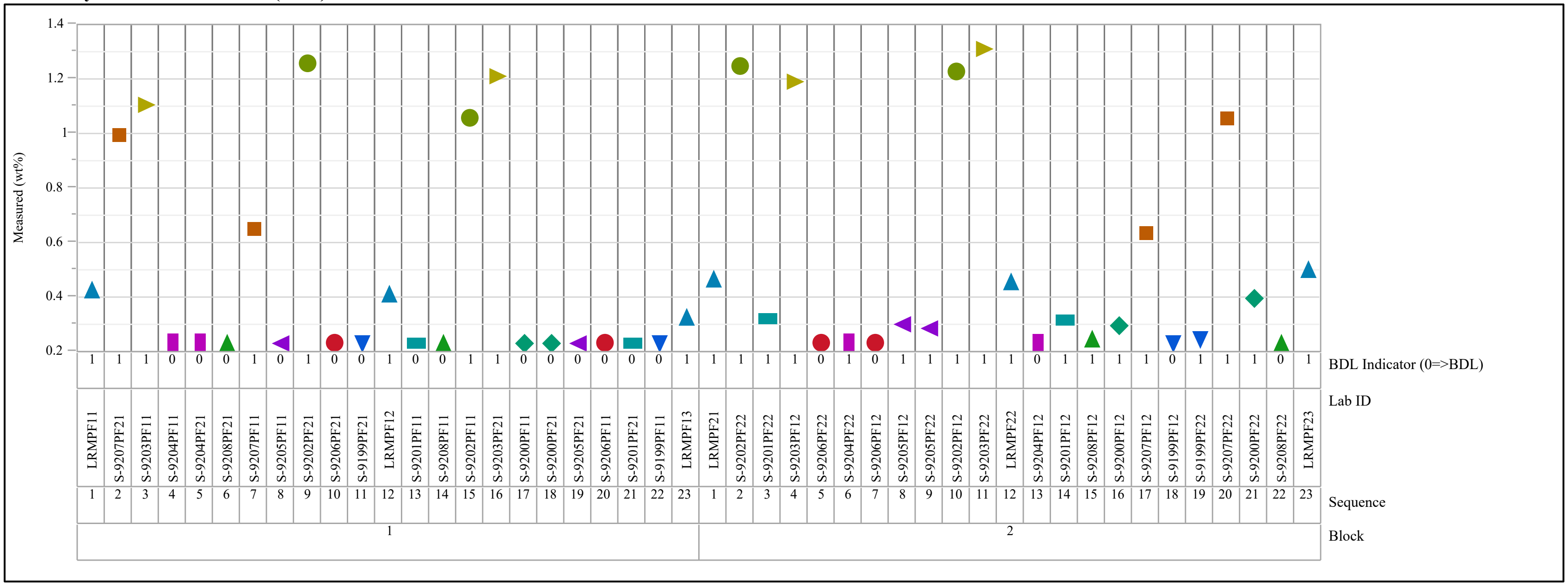


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

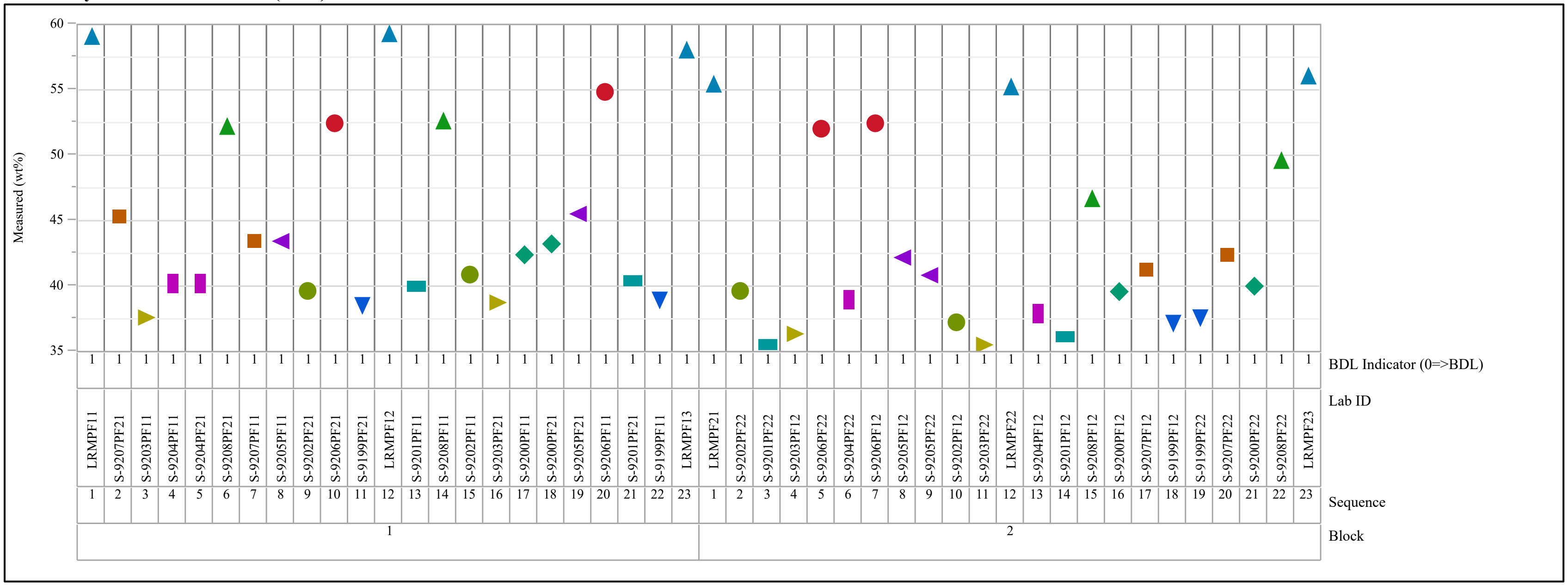


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

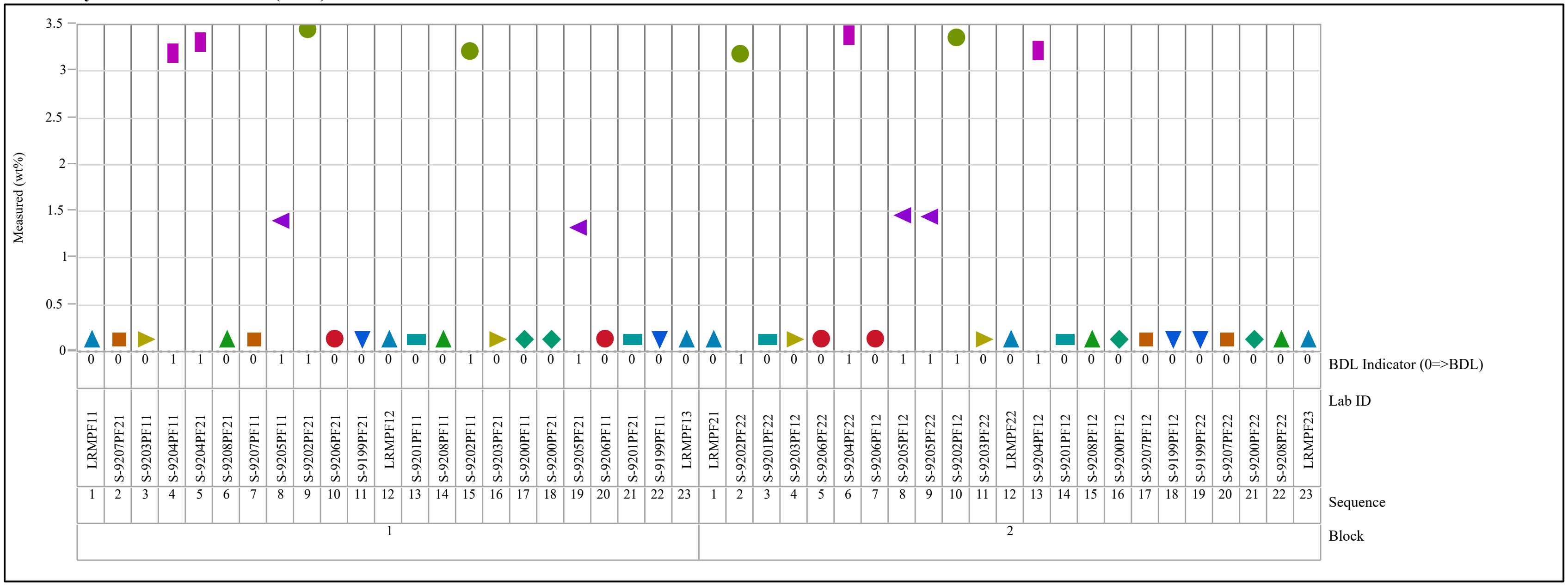


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

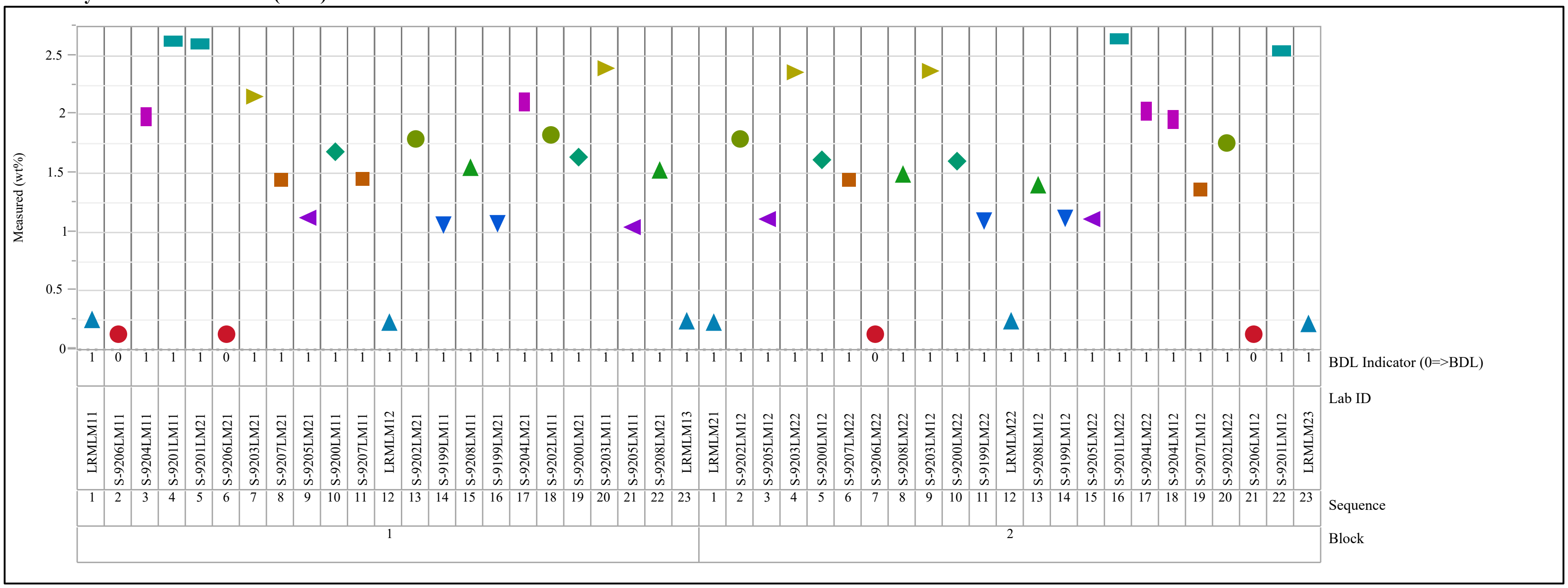


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

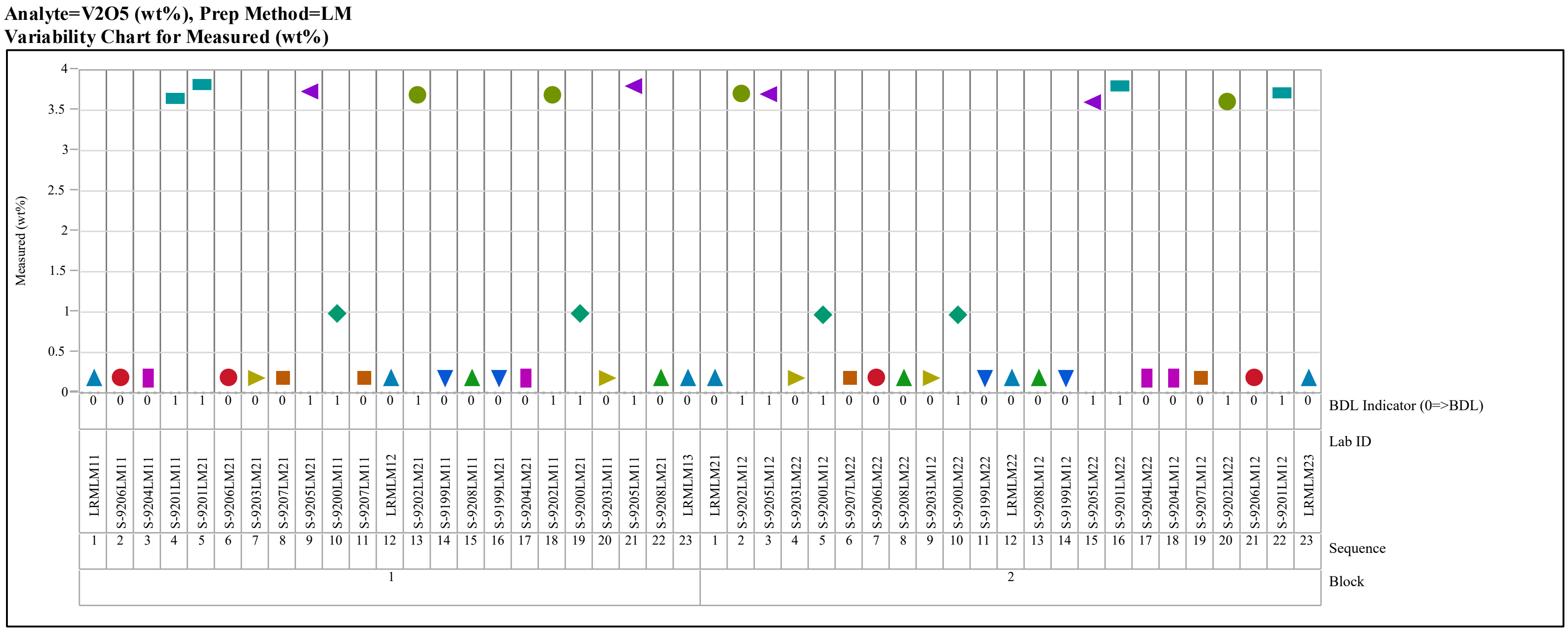


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

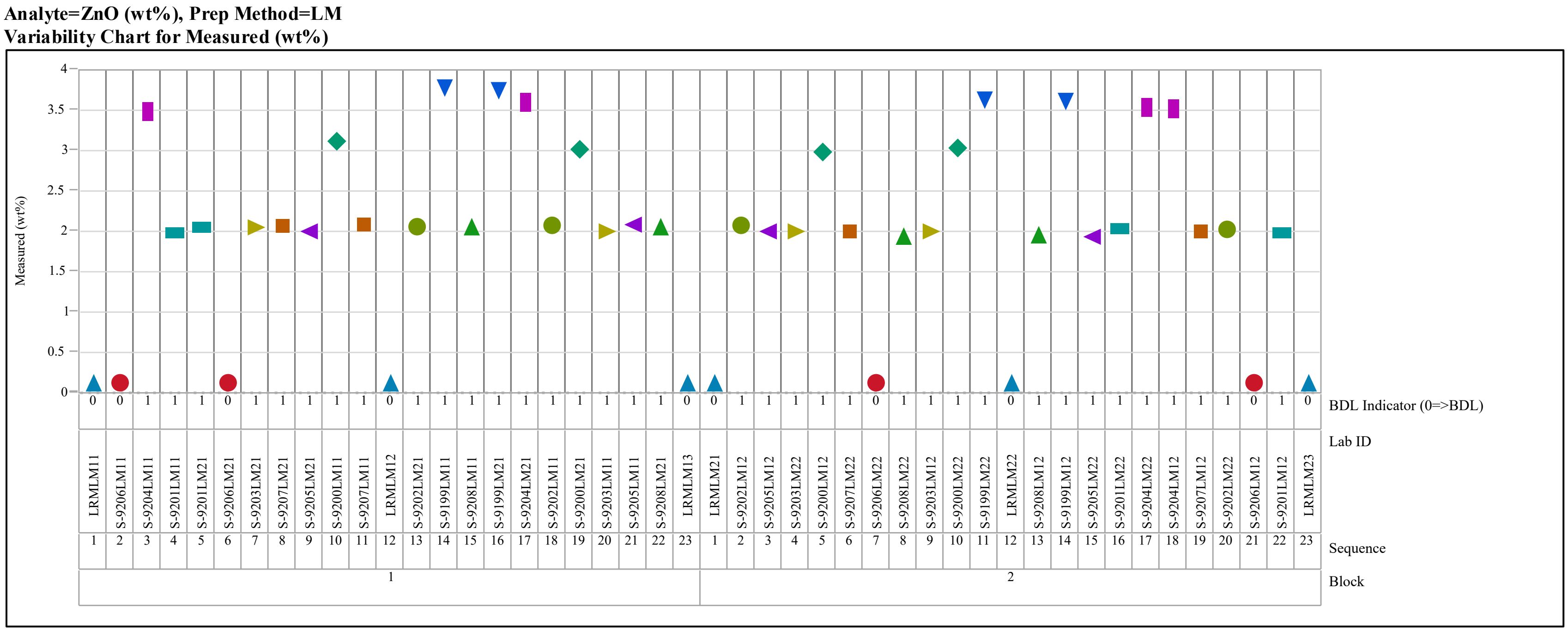


Exhibit A-1. Plots of Oxide Measurements in Analytical Sequence (continued)

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

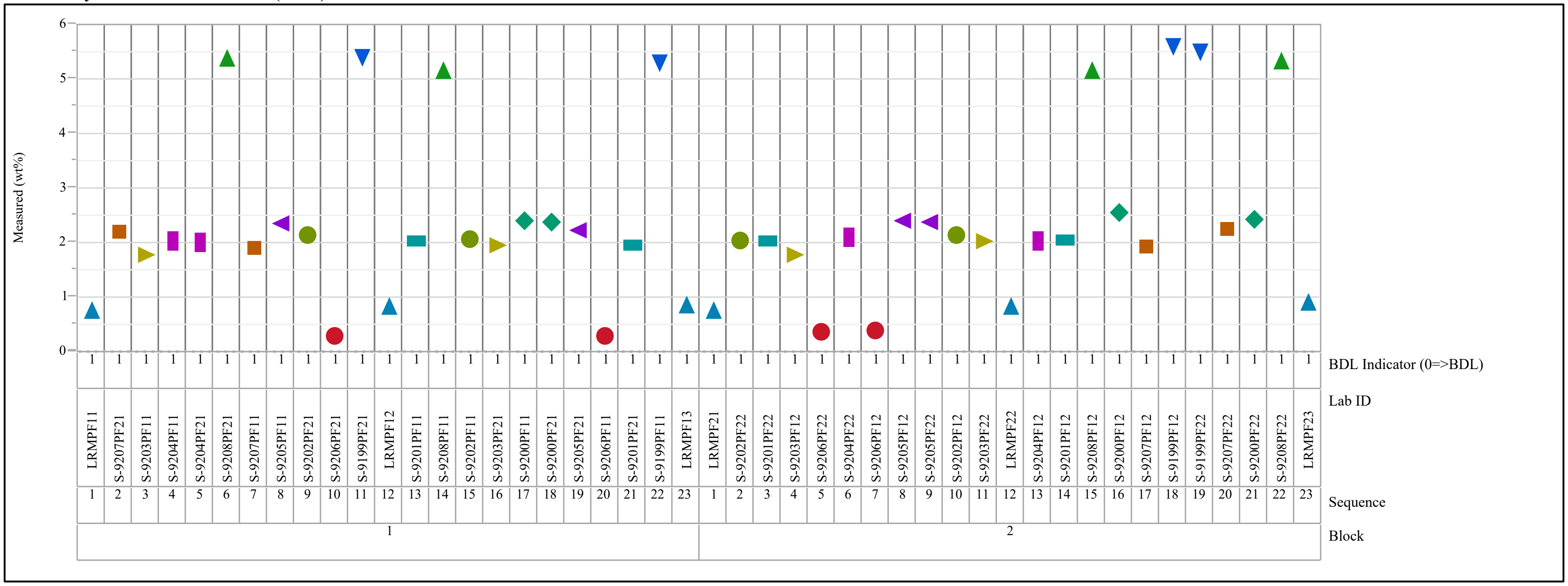


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier

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

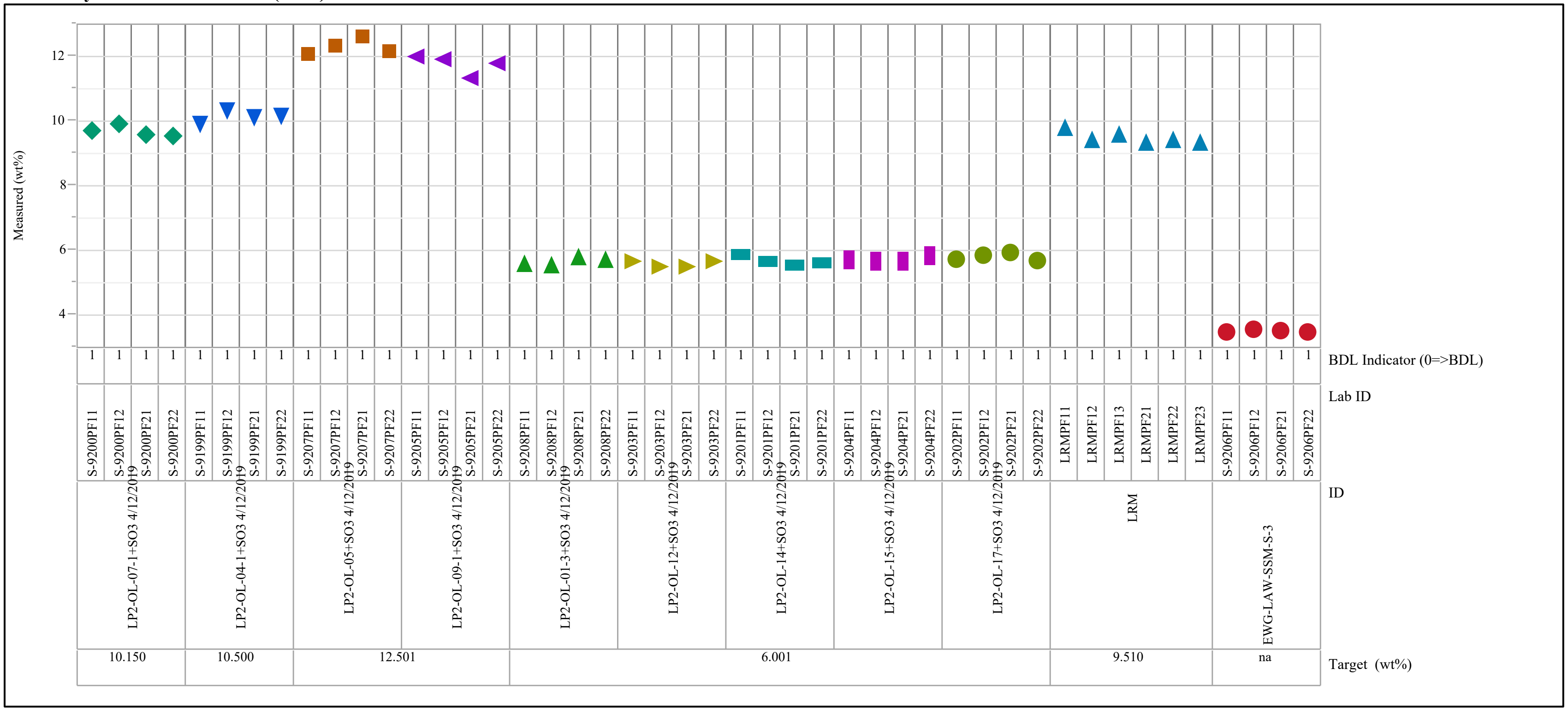


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

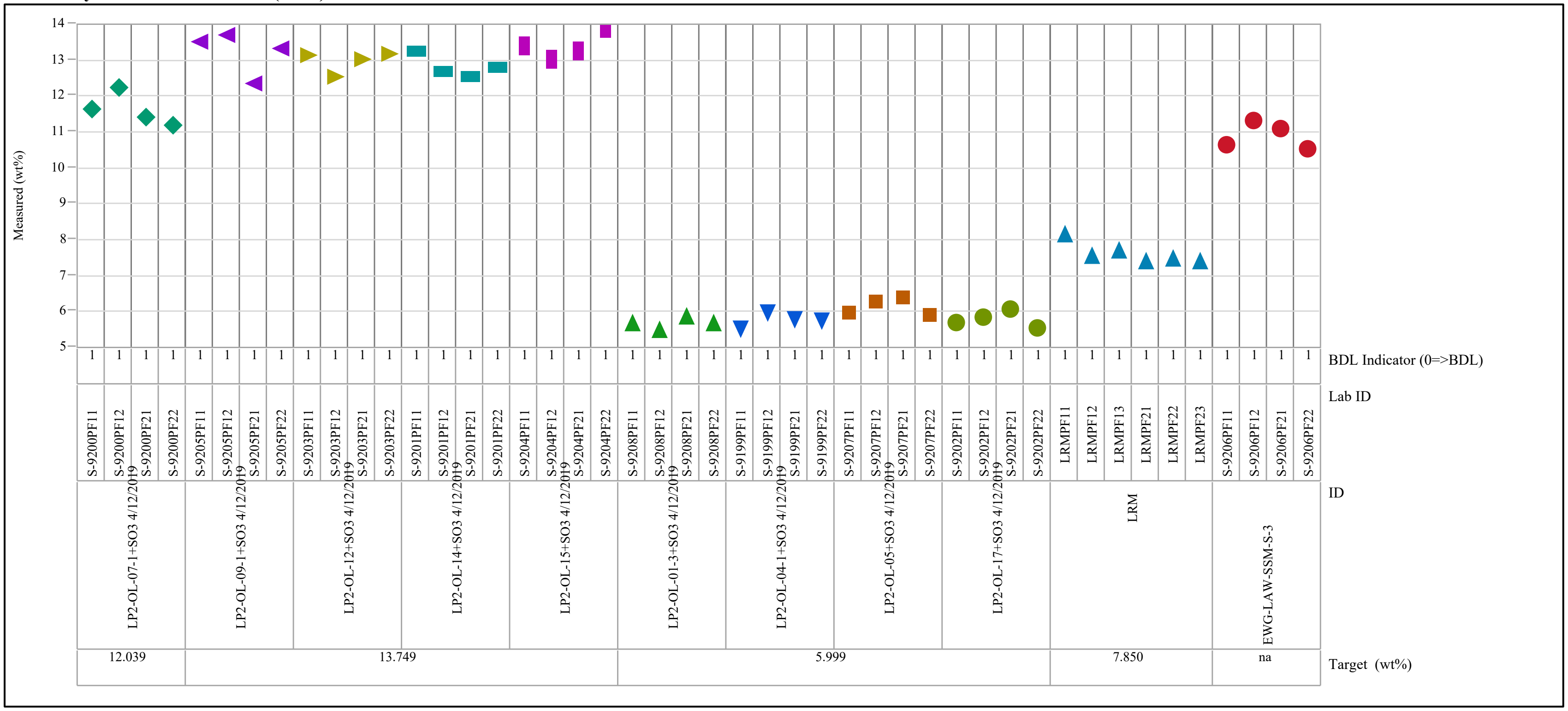


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

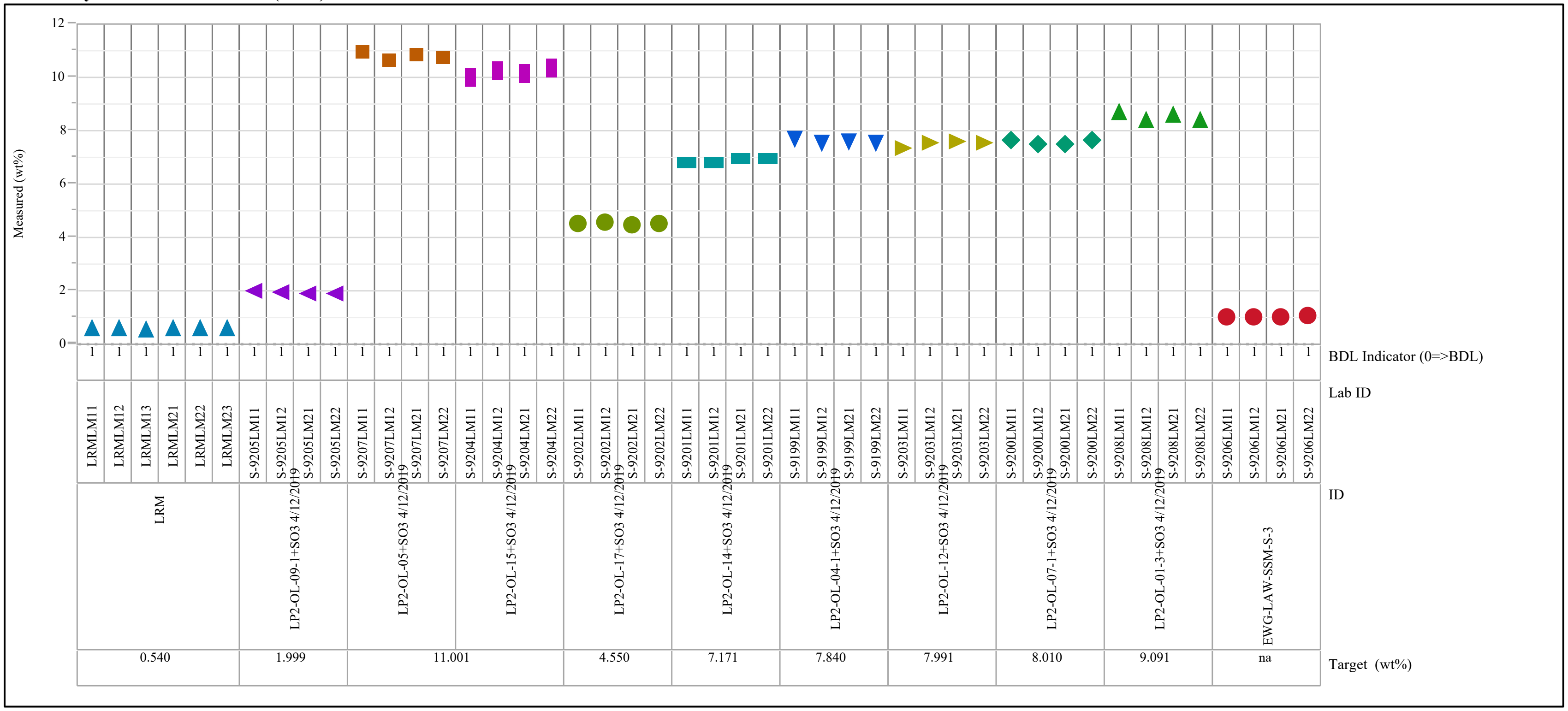


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

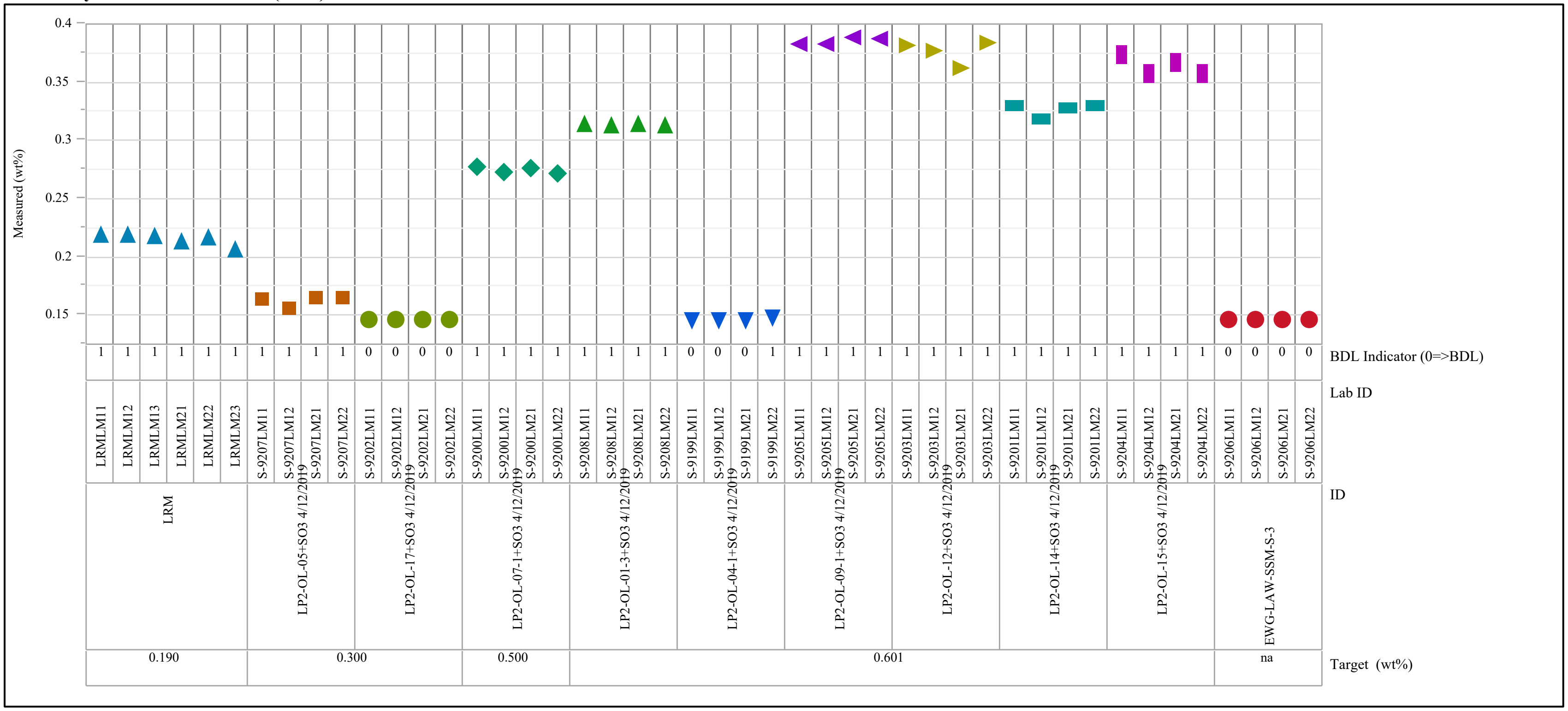


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

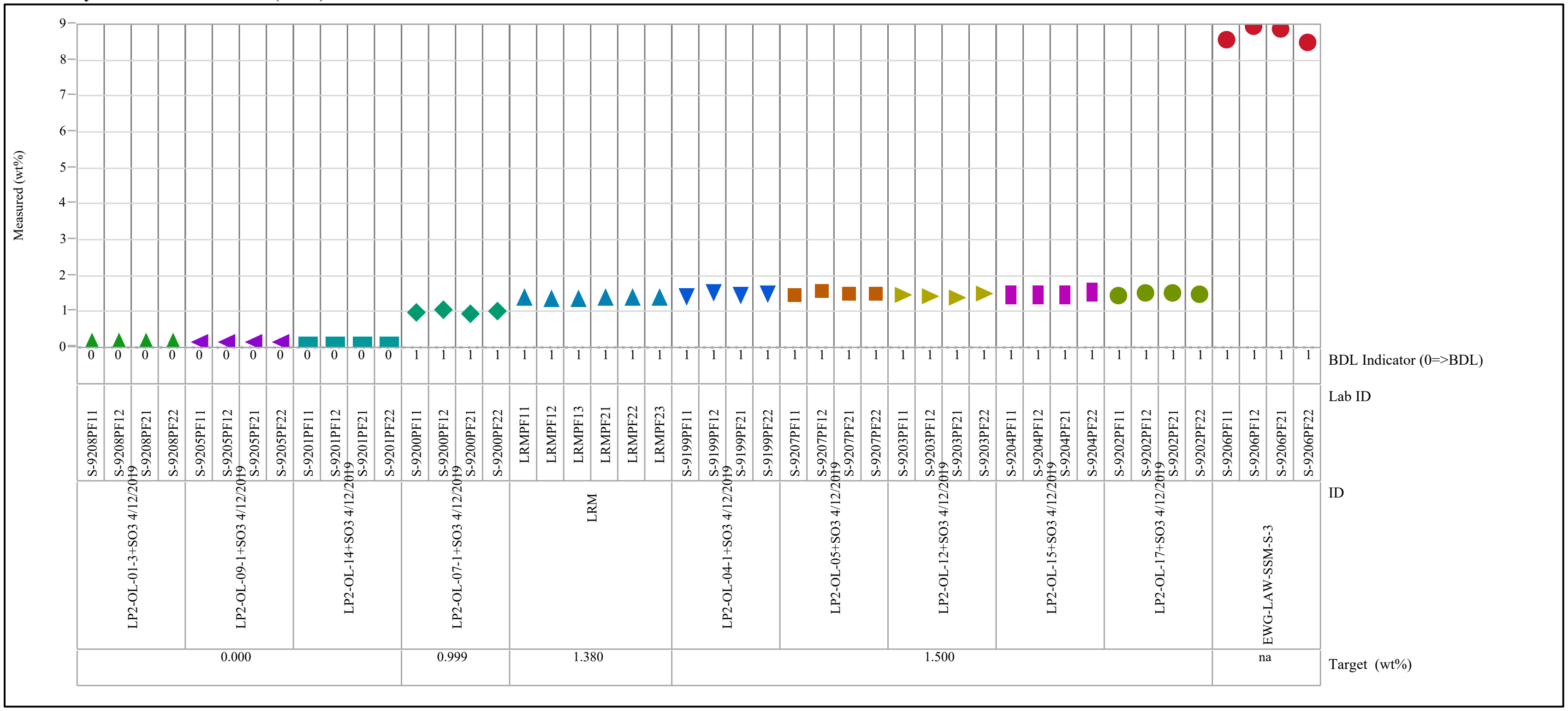


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

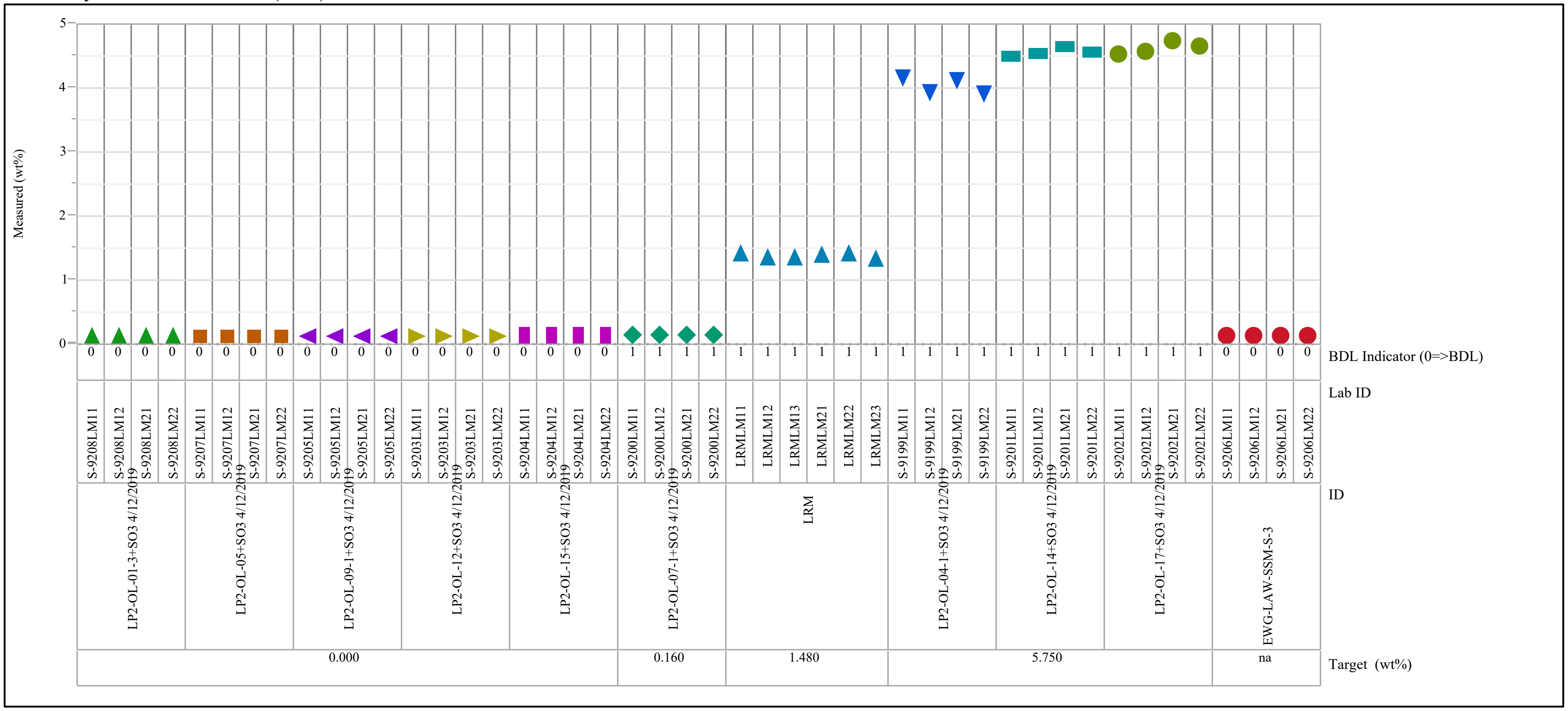


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

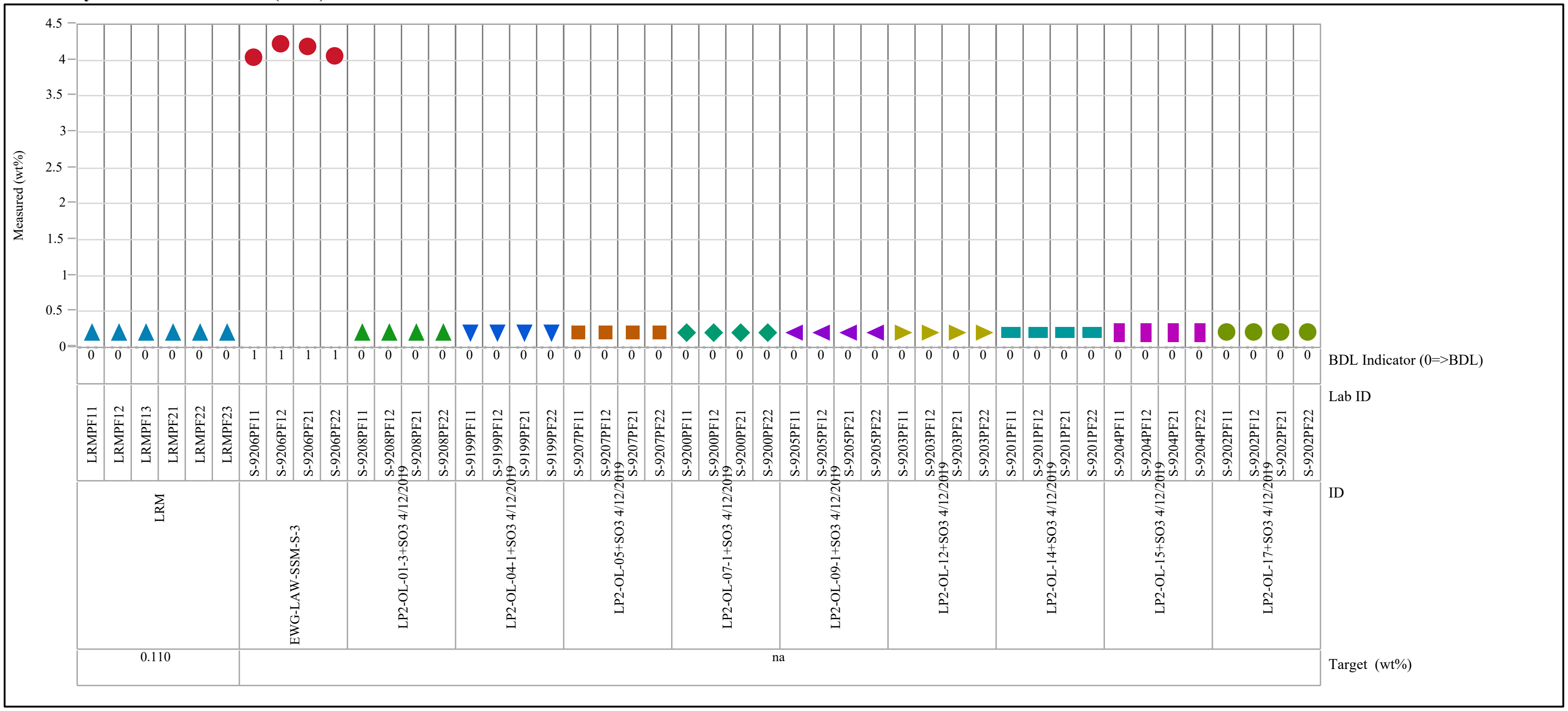


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

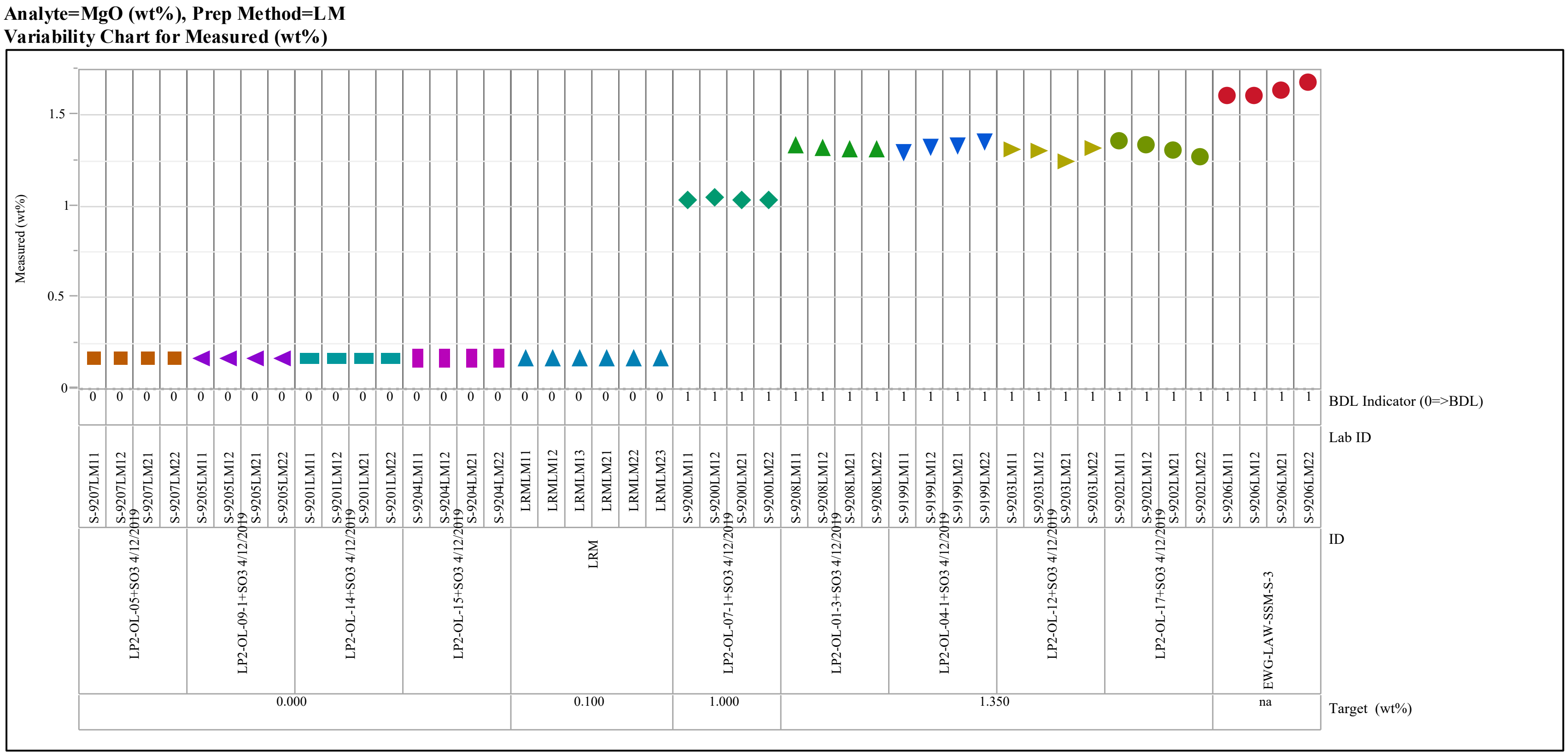


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

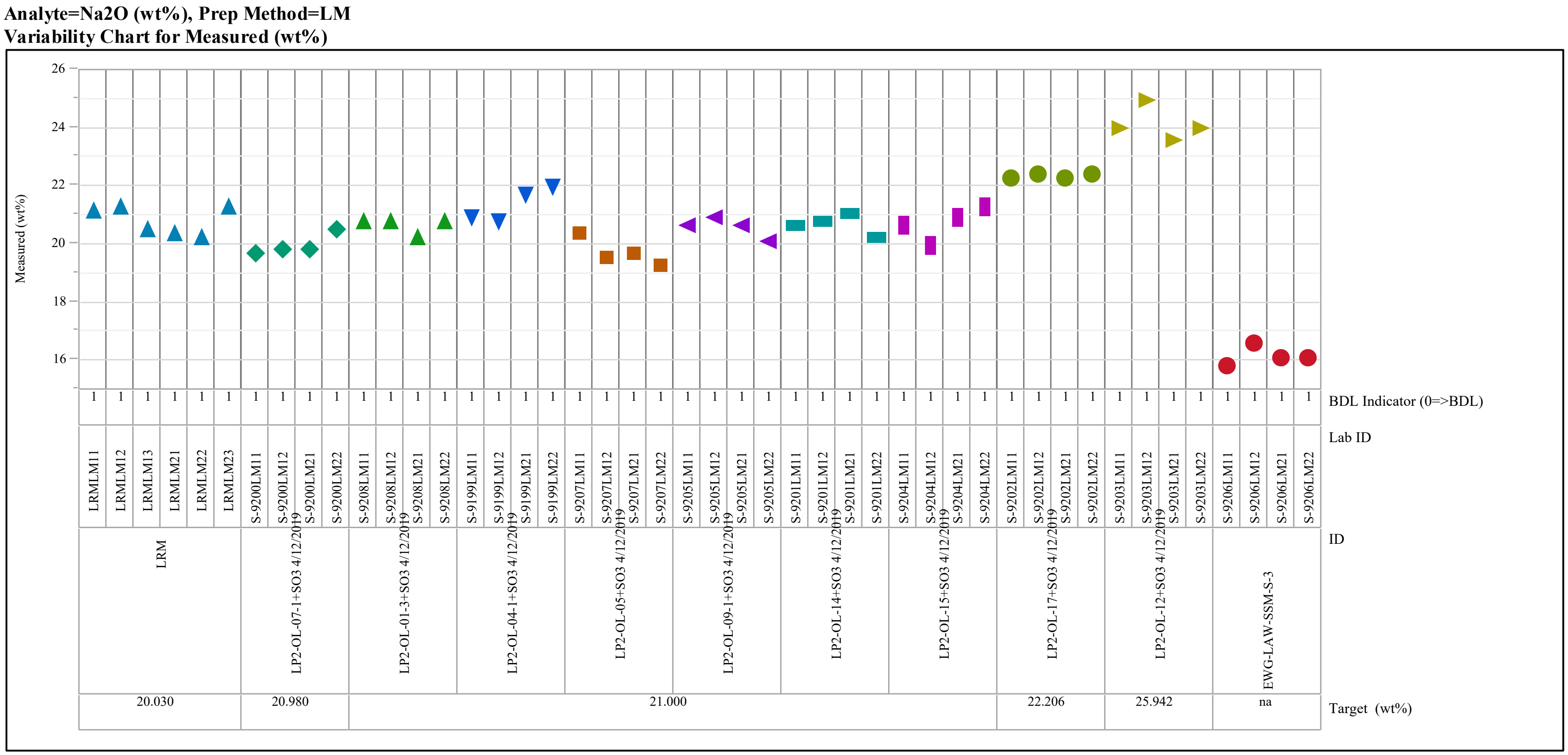


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

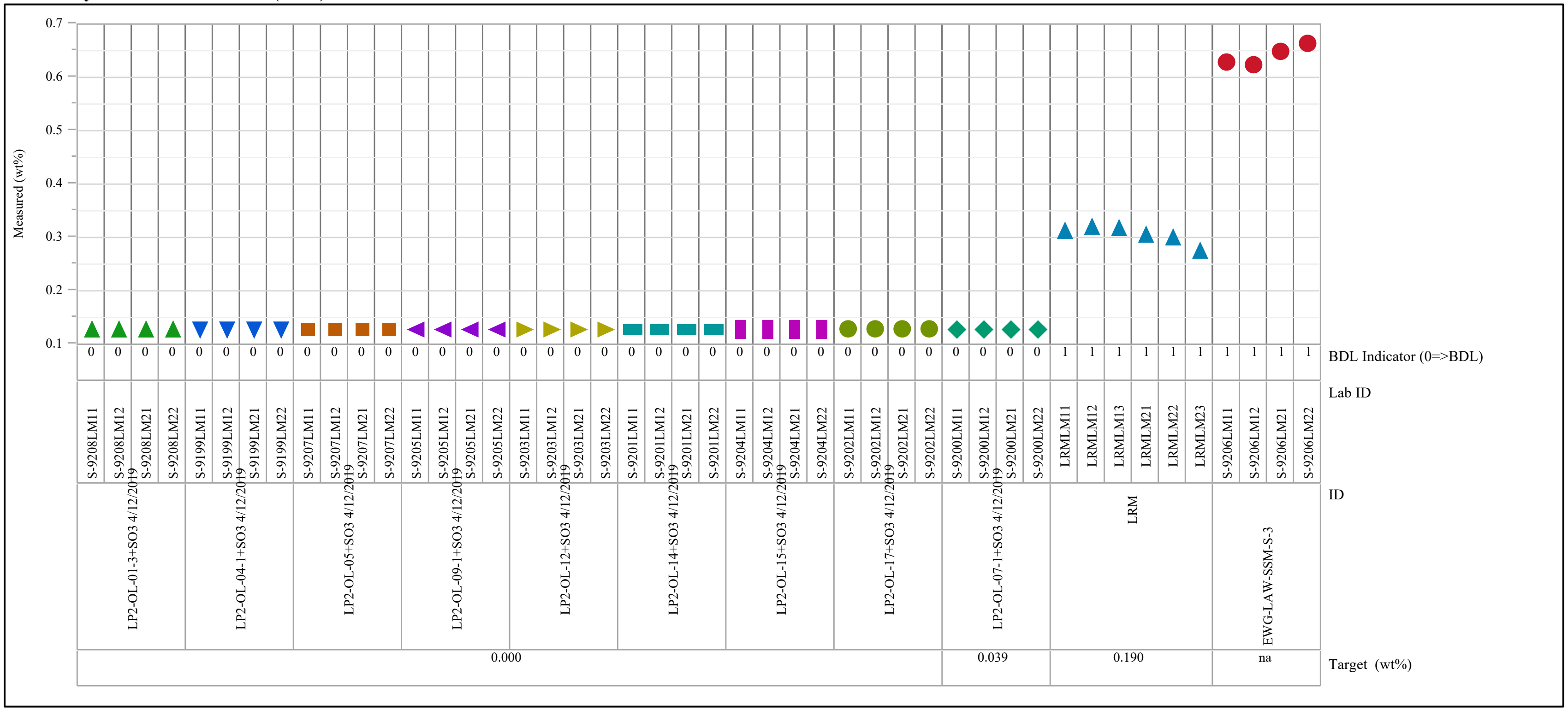


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

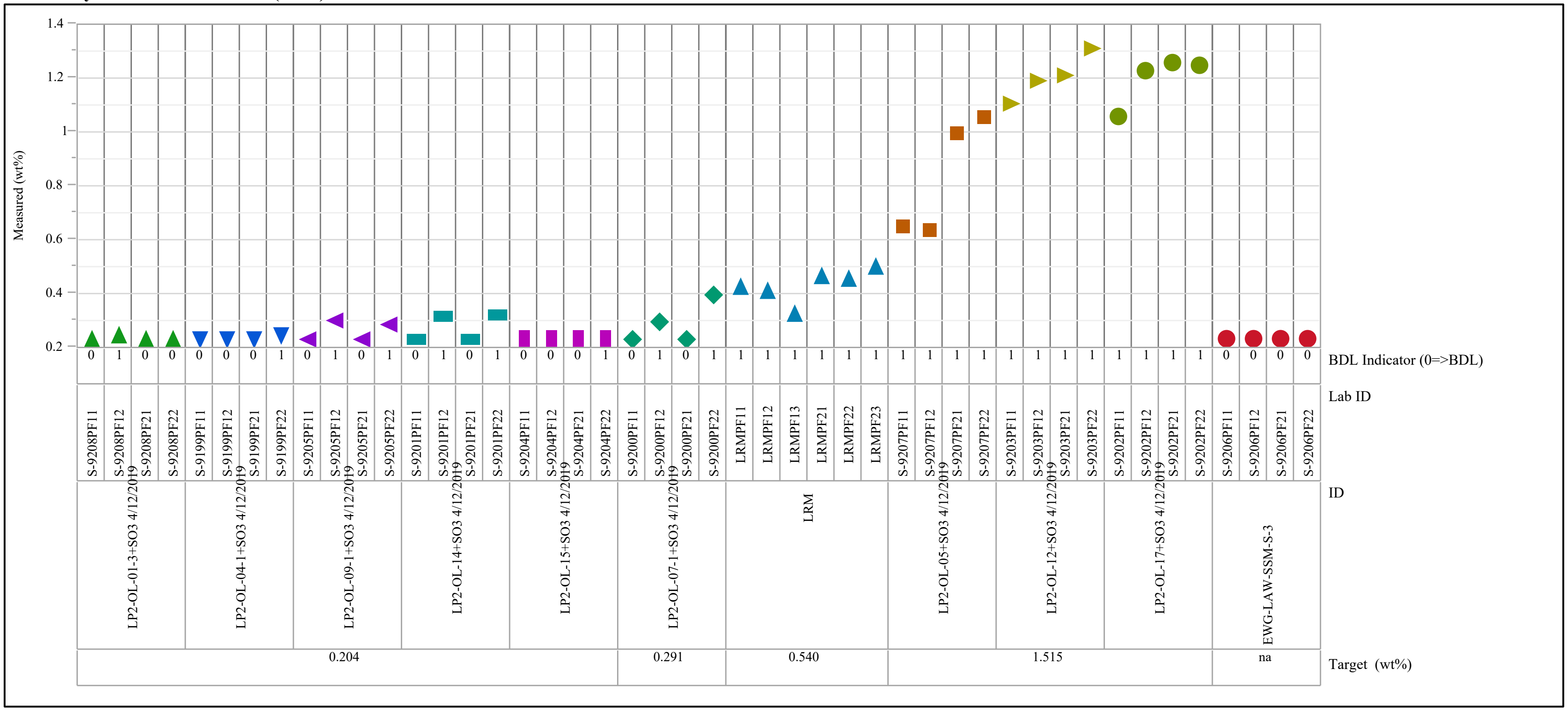


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

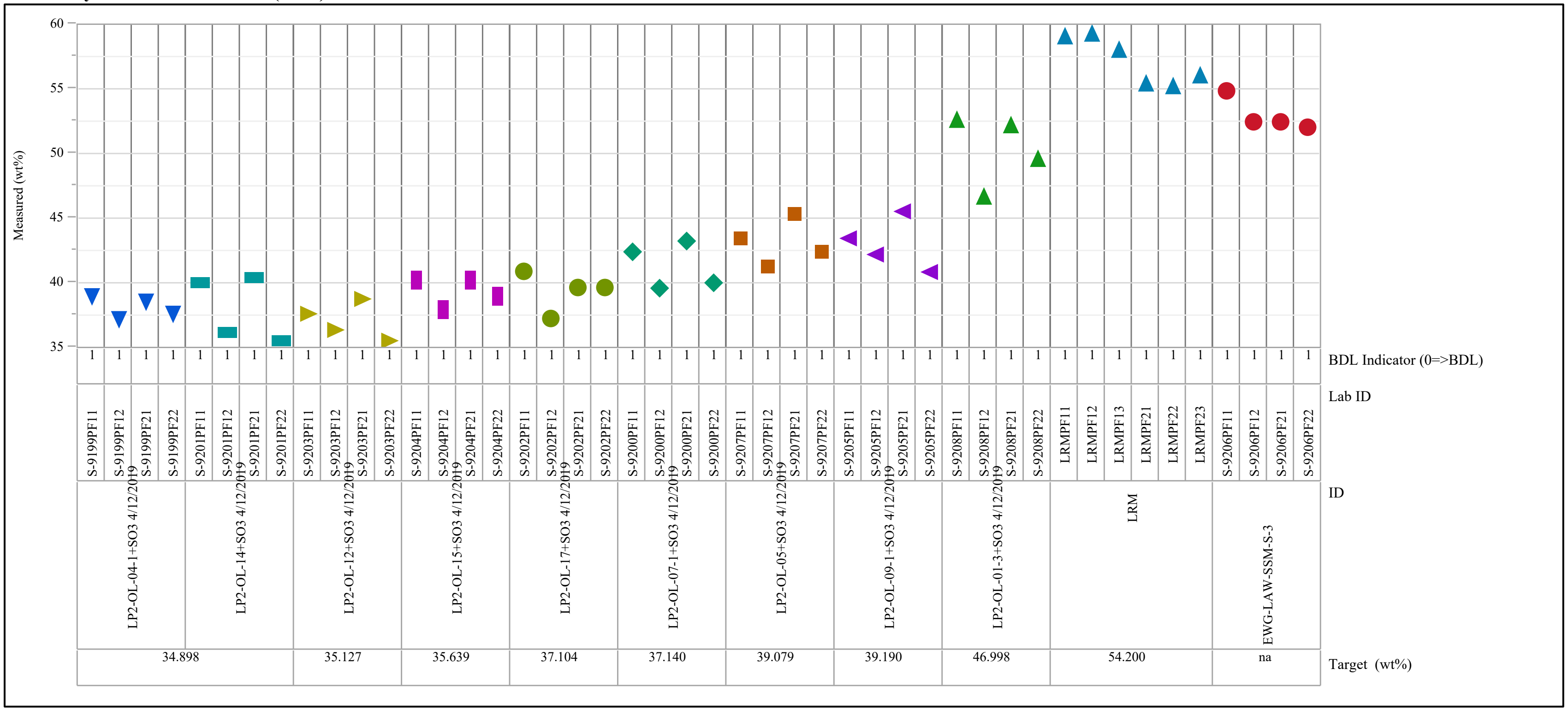


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

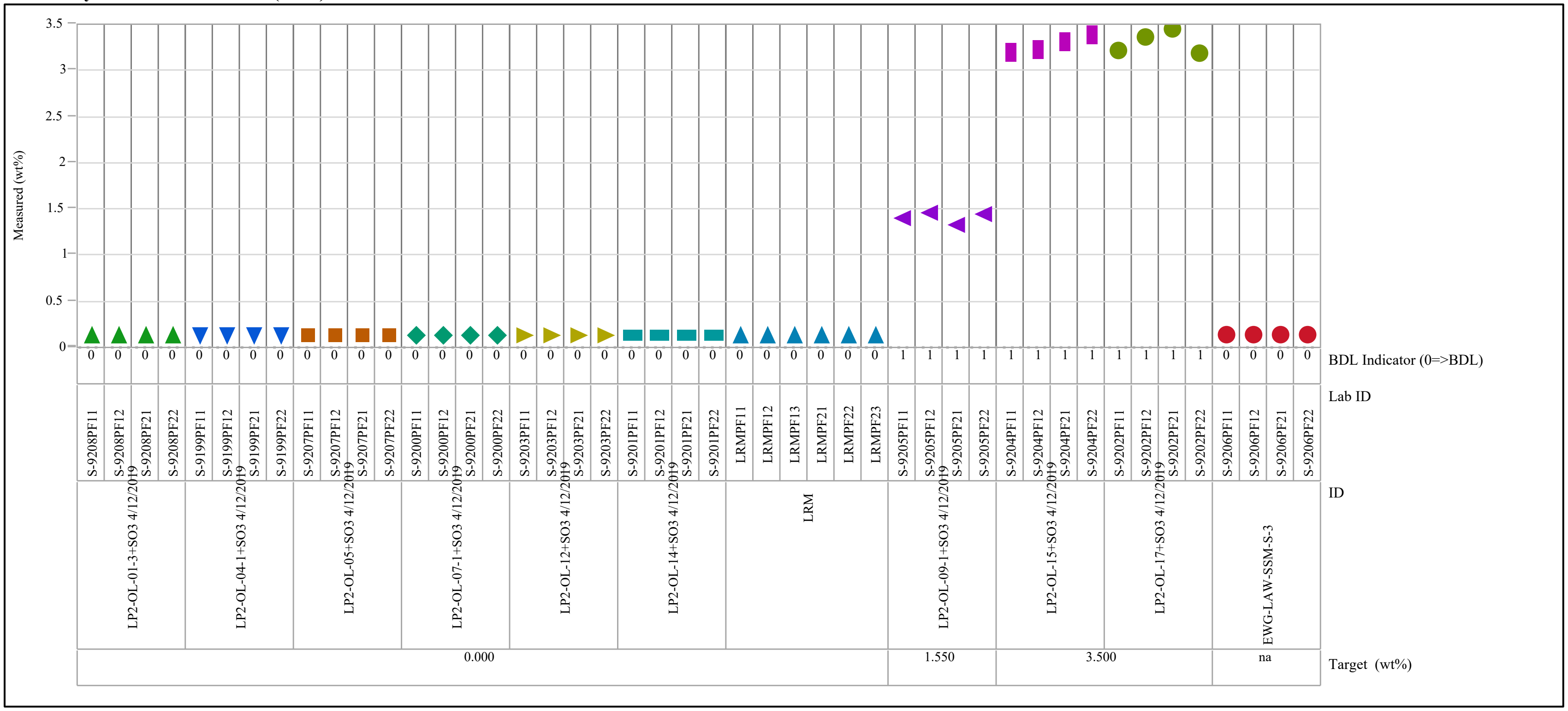


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

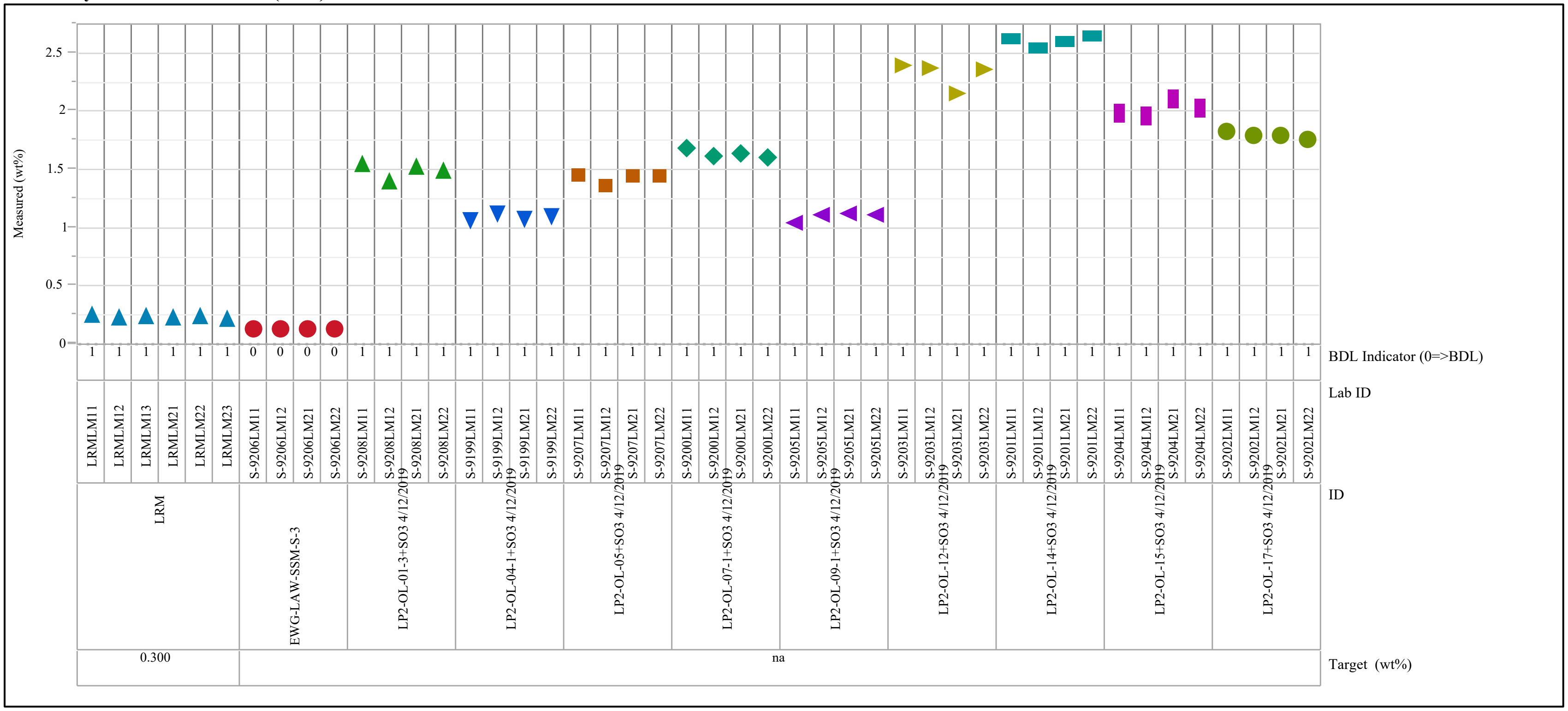


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

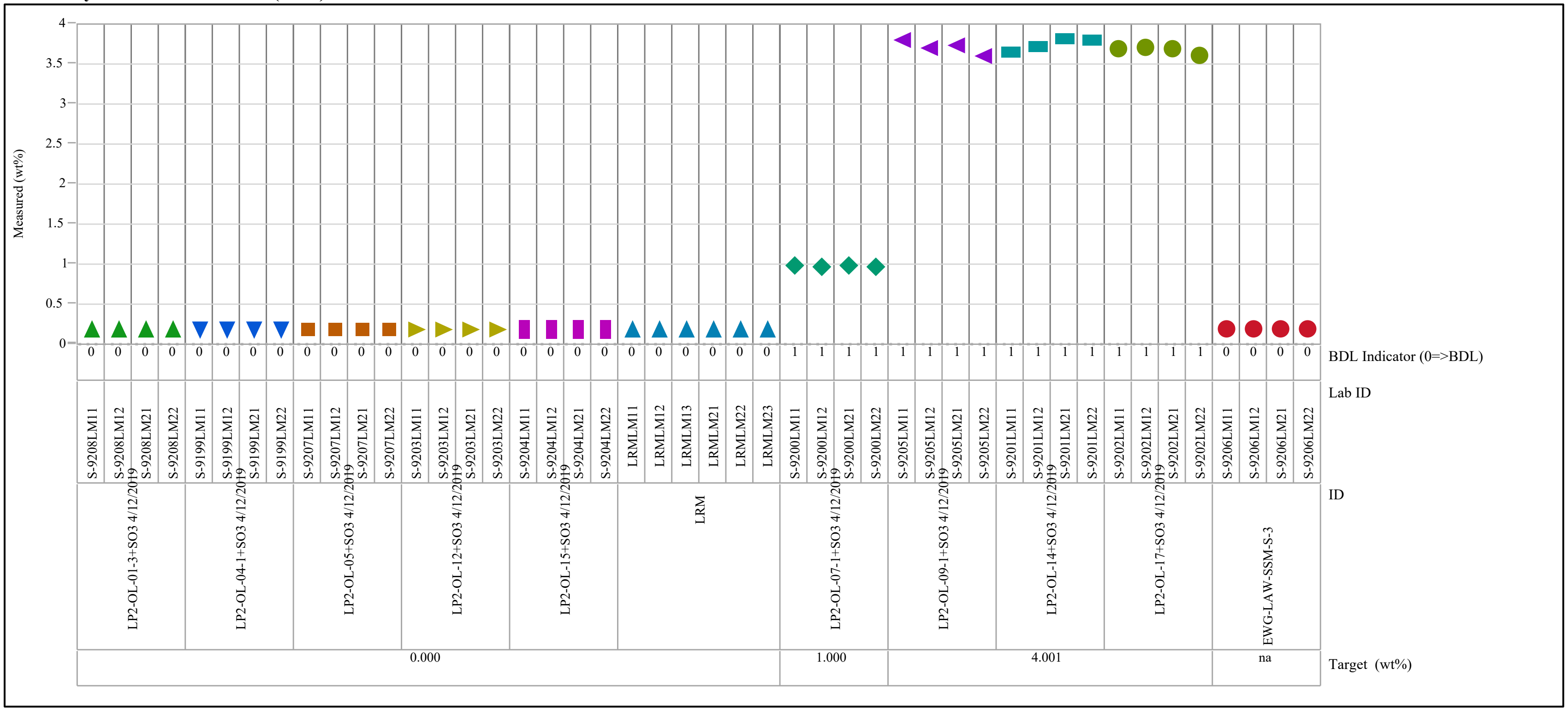


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

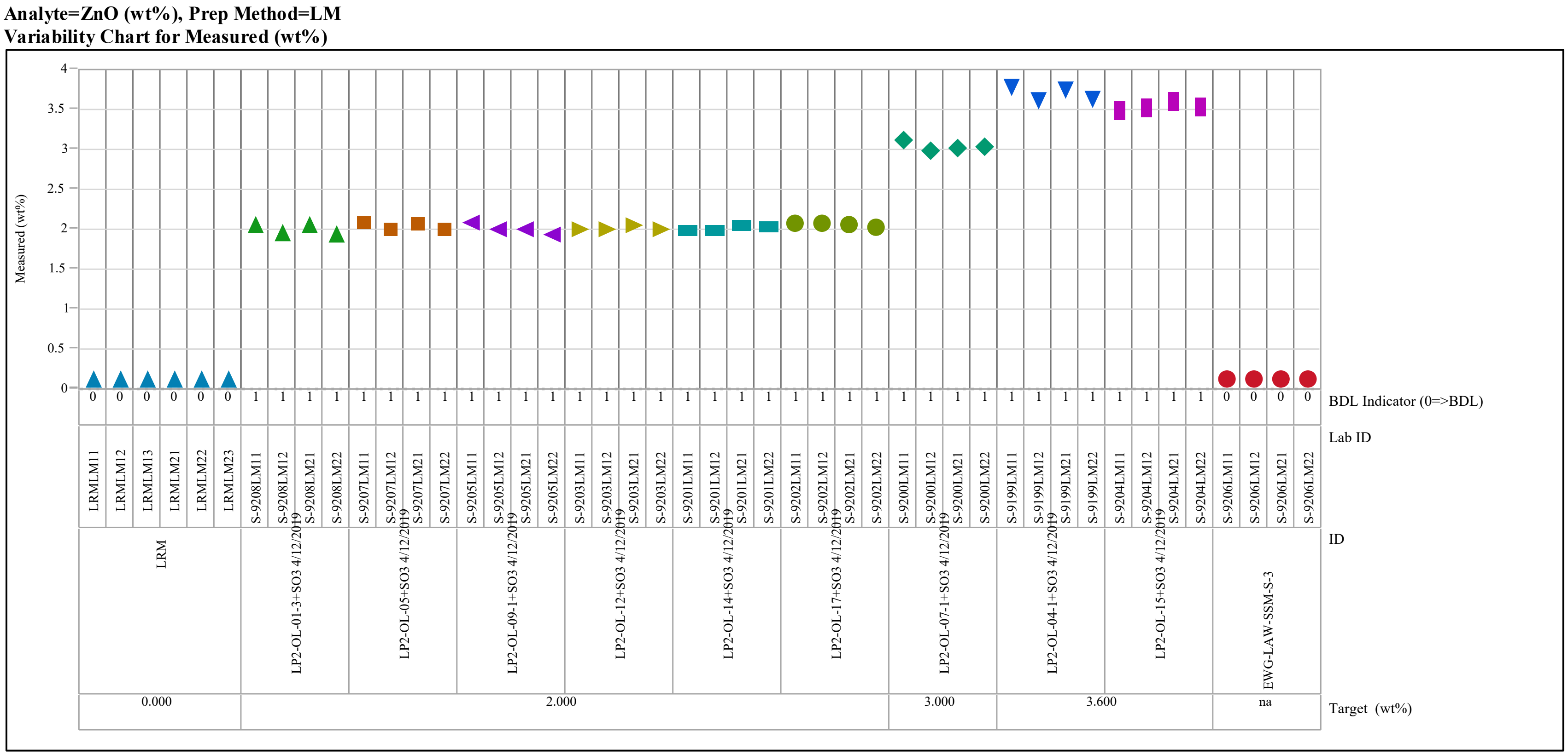


Exhibit A-2. Plots of Oxide Measurements Grouped by Glass Identifier (continued)

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

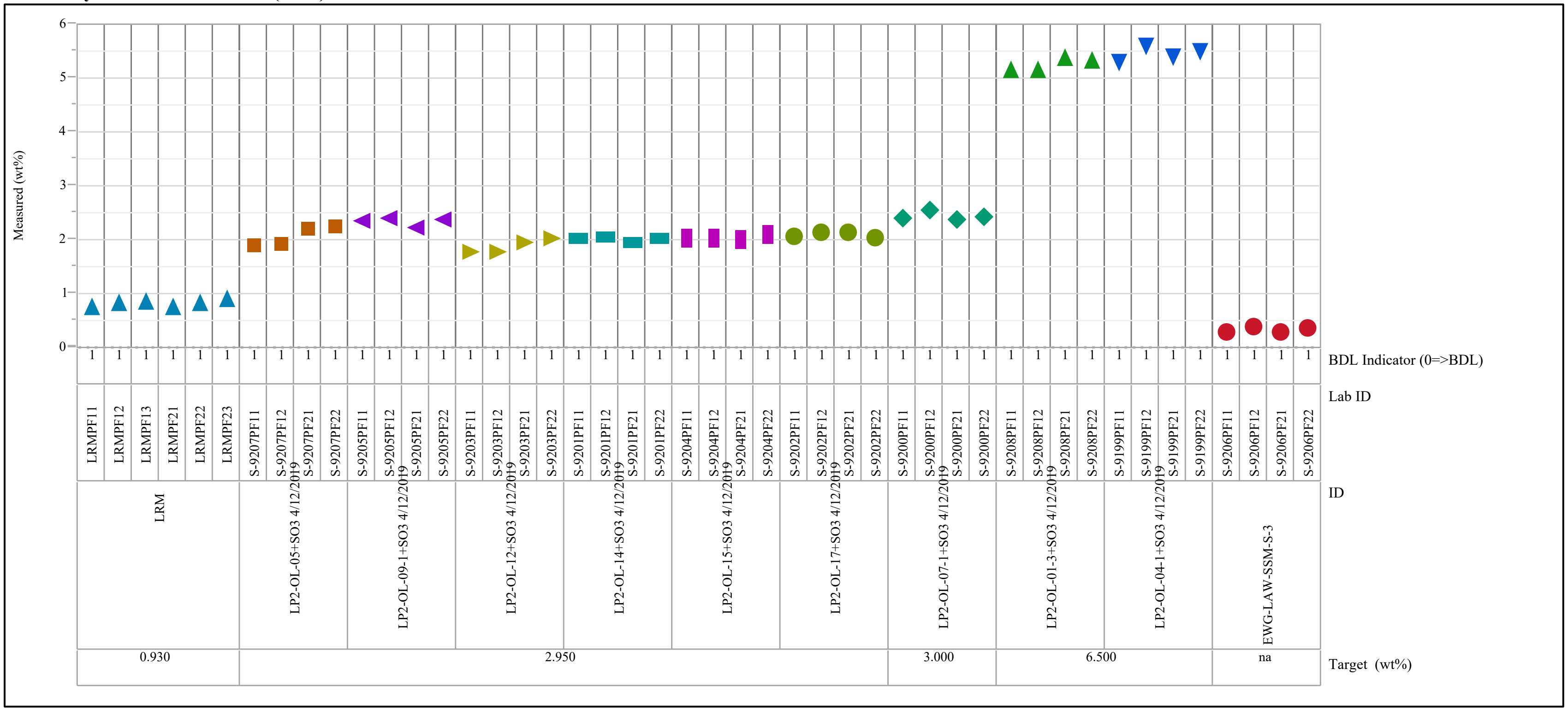
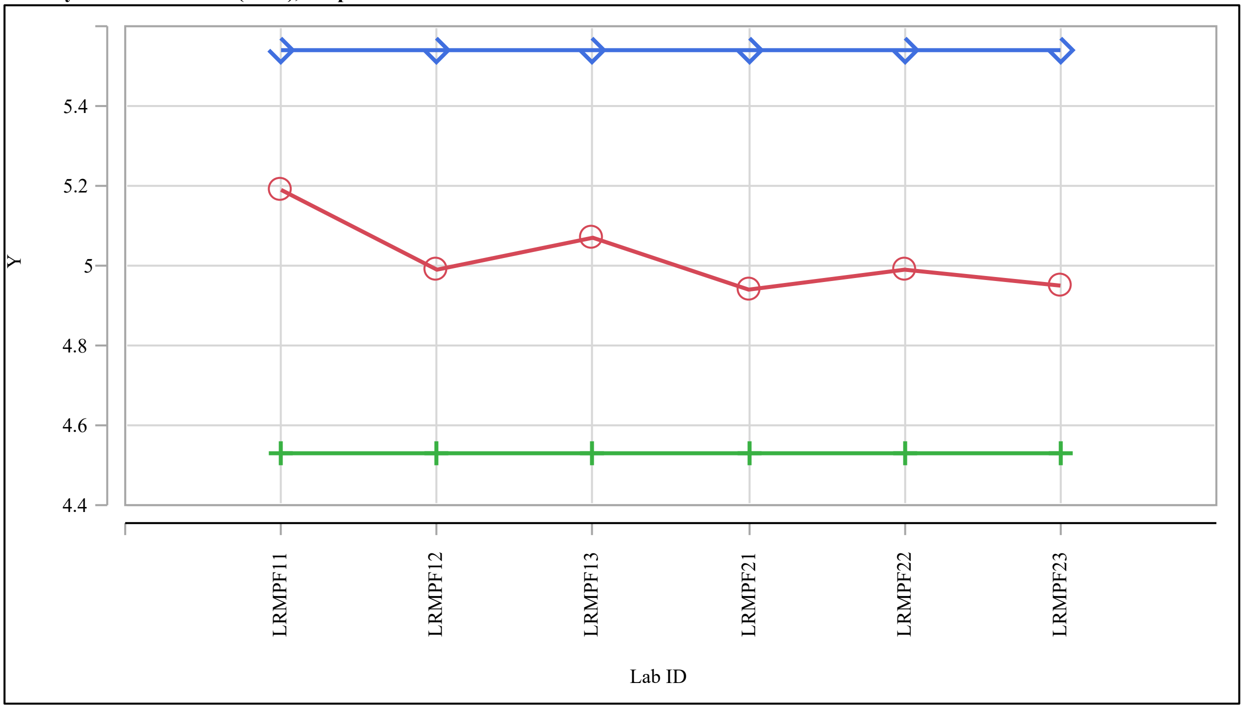
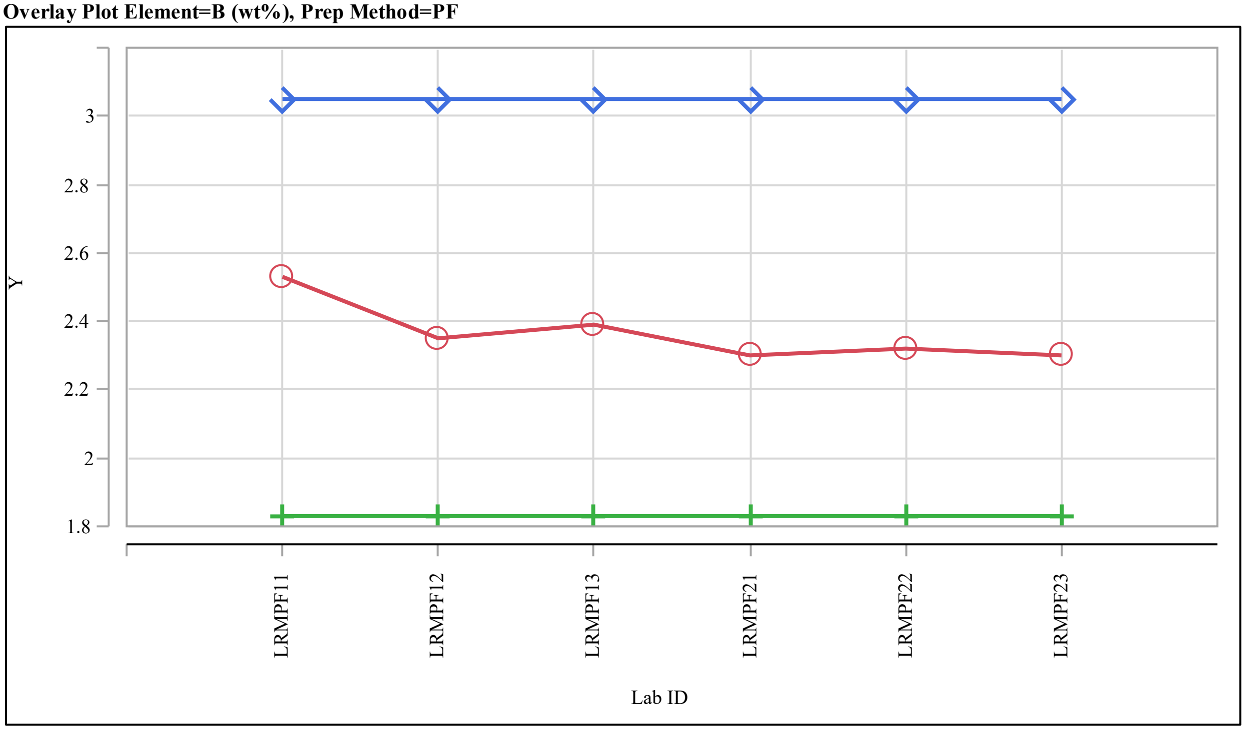


Exhibit A-3. Acceptability Evaluation for Measurements of the LRM Standard Glass

Overlay Plot Element=Al (wt%), Prep Method=PF



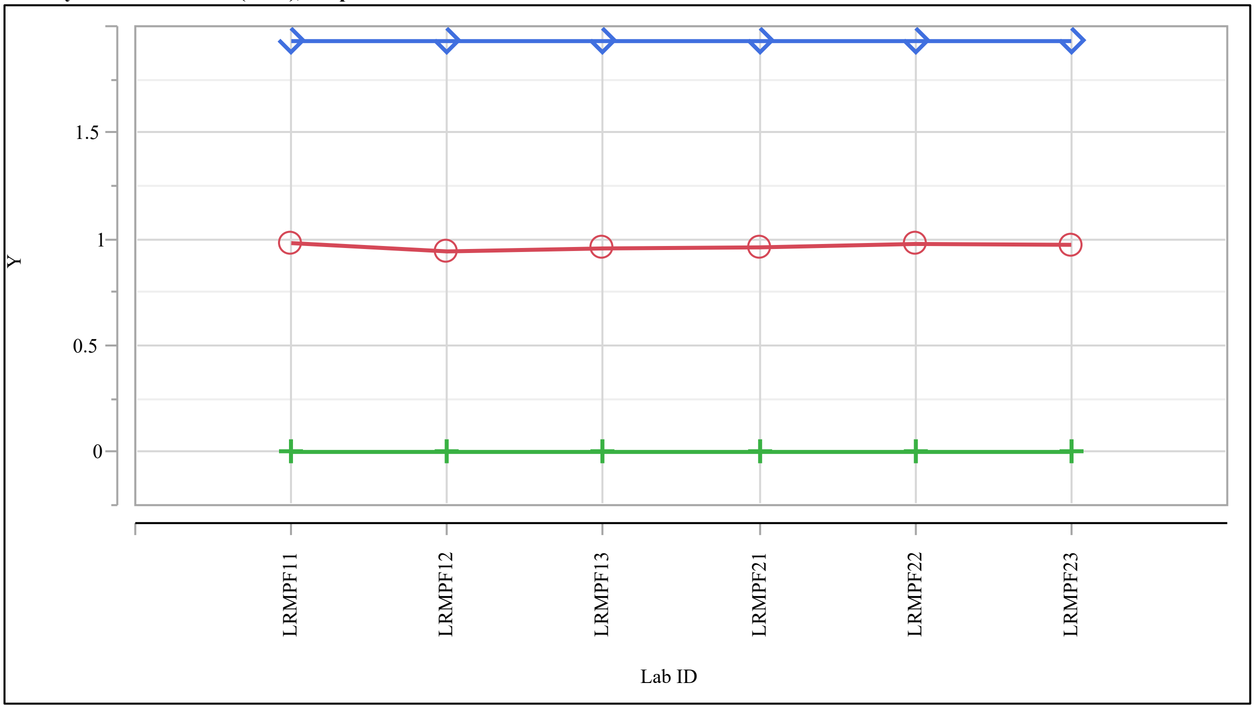
Overlay Plot Element=B (wt%), Prep Method=PF



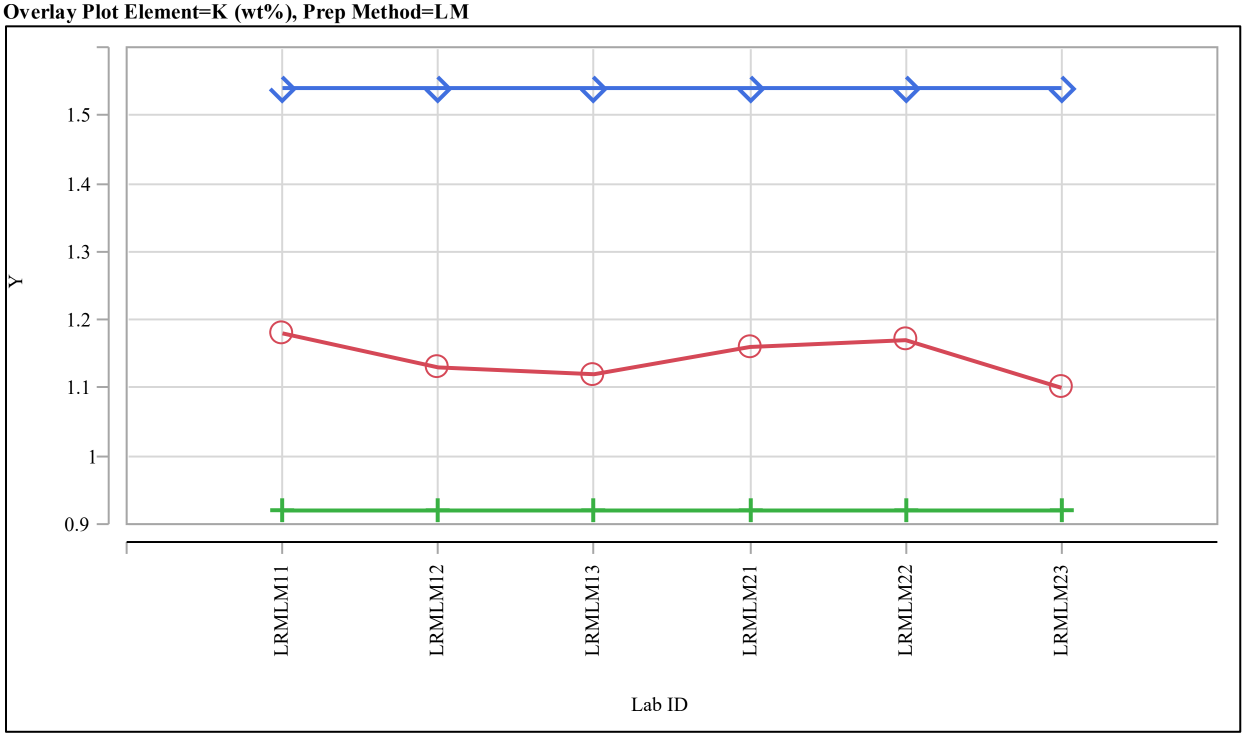
Y ○ —— Measurement + —— lower acceptability limit ◇ —— upper acceptability limit

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

Overlay Plot Element=Fe (wt%), Prep Method=PF



Overlay Plot Element=K (wt%), Prep Method=LM



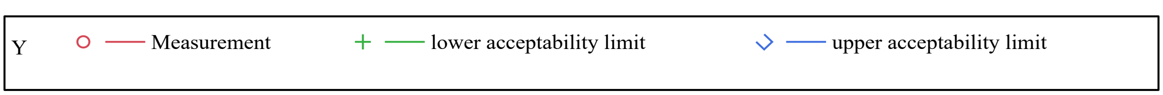
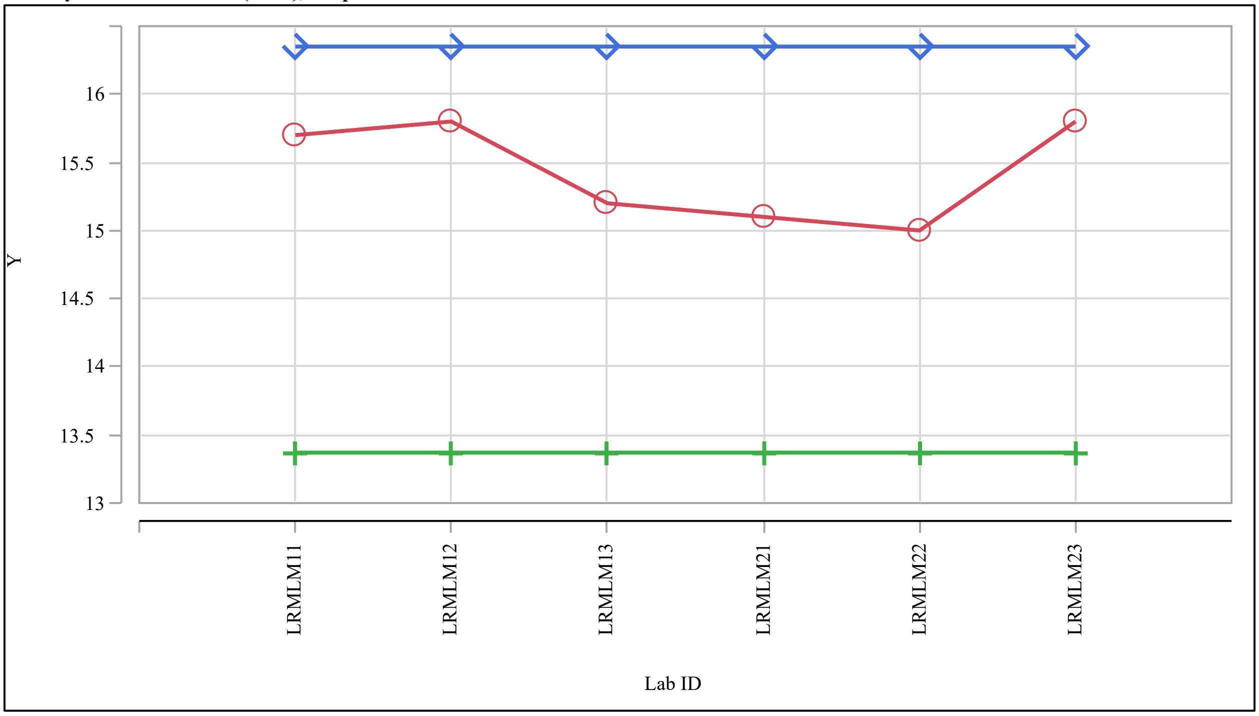
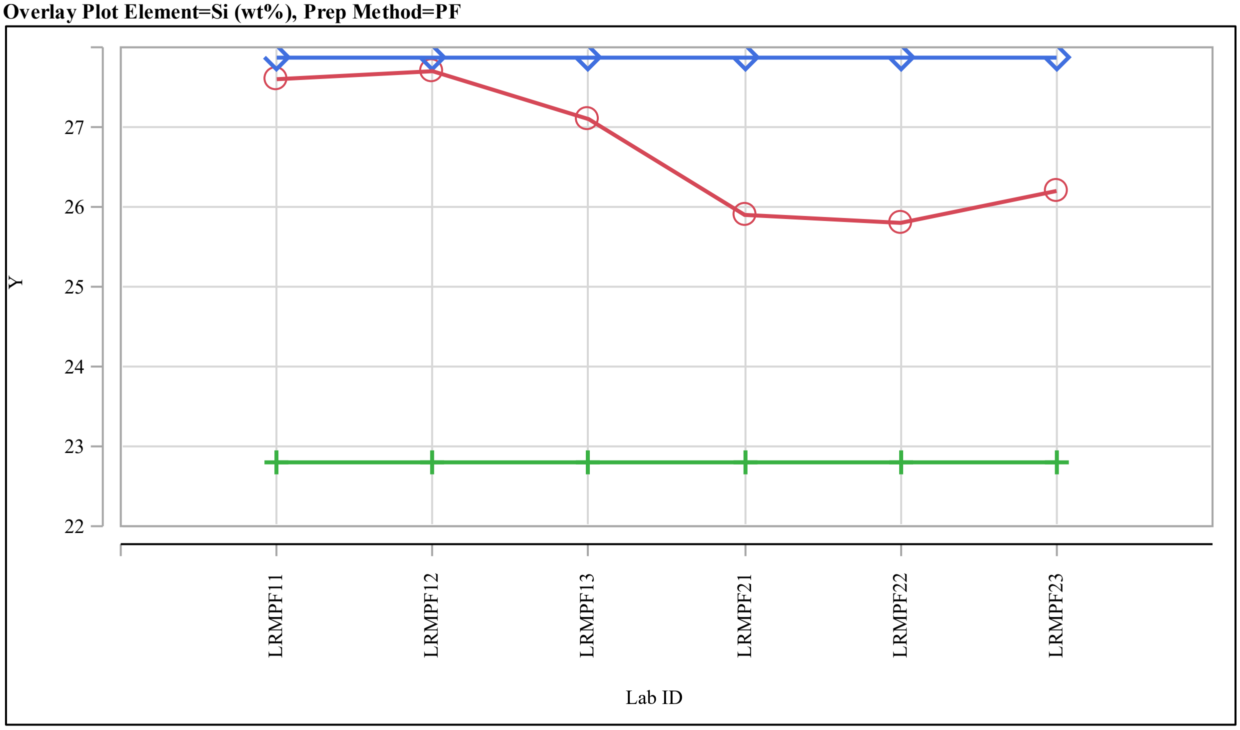


Exhibit A-3. Acceptability Evaluation for Measurements of the LRM Standard Glass (continued)

Overlay Plot Element=Na (wt%), Prep Method=LM



Overlay Plot Element=Si (wt%), Prep Method=PF



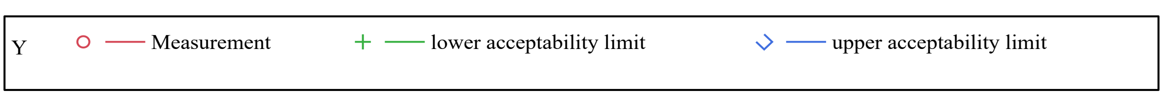


Exhibit A-3. Acceptability Evaluation for Measurements of the LRM Standard Glass (continued)

Overlay Plot Element=Zr (wt%), Prep Method=PF

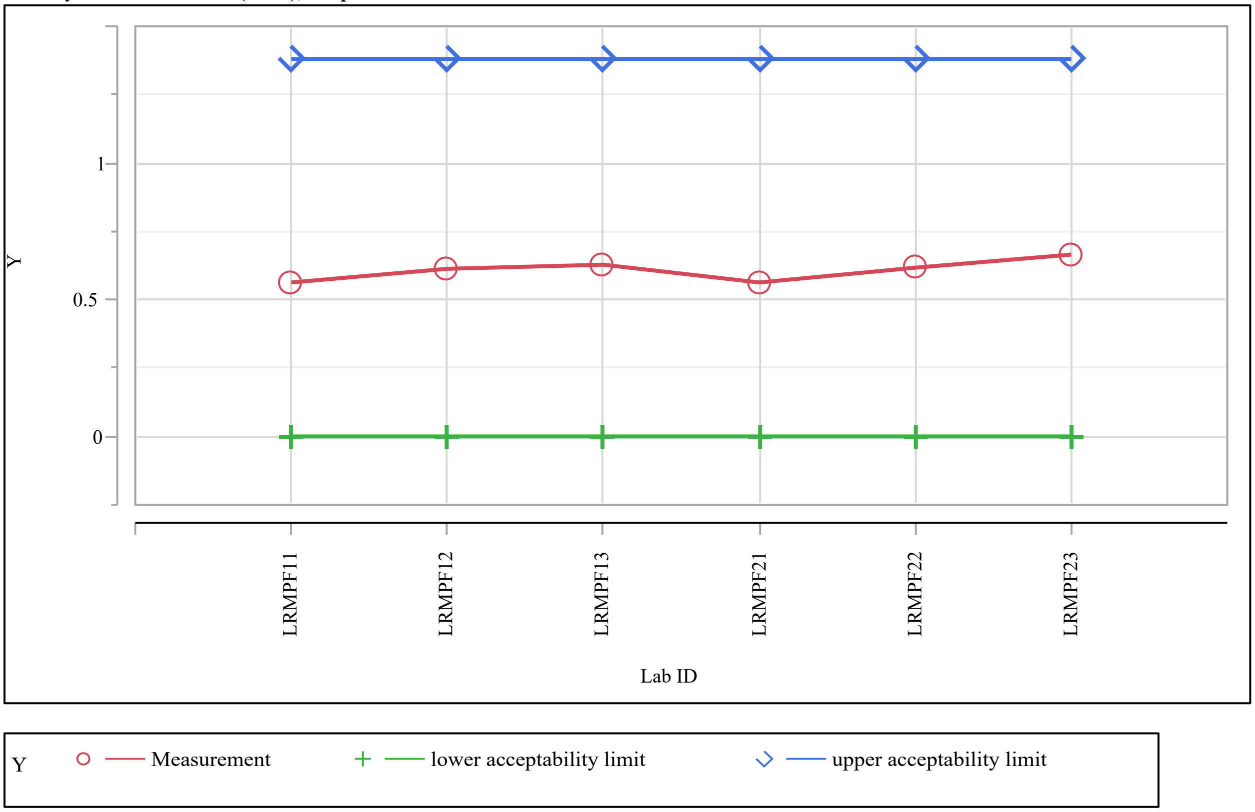
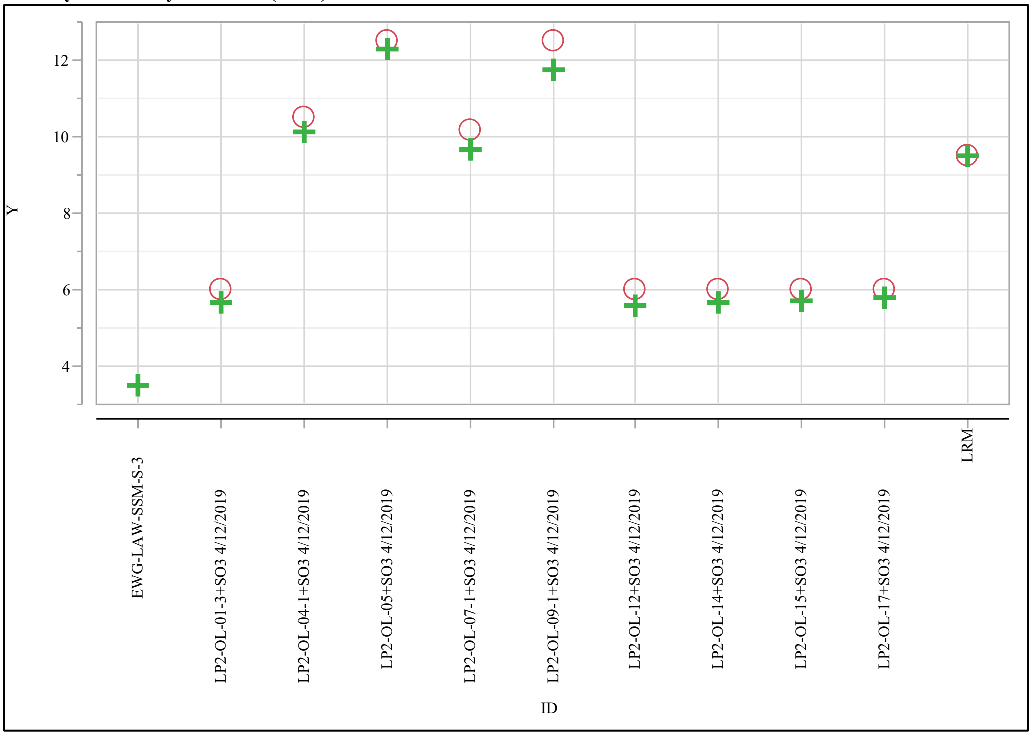
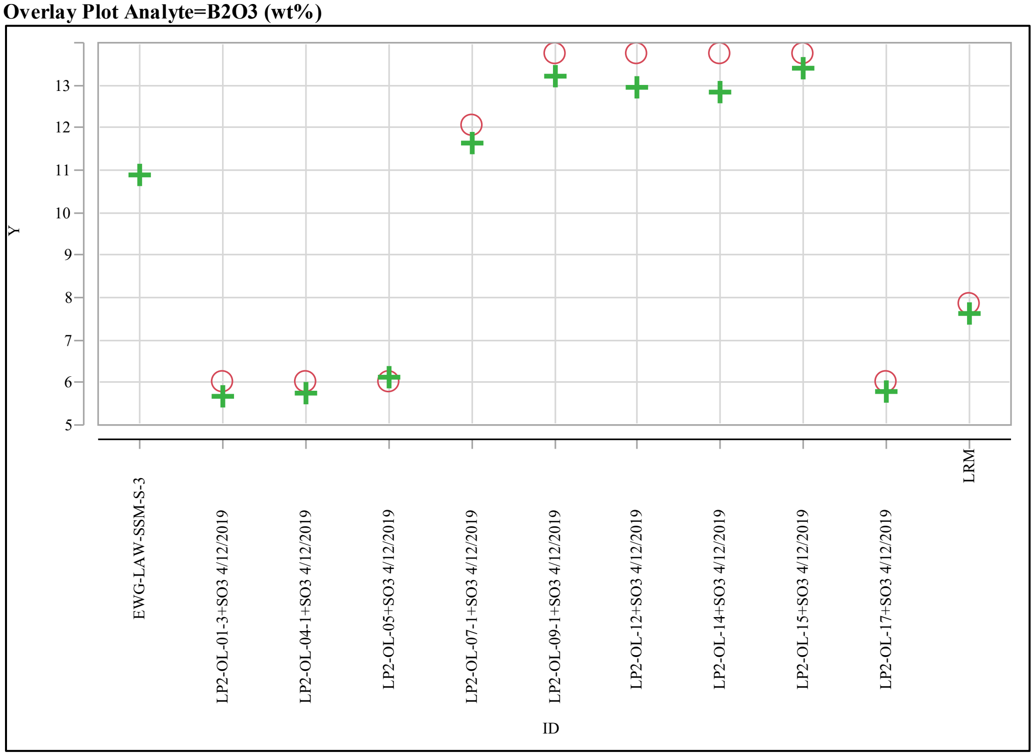


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide

Overlay Plot Analyte=Al2O3 (wt%)



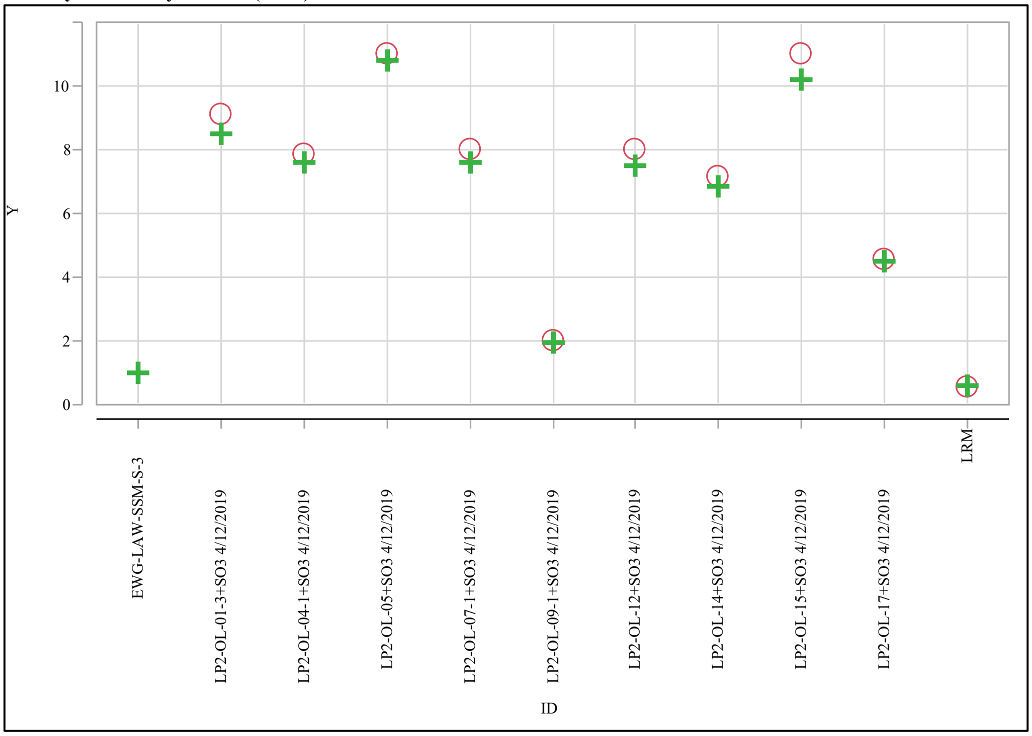
Overlay Plot Analyte=B2O3 (wt%)



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

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

Overlay Plot Analyte=CaO (wt%)



Overlay Plot Analyte=Cr2O3 (wt%)

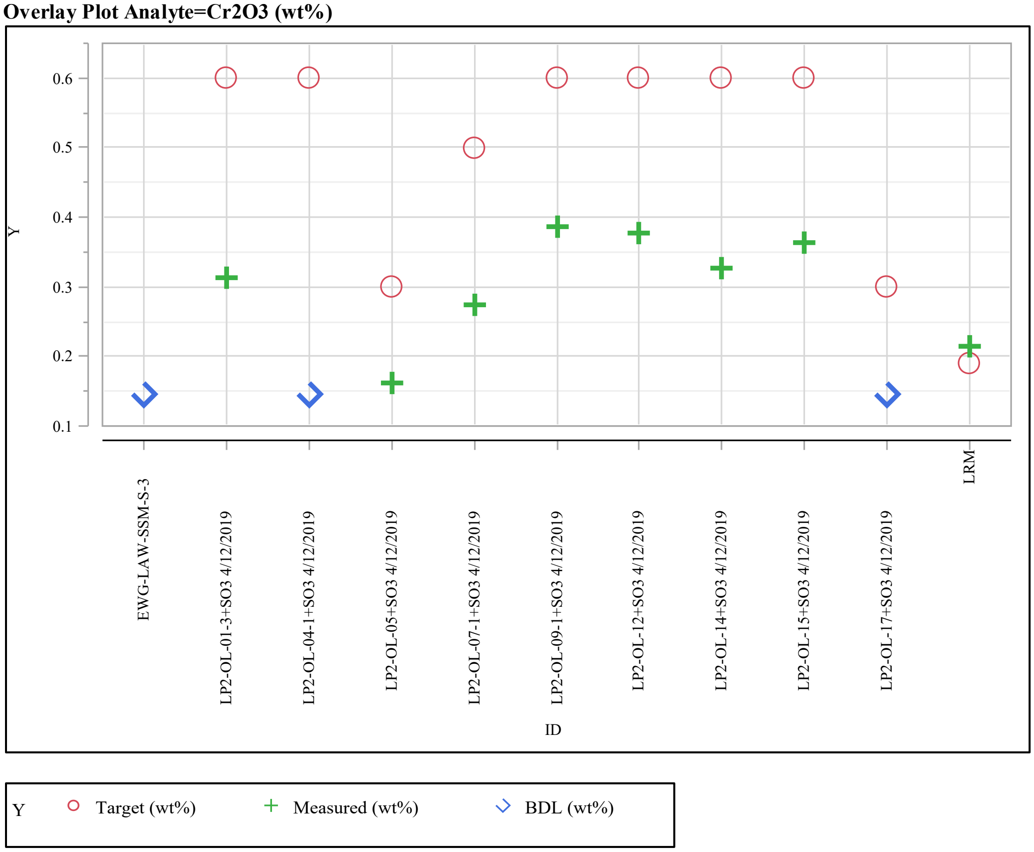
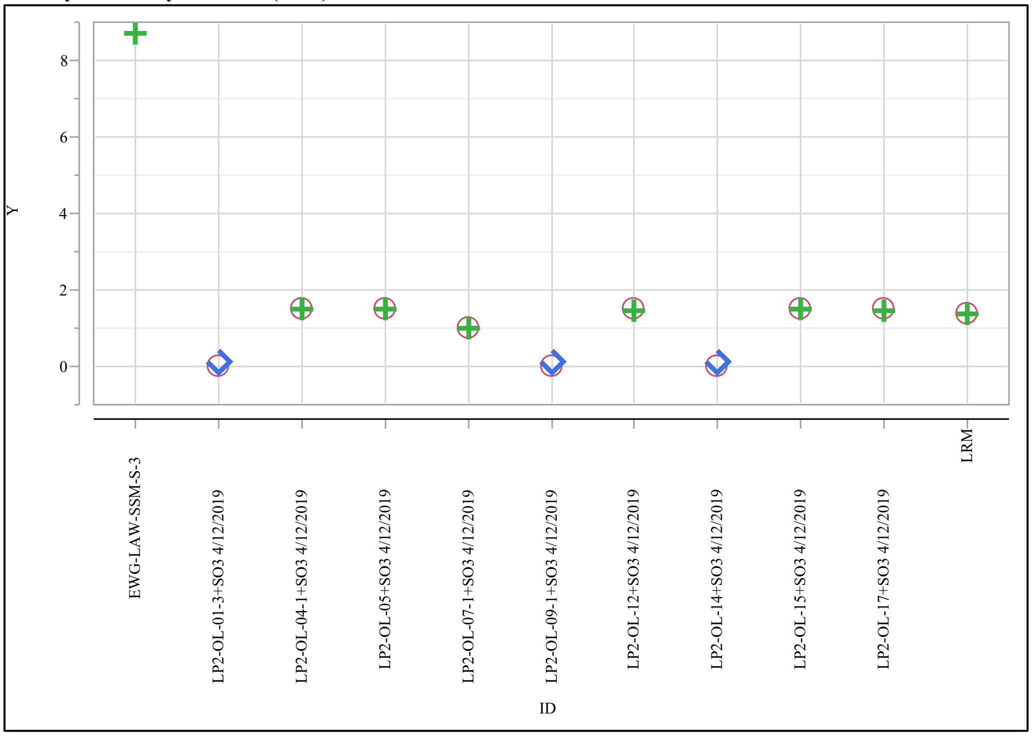


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Overlay Plot Analyte=Fe2O3 (wt%)



Overlay Plot Analyte=K2O (wt%)

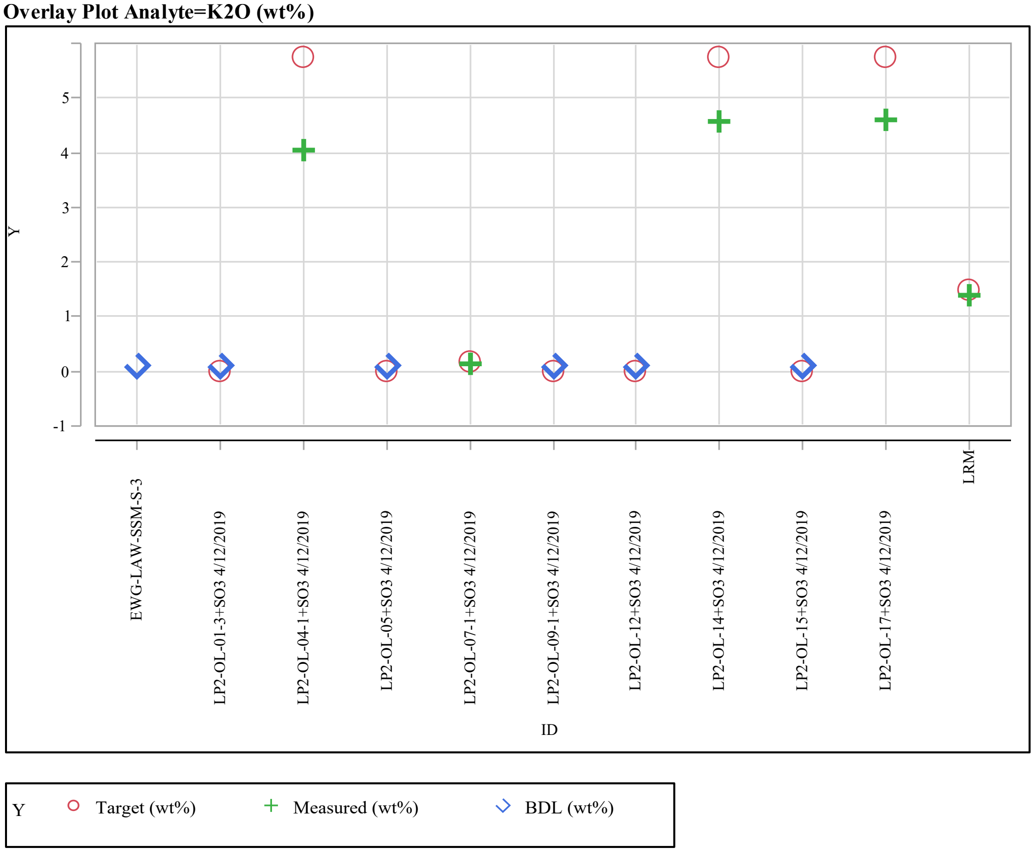
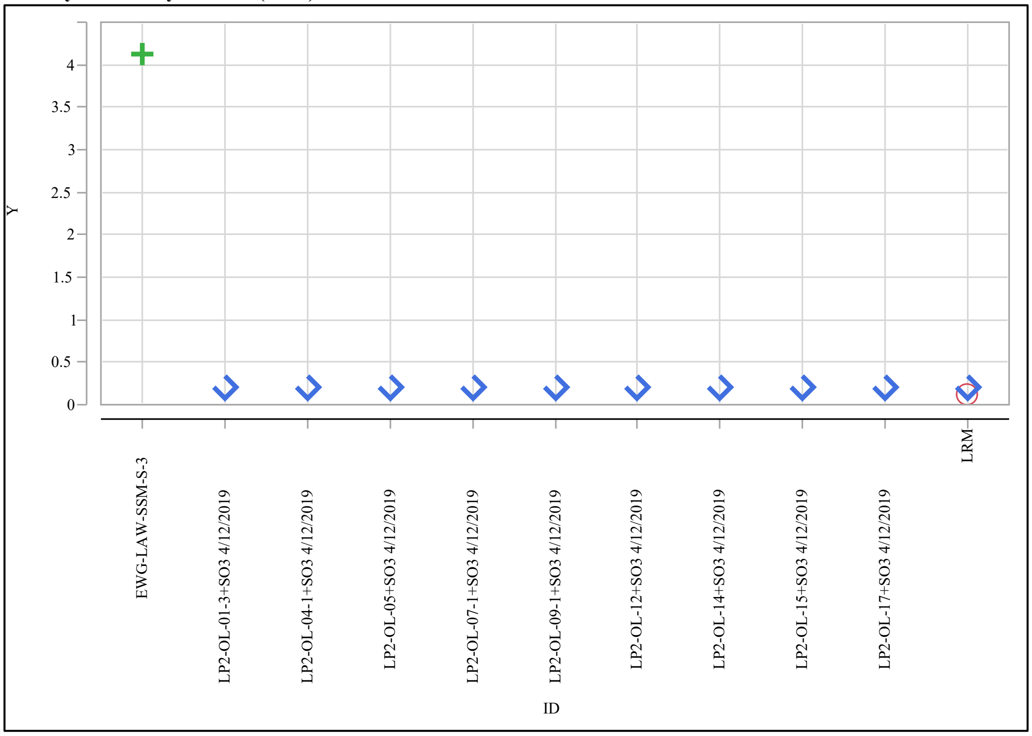
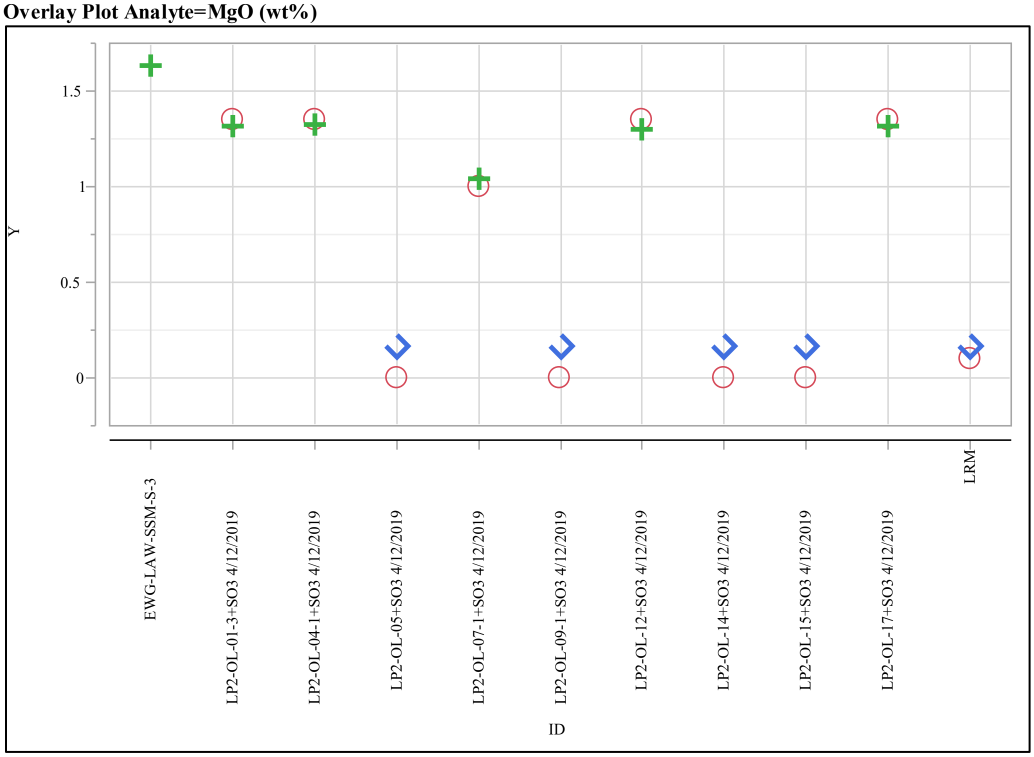


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Overlay Plot Analyte=Li2O (wt%)



Overlay Plot Analyte=MgO (wt%)



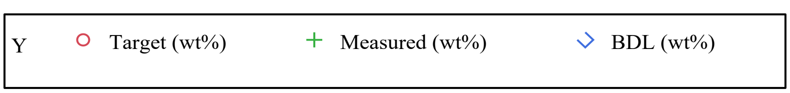
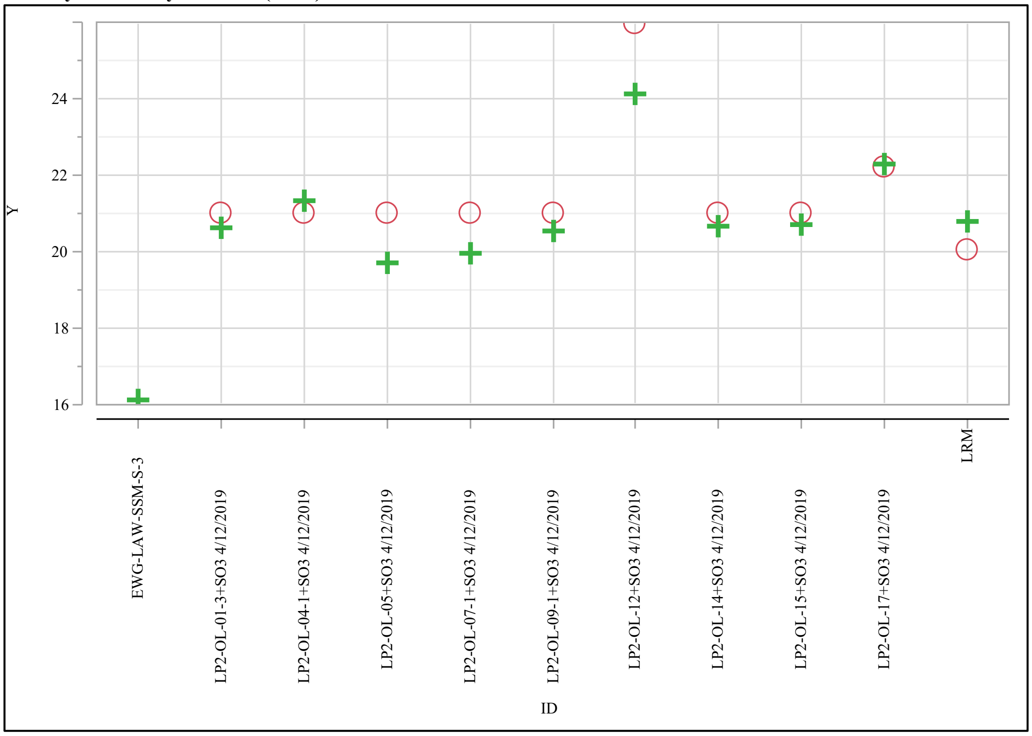
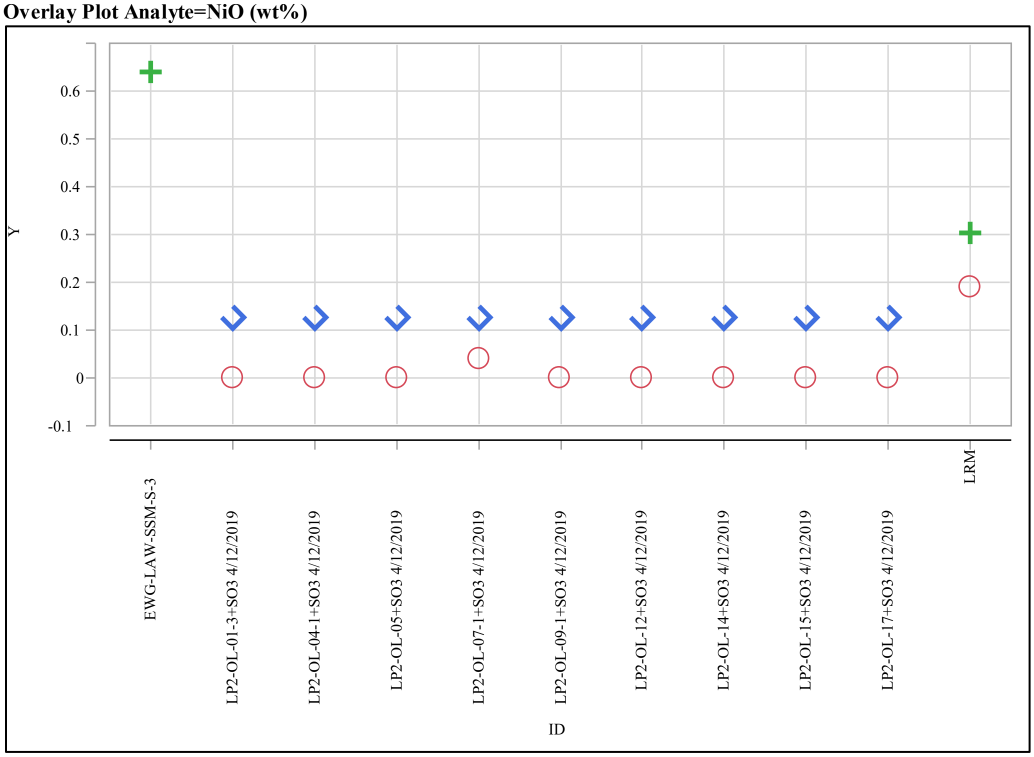


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Overlay Plot Analyte=Na2O (wt%)



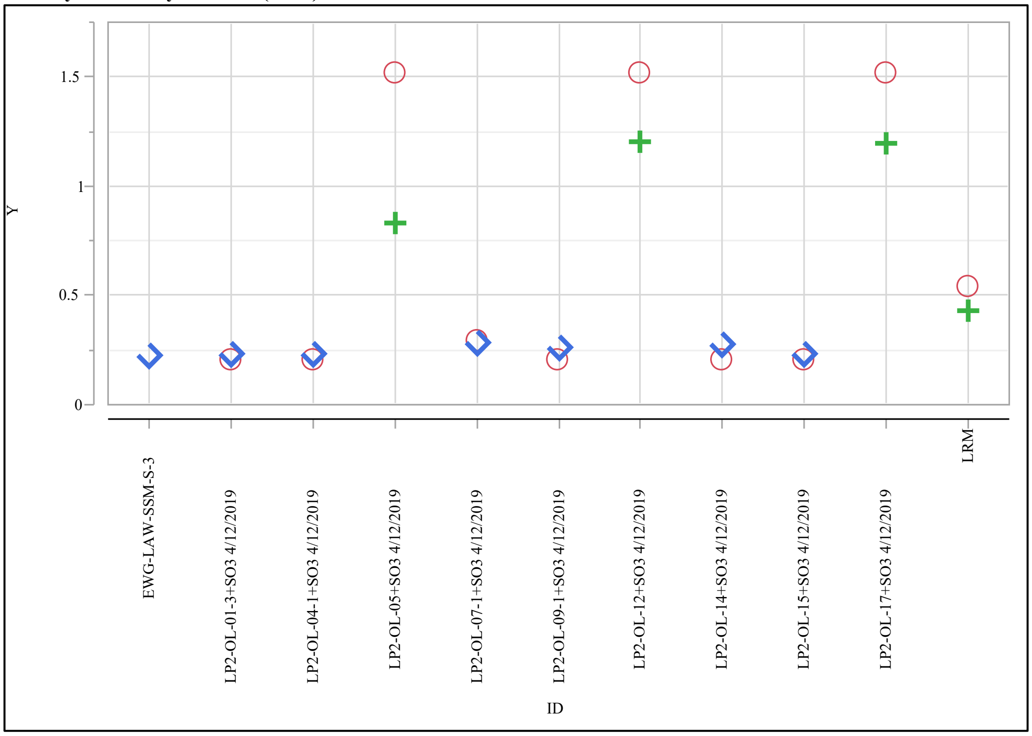
Overlay Plot Analyte=NiO (wt%)



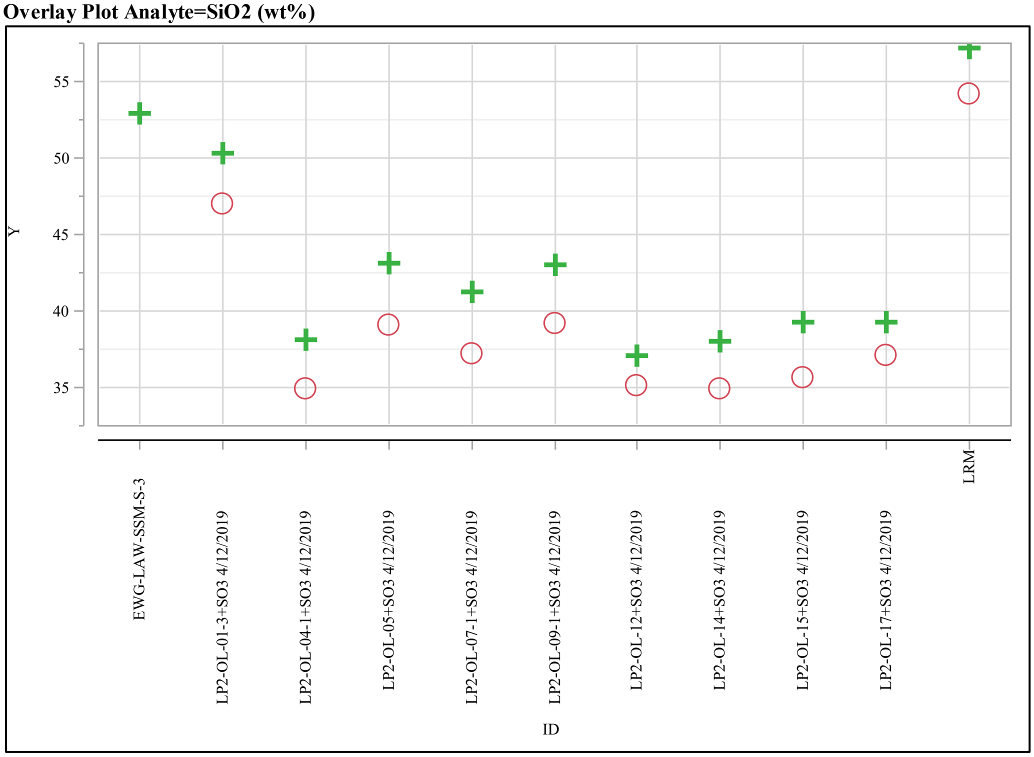
Y ○ Target (wt%) + Measured (wt%) ◇ BDL (wt%)

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

Overlay Plot Analyte=P2O5 (wt%)



Overlay Plot Analyte=SiO2 (wt%)



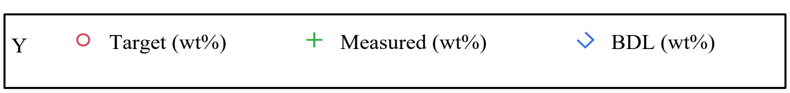
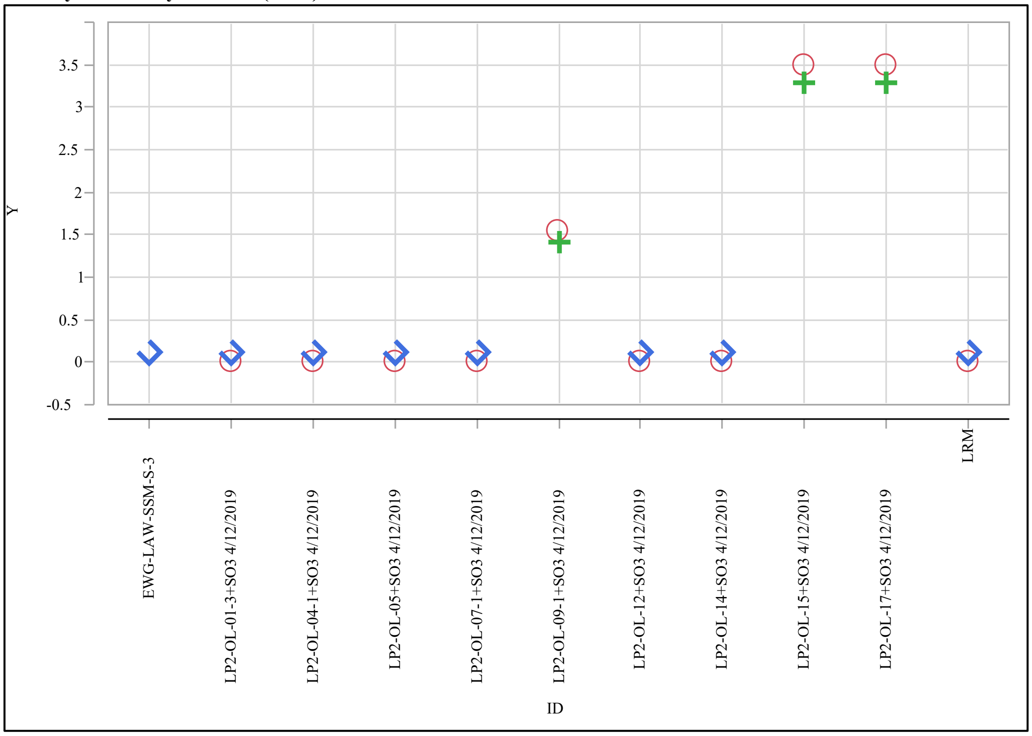


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Overlay Plot Analyte=SnO2 (wt%)



Overlay Plot Analyte=SO3 (wt%)

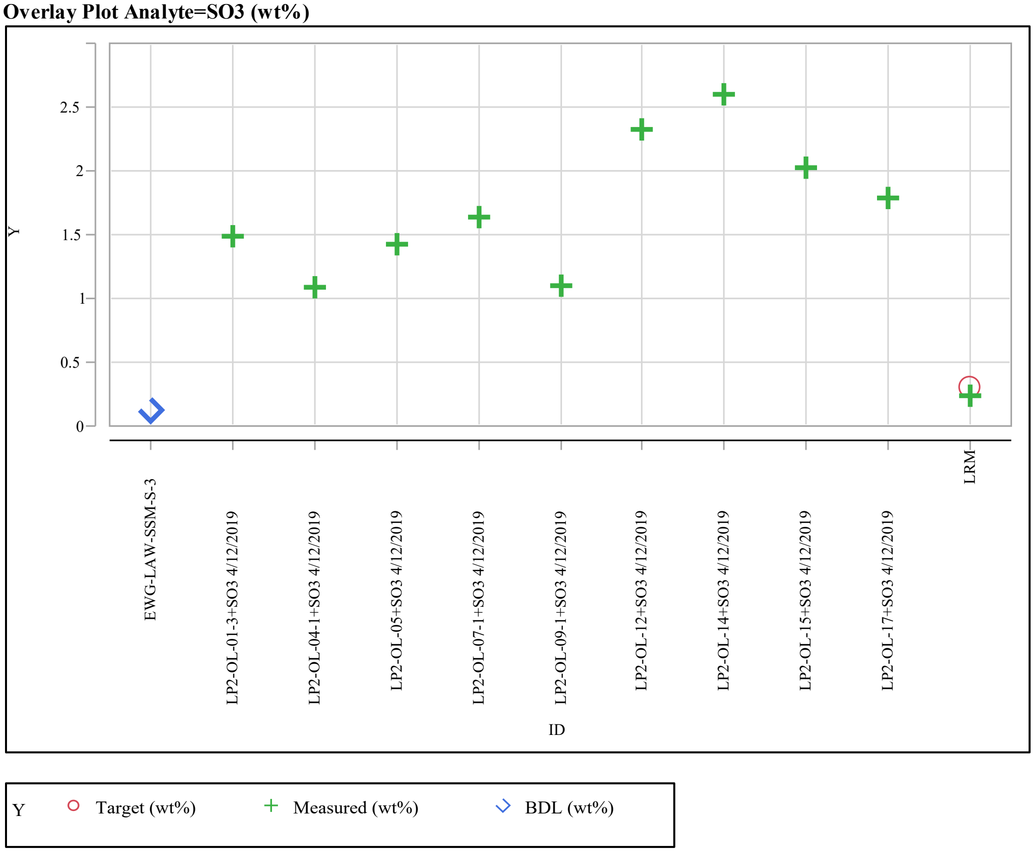
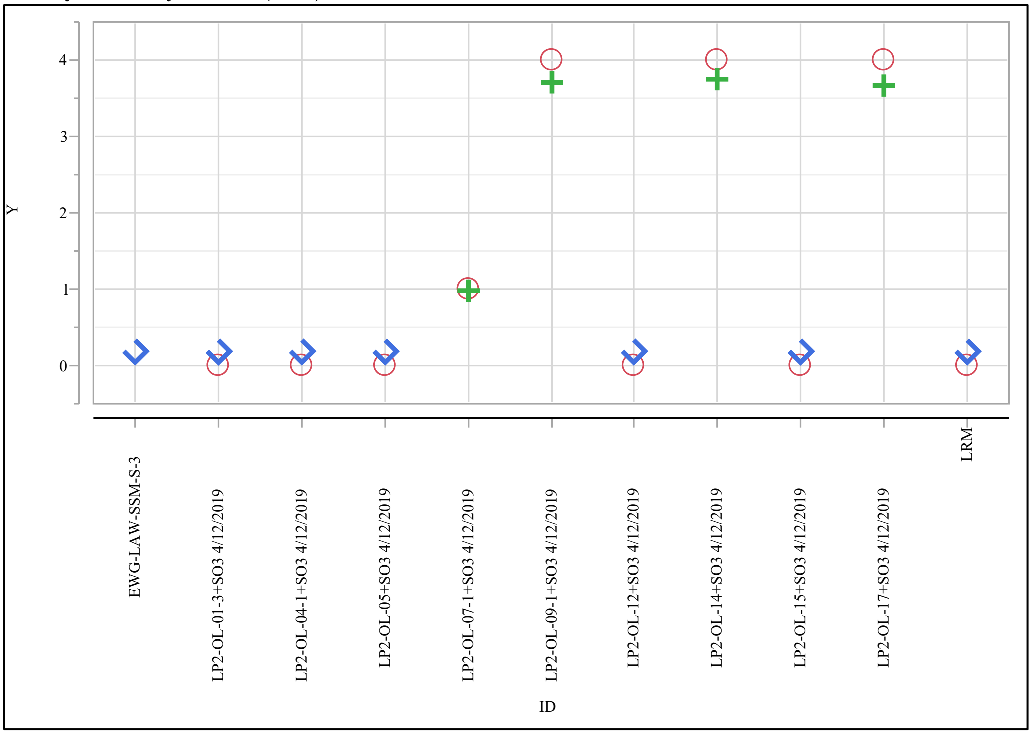
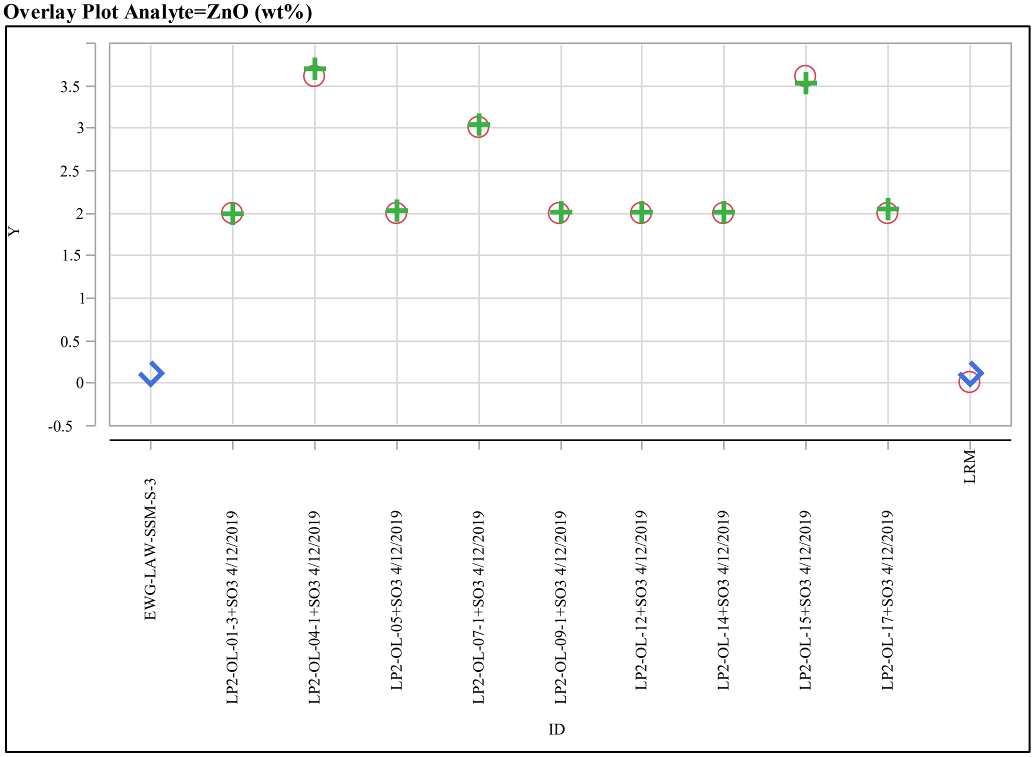


Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Overlay Plot Analyte=V2O5 (wt%)



Overlay Plot Analyte=ZnO (wt%)



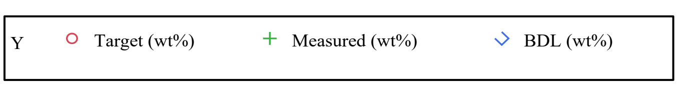
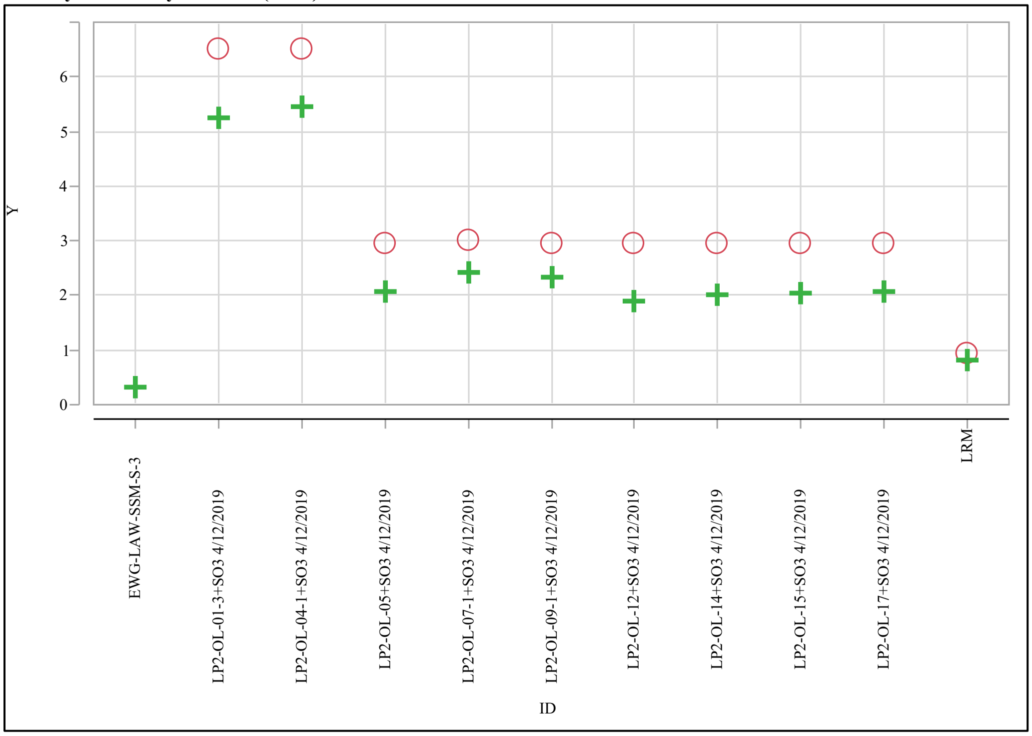
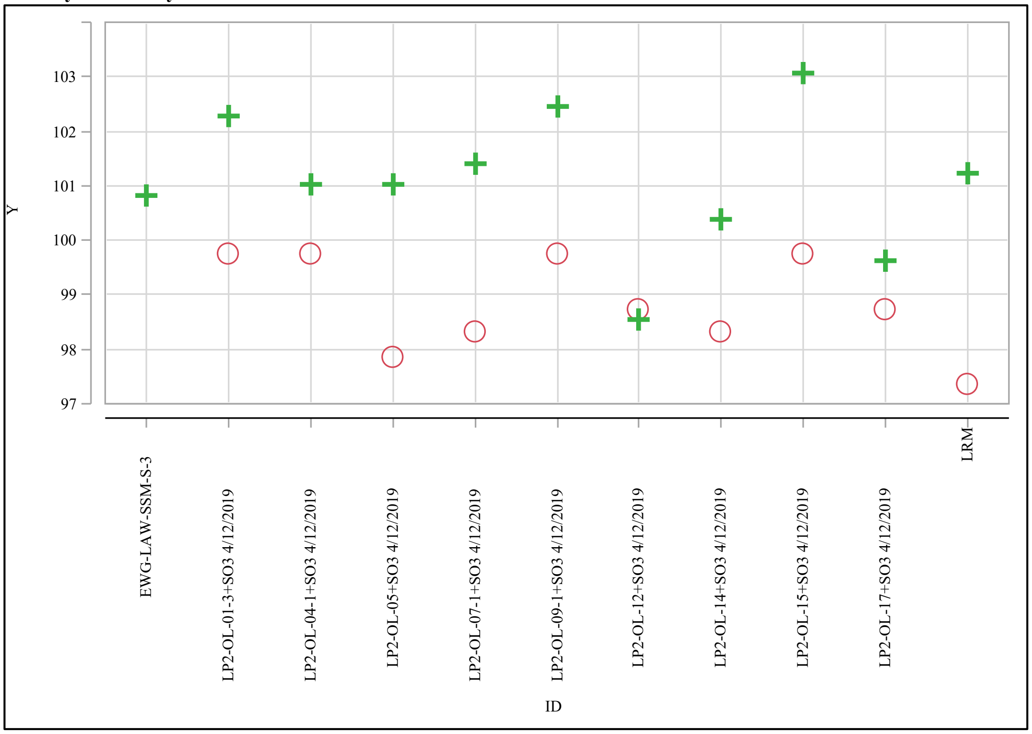


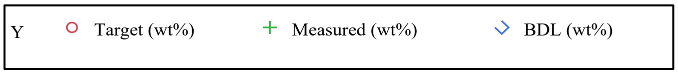
Exhibit A-4. Measured versus Targeted Concentrations by Glass ID by Oxide (continued)

Overlay Plot Analyte=ZrO2 (wt%)



Overlay Plot Analyte= Sums for the Measured Oxides





Distribution:

J. W. Amoroso, 999-W
A. D. Cozzi, 999-W
C. L. Crawford, 773-42A
W. C. Eaton, PNNL
T. B. Edwards, 999-W
A. P. Fellinger, 773-42A
S. D. Fink, 773-A
K. M. Fox, 999-W
H. K. Hall, 999-W
C. C. Herman, 773-A
A. M. Howe, 999-W
T. Jin, PNNL
F. C. Johnson, 999-W
A. A. Kruger, DOE-ORP
C. E. Lonergan, PNNL
J. Manna, 999-W
D. J. McCabe, 773-42A
D. L. McClane, 999-W
K. E. Miles, 999-1W
G. A. Morgan, 999-W
F. M. Pennebaker, 773-42A
W. T. Riley, 999-1W
R. L. Russell, PNNL
M. J. Schweiger, PNNL
C. L. Trivelpiece, 999-W
J. D. Vienna, PNNL
B. J. Wiedenman, 773-42A
W. R. Wilmarth, 773-A
Records Administration (EDWS)