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Composition Measurements of the Environmental Management Headquarters (EMHQ) Low-Activity Waste (LAW) Glasses

M. C. Hsieh

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REVIEWS AND APPROVALS

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TECHNICAL REVIEW:

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APPROVAL:

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EXECUTIVE SUMMARY

This report provides the results from the chemical analyses of glass compositions for the Environmental Management Headquarters Low-Activity Waste study glasses, a series of simulated nuclear waste glasses fabricated at Pacific Northwest National Laboratory. These data will be used in the development, validation, and implementation of enhanced property/composition models for waste glass vitrification at Hanford.

Chemical analyses were performed on a representative sample of each of the quenched glasses to allow for comparisons with targeted compositions. The relative differences between the targeted and measured concentrations of Na_2O, Li_2O, and SO_3 for several of the glasses and B_2O_3in one of the glasses were greater than 10%. These results can be used in further characterization of this series of glasses, including the normalization of Product Consistency Test results.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

BDL	below detection limit
DOE	Department of Energy
EMHQ	Environmental Management Headquarters
IC	ion chromatography
ICP-OES	inductively coupled plasma – optical emission spectroscopy
ID	identifier
KH	potassium hydroxide fusion
LAW	low-activity waste
LM	lithium metaborate fusion
LRM	low-activity test reference material
ORP	Office of River Protection
PF	sodium peroxide fusion
PNNL	Pacific Northwest National Laboratory
seq	sequence
SRNL	Savannah River National Laboratory
TTQAP	Task Technical and Quality Assurance Plan
wt.%	weight percent
WTP	Hanford Waste Treatment and Immobilization Plant

1.0 Introduction

The U.S. Department of Energy (DOE) is responsible for 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 Office of River Protection (ORP) has requested that the Savannah River National Laboratory (SRNL) contribute in areas of recognized capabilities and expertise for glass waste form development to support successful startup of the WTP.

Successful efforts have allowed for demonstration of greatly enhanced treatment efficiencies of those projected from the minimum requirements set forth in the WTP Contract[a]. Additional flexibility and expansion of the qualified glass forming region are the current focus.[1] SRNL support of this work is defined in the Task Technical and Quality Assurance Plan (TTQAP).[2]

This report provides results from the chemical analyses of the baseline (quenched) versions of a series of simulated nuclear waste glasses designed and fabricated at Pacific Northwest National Laboratory (PNNL). The 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 glasses were designated the Environmental Management Headquarters (EMHQ) Low-Activity Waste (LAW) study glasses. The resulting data will be used in the development, validation, and implementation of enhanced property/composition models for nuclear waste glasses.[1]

2.0 Experimental Procedure

2.1 Quality Assurance

Requirements for performing reviews of technical reports and the extent of review are established in Manual E7, Procedure 2.60.[4] SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011.[5] Laboratory data for this study were recorded in the SRNL Electronic Laboratory Notebook system, experiment L6390-00441-04. The glasses provided by PNNL were designed and fabricated following a Task Plan.[1]

2.2 Glasses Selected for Study

The baseline (quenched) glass compositions in this study were selected and fabricated by PNNL. Samples of the quenched baseline glasses were received at SRNL for chemical composition analysis. PNNL identifiers (IDs) for the glass samples and the associated SRNL sample identifiers are listed in Table 2-1.

[a]Contract DE-AC27-01RV14136, as amended, U.S. Department of Energy, Richland, WA (2000).

Table 2-1. Identifiers for the EMHQ LAW Study Glasses

PNNL ID	Lab ID
EMHQ-LBE-01	S-13338
EMHQ-LBE-02	S-13339
EMHQ-LBE-03	S-13340
EMHQ-LBE-04	S-13341
EMHQ-LBE-05	S-13342
EMHQ-LBE-06	S-13343
EMHQ-LBE-07	S-13344
EMHQ-LBE-08	S-13345
EMHQ-LBE-09	S-13346
EMHQ-LBE-10	S-13347

2.3 Glass Composition Analysis

Chemical analyses were performed under the auspices of an analytical plan[6] on a representative sample of each of the glasses listed in Table 2-1 to allow for comparisons with the targeted compositions. Three dissolution techniques (potassium hydroxide fusion (KH), lithium metaborate fusion (LM), and sodium peroxide fusion (PF)) were used for preparing each of the glass samples, in duplicate, for analysis.[7-9] Note that for some analytes, the analytical plan specified more than one preparation method for analysis. The results were reviewed and, in general, the method that provided better recovery of the analyte was selected for reporting.

Each of the duplicate samples was analyzed twice for each element of interest by inductively coupled plasma – optical emission spectroscopy (ICP-OES)[10] or ion chromatography (IC),[11] for a total of four measurements per element per glass. Glass standards were also intermittently measured to assess the performance of the ICP-OES and IC instruments over the course of these analyses. Specifically, several samples of the low-activity test reference material (LRM) were included as part of the analytical plans. The LRM composition reported as the "Consensus Average" is used as the reference composition of this glass.[12] The preparation and measurement methods used for each of the reported glass components are listed in Table 2-2.

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

Analyte	Measurement Method	Preparation Method
Al	ICP-OES	PF
B	ICP-OES	PF
Ca	ICP-OES	LM
Cl	IC	KH
Cr	ICP-OES	LM
F	IC	KH
Fe	ICP-OES	LM
K	ICP-OES	LM
Li	ICP-OES	PF
Mg	ICP-OES	LM
Mn	ICP-OES	LM
Na	ICP-OES	LM
P	ICP-OES	LM
S	ICP-OES	LM
Si	ICP-OES	PF
Sn	ICP-OES	LM
Ti	ICP-OES	LM
V	ICP-OES	LM
Zr	ICP-OES	LM

3.0 Results and Discussion

JMP® Version 14.3.0 (SAS Institute, Inc.)[13] was used to support these analyses.

3.1 Review and Evaluation of the Quenched Glass Composition Measurements

Table A-1, Table A-2, and Table A-3 in Appendix A provide the elemental concentration measurements in weight percent (wt.%) from glasses prepared using KH, LM, and PF methods, respectively. Elemental measurements for samples of the LRM glass are also included in these tables of Appendix A.

3.1.1 Treatment of Detection Limits

The elemental concentrations in Table A-1, Table A-2, and Table A-3 in Appendix A were converted to oxide concentrations by multiplying the values of each element by the gravimetric factor for the corresponding oxide. A concentration measurement that was reported to be below the detection limit was set to the detection limit for the purposes of data review and calculating a sum of oxides for each glass. Concentration measurements that were below the detection limit (BDL) are denoted with a less than symbol (<).

3.1.2 Composition Measurements by Glass Identifier

Exhibit A-1 in Appendix A provides plots of the oxide concentration measurements by the PNNL Glass ID (including the LRM glasses) 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. There were no indications of errors in preparation or measurement that had to be addressed in treatment of the data.

3.1.3 Results for the LRM Standard Glass

Exhibit A-2 in Appendix A provides a comparison of the LRM results to their acceptability limits utilized by SRNL.[10] 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 each element of interest. The results show that all measurements of the LRM elements of interest were within the acceptability limits during the execution of these analyses.

3.1.4 Measured versus Target Compositions

All measurements for each element in each glass (Table A-1, Table A-2, and Table A-3 in Appendix A) were used in calculating oxide values, which were then averaged to determine a representative chemical composition for each glass. A sum of oxides was also computed for each glass based upon the averaged oxide values. Exhibit A-3 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.

Table A-4 in Appendix A provides a summary of the average compositions, targeted compositions and some associated differences and relative differences. The measured sums of oxides for all glasses fall within the interval of 96.8 wt.% to 98.1 wt. %, indicating acceptable recovery of the glass components.[14] Entries in Table A-4 show the relative differences between the measured and targeted values for the analytes with measured and targeted values above 1 wt.%. The relative differences were shaded if they are 10% or more and are summarized below.

- Na_2O relative differences were 10% or greater for EMHQ-LBE-04, EMHQ-LBE-05, and EMHQ-LBE-06.
- Li_2O relative differences were 10% or greater for EMHQ-LBE-04 and EMHQ-LBE-06.
- SO_3 relative differences were 10% or more for EMHQ-LBE-01, EMHQ-LBE-04, EMHQ-LBE-05, and EMHQ-LBE-06.
- B_2O_3 relative difference was 10% for EMHQ-LBE-05.

4.0 Summary

Chemical analyses were performed on a representative sample of each of the EMHQ LAW quenched glasses to allow for comparisons with the targeted compositions. The relative differences between the targeted and measured concentrations Na_2O, Li_2O, and SO_3 for several of the glasses and B_2O_3 for one of the glasses were greater than 10%. These results can be used in further characterization of this series of glasses, including the normalization of Product Consistency Test results.

5.0 References

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Appendix A. Tables and Exhibits Supporting the EMHQ LAW Glass Composition Measurements

Table A-1. KH Measurements (wt.%) of the Study Glasses

PNNL ID	Block	Sub – Block	Seq	Lab ID	Cl^-	F^-
LRM	1	1	1	LRMKH111	<0.0250	0.854
EMHQ-LBE-04	1	1	2	S-13341KH21	0.0695	0.0714
EMHQ-LBE-07	1	1	3	S-13344KH11	0.0674	0.0646
EMHQ-LBE-08	1	1	4	S-13345KH21	0.0701	0.0671
EMHQ-LBE-10	1	1	5	S-13347KH21	0.0621	0.0672
EMHQ-LBE-05	1	1	6	S-13342KH11	0.0639	0.0676
EMHQ-LBE-01	1	1	7	S-13338KH11	0.106	0.0896
EMHQ-LBE-03	1	1	8	S-13340KH11	0.109	0.0905
EMHQ-LBE-01	1	1	9	S-13338KH21	0.102	0.0937
EMHQ-LBE-08	1	1	10	S-13345KH11	0.0585	0.0576
EMHQ-LBE-09	1	1	11	S-13346KH11	0.0697	0.0684
LRM	1	1	12	LRMKH112	<0.0250	0.868
EMHQ-LBE-07	1	1	13	S-13344KH21	0.0640	0.0628
EMHQ-LBE-05	1	1	14	S-13342KH21	0.0625	0.0673
EMHQ-LBE-02	1	1	15	S-13339KH11	0.103	0.0870
EMHQ-LBE-09	1	1	16	S-13346KH21	0.0690	0.0669
EMHQ-LBE-06	1	1	17	S-13343KH11	0.0686	0.0701
EMHQ-LBE-04	1	1	18	S-13341KH11	0.0668	0.0686
EMHQ-LBE-02	1	1	19	S-13339KH21	0.0986	0.0840
EMHQ-LBE-03	1	1	20	S-13340KH21	0.106	0.0912
EMHQ-LBE-06	1	1	21	S-13343KH21	0.0692	0.0696
EMHQ-LBE-10	1	1	22	S-13347KH11	0.0693	0.0637
LRM	1	1	23	LRMKH113	<0.0250	0.866
LRM	1	2	1	LRMKH121	<0.0250	0.868
EMHQ-LBE-03	1	2	2	S-13340KH22	0.106	0.0929
EMHQ-LBE-02	1	2	3	S-13339KH12	0.103	0.0883
EMHQ-LBE-08	1	2	4	S-13345KH22	0.0676	0.0666
EMHQ-LBE-10	1	2	5	S-13347KH22	0.0602	0.0668
EMHQ-LBE-05	1	2	6	S-13342KH22	0.0616	0.0679
EMHQ-LBE-02	1	2	7	S-13339KH22	0.0987	0.0844
EMHQ-LBE-09	1	2	8	S-13346KH12	0.0684	0.0686
EMHQ-LBE-09	1	2	9	S-13346KH22	0.0688	0.0674
EMHQ-LBE-03	1	2	10	S-13340KH12	0.107	0.0907
EMHQ-LBE-01	1	2	11	S-13338KH22	0.102	0.0971
LRM	1	2	12	LRMKH122	<0.0250	0.903
EMHQ-LBE-06	1	2	13	S-13343KH12	0.0696	0.0722
EMHQ-LBE-07	1	2	14	S-13344KH22	0.0647	0.0654
EMHQ-LBE-06	1	2	15	S-13343KH22	0.0707	0.0725
EMHQ-LBE-05	1	2	16	S-13342KH12	0.0637	0.0698
EMHQ-LBE-07	1	2	17	S-13344KH12	0.0666	0.0660
EMHQ-LBE-01	1	2	18	S-13338KH12	0.106	0.0940
EMHQ-LBE-04	1	2	19	S-13341KH22	0.0664	0.0712
EMHQ-LBE-10	1	2	20	S-13347KH12	0.0715	0.0669
EMHQ-LBE-04	1	2	21	S-13341KH12	0.0687	0.0720
EMHQ-LBE-08	1	2	22	S-13345KH12	0.0578	0.0582
LRM	1	2	23	LRMKH123	<0.0250	0.906

Table A-2. LM Measurements (wt.%) of the Study Glasses

PNNL ID	Block	Sub – Block	Seq	Lab ID	Ca	Cr	Fe	K	Mg	Mn	Na	P	S	Sn	Ti	V	Zr
LRM	1	1	1	LRMLM111	0.367	0.130	0.995	1.17	0.0657	0.0613	14.6	0.207	0.0831	<0.100	0.0614	<0.100	0.689
EMHQ-LBE-05	1	1	2	S-13342LM21	8.30	0.0176	0.0988	0.0456	0.120	0.407	8.21	0.0642	0.545	<0.100	0.0664	2.24	1.48
EMHQ-LBE-02	1	1	3	S-13339LM21	6.63	0.0333	0.0906	0.0816	0.0958	0.404	14.6	0.120	0.559	<0.100	0.0666	2.25	2.74
EMHQ-LBE-04	1	1	4	S-13341LM11	8.29	0.0148	0.0841	0.0475	0.117	<0.0100	8.36	0.0626	0.542	<0.100	0.0444	2.26	1.47
EMHQ-LBE-10	1	1	5	S-13347LM11	5.37	0.105	0.0749	0.0440	0.0772	0.207	16.6	0.127	0.0765	3.37	0.0808	<0.100	4.28
EMHQ-LBE-08	1	1	6	S-13345LM21	5.30	0.107	0.0947	0.0464	0.0780	0.405	16.4	0.128	0.0813	3.36	0.0782	<0.100	4.23
EMHQ-LBE-08	1	1	7	S-13345LM11	5.29	0.108	0.0893	0.0471	0.0805	0.406	16.4	0.127	0.0765	3.35	0.0783	<0.100	4.25
EMHQ-LBE-06	1	1	8	S-13343LM11	8.10	0.0180	0.0913	0.0393	0.118	0.410	8.09	0.0621	0.539	<0.100	0.0450	2.21	1.45
EMHQ-LBE-10	1	1	9	S-13347LM21	5.35	0.104	0.0757	0.0423	0.0764	0.206	16.5	0.128	0.0747	3.37	0.0802	<0.100	4.28
EMHQ-LBE-07	1	1	10	S-13344LM21	5.30	0.103	0.0839	0.0413	0.0766	<0.0100	16.6	0.127	0.0798	3.39	0.0793	<0.100	4.28
EMHQ-LBE-03	1	1	11	S-13340LM11	6.64	0.0335	0.0824	0.0807	0.0943	0.400	14.7	0.117	0.555	<0.100	0.0650	2.21	2.73
LRM	1	1	12	LRMLM112	0.376	0.132	0.993	1.16	0.0659	0.0616	14.8	0.205	0.0861	<0.100	0.0619	<0.100	0.714
EMHQ-LBE-06	1	1	13	S-13343LM21	8.16	0.0147	0.0884	0.0459	0.117	0.409	8.16	0.0618	0.541	<0.100	0.0453	2.22	1.44
EMHQ-LBE-03	1	1	14	S-13340LM21	6.59	0.0315	0.0821	0.0803	0.0947	0.405	14.6	0.120	0.562	<0.100	0.0656	2.21	2.72
EMHQ-LBE-09	1	1	15	S-13346LM11	5.31	0.105	0.0737	0.0447	0.0765	0.410	16.3	0.126	0.0786	3.35	0.0813	<0.100	4.24
EMHQ-LBE-04	1	1	16	S-13341LM21	8.32	0.0154	0.0844	0.0488	0.117	<0.0100	8.36	0.0629	0.531	<0.100	0.0454	2.26	1.46
EMHQ-LBE-01	1	1	17	S-13338LM21	6.63	0.0340	0.0829	0.0867	0.101	<0.0100	14.6	0.119	0.550	<0.100	0.0831	2.22	2.73
EMHQ-LBE-07	1	1	18	S-13344LM11	5.36	0.106	0.0800	0.0455	0.0774	<0.0100	16.6	0.130	0.0763	3.34	0.0807	<0.100	4.28
EMHQ-LBE-05	1	1	19	S-13342LM11	8.22	0.0171	0.0969	0.0478	0.118	0.405	8.27	0.0640	0.550	<0.100	0.0662	2.24	1.49
EMHQ-LBE-01	1	1	20	S-13338LM11	6.61	0.0319	0.0831	0.0889	0.0953	<0.0100	14.9	0.119	0.555	<0.100	0.0824	2.22	2.74
EMHQ-LBE-09	1	1	21	S-13346LM21	5.29	0.104	0.0756	0.0419	0.0751	0.411	16.4	0.124	0.0761	3.35	0.0820	<0.100	4.24
EMHQ-LBE-02	1	1	22	S-13339LM11	6.62	0.0326	0.0849	0.0832	0.0955	0.409	14.6	0.119	0.566	<0.100	0.0676	2.22	2.70
LRM	1	1	23	LRMLM113	0.378	0.130	0.997	1.16	0.0654	0.0612	15.0	0.206	0.0888	<0.100	0.0617	<0.100	0.714
LRM	1	2	1	LRMLM121	0.376	0.130	0.981	1.13	0.0671	0.0612	15.3	0.207	0.0875	<0.100	0.0610	<0.100	0.690
EMHQ-LBE-01	1	2	2	S-13338LM12	6.78	0.0317	0.0830	0.0791	0.0987	<0.0100	15.8	0.121	0.553	<0.100	0.0821	2.27	2.75
EMHQ-LBE-09	1	2	3	S-13346LM12	5.50	0.104	0.0738	0.0447	0.0791	0.407	17.4	0.127	0.0732	3.39	0.0809	<0.100	4.26
EMHQ-LBE-06	1	2	4	S-13343LM12	8.39	0.0182	0.0907	0.0403	0.121	0.407	8.80	0.0619	0.545	<0.100	0.0442	2.26	1.45
EMHQ-LBE-10	1	2	5	S-13347LM22	5.49	0.104	0.0752	0.0378	0.0781	0.206	17.6	0.125	0.0756	3.41	0.0795	<0.100	4.23
EMHQ-LBE-03	1	2	6	S-13340LM12	6.68	0.0336	0.0821	0.0745	0.0968	0.400	15.4	0.118	0.564	<0.100	0.0646	2.22	2.68
EMHQ-LBE-07	1	2	7	S-13344LM12	5.48	0.103	0.0793	0.0396	0.0795	<0.0100	17.5	0.130	0.0764	3.42	0.0799	<0.100	4.23
EMHQ-LBE-08	1	2	8	S-13345LM12	5.40	0.108	0.0886	0.0372	0.0824	0.404	17.4	0.128	0.0776	3.41	0.0778	<0.100	4.22
EMHQ-LBE-04	1	2	9	S-13341LM12	8.39	0.0151	0.0838	0.0459	0.121	<0.0100	8.76	0.0642	0.545	<0.100	0.0445	2.26	1.46
EMHQ-LBE-05	1	2	10	S-13342LM22	8.35	0.0178	0.0970	0.0415	0.122	0.402	8.79	0.0614	0.547	<0.100	0.0648	2.27	1.47
EMHQ-LBE-01	1	2	11	S-13338LM22	6.68	0.0327	0.0819	0.0777	0.103	<0.0100	15.5	0.119	0.556	<0.100	0.0816	2.24	2.71
LRM	1	2	12	LRMLM122	0.374	0.132	0.991	1.09	0.0678	0.0616	15.8	0.204	0.0862	<0.100	0.0617	<0.100	0.687
EMHQ-LBE-02	1	2	13	S-13339LM22	6.71	0.0333	0.0905	0.0793	0.0987	0.404	15.2	0.122	0.563	<0.100	0.0669	2.24	2.68
EMHQ-LBE-05	1	2	14	S-13342LM12	8.36	0.0178	0.0967	0.0431	0.122	0.408	8.76	0.0651	0.554	<0.100	0.0651	2.26	1.47
EMHQ-LBE-06	1	2	15	S-13343LM22	8.26	0.0149	0.0875	0.0494	0.121	0.408	8.60	0.0612	0.543	<0.100	0.0445	2.22	1.41
EMHQ-LBE-08	1	2	16	S-13345LM22	5.32	0.108	0.0951	0.0400	0.0807	0.410	17.1	0.130	0.0779	3.38	0.0787	<0.100	4.14
EMHQ-LBE-09	1	2	17	S-13346LM22	5.38	0.107	0.0757	0.0428	0.0783	0.414	17.1	0.127	0.0772	3.36	0.0818	<0.100	4.19
EMHQ-LBE-10	1	2	18	S-13347LM12	5.38	0.107	0.0753	0.0340	0.0803	0.210	17.2	0.132	0.0748	3.41	0.0814	<0.100	4.20
EMHQ-LBE-07	1	2	19	S-13344LM22	5.43	0.106	0.0842	0.0466	0.0795	<0.0100	17.2	0.132	0.0772	3.40	0.0797	<0.100	4.19
EMHQ-LBE-04	1	2	20	S-13341LM22	8.29	0.0157	0.0845	0.0428	0.120	<0.0100	8.66	0.0620	0.551	<0.100	0.0447	2.22	1.41
EMHQ-LBE-02	1	2	21	S-13339LM12	6.66	0.0331	0.0844	0.0825	0.0979	0.405	15.3	0.119	0.569	<0.100	0.0662	2.22	2.64
EMHQ-LBE-03	1	2	22	S-13340LM22	6.54	0.0339	0.0831	0.0777	0.0989	0.407	15.1	0.118	0.568	<0.100	0.0670	2.19	2.65
LRM	1	2	23	LRMLM123	0.372	0.131	1.01	1.19	0.0680	0.0618	15.5	0.211	0.0820	<0.100	0.0619	<0.100	0.683

Table A-3. PF Measurements (wt.%) of the Study Glasses

PNNL ID	Block	Sub – Block	Seq	Lab ID	Al	B	Li	Si
LRM	1	1	1	LRMPF111	5.44	2.30	<0.100	24.7
EMHQ-LBE-07	1	1	2	S-13344PF11	4.63	2.48	<0.100	17.9
EMHQ-LBE-10	1	1	3	S-13347PF11	4.74	2.44	<0.100	17.9
EMHQ-LBE-06	1	1	4	S-13343PF21	1.86	3.73	0.829	21.9
EMHQ-LBE-05	1	1	5	S-13342PF11	1.85	3.74	0.819	21.8
EMHQ-LBE-05	1	1	6	S-13342PF21	1.86	3.76	0.830	21.9
EMHQ-LBE-08	1	1	7	S-13345PF21	4.75	2.48	<0.100	18.1
EMHQ-LBE-08	1	1	8	S-13345PF11	4.65	2.47	<0.100	18.0
EMHQ-LBE-04	1	1	9	S-13341PF11	1.93	3.83	0.879	22.2
EMHQ-LBE-02	1	1	10	S-13339PF11	2.83	3.61	<0.100	18.4
EMHQ-LBE-10	1	1	11	S-13347PF21	4.60	2.42	<0.100	17.7
LRM	1	1	12	LRMPF112	5.31	2.24	<0.100	24.5
EMHQ-LBE-09	1	1	13	S-13346PF11	4.62	2.45	<0.100	17.8
EMHQ-LBE-03	1	1	14	S-13340PF11	2.88	3.66	<0.100	18.6
EMHQ-LBE-01	1	1	15	S-13338PF11	2.88	3.66	<0.100	18.7
EMHQ-LBE-04	1	1	16	S-13341PF21	1.87	3.81	0.828	22.2
EMHQ-LBE-07	1	1	17	S-13344PF21	4.75	2.45	<0.100	18.0
EMHQ-LBE-01	1	1	18	S-13338PF21	2.90	3.66	<0.100	18.7
EMHQ-LBE-02	1	1	19	S-13339PF21	2.79	3.65	<0.100	18.5
EMHQ-LBE-06	1	1	20	S-13343PF11	1.86	3.80	0.823	22.1
EMHQ-LBE-09	1	1	21	S-13346PF21	4.68	2.43	<0.100	17.9
EMHQ-LBE-03	1	1	22	S-13340PF21	2.85	3.60	<0.100	18.6
LRM	1	1	23	LRMPF113	5.32	2.20	<0.100	24.6
LRM	1	2	1	LRMPF121	5.42	2.34	<0.100	25.3
EMHQ-LBE-05	1	2	2	S-13342PF12	1.86	3.88	0.852	22.5
EMHQ-LBE-07	1	2	3	S-13344PF22	4.67	2.48	<0.100	18.0
EMHQ-LBE-10	1	2	4	S-13347PF12	4.70	2.52	<0.100	18.3
EMHQ-LBE-02	1	2	5	S-13339PF12	2.83	3.73	<0.100	18.8
EMHQ-LBE-06	1	2	6	S-13343PF12	1.90	3.95	0.870	22.8
EMHQ-LBE-02	1	2	7	S-13339PF22	2.82	3.72	<0.100	18.8
EMHQ-LBE-01	1	2	8	S-13338PF22	2.85	3.66	<0.100	18.7
EMHQ-LBE-05	1	2	9	S-13342PF22	1.87	3.81	0.857	22.3
EMHQ-LBE-08	1	2	10	S-13345PF12	4.64	2.49	<0.100	18.1
EMHQ-LBE-10	1	2	11	S-13347PF22	4.67	2.52	<0.100	18.2
LRM	1	2	12	LRMPF122	5.40	2.32	<0.100	25.2
EMHQ-LBE-01	1	2	13	S-13338PF12	2.83	3.70	<0.100	18.8
EMHQ-LBE-03	1	2	14	S-13340PF12	2.79	3.65	<0.100	18.5
EMHQ-LBE-08	1	2	15	S-13345PF22	4.71	2.52	<0.100	18.5
EMHQ-LBE-07	1	2	16	S-13344PF12	4.62	2.55	<0.100	18.3
EMHQ-LBE-04	1	2	17	S-13341PF12	1.91	3.88	0.892	22.4
EMHQ-LBE-09	1	2	18	S-13346PF12	4.70	2.49	<0.100	18.2
EMHQ-LBE-03	1	2	19	S-13340PF22	2.82	3.63	<0.100	18.6
EMHQ-LBE-09	1	2	20	S-13346PF22	4.72	2.49	<0.100	18.3
EMHQ-LBE-04	1	2	21	S-13341PF22	1.87	3.85	0.840	22.5
EMHQ-LBE-06	1	2	22	S-13343PF22	1.83	3.80	0.836	22.2
LRM	1	2	23	LRMPF123	5.35	2.31	<0.100	25.1

Table A-4. Comparison of Measured versus Target Compositions

PNNL ID	Oxide	Mean Measurement (wt.%)	Target (wt.%)	Difference of Measured versus Target	% Difference Measured versus Target
LRM	Al_2O_3	10.2	9.51	0.643	7%
LRM	B_2O_3	7.36	7.85	-0.493	-6%
LRM	CaO	0.523	0.540	-0.017	
LRM	Cl^-	<0.025	0	0.025	
LRM	Cr_2O_3	0.191	0.190	0.001	
LRM	F^-	0.878	0.860	0.017	
LRM	Fe_2O_3	1.42	1.38	0.042	3%
LRM	K_2O	1.39	1.48	-0.095	-6%
LRM	Li_2O	<0.215	0.110	0.105	
LRM	MgO	0.111	0.100	0.011	
LRM	MnO	0.0793	0.0800	-0.001	
LRM	Na_2O	20.4	20.0	0.415	2%
LRM	P_2O_5	0.474	0.540	-0.066	
LRM	SiO_2	53.3	54.2	-0.931	-2%
LRM	SnO_2	<0.127	0	0.127	
LRM	SO_3	0.214	0.300	-0.086	
LRM	TiO_2	0.103	0.100	0.003	
LRM	V_2O_5	<0.179	0	0.179	
LRM	ZrO_2	0.940	0.930	0.01	
LRM	**Sum of Oxides**	**98.1**	**98.2**	**-0.111**	**0%**
EMHQ-LBE-01	Al_2O_3	5.41	5.35	0.062	1%
EMHQ-LBE-01	B_2O_3	11.8	12.9	-1.06	-8%
EMHQ-LBE-01	CaO	9.34	9.75	-0.413	-4%
EMHQ-LBE-01	Cl^-	0.104	0.118	-0.014	
EMHQ-LBE-01	Cr_2O_3	0.0476	0.0540	-0.006	
EMHQ-LBE-01	F^-	0.0936	0.114	-0.02	
EMHQ-LBE-01	Fe_2O_3	0.118	0.132	-0.014	
EMHQ-LBE-01	K_2O	0.100	0.126	-0.026	
EMHQ-LBE-01	Li_2O	<0.215	0	0.215	
EMHQ-LBE-01	MgO	0.165	0.144	0.021	
EMHQ-LBE-01	MnO	<0.0129	0.0100	0.003	
EMHQ-LBE-01	Na_2O	20.5	19.4	1.085	6%
EMHQ-LBE-01	P_2O_5	0.274	0.305	-0.031	
EMHQ-LBE-01	SiO_2	40.1	41.3	-1.234	-3%
EMHQ-LBE-01	SnO_2	<0.127	0	0.127	
EMHQ-LBE-01	SO_3	1.38	1.54	-0.158	-10%
EMHQ-LBE-01	TiO_2	0.137	0.126	0.011	
EMHQ-LBE-01	V_2O_5	3.99	4.01	-0.013	0%
EMHQ-LBE-01	ZrO_2	3.69	3.75	-0.054	-1%
EMHQ-LBE-01	**Sum of Oxides**	**97.6**	**99.1**	**-1.518**	**-2%**
EMHQ-LBE-02	Al_2O_3	5.32	5.35	-0.027	-1%
EMHQ-LBE-02	B_2O_3	11.8	12.9	-1.035	-8%
EMHQ-LBE-02	CaO	9.31	9.75	-0.441	-5%
EMHQ-LBE-02	Cl^-	0.101	0.118	-0.017	
EMHQ-LBE-02	Cr_2O_3	0.0483	0.0540	-0.006	
EMHQ-LBE-02	F^-	0.0859	0.114	-0.028	

Table A-4. Comparison of Measured versus Target Compositions (continued)

PNNL ID	Oxide	Mean Measurement (wt.%)	Target (wt.%)	Difference of Measured versus Target	% Difference Measured versus Target
EMHQ-LBE-02	Fe_2O_3	0.125	0.132	-0.007	
EMHQ-LBE-02	K_2O	0.0984	0.126	-0.028	
EMHQ-LBE-02	Li_2O	<0.215	0	0.215	
EMHQ-LBE-02	MgO	0.161	0.144	0.017	
EMHQ-LBE-02	MnO	0.524	0.555	-0.031	
EMHQ-LBE-02	Na_2O	20.1	19.4	0.714	4%
EMHQ-LBE-02	P_2O_5	0.275	0.305	-0.03	
EMHQ-LBE-02	SiO_2	39.8	41.3	-1.448	-4%
EMHQ-LBE-02	SnO_2	<0.127	0	0.127	
EMHQ-LBE-02	SO_3	1.41	1.54	-0.131	-9%
EMHQ-LBE-02	TiO_2	0.111	0.126	-0.015	
EMHQ-LBE-02	V_2O_5	3.99	4.01	-0.022	-1%
EMHQ-LBE-02	ZrO_2	3.63	3.75	-0.111	-3%
EMHQ-LBE-02	**Sum of Oxides**	**97.3**	**99.1**	**-1.758**	**-2%**
EMHQ-LBE-03	Al_2O_3	5.36	5.30	0.06	1%
EMHQ-LBE-03	B_2O_3	11.7	12.7	-1.041	-8%
EMHQ-LBE-03	CaO	9.25	9.56	-0.304	-3%
EMHQ-LBE-03	Cl^-	0.107	0.117	-0.01	
EMHQ-LBE-03	Cr_2O_3	0.0484	0.0540	-0.006	
EMHQ-LBE-03	F^-	0.0913	0.113	-0.022	
EMHQ-LBE-03	Fe_2O_3	0.118	0.131	-0.013	
EMHQ-LBE-03	K_2O	0.0943	0.125	-0.031	
EMHQ-LBE-03	Li_2O	<0.215	0	0.215	
EMHQ-LBE-03	MgO	0.159	0.142	0.017	
EMHQ-LBE-03	MnO	0.520	0.555	-0.035	
EMHQ-LBE-03	Na_2O	20.2	19.2	0.944	5%
EMHQ-LBE-03	P_2O_5	0.271	0.301	-0.03	
EMHQ-LBE-03	SiO_2	39.7	40.9	-1.137	-3%
EMHQ-LBE-03	SnO_2	<0.127	0	0.127	
EMHQ-LBE-03	SO_3	1.40	1.53	-0.121	-8%
EMHQ-LBE-03	TiO_2	0.109	0.125	-0.016	
EMHQ-LBE-03	V_2O_5	3.94	3.97	-0.025	-1%
EMHQ-LBE-03	ZrO_2	3.64	3.71	-0.067	-2%
EMHQ-LBE-03	**Sum of Oxides**	**97.0**	**98.0**	**-0.947**	**-1%**
EMHQ-LBE-04	Al_2O_3	3.58	3.54	0.043	1%
EMHQ-LBE-04	B_2O_3	12.4	13.5	-1.168	-9%
EMHQ-LBE-04	CaO	11.6	12.2	-0.595	-5%
EMHQ-LBE-04	Cl^-	0.0679	0.0760	-0.008	
EMHQ-LBE-04	Cr_2O_3	0.0223	0.0250	-0.003	
EMHQ-LBE-04	F^-	0.0708	0.0950	-0.024	
EMHQ-LBE-04	Fe_2O_3	0.120	0.131	-0.011	
EMHQ-LBE-04	K_2O	0.0557	0.0870	-0.031	
EMHQ-LBE-04	Li_2O	1.85	1.67	0.186	11%
EMHQ-LBE-04	MgO	0.197	0.180	0.017	
EMHQ-LBE-04	MnO	<0.0129	0.0130	0	
EMHQ-LBE-04	Na_2O	11.5	9.81	1.699	17%
EMHQ-LBE-04	P_2O_5	0.144	0.158	-0.014	

Table A-4. Comparison of Measured versus Target Compositions (continued)

PNNL ID	Oxide	Mean Measurement (wt.%)	Target (wt.%)	Difference of Measured versus Target	% Difference Measured versus Target
EMHQ-LBE-04	SiO_2	47.8	49.6	-1.889	-4%
EMHQ-LBE-04	SnO_2	<0.127	0	0.127	
EMHQ-LBE-04	SO_3	1.35	1.69	-0.331	-20%
EMHQ-LBE-04	TiO_2	0.0746	0.0910	-0.016	
EMHQ-LBE-04	V_2O_5	4.02	4.03	-0.014	0%
EMHQ-LBE-04	ZrO_2	1.96	2.00	-0.039	-2%
EMHQ-LBE-04	**Sum of Oxides**	**96.9**	**99.0**	**-2.072**	**-2%**
EMHQ-LBE-05	Al_2O_3	3.51	3.54	-0.024	-1%
EMHQ-LBE-05	B_2O_3	12.2	13.5	-1.312	-10%
EMHQ-LBE-05	CaO	11.6	12.2	-0.616	-5%
EMHQ-LBE-05	Cl^-	0.0629	0.0760	-0.013	
EMHQ-LBE-05	Cr_2O_3	0.0257	0.0250	0.001	
EMHQ-LBE-05	F^-	0.0682	0.0950	-0.027	
EMHQ-LBE-05	Fe_2O_3	0.139	0.131	0.008	
EMHQ-LBE-05	K_2O	0.0536	0.0870	-0.033	
EMHQ-LBE-05	Li_2O	1.81	1.67	0.142	9%
EMHQ-LBE-05	MgO	0.200	0.180	0.02	
EMHQ-LBE-05	MnO	0.524	0.558	-0.034	
EMHQ-LBE-05	Na_2O	11.5	9.81	1.662	17%
EMHQ-LBE-05	P_2O_5	0.146	0.158	-0.012	
EMHQ-LBE-05	SiO_2	47.3	49.6	-2.317	-5%
EMHQ-LBE-05	SnO_2	<0.127	0	0.127	
EMHQ-LBE-05	SO_3	1.37	1.69	-0.314	-19%
EMHQ-LBE-05	TiO_2	0.109	0.0910	0.018	
EMHQ-LBE-05	V_2O_5	4.02	4.03	-0.01	0%
EMHQ-LBE-05	ZrO_2	2.00	2.00	-0.002	0%
EMHQ-LBE-05	**Sum of Oxides**	**96.8**	**99.0**	**-2.192**	**-2%**
EMHQ-LBE-06	Al_2O_3	3.52	3.50	0.016	0%
EMHQ-LBE-06	B_2O_3	12.3	13.4	-1.103	-8%
EMHQ-LBE-06	CaO	11.5	12.1	-0.604	-5%
EMHQ-LBE-06	Cl^-	0.0695	0.0750	-0.005	
EMHQ-LBE-06	Cr_2O_3	0.024	0.0250	-0.001	
EMHQ-LBE-06	F^-	0.0711	0.0940	-0.023	
EMHQ-LBE-06	Fe_2O_3	0.128	0.129	-0.001	
EMHQ-LBE-06	K_2O	0.0527	0.0870	-0.034	
EMHQ-LBE-06	Li_2O	1.81	1.64	0.169	10%
EMHQ-LBE-06	MgO	0.198	0.179	0.019	
EMHQ-LBE-06	MnO	0.527	0.558	-0.031	
EMHQ-LBE-06	Na_2O	11.3	9.71	1.633	17%
EMHQ-LBE-06	P_2O_5	0.141	0.157	-0.016	
EMHQ-LBE-06	SiO_2	47.6	49.1	-1.548	-3%
EMHQ-LBE-06	SnO_2	<0.127	0	0.127	
EMHQ-LBE-06	SO_3	1.35	1.67	-0.315	-19%
EMHQ-LBE-06	TiO_2	0.0746	0.0900	-0.015	
EMHQ-LBE-06	V_2O_5	3.98	3.99	-0.013	0%
EMHQ-LBE-06	ZrO_2	1.94	1.98	-0.036	-2%
EMHQ-LBE-06	**Sum of Oxides**	**96.8**	**98.0**	**-1.236**	**-1%**

Table A-4. Comparison of Measured versus Target Compositions (continued)

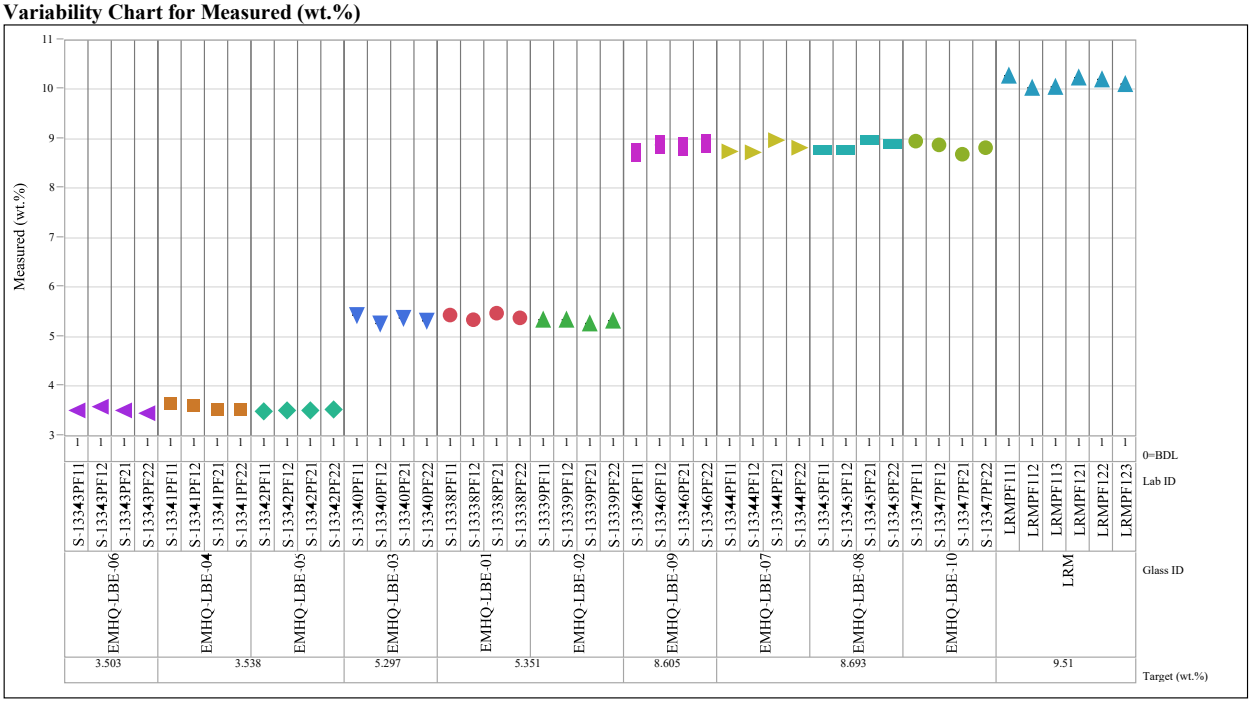
PNNL ID	Oxide	Mean Measurement (wt.%)	Target (wt.%)	Difference of Measured versus Target	% Difference Measured versus Target
EMHQ-LBE-07	Al_2O_3	8.82	8.69	0.126	1%
EMHQ-LBE-07	B_2O_3	8.02	8.64	-0.619	-7%
EMHQ-LBE-07	CaO	7.55	7.63	-0.087	-1%
EMHQ-LBE-07	Cl^-	0.0657	0.0770	-0.011	
EMHQ-LBE-07	Cr_2O_3	0.153	0.167	-0.014	
EMHQ-LBE-07	F^-	0.0647	0.0670	-0.002	
EMHQ-LBE-07	Fe_2O_3	0.117	0.124	-0.007	
EMHQ-LBE-07	K_2O	0.0521	0.0710	-0.019	
EMHQ-LBE-07	Li_2O	<0.215	0	0.215	
EMHQ-LBE-07	MgO	0.130	0.115	0.015	
EMHQ-LBE-07	MnO	<0.0129	0.00800	0.005	
EMHQ-LBE-07	Na_2O	22.9	23.2	-0.362	-2%
EMHQ-LBE-07	P_2O_5	0.297	0.310	-0.013	
EMHQ-LBE-07	SiO_2	38.6	39.4	-0.749	-2%
EMHQ-LBE-07	SnO_2	4.30	4.34	-0.036	-1%
EMHQ-LBE-07	SO_3	0.193	0.190	0.003	
EMHQ-LBE-07	TiO_2	0.133	0.139	-0.006	
EMHQ-LBE-07	V_2O_5	<0.179	0	0.179	
EMHQ-LBE-07	ZrO_2	5.73	5.82	-0.086	-1%
EMHQ-LBE-07	**Sum of Oxides**	**97.5**	**99.0**	**-1.468**	**-1%**
EMHQ-LBE-08	Al_2O_3	8.86	8.69	0.164	2%
EMHQ-LBE-08	B_2O_3	8.02	8.64	-0.619	-7%
EMHQ-LBE-08	CaO	7.45	7.63	-0.178	-2%
EMHQ-LBE-08	Cl^-	0.0635	0.0770	-0.014	
EMHQ-LBE-08	Cr_2O_3	0.157	0.167	-0.01	
EMHQ-LBE-08	F^-	0.0624	0.0670	-0.005	
EMHQ-LBE-08	Fe_2O_3	0.131	0.124	0.007	
EMHQ-LBE-08	K_2O	0.0514	0.0710	-0.02	
EMHQ-LBE-08	Li_2O	<0.215	0	0.215	
EMHQ-LBE-08	MgO	0.133	0.115	0.018	
EMHQ-LBE-08	MnO	0.525	0.553	-0.028	
EMHQ-LBE-08	Na_2O	22.7	23.2	-0.564	-2%
EMHQ-LBE-08	P_2O_5	0.294	0.310	-0.016	
EMHQ-LBE-08	SiO_2	38.9	39.4	-0.481	-1%
EMHQ-LBE-08	SnO_2	4.28	4.34	-0.052	-1%
EMHQ-LBE-08	SO_3	0.196	0.190	0.006	
EMHQ-LBE-08	TiO_2	0.131	0.139	-0.008	
EMHQ-LBE-08	V_2O_5	<0.179	0	0.179	
EMHQ-LBE-08	ZrO_2	5.69	5.82	-0.133	-2%
EMHQ-LBE-08	**Sum of Oxides**	**98.0**	**99.0**	**-0.994**	**-1%**
EMHQ-LBE-09	Al_2O_3	8.84	8.61	0.238	3%
EMHQ-LBE-09	B_2O_3	7.94	8.55	-0.613	-7%
EMHQ-LBE-09	CaO	7.51	7.56	-0.041	-1%
EMHQ-LBE-09	Cl^-	0.0690	0.0760	-0.007	
EMHQ-LBE-09	Cr_2O_3	0.153	0.165	-0.012	
EMHQ-LBE-09	F^-	0.0678	0.0660	0.002	
EMHQ-LBE-09	Fe_2O_3	0.107	0.123	-0.016	

Table A-4. Comparison of Measured versus Target Compositions (continued)

PNNL ID	Oxide	Mean Measurement (wt.%)	Target (wt.%)	Difference of Measured versus Target	% Difference Measured versus Target
EMHQ-LBE-09	K_2O	0.0524	0.0710	-0.019	
EMHQ-LBE-09	Li_2O	<0.215	0	0.215	
EMHQ-LBE-09	MgO	0.128	0.114	0.014	
EMHQ-LBE-09	MnO	0.530	0.553	-0.023	
EMHQ-LBE-09	Na_2O	22.6	23.0	-0.364	-2%
EMHQ-LBE-09	P_2O_5	0.289	0.307	-0.018	
EMHQ-LBE-09	SiO_2	38.6	39.0	-0.351	-1%
EMHQ-LBE-09	SnO_2	4.27	4.29	-0.025	-1%
EMHQ-LBE-09	SO_3	0.190	0.188	0.002	
EMHQ-LBE-09	TiO_2	0.136	0.138	-0.002	
EMHQ-LBE-09	V_2O_5	<0.179	0	0.179	
EMHQ-LBE-09	ZrO_2	5.72	5.76	-0.044	-1%
EMHQ-LBE-09	**Sum of Oxides**	**97.7**	**99.0**	**-0.339**	**0%**
EMHQ-LBE-10	Al_2O_3	8.84	8.69	0.145	2%
EMHQ-LBE-10	B_2O_3	7.97	8.64	-0.668	-8%
EMHQ-LBE-10	CaO	7.55	7.63	-0.08	-1%
EMHQ-LBE-10	Cl^-	0.0658	0.0770	-0.011	
EMHQ-LBE-10	Cr_2O_3	0.153	0.167	-0.014	
EMHQ-LBE-10	F^-	0.0662	0.0670	-0.001	
EMHQ-LBE-10	Fe_2O_3	0.108	0.124	-0.016	
EMHQ-LBE-10	K_2O	0.0476	0.0710	-0.023	
EMHQ-LBE-10	Li_2O	<0.215	0	0.215	
EMHQ-LBE-10	MgO	0.129	0.115	0.014	
EMHQ-LBE-10	MnO	0.268	0.281	-0.013	
EMHQ-LBE-10	Na_2O	22.9	23.2	-0.362	-2%
EMHQ-LBE-10	P_2O_5	0.293	0.310	-0.017	
EMHQ-LBE-10	SiO_2	38.6	39.4	-0.802	-2%
EMHQ-LBE-10	SnO_2	4.30	4.34	-0.033	-1%
EMHQ-LBE-10	SO_3	0.188	0.190	-0.002	
EMHQ-LBE-10	TiO_2	0.134	0.139	-0.005	
EMHQ-LBE-10	V_2O_5	<0.179	0	0.179	
EMHQ-LBE-10	ZrO_2	5.74	5.82	-0.082	-1%
EMHQ-LBE-10	**Sum of Oxides**	**97.7**	**99.0**	**-1.303**	**-1%**

Exhibit A-1. Plots of Oxide Measurements by Glass Identifier by Target Concentrations

Oxide=Al_2O_3 (wt%), Prep Method=PF
Variability Chart for Measured (wt.%)



Oxide=B_2O_3 (wt%), Prep Method=PF
Variability Chart for Measured (wt.%)

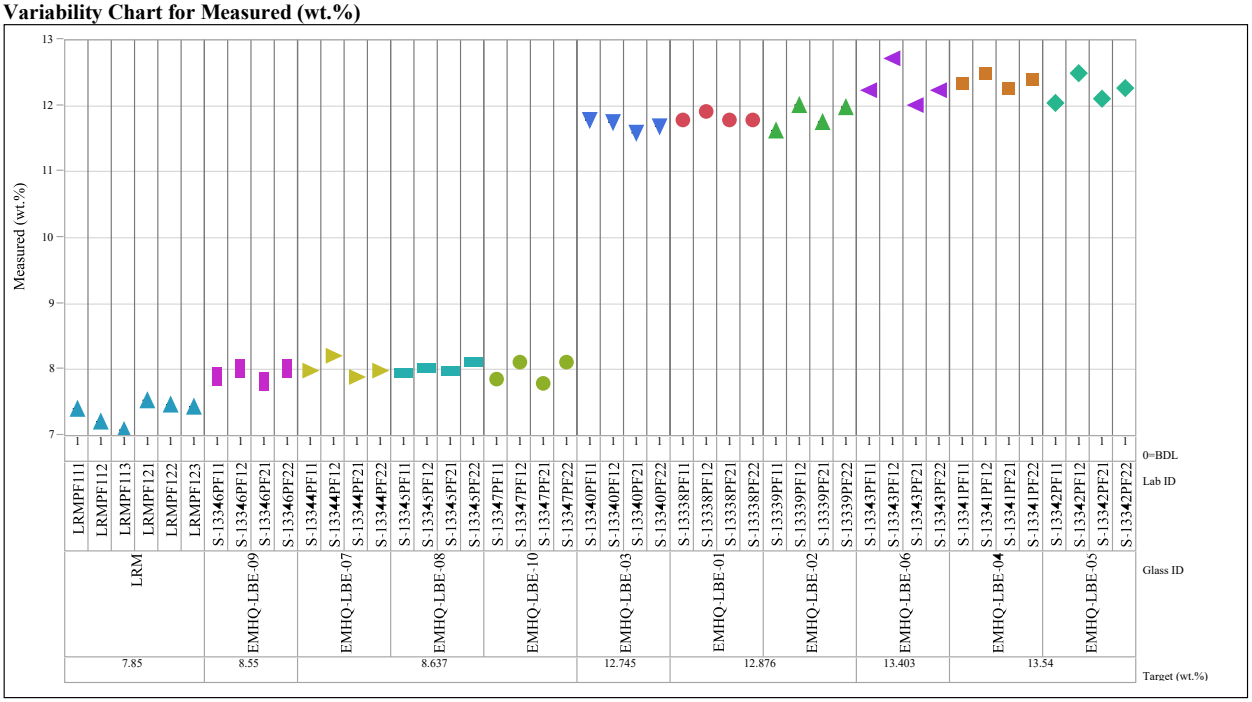
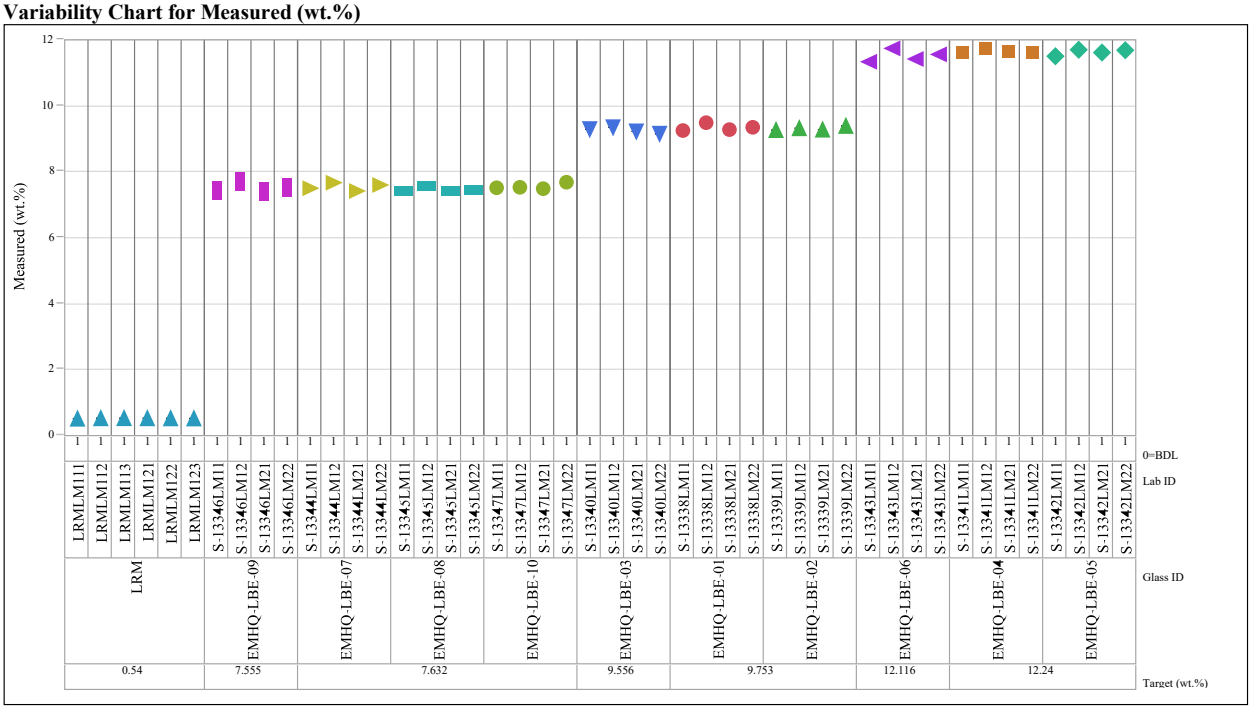


Exhibit A-1. Plots of Oxide Measurements by Glass Identifier by Target Concentrations (continued)

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



Oxide=Cl⁻ (wt%), Prep Method=KH
Variability Chart for Measured (wt.%)

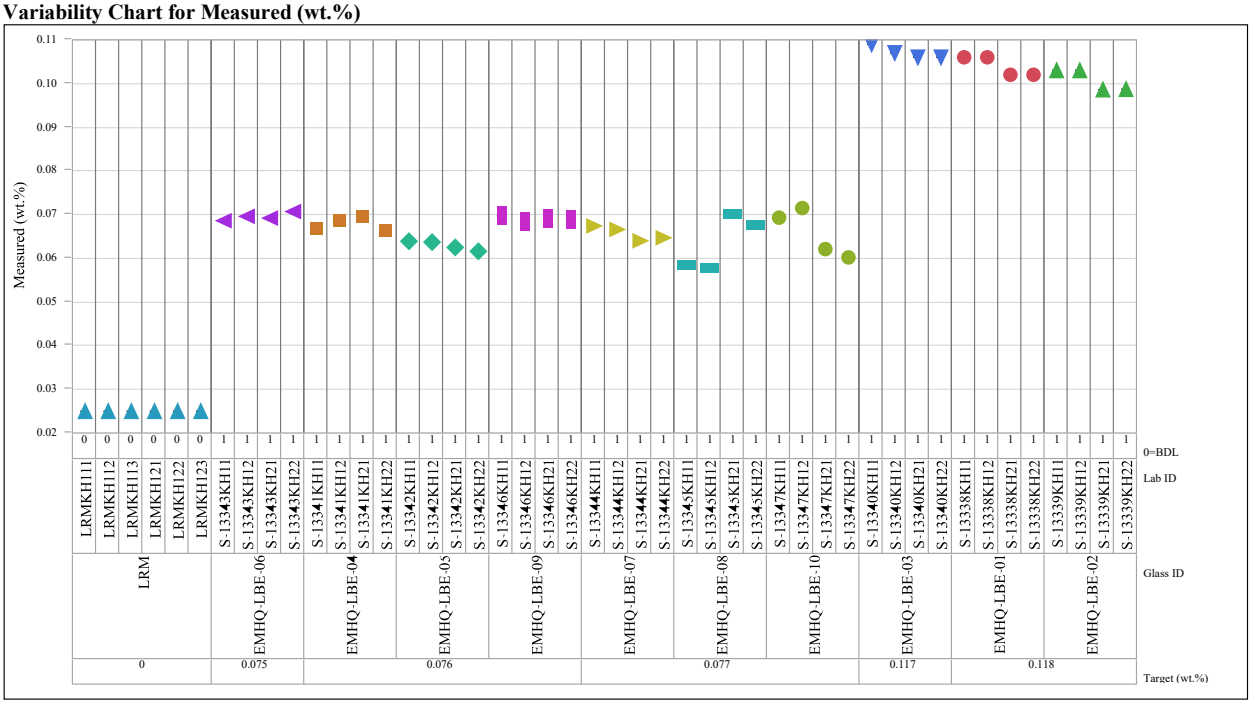
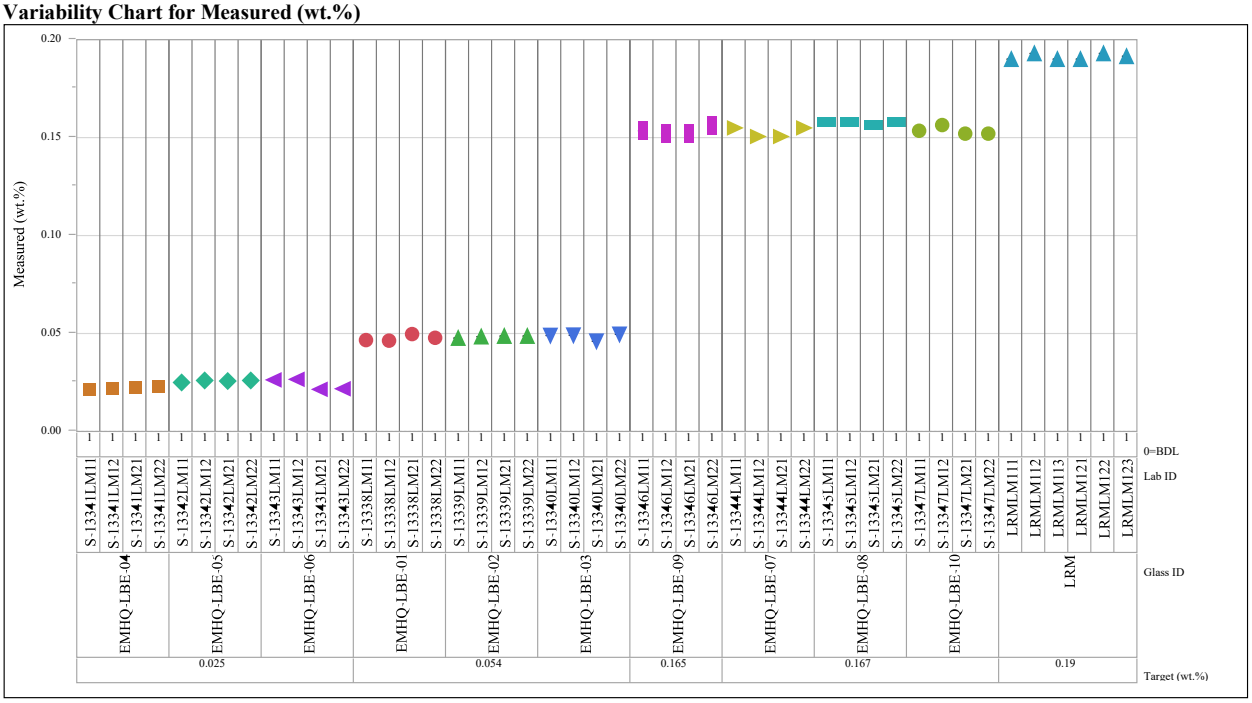


Exhibit A-1. Plots of Oxide Measurements by Glass Identifier by Target Concentrations (continued)

Oxide=Cr_2O_3 (wt%), Prep Method=LM
Variability Chart for Measured (wt.%)



Oxide=F^- (wt%), Prep Method=KH
Variability Chart for Measured (wt.%)

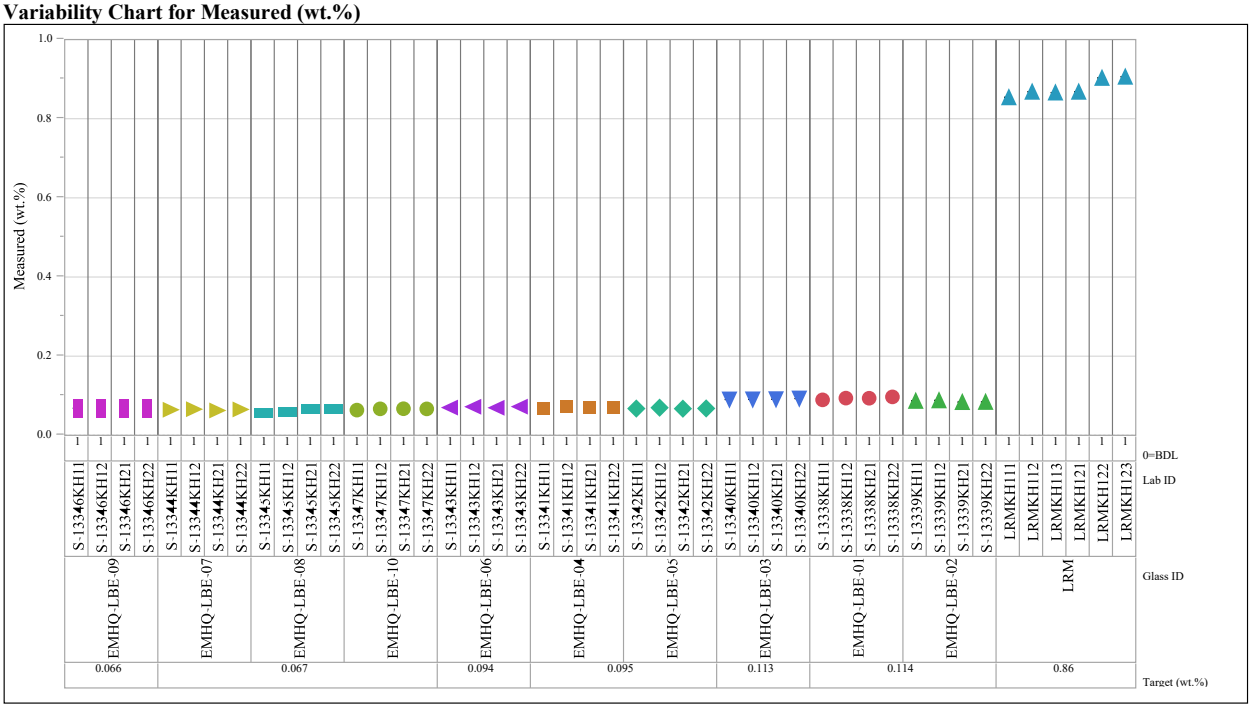
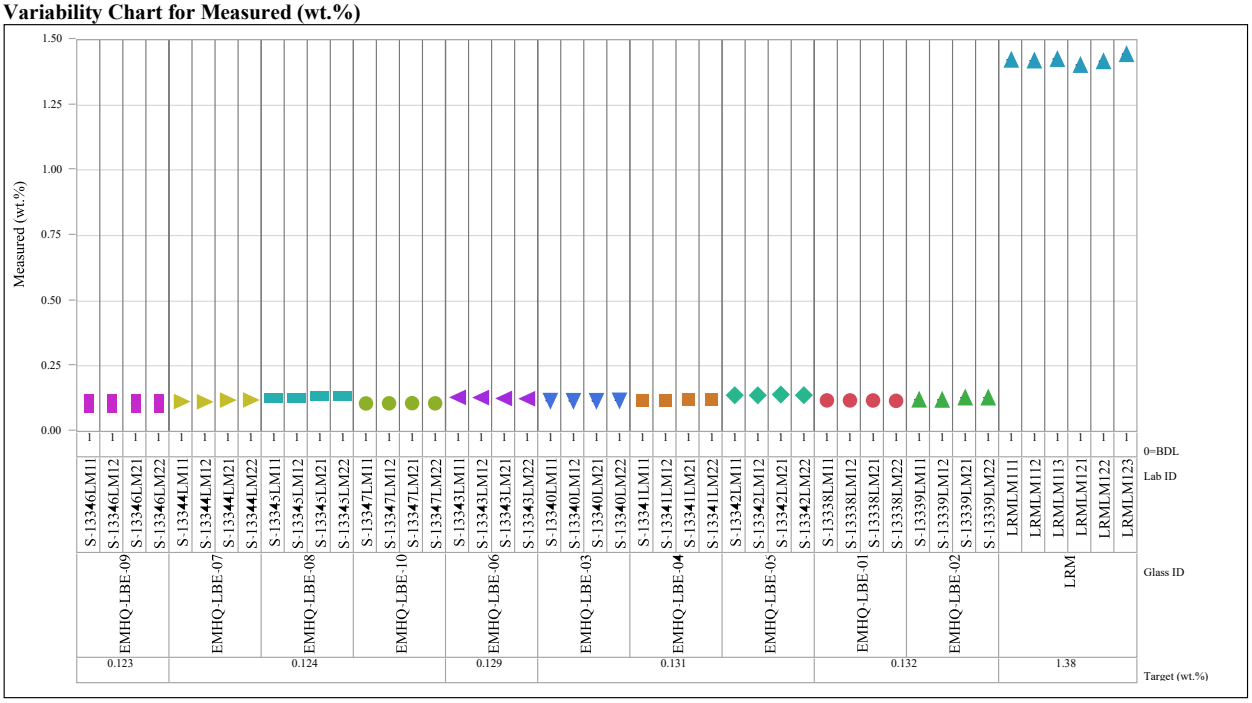


Exhibit A-1. Plots of Oxide Measurements by Glass Identifier by Target Concentrations (continued)

Oxide=Fe_2O_3 (wt%), Prep Method=LM
Variability Chart for Measured (wt.%)



Oxide=K_2O (wt%), Prep Method=LM
Variability Chart for Measured (wt.%)

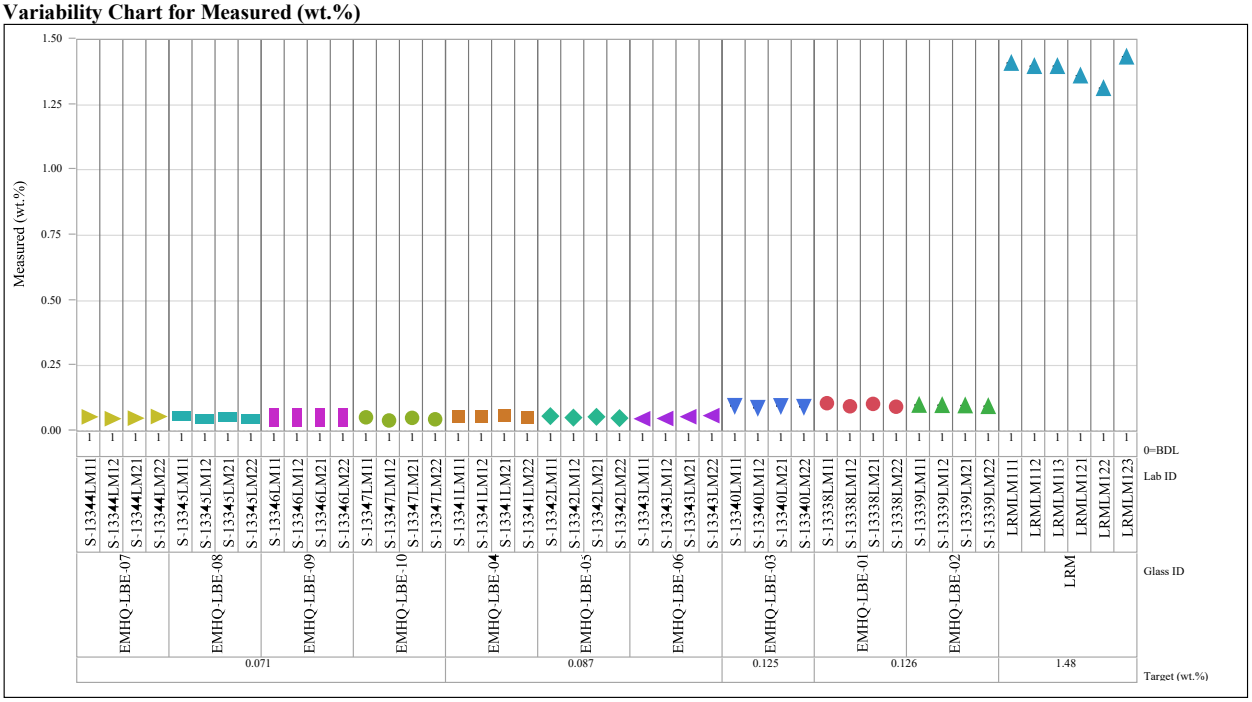
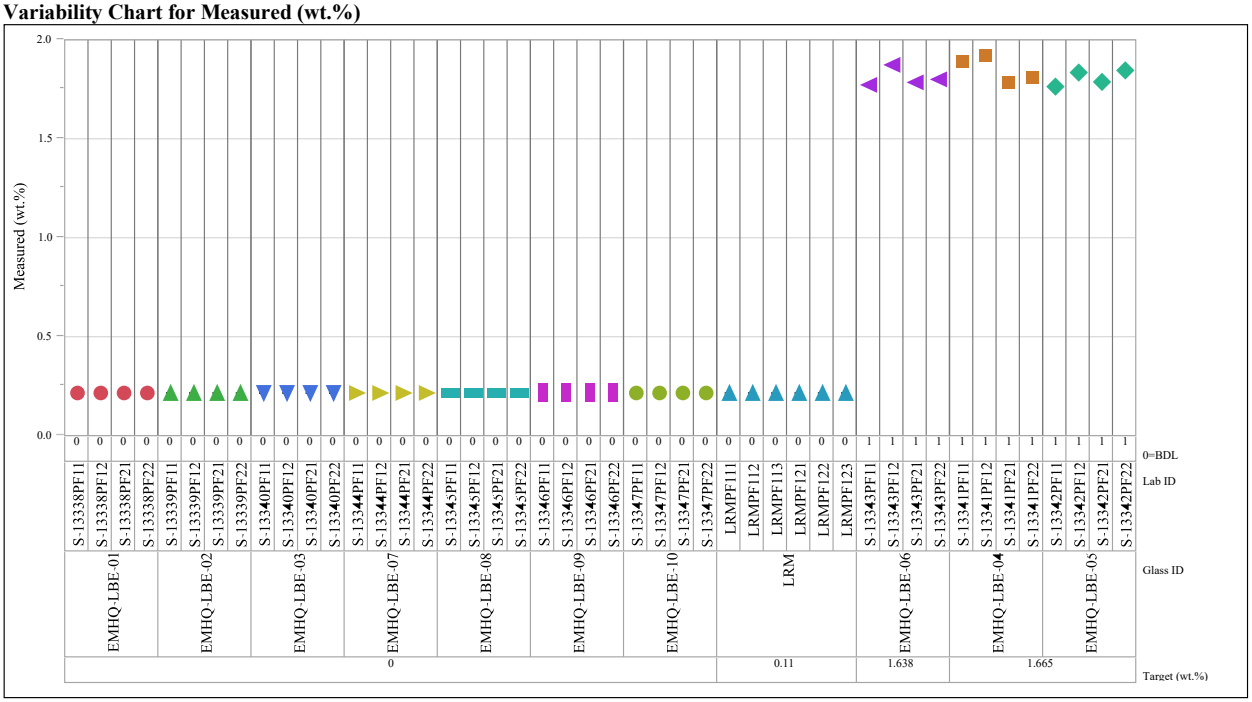


Exhibit A-1. Plots of Oxide Measurements by Glass Identifier by Target Concentrations (continued)

Oxide=Li_2O (wt%), Prep Method=PF
Variability Chart for Measured (wt.%)



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

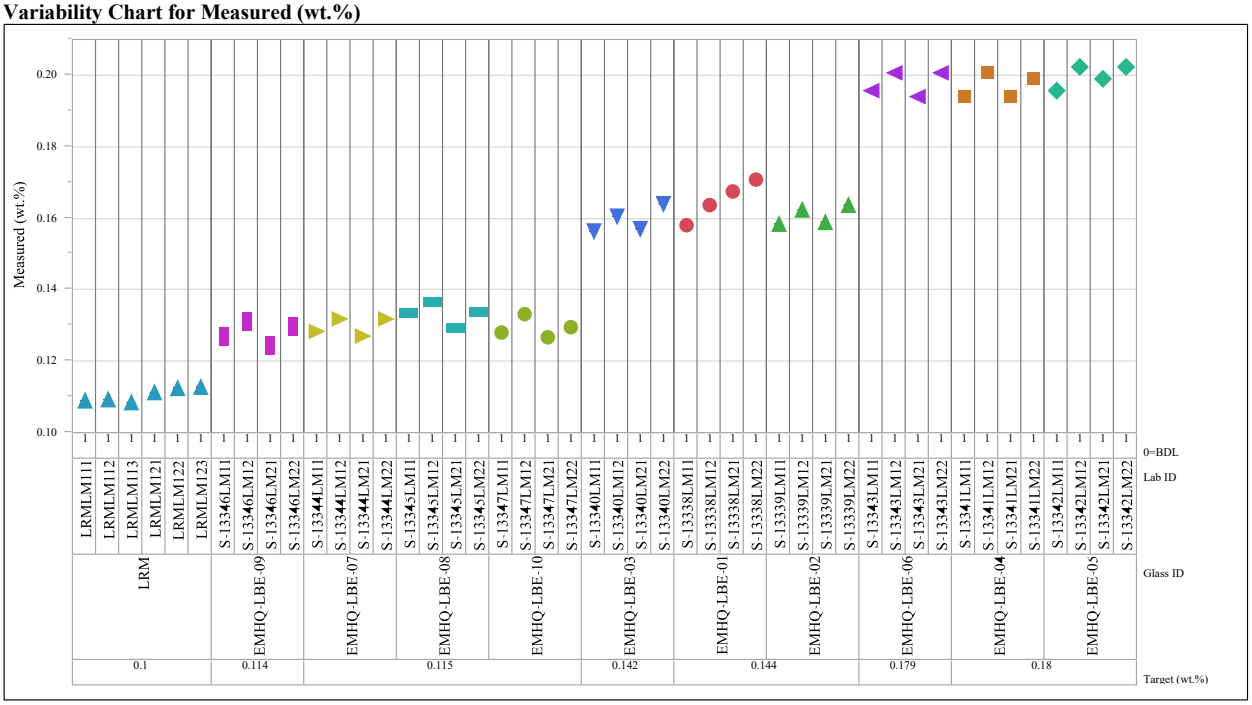
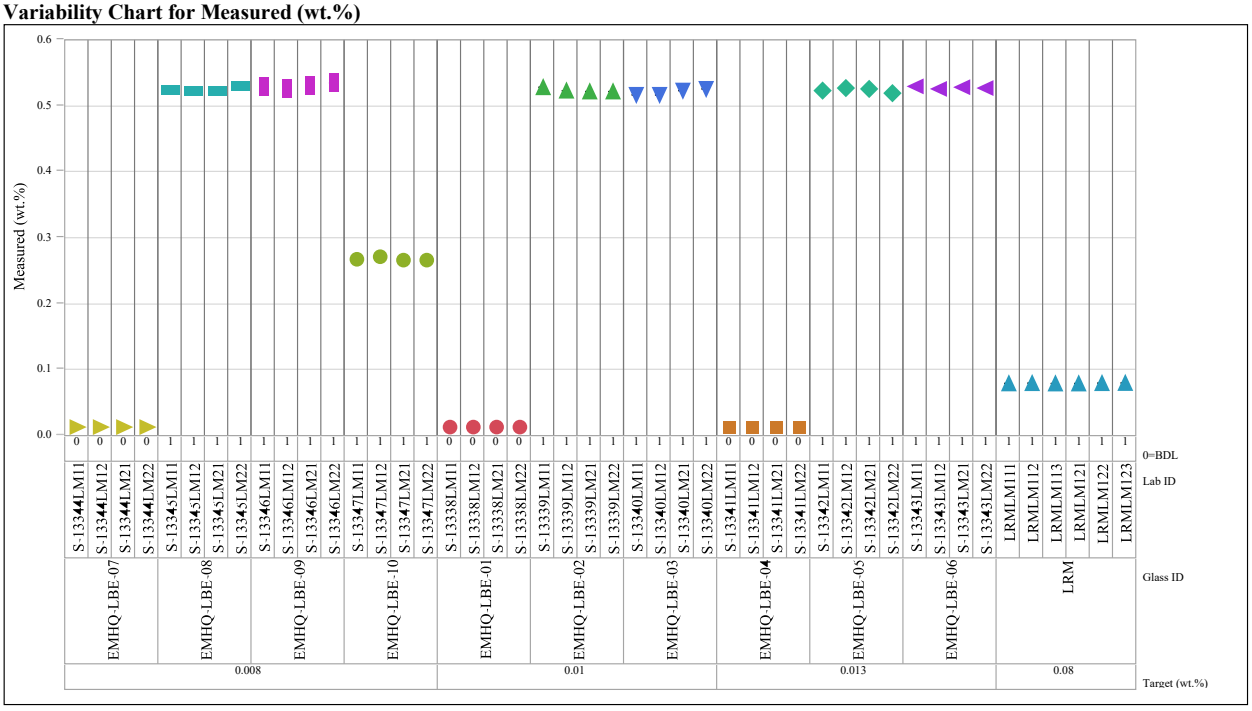


Exhibit A-1. Plots of Oxide Measurements by Glass Identifier by Target Concentrations (continued)

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



Oxide=Na_2O (wt%), Prep Method=LM
Variability Chart for Measured (wt.%)

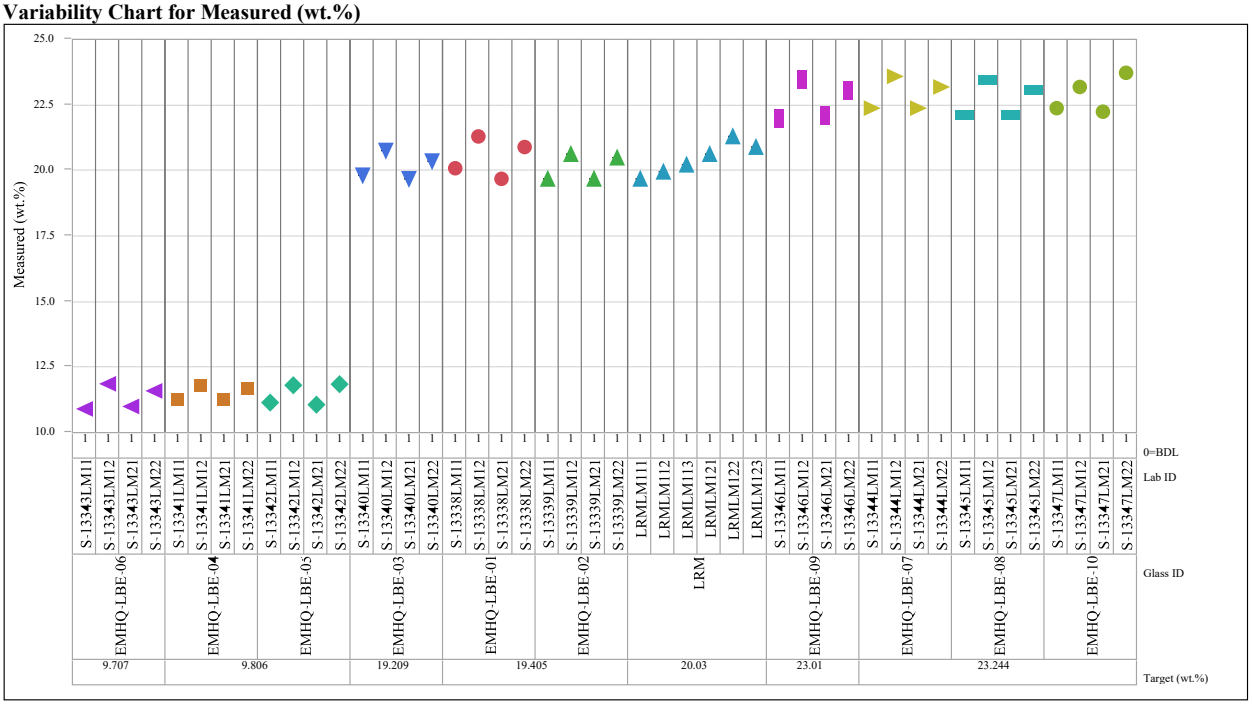
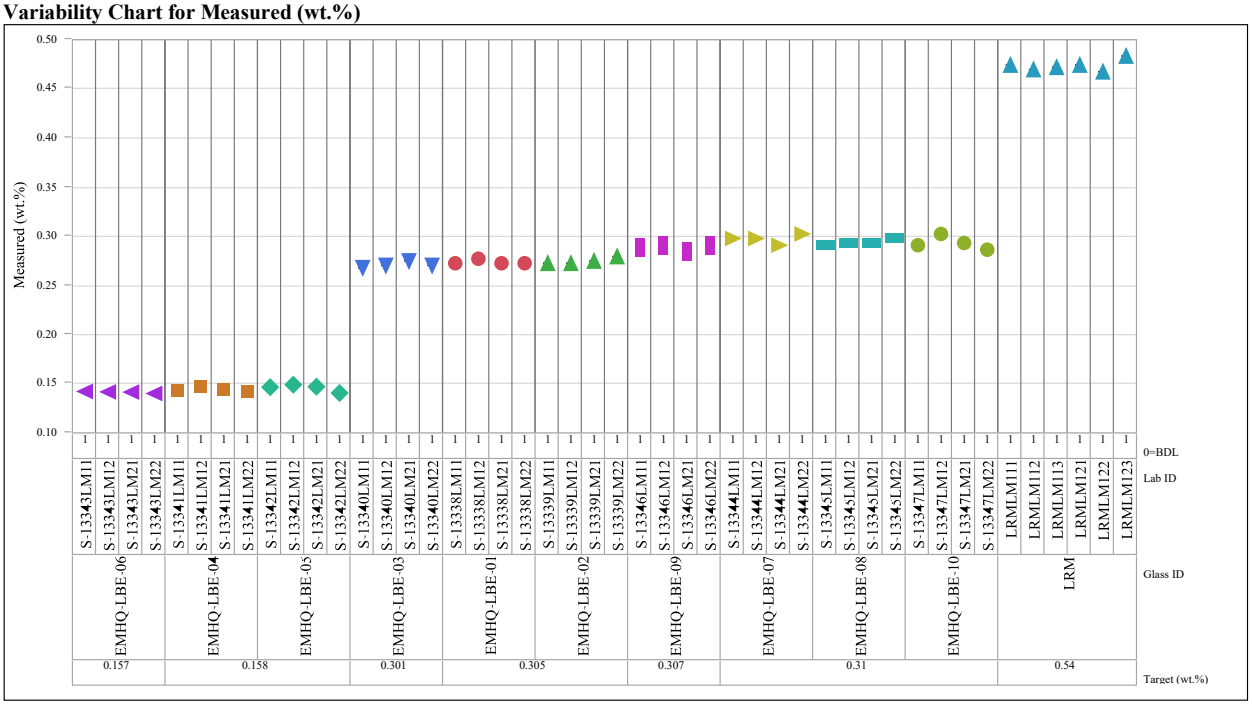


Exhibit A-1. Plots of Oxide Measurements by Glass Identifier by Target Concentrations (continued)

Oxide=P_2O_5 (wt%), Prep Method=LM
Variability Chart for Measured (wt.%)



Oxide=SiO_2 (wt%), Prep Method=PF
Variability Chart for Measured (wt.%)

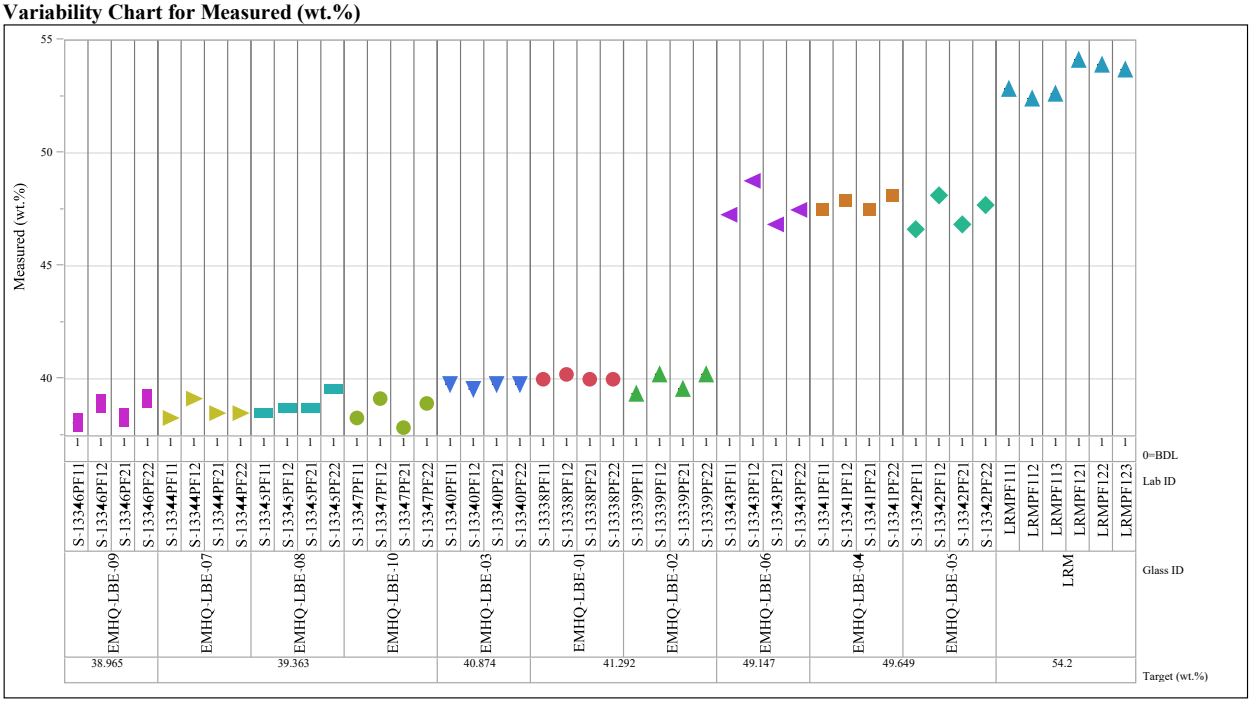
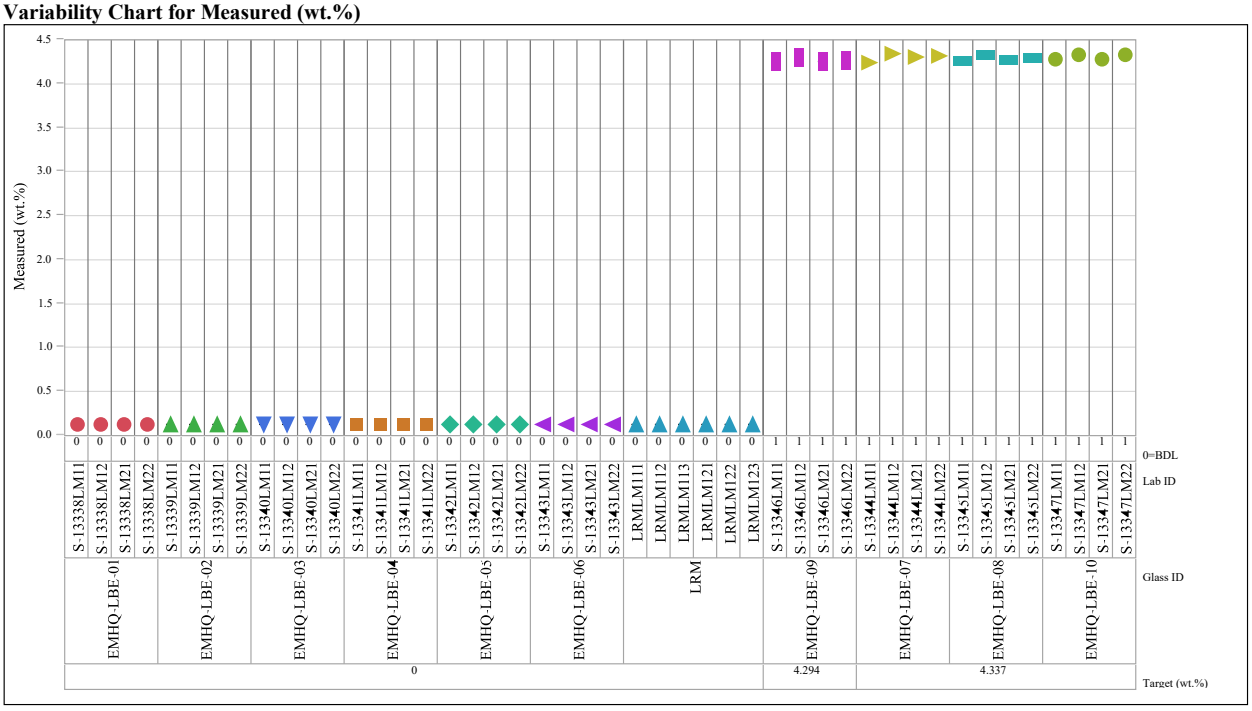


Exhibit A-1. Plots of Oxide Measurements by Glass Identifier by Target Concentrations (continued)

Oxide=SnO_2 (wt%), Prep Method=LM
Variability Chart for Measured (wt.%)



Oxide=SO_3 (wt%), Prep Method=LM
Variability Chart for Measured (wt.%)

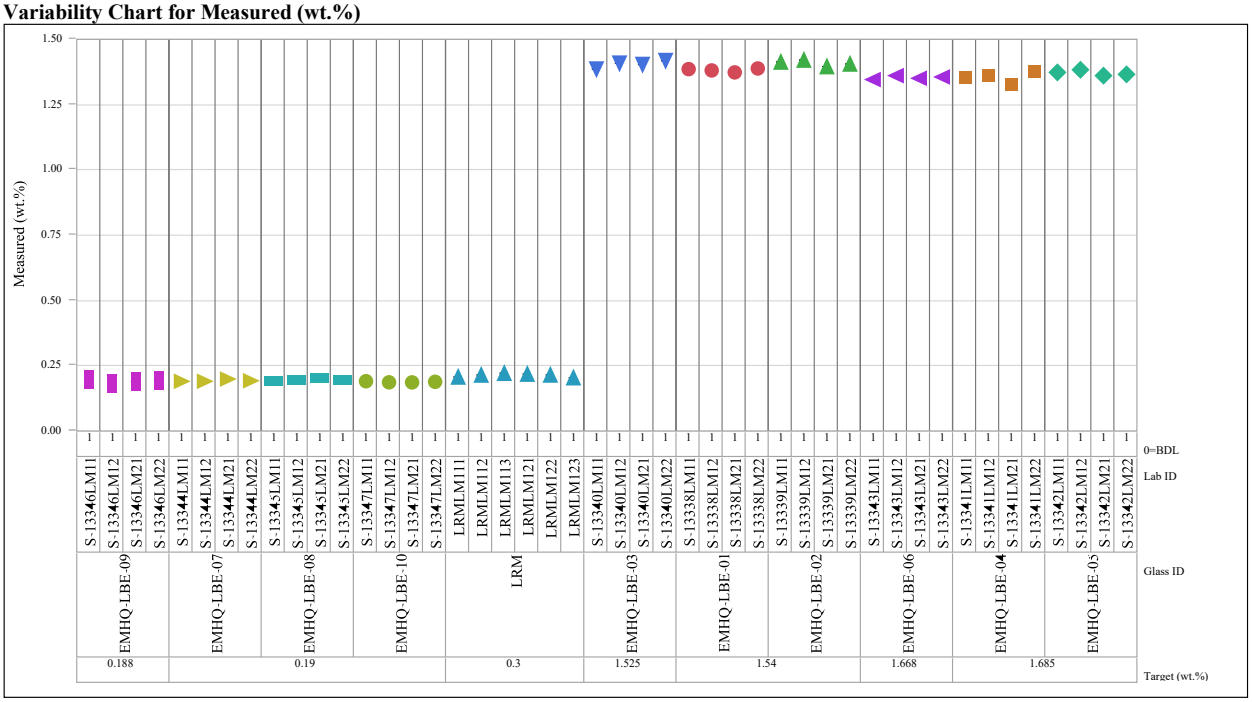
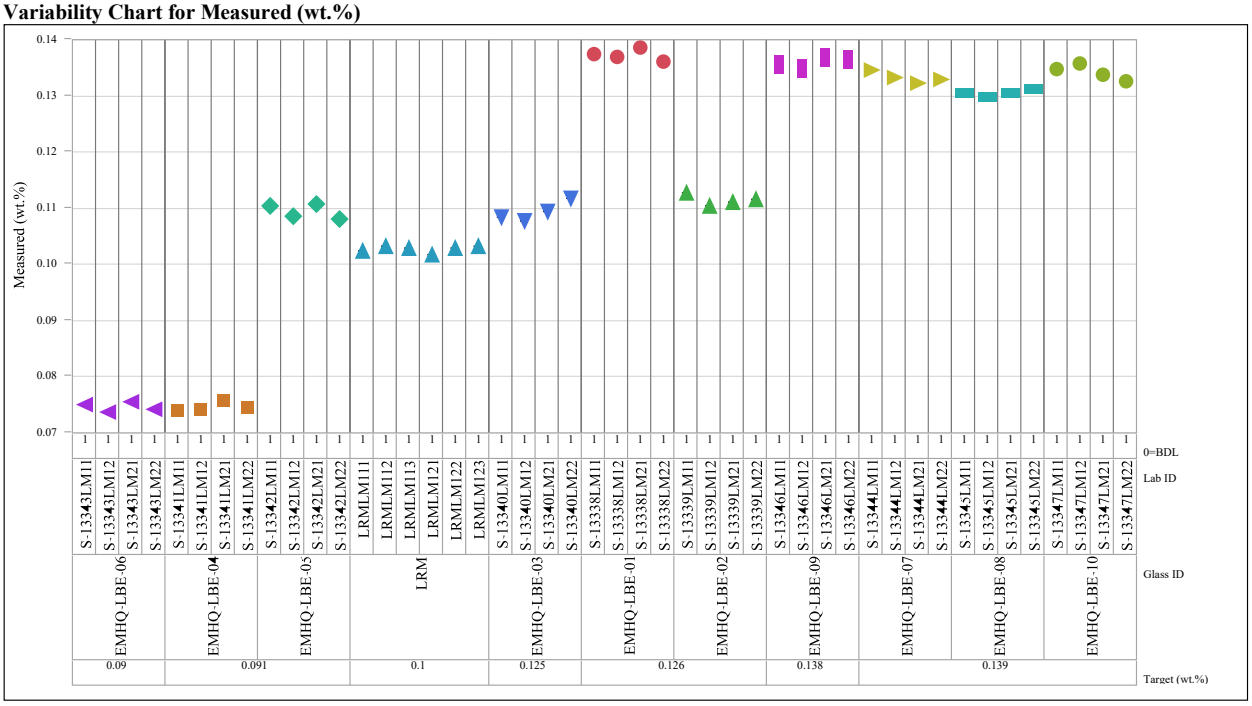


Exhibit A-1. Plots of Oxide Measurements by Glass Identifier by Target Concentrations (continued)

Oxide=TiO_2 (wt%), Prep Method=LM
Variability Chart for Measured (wt.%)



Oxide=V_2O_5 (wt%), Prep Method=LM
Variability Chart for Measured (wt.%)

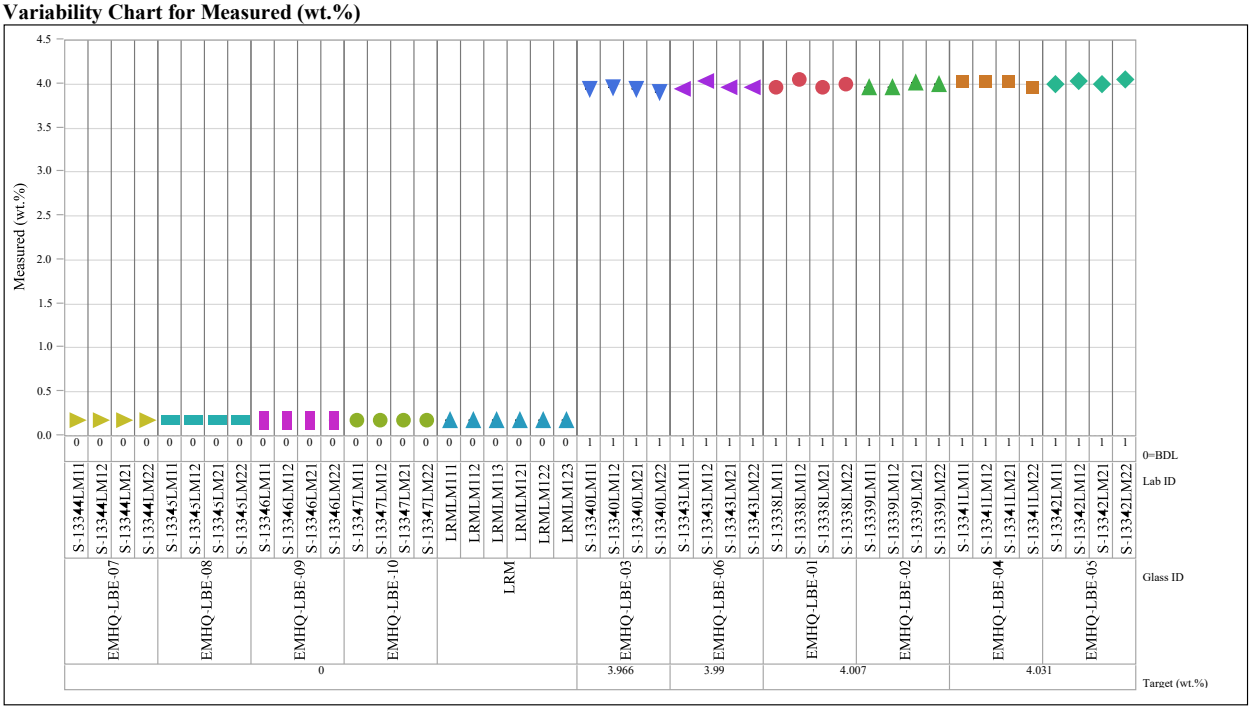


Exhibit A-1. Plots of Oxide Measurements by Glass Identifier by Target Concentrations (continued)

Oxide=Z_rO_2 (wt%), Prep Method=LM
Variability Chart for Measured (wt.%)

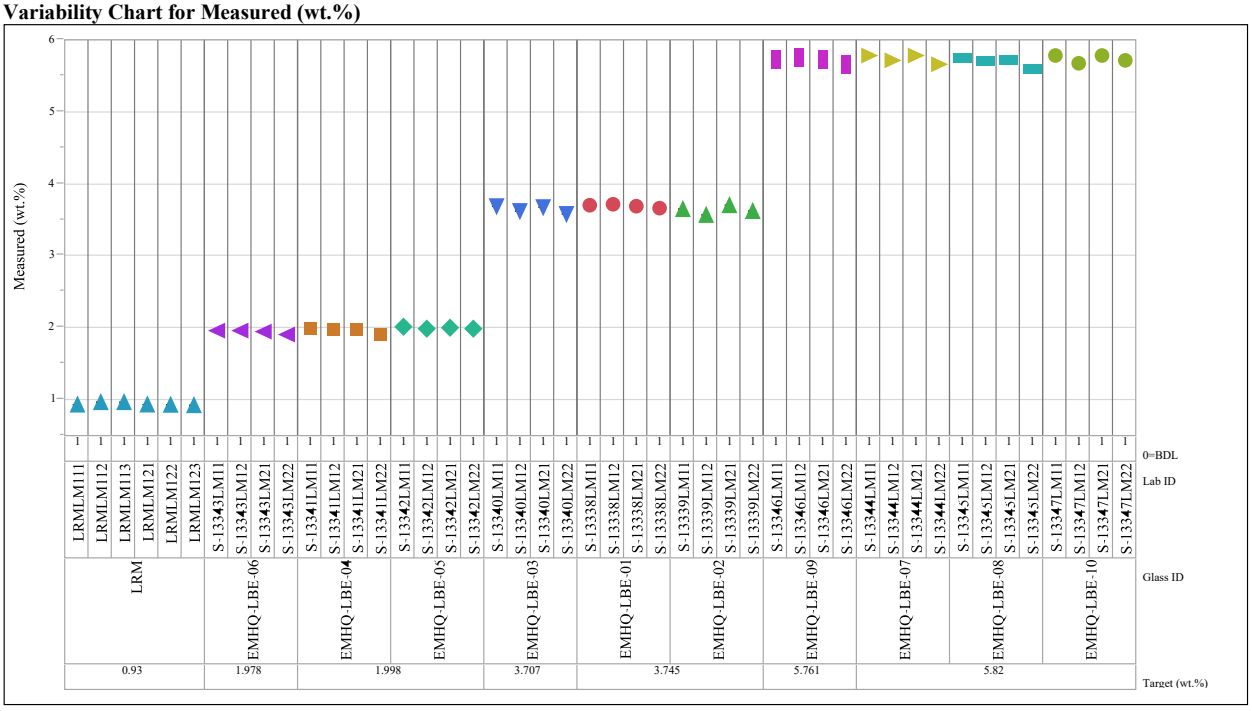
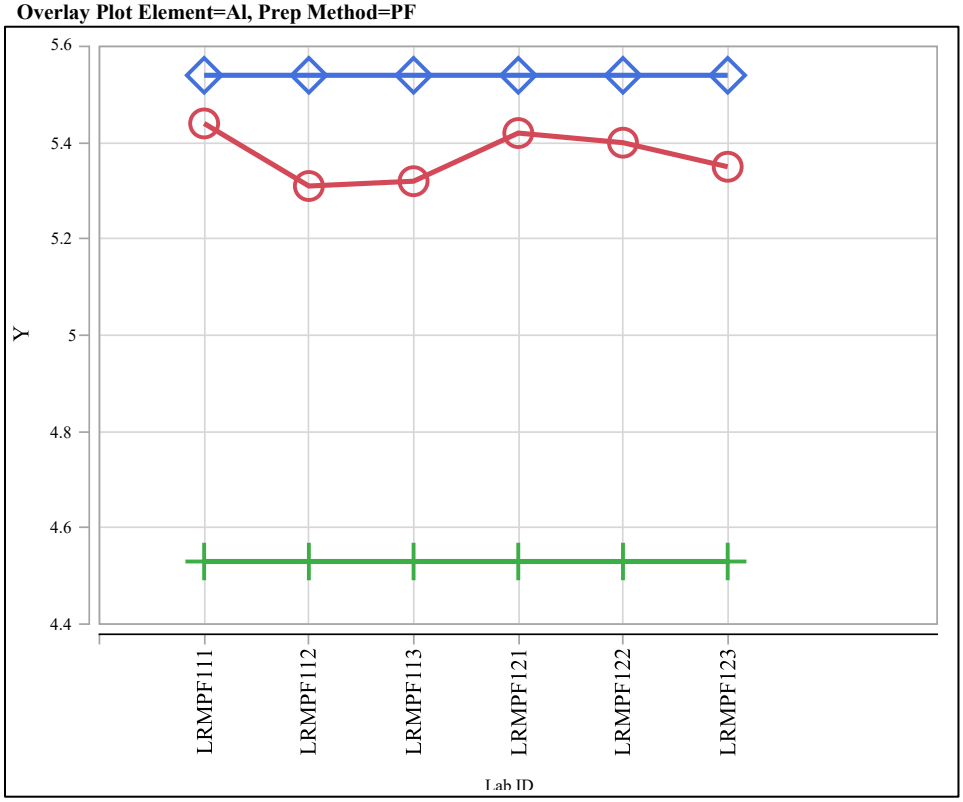
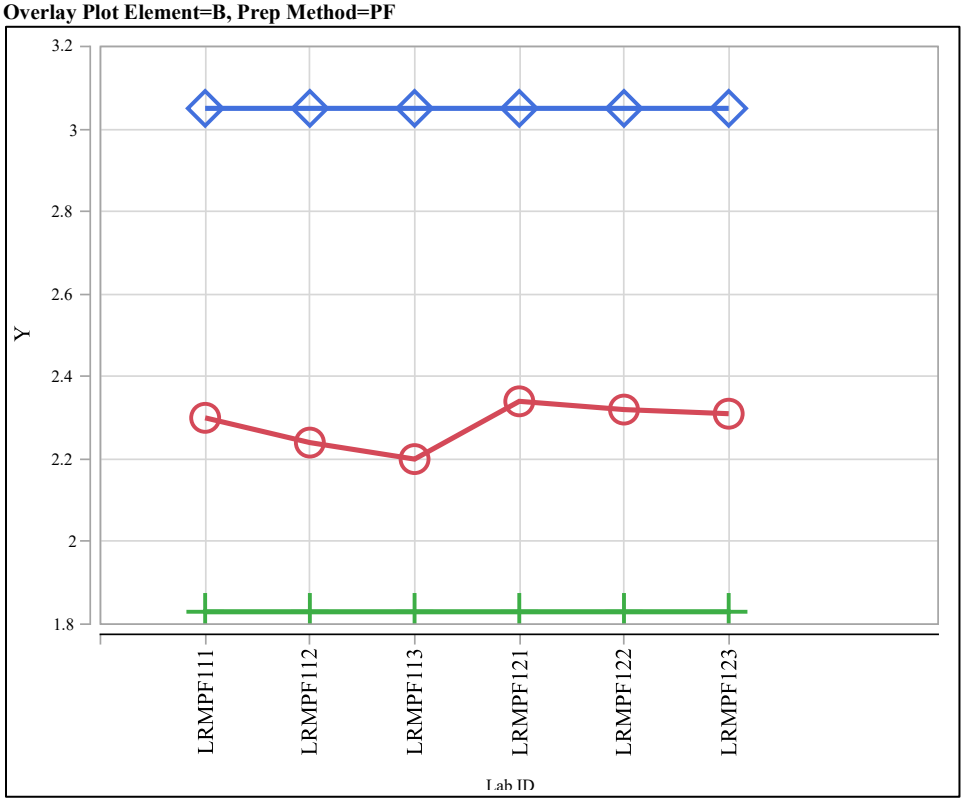


Exhibit A-2. Acceptability Evaluation for Measurements of the LRM Glass

Overlay Plot Element=Al, Prep Method=PF



Overlay Plot Element=B, Prep Method=PF



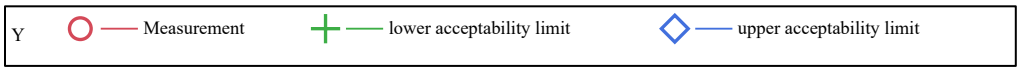
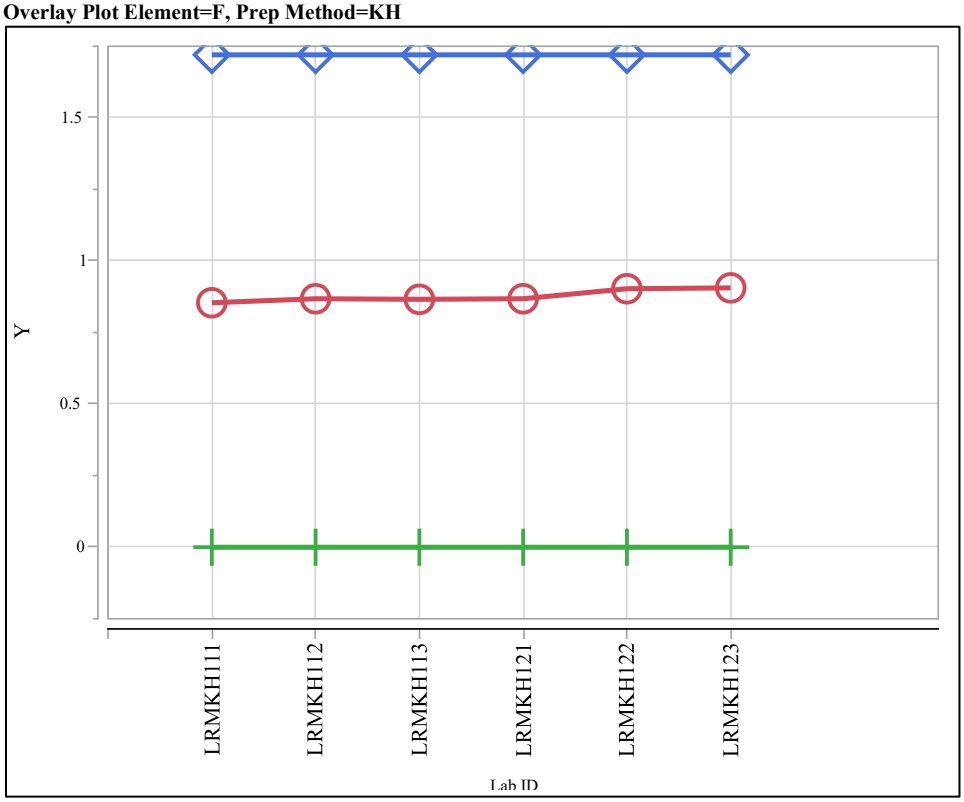
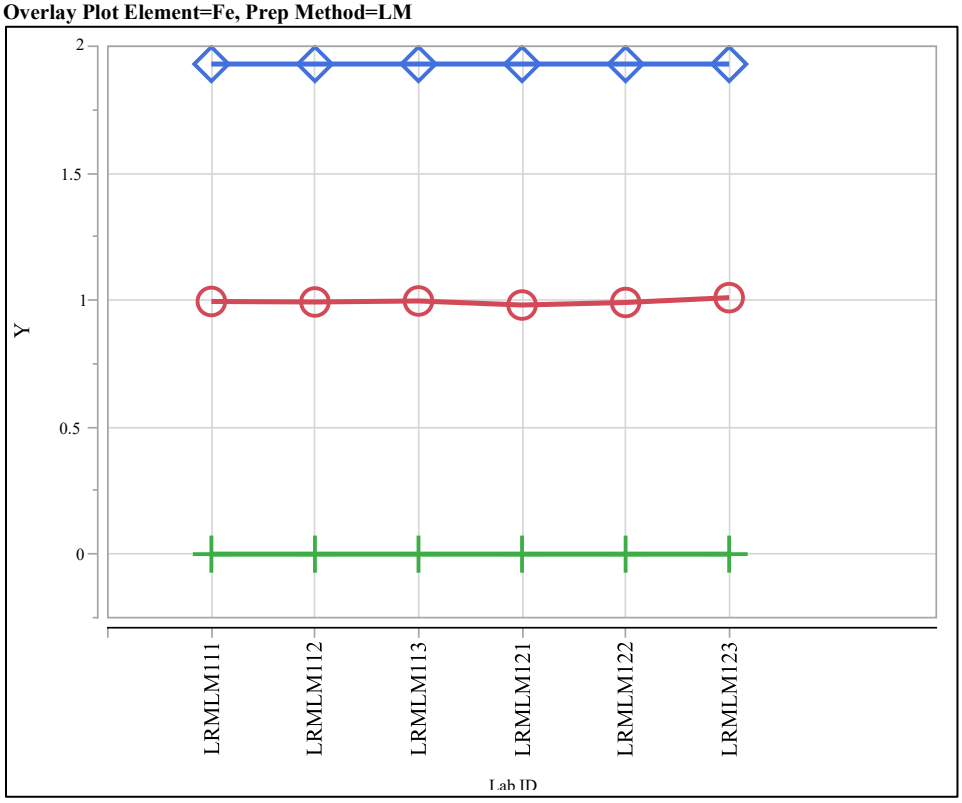


Exhibit A-2. Acceptability Evaluation for Measurements of the LRM Glass (continued)

Overlay Plot Element=F, Prep Method=KH



Overlay Plot Element=Fe, Prep Method=LM



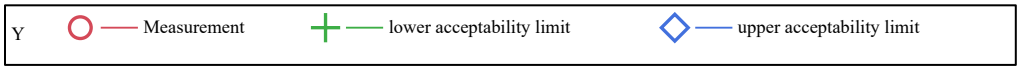
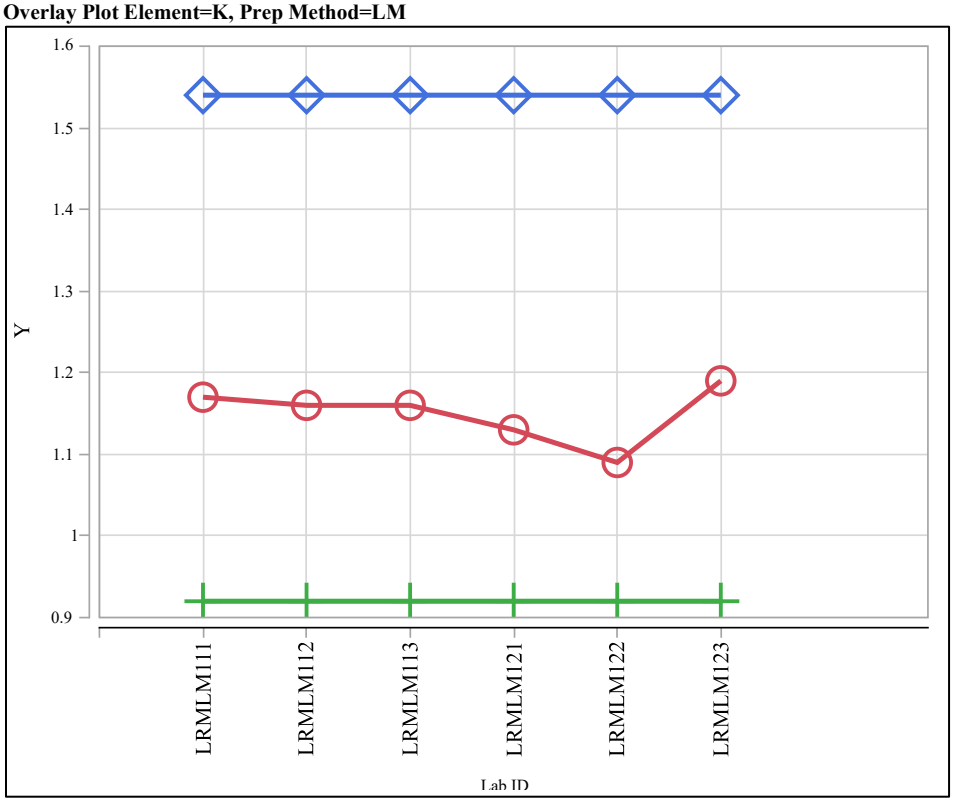
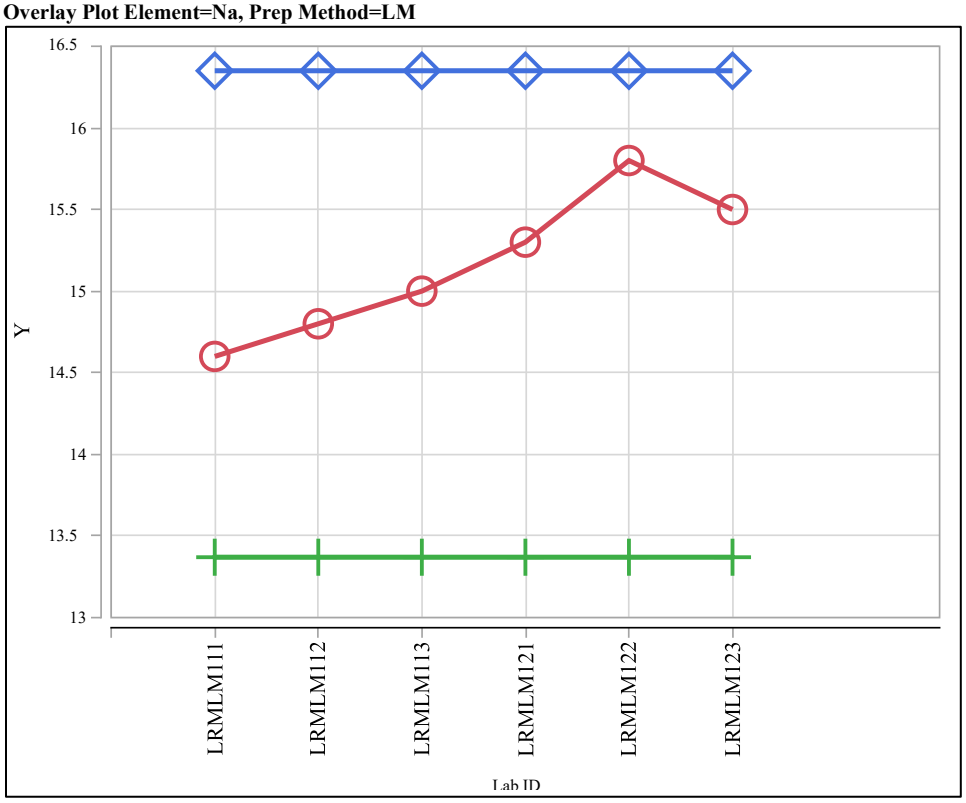


Exhibit A-2. Acceptability Evaluation for Measurements of the LRM Glass (continued)

Overlay Plot Element=K, Prep Method=LM



Overlay Plot Element=Na, Prep Method=LM



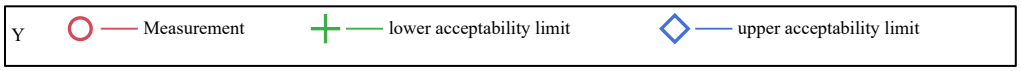
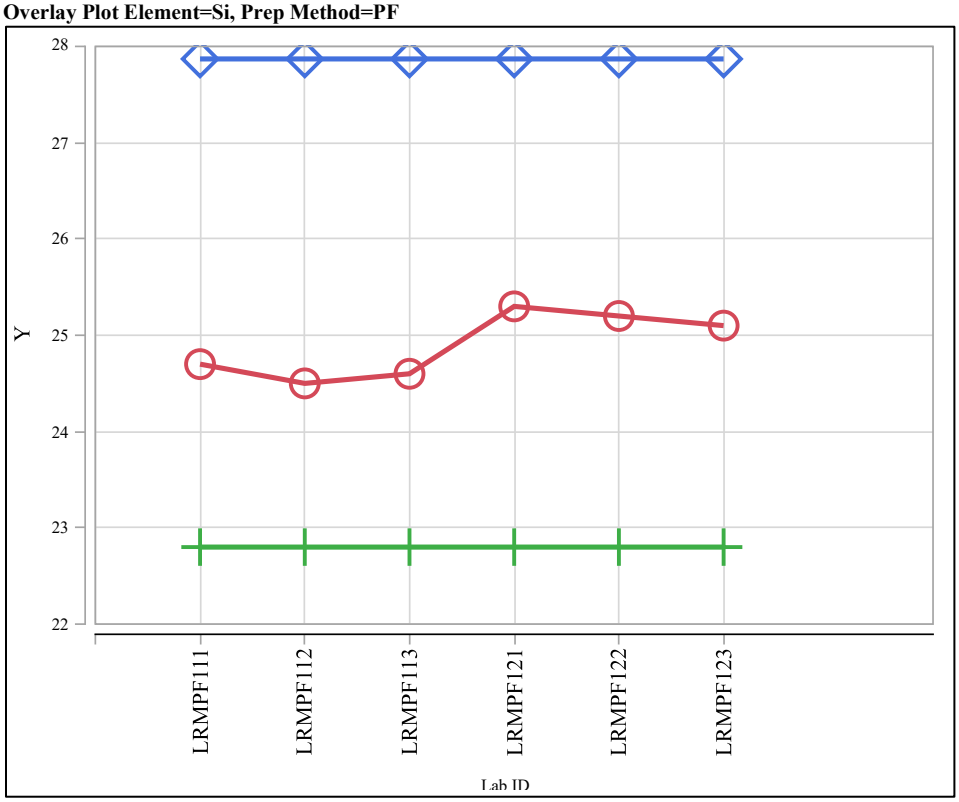
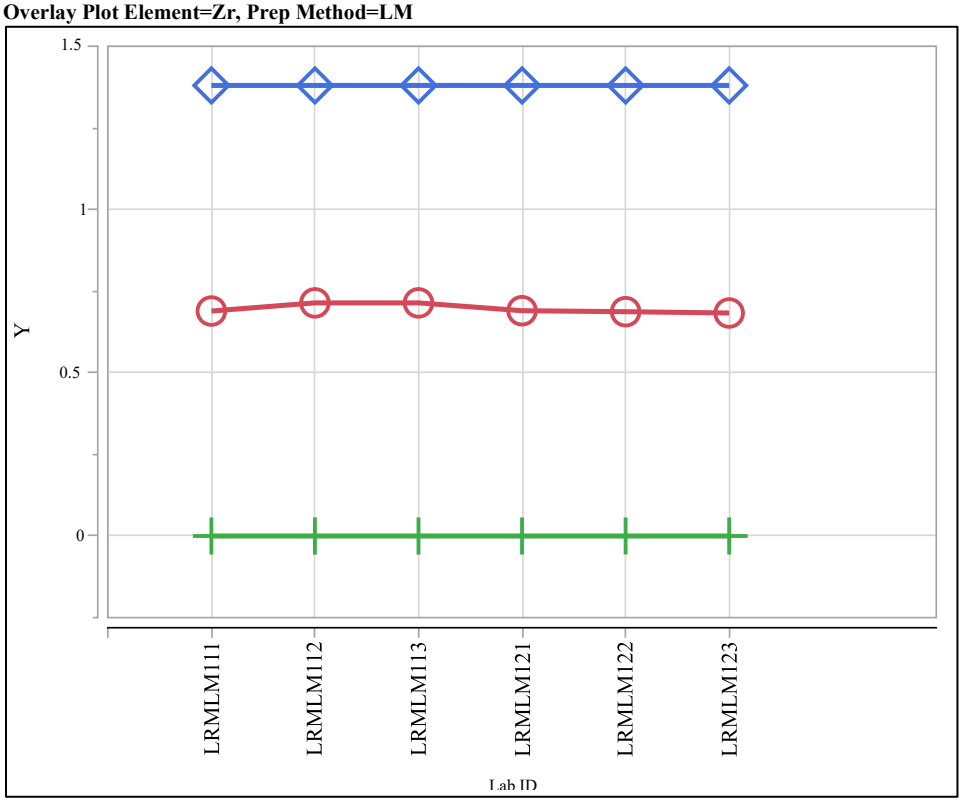


Exhibit A-2. Acceptability Evaluation for Measurements of the LRM Glass (continued)

Overlay Plot Element=Si, Prep Method=PF



Overlay Plot Element=Zr, Prep Method=LM



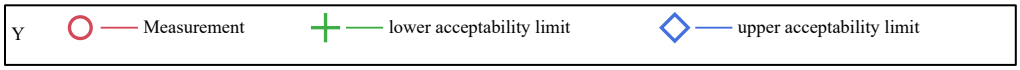
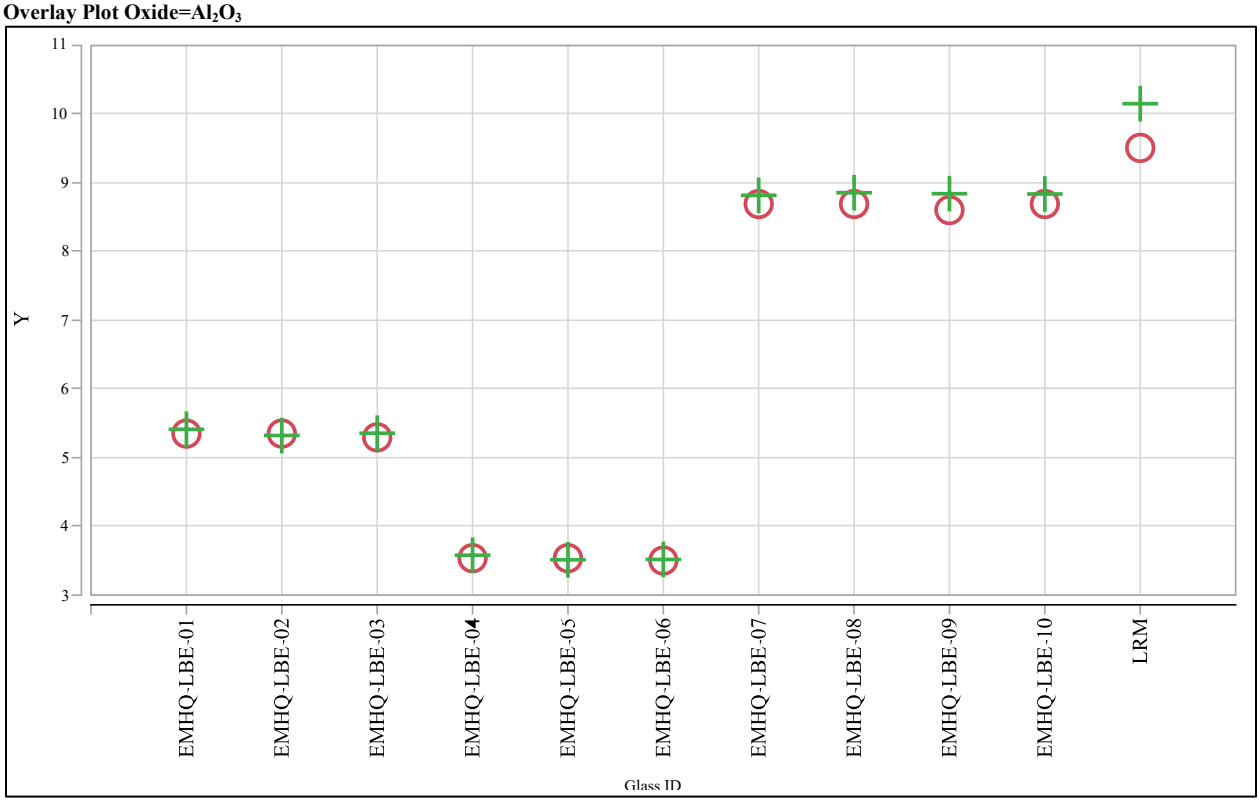
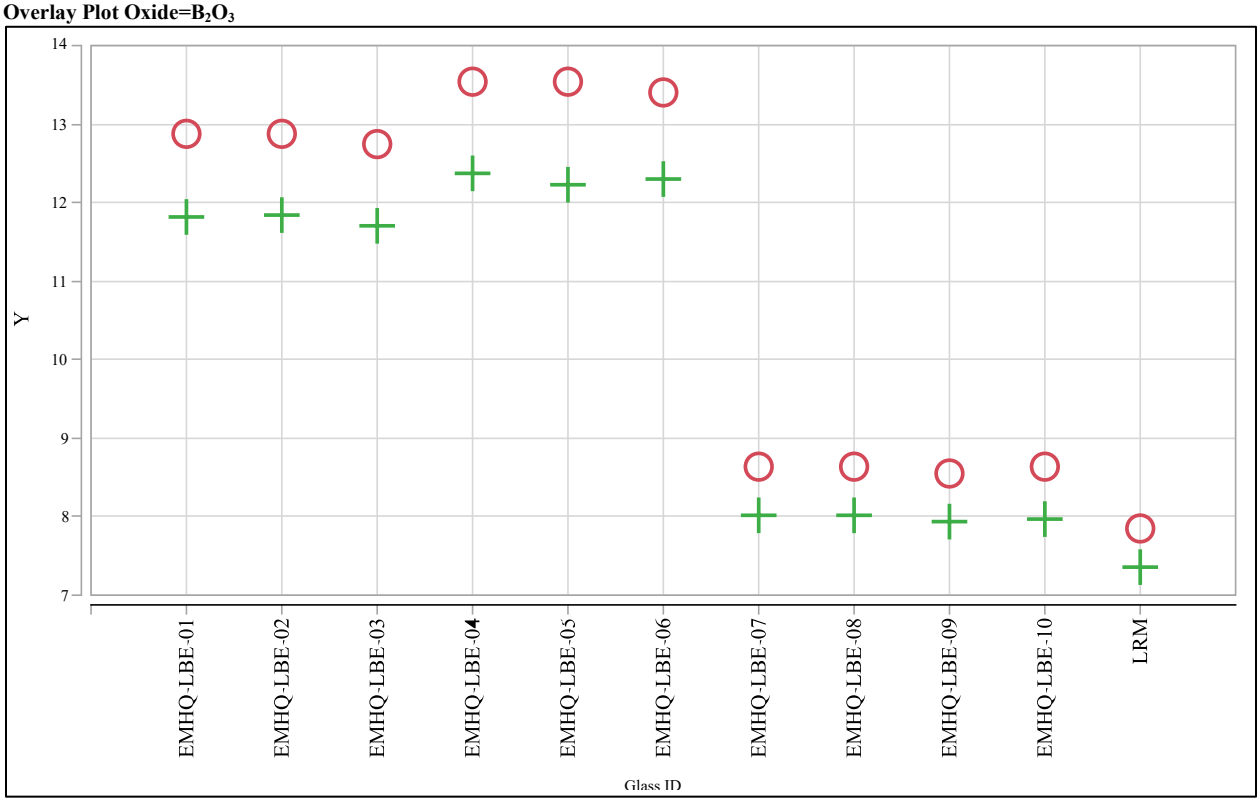


Exhibit A-3. Measured versus Target Concentrations by Glass ID by Oxide

Overlay Plot Oxide=Al_2O_3



Overlay Plot Oxide=B_2O_3



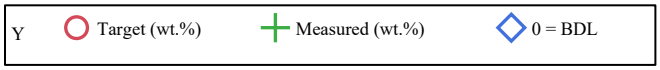
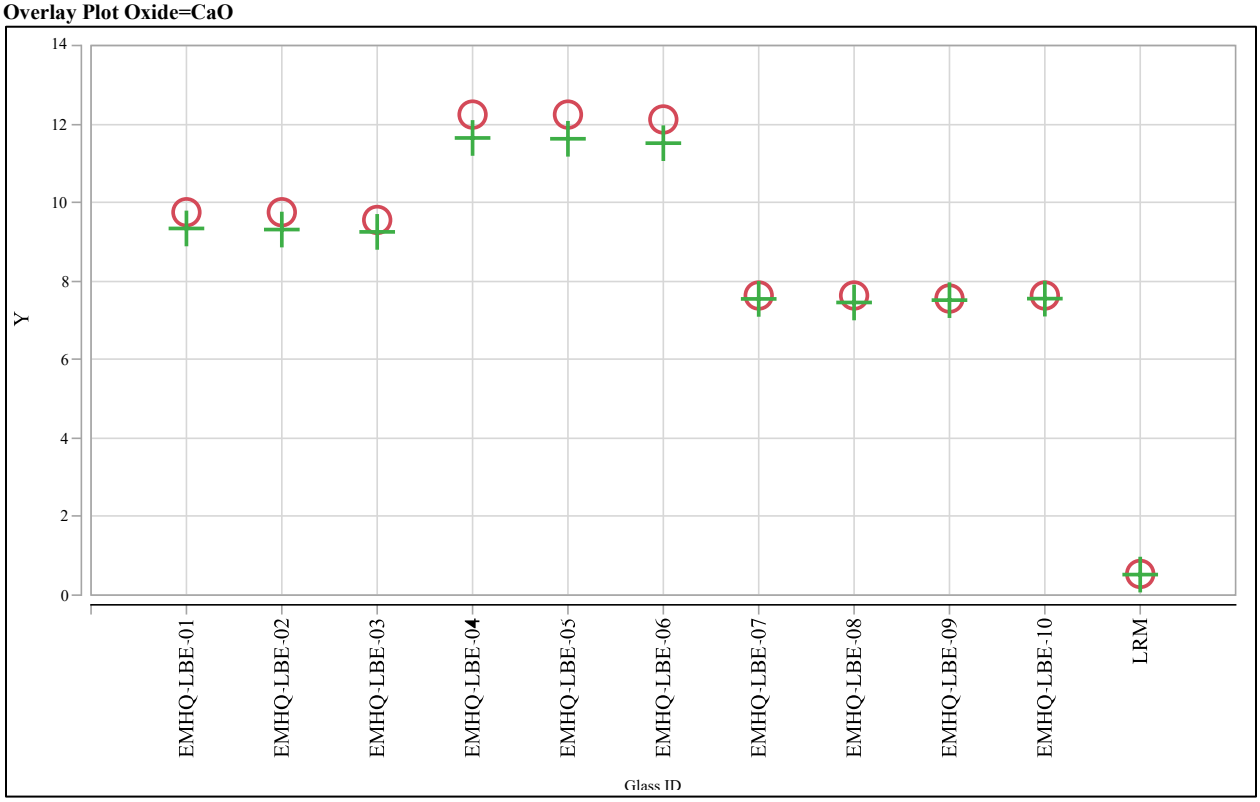
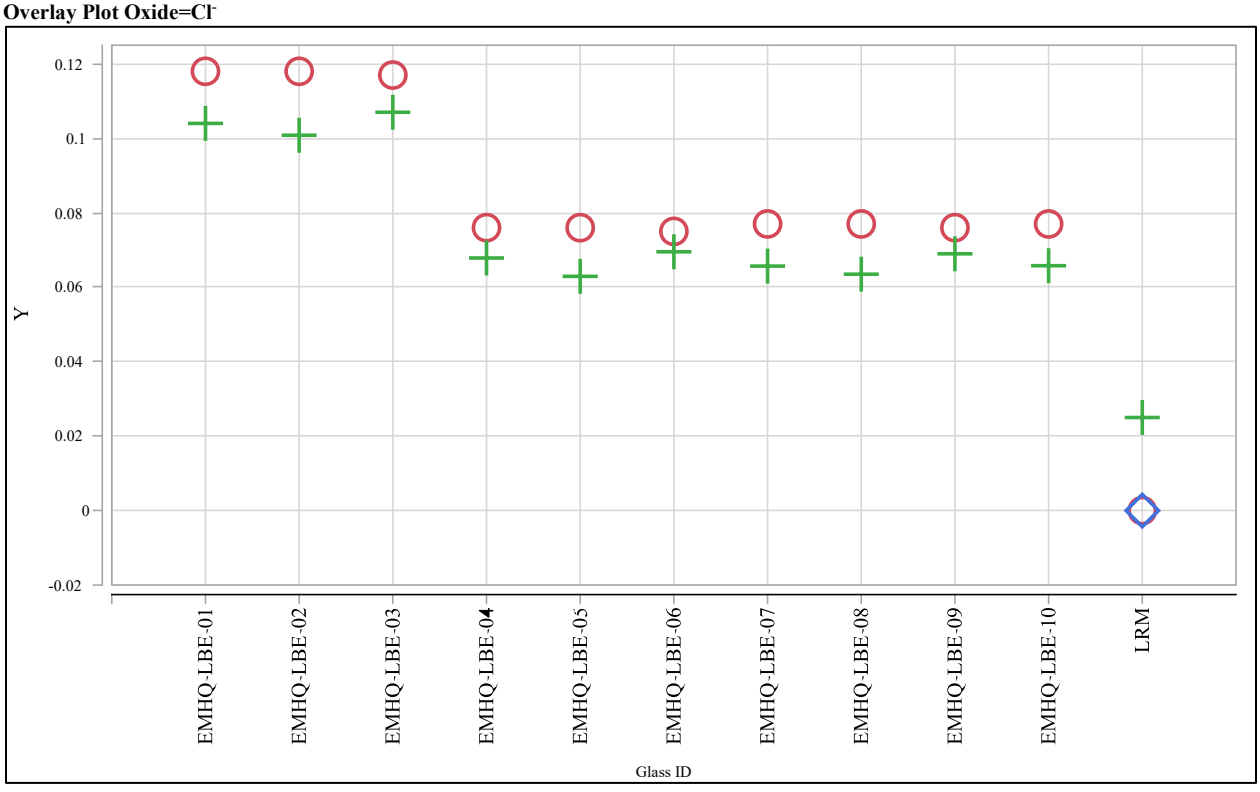


Exhibit A-3. Measured versus Target Concentrations by Glass ID by Oxide (continued)

Overlay Plot Oxide=CaO



Overlay Plot Oxide=Cl⁻



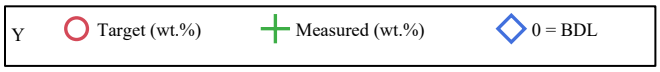
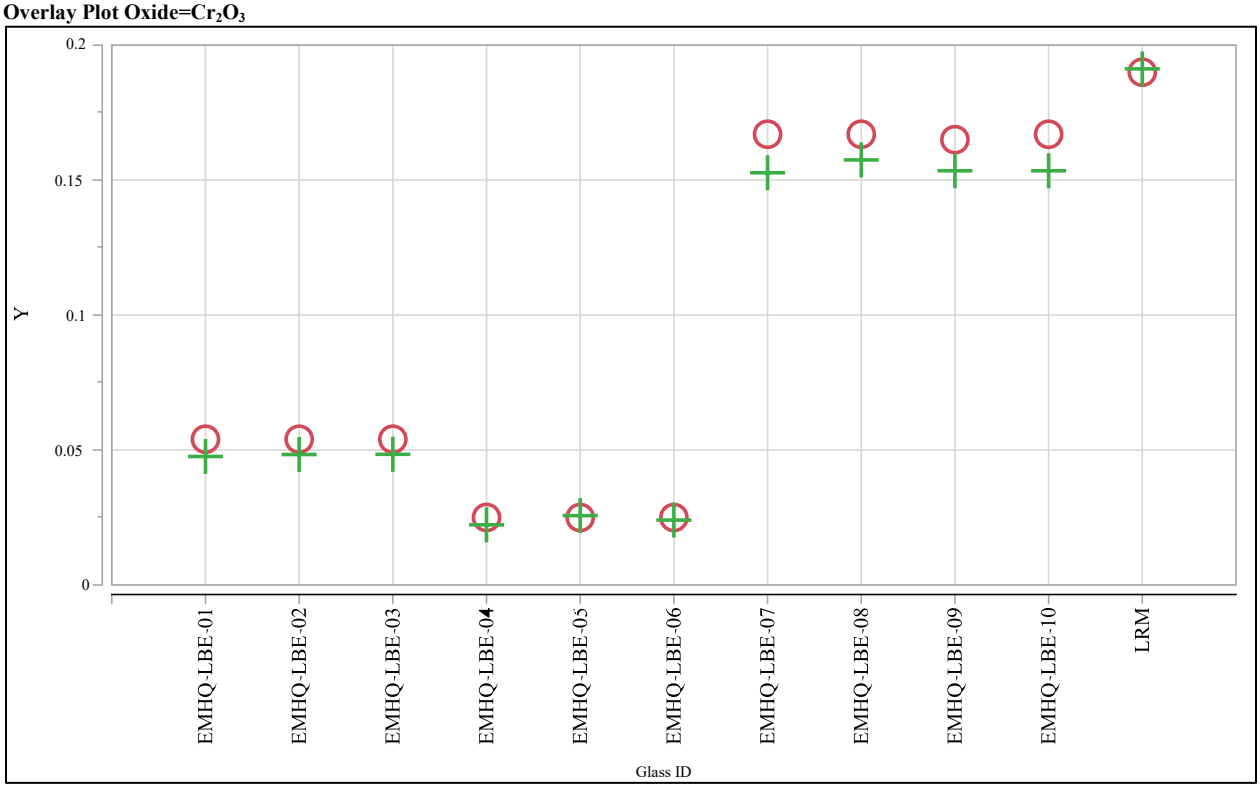
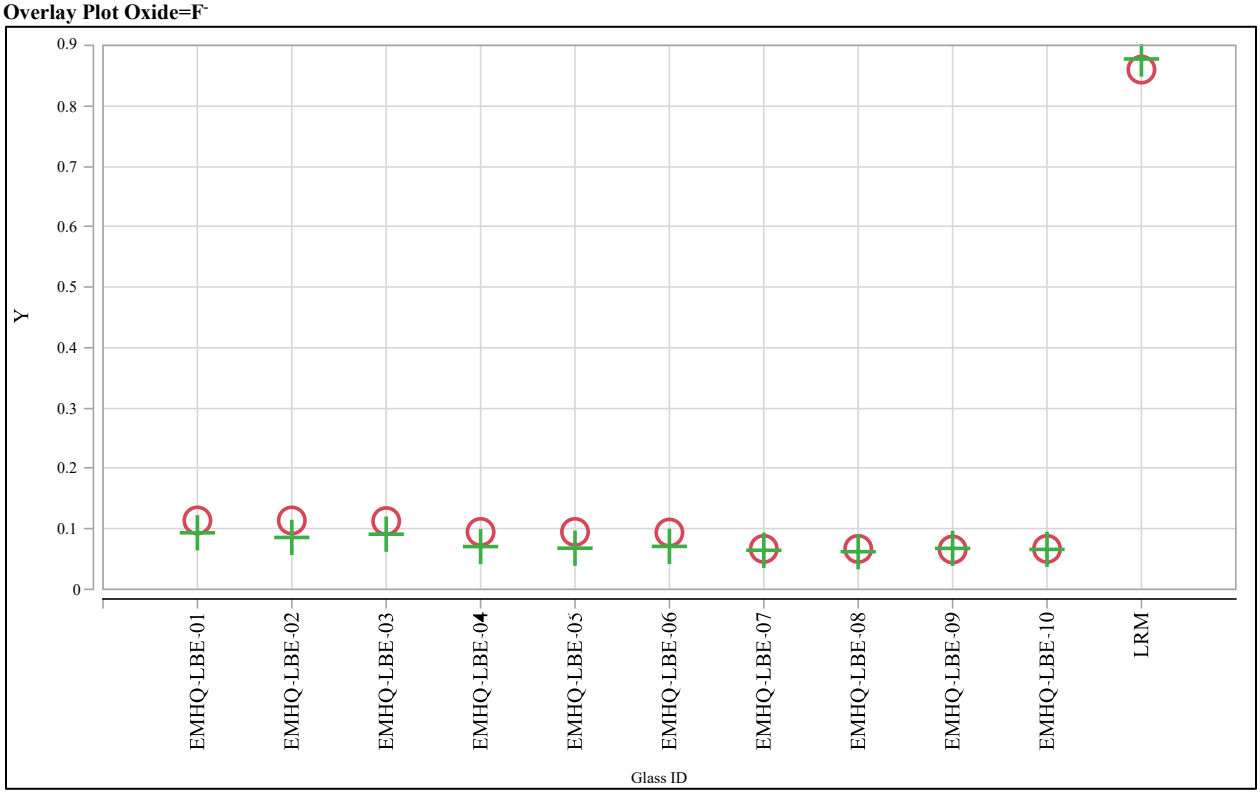


Exhibit A-3. Measured versus Target Concentrations by Glass ID by Oxide (continued)

Overlay Plot Oxide=Cr_2O_3



Overlay Plot Oxide=F^-



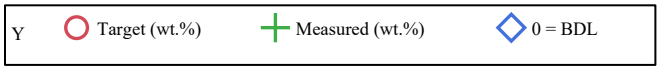
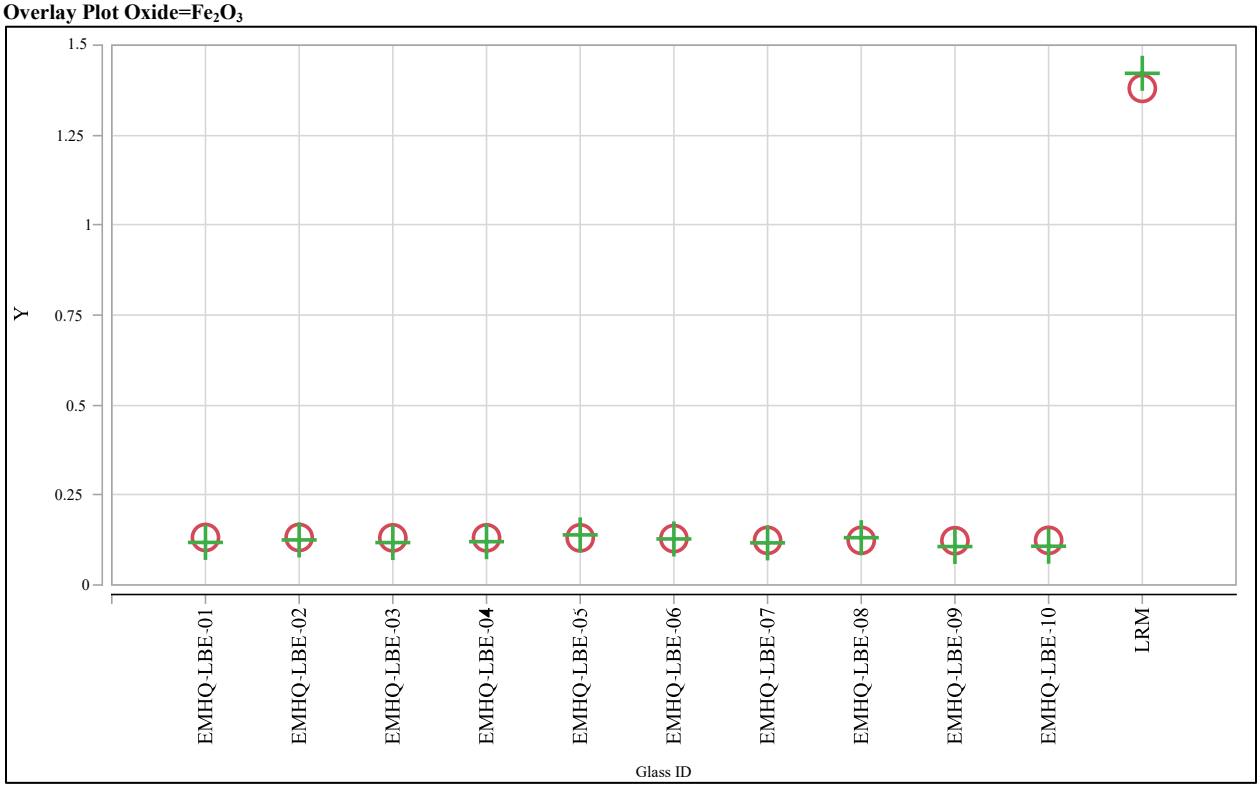
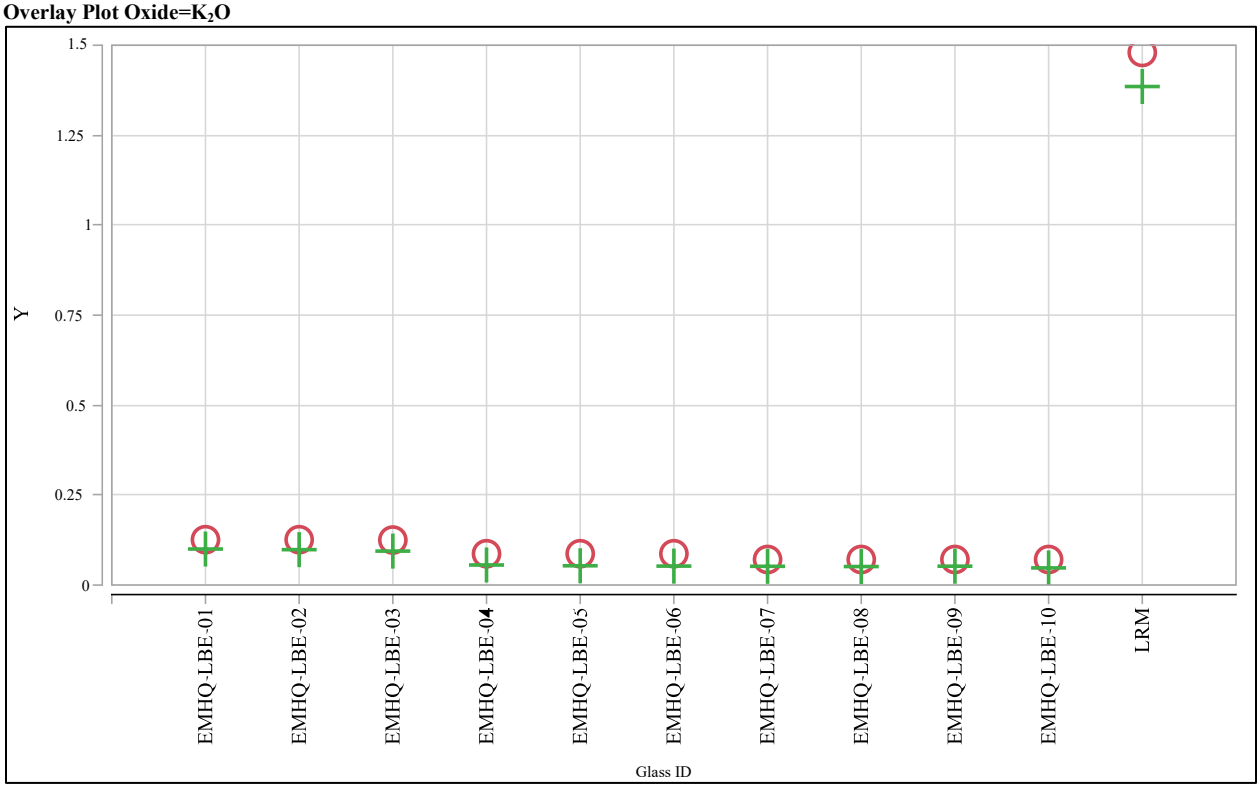


Exhibit A-3. Measured versus Target Concentrations by Glass ID by Oxide (continued)

Overlay Plot Oxide=Fe_2O_3



Overlay Plot Oxide=K_2O



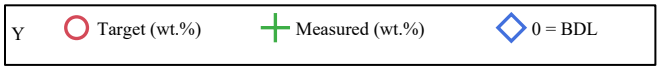
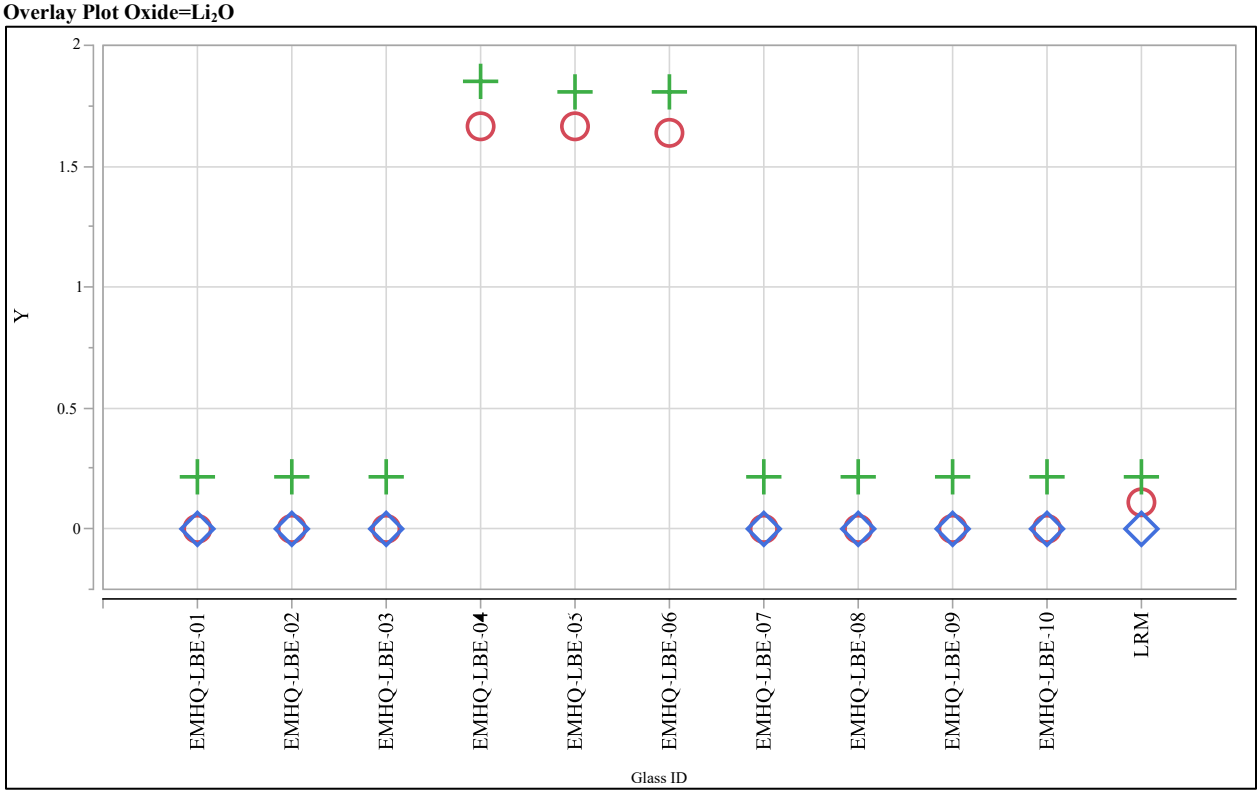
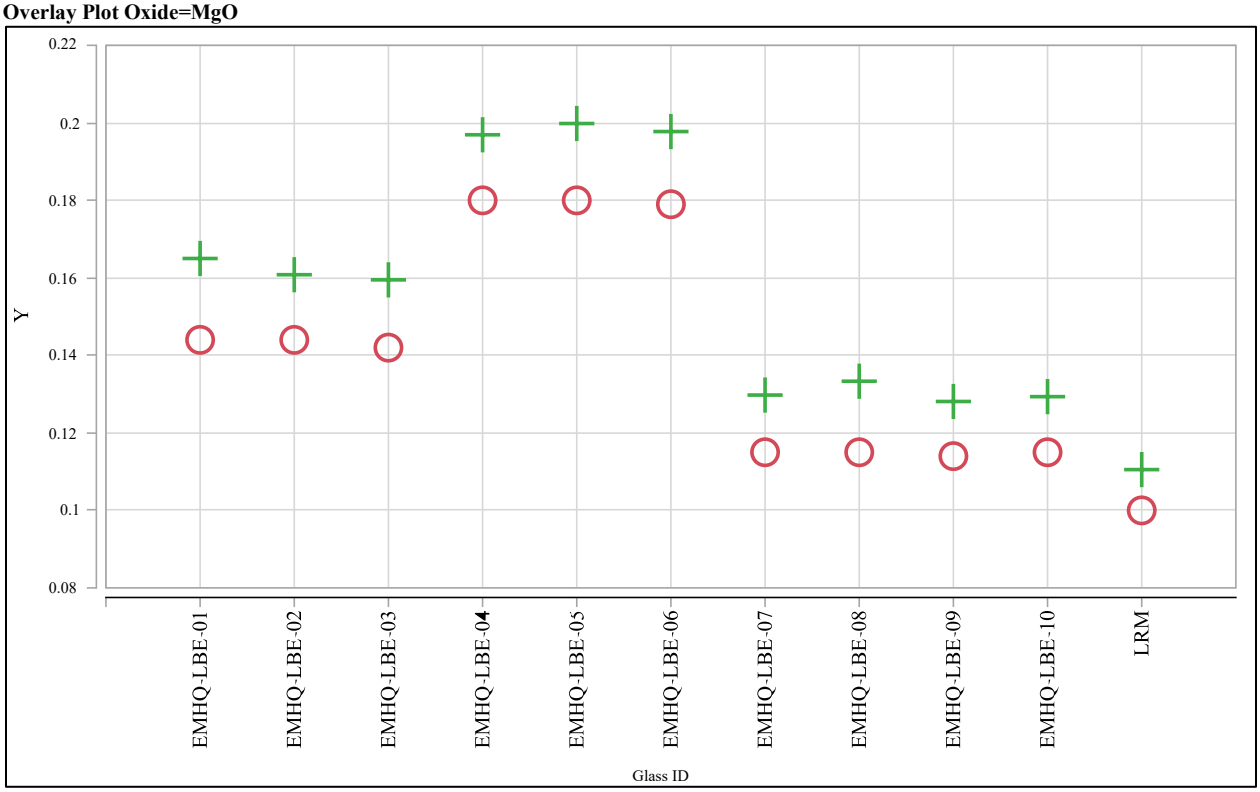


Exhibit A-3. Measured versus Target Concentrations by Glass ID by Oxide (continued)

Overlay Plot Oxide=Li_2O



Overlay Plot Oxide=MgO



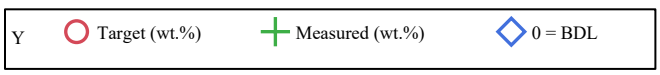
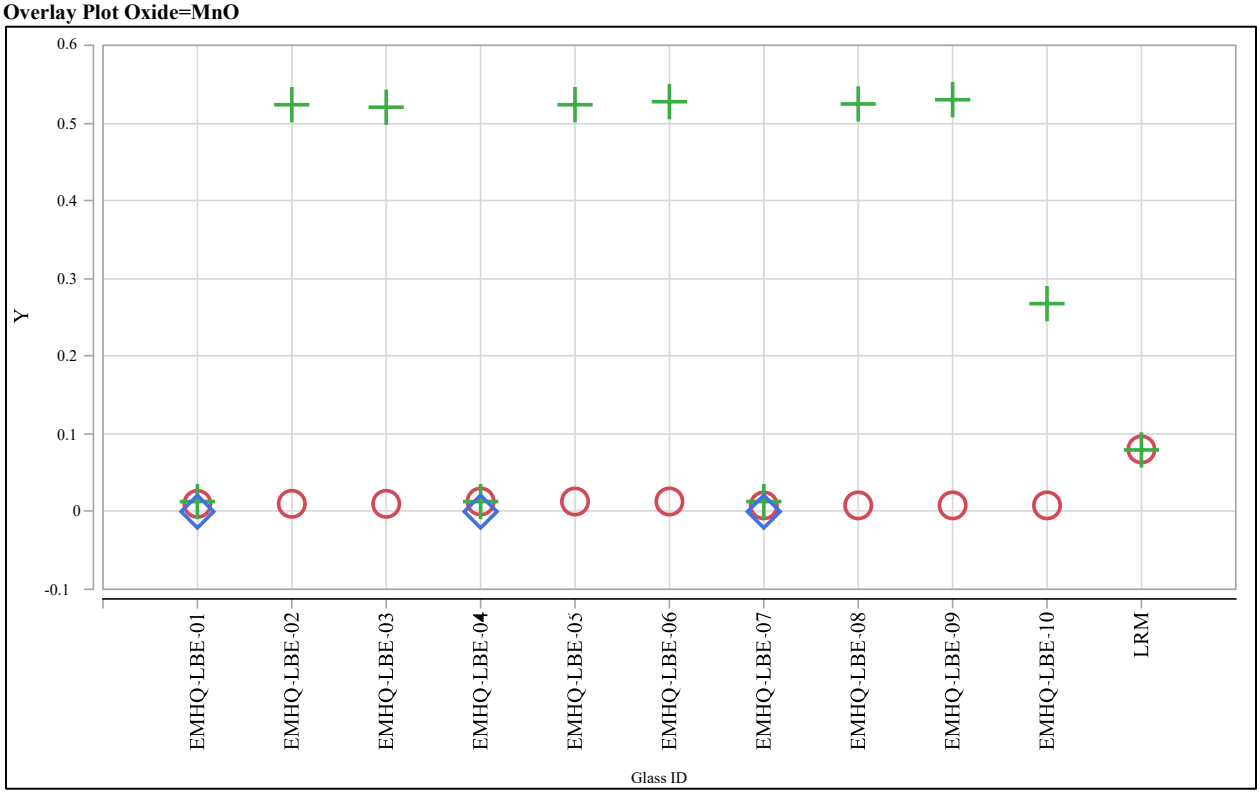
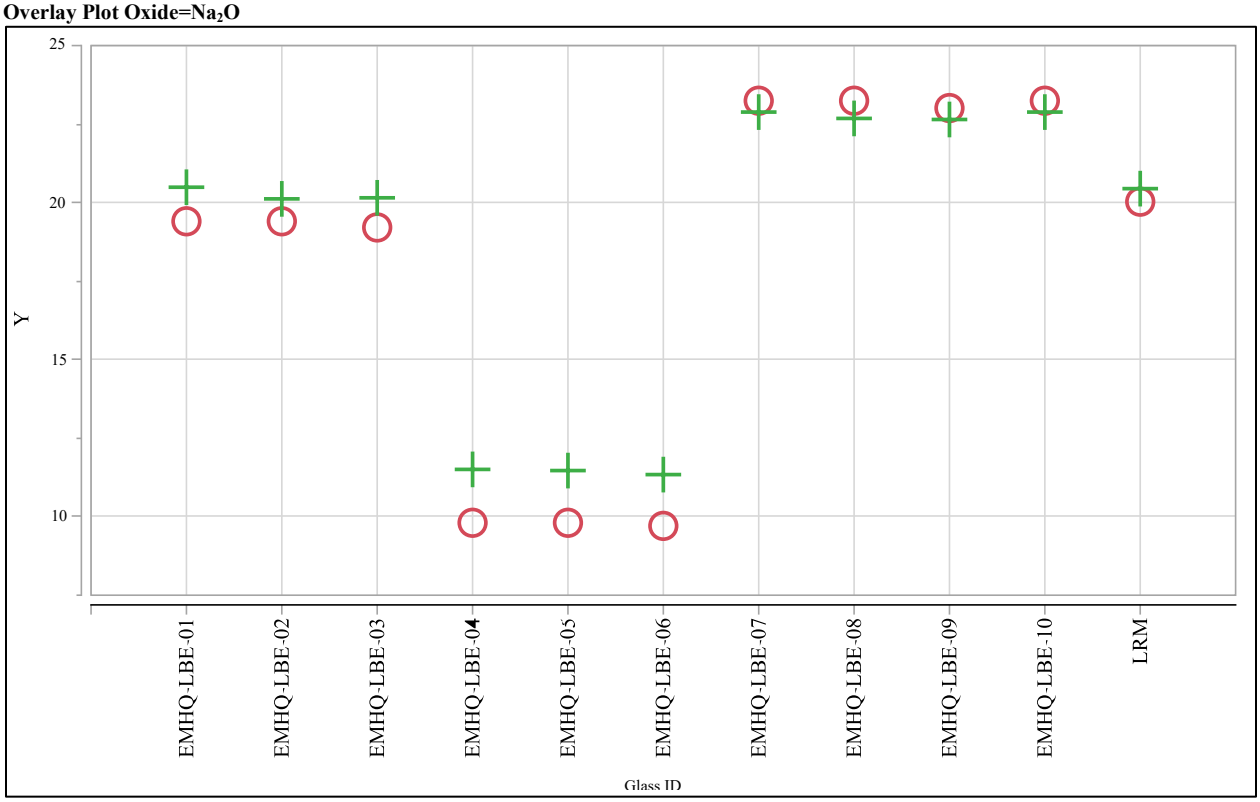


Exhibit A-3. Measured versus Target Concentrations by Glass ID by Oxide (continued)

Overlay Plot Oxide=MnO



Overlay Plot Oxide=Na_2O



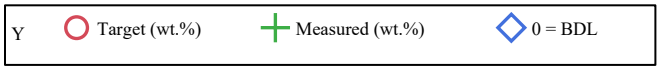
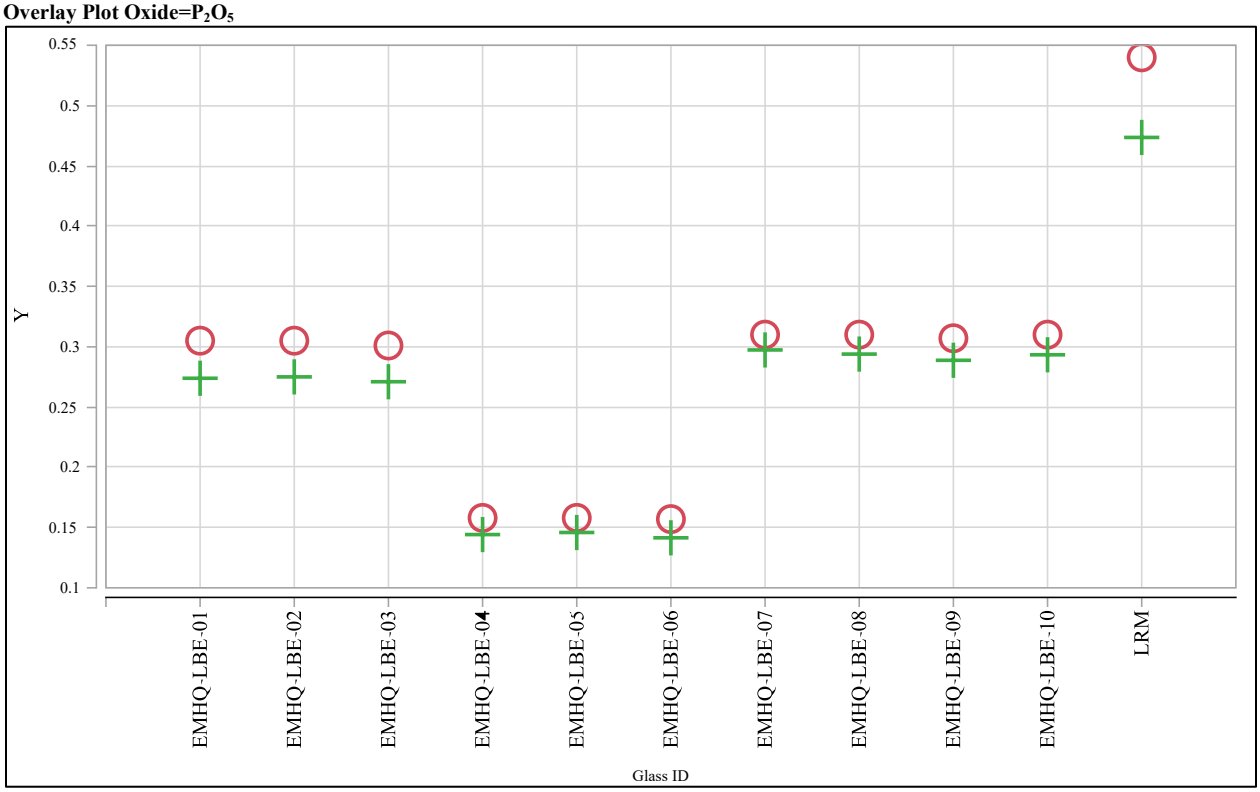
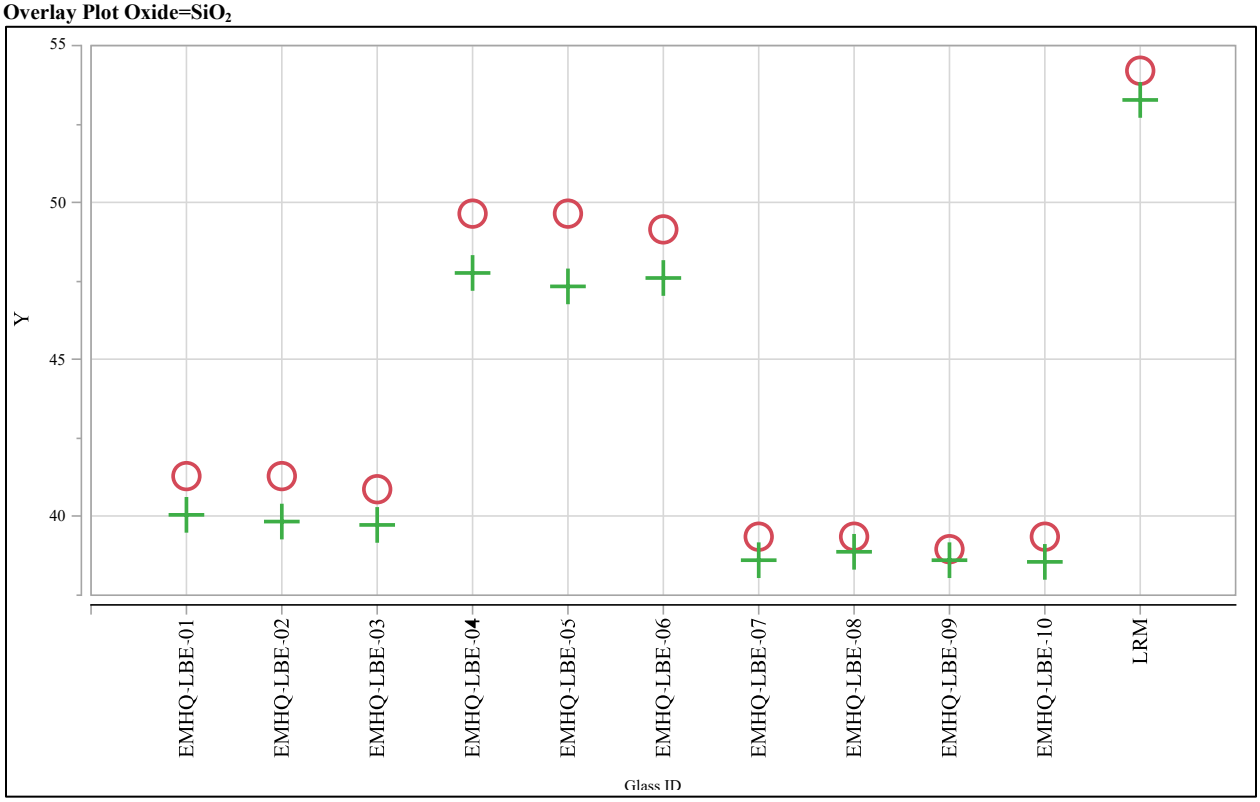


Exhibit A-3. Measured versus Target Concentrations by Glass ID by Oxide (continued)

Overlay Plot Oxide=P_2O_5



Overlay Plot Oxide=SiO_2



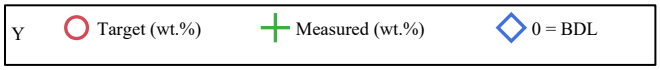
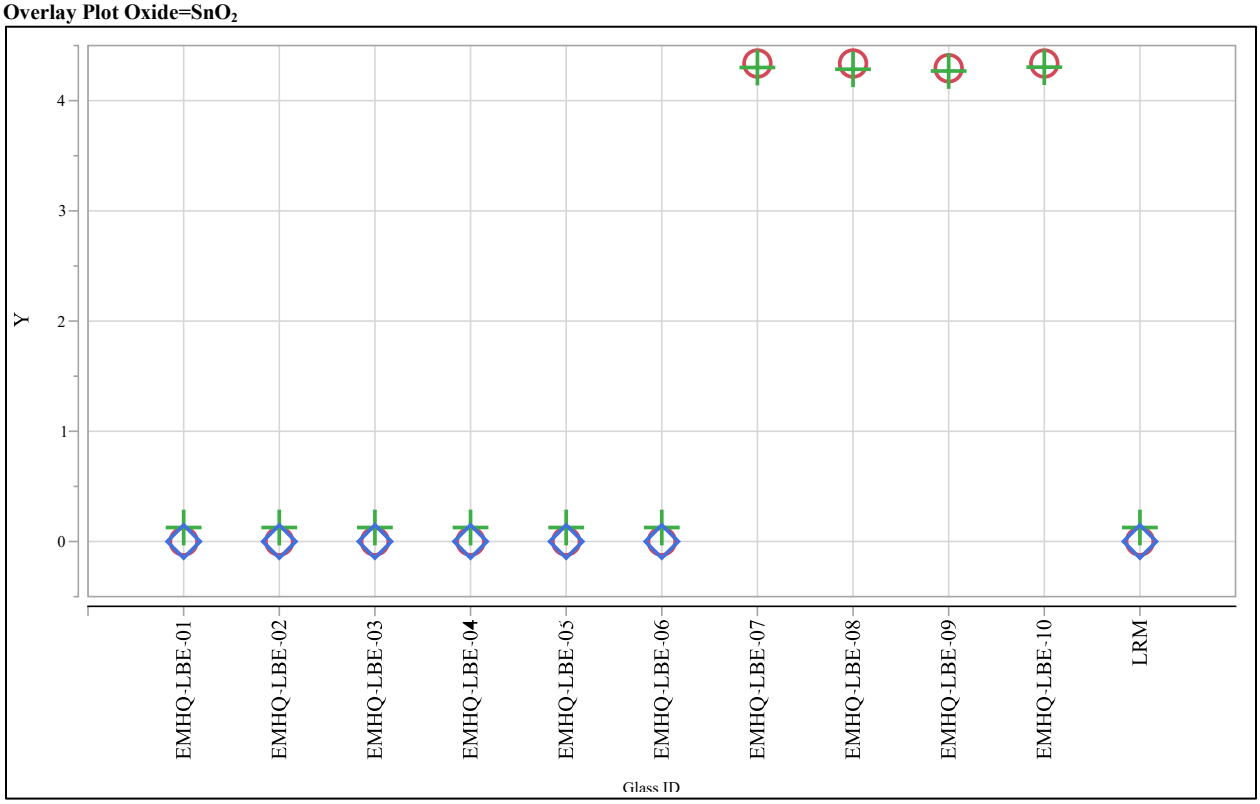
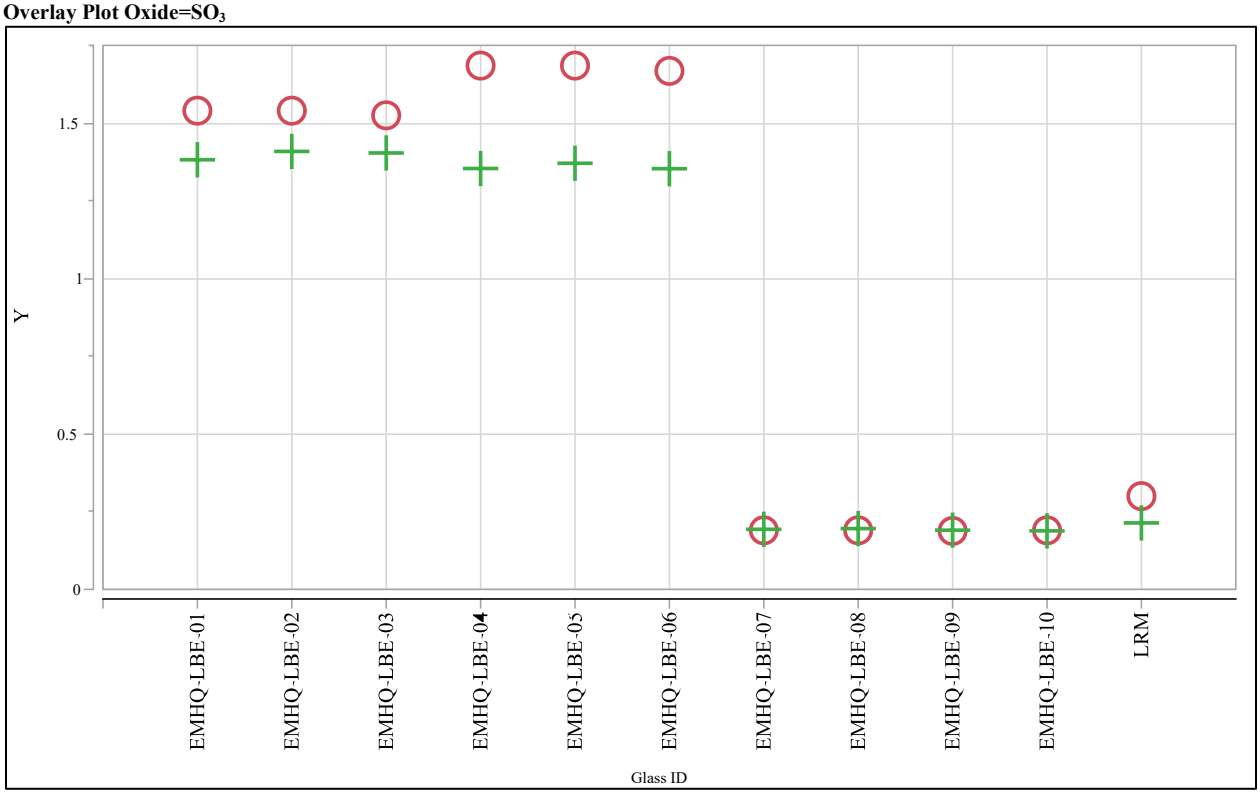


Exhibit A-3. Measured versus Target Concentrations by Glass ID by Oxide (continued)

Overlay Plot Oxide=SnO_2



Overlay Plot Oxide=SO_3



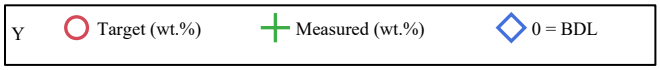
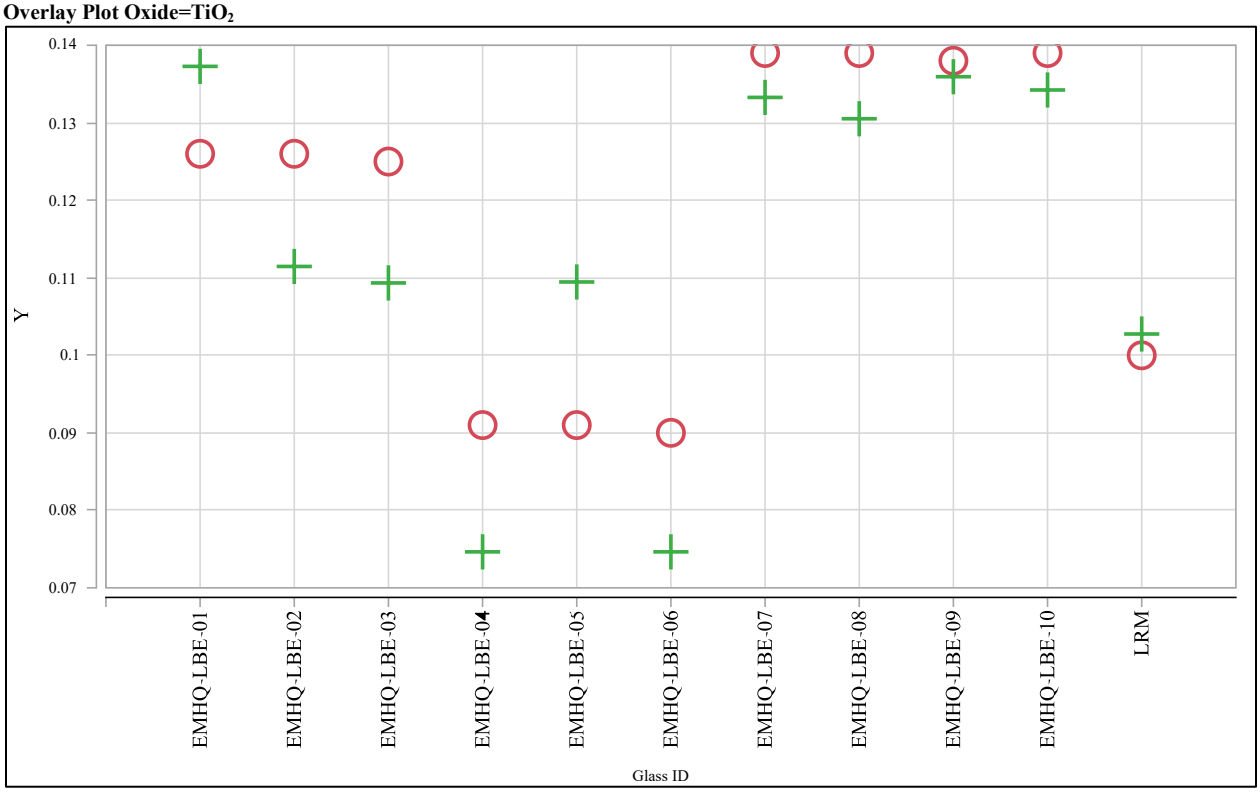
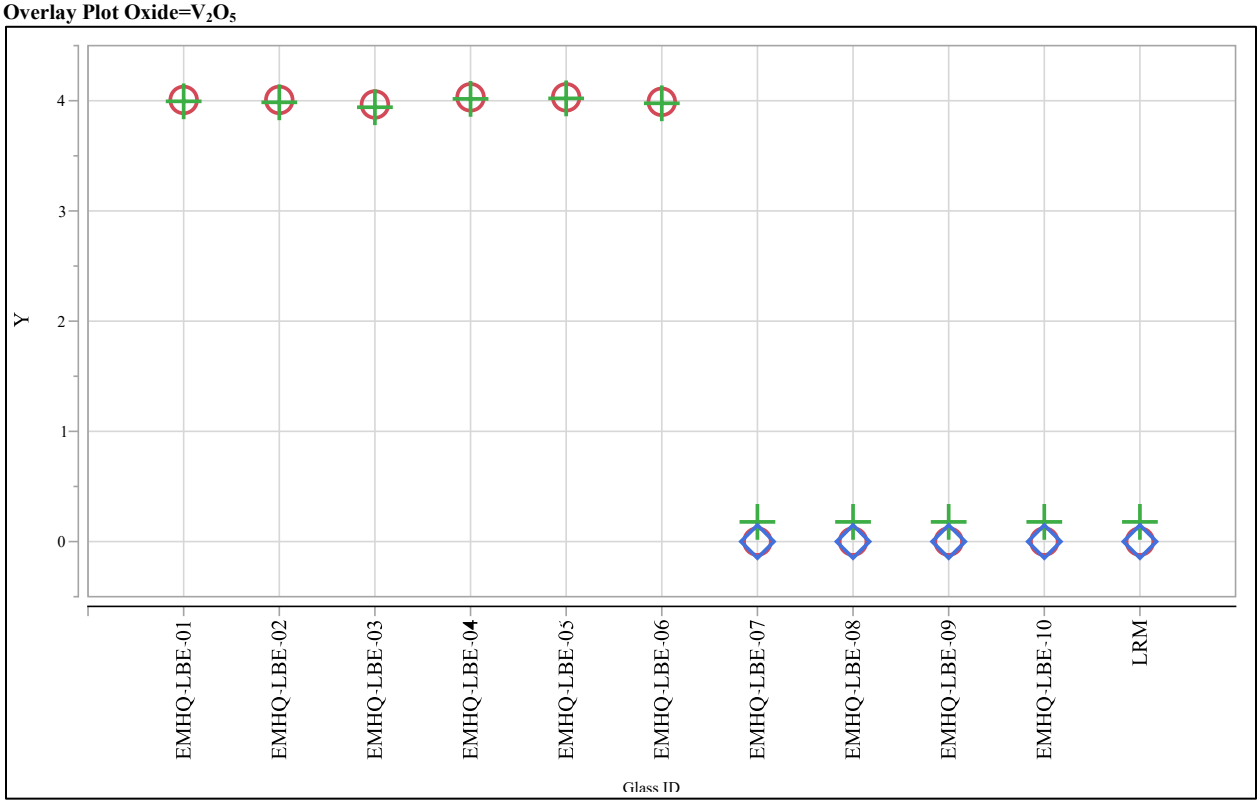


Exhibit A-3. Measured versus Target Concentrations by Glass ID by Oxide (continued)

Overlay Plot Oxide=TiO_2



Overlay Plot Oxide=V_2O_5



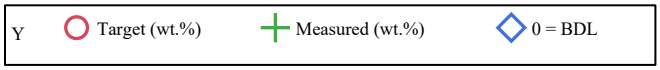
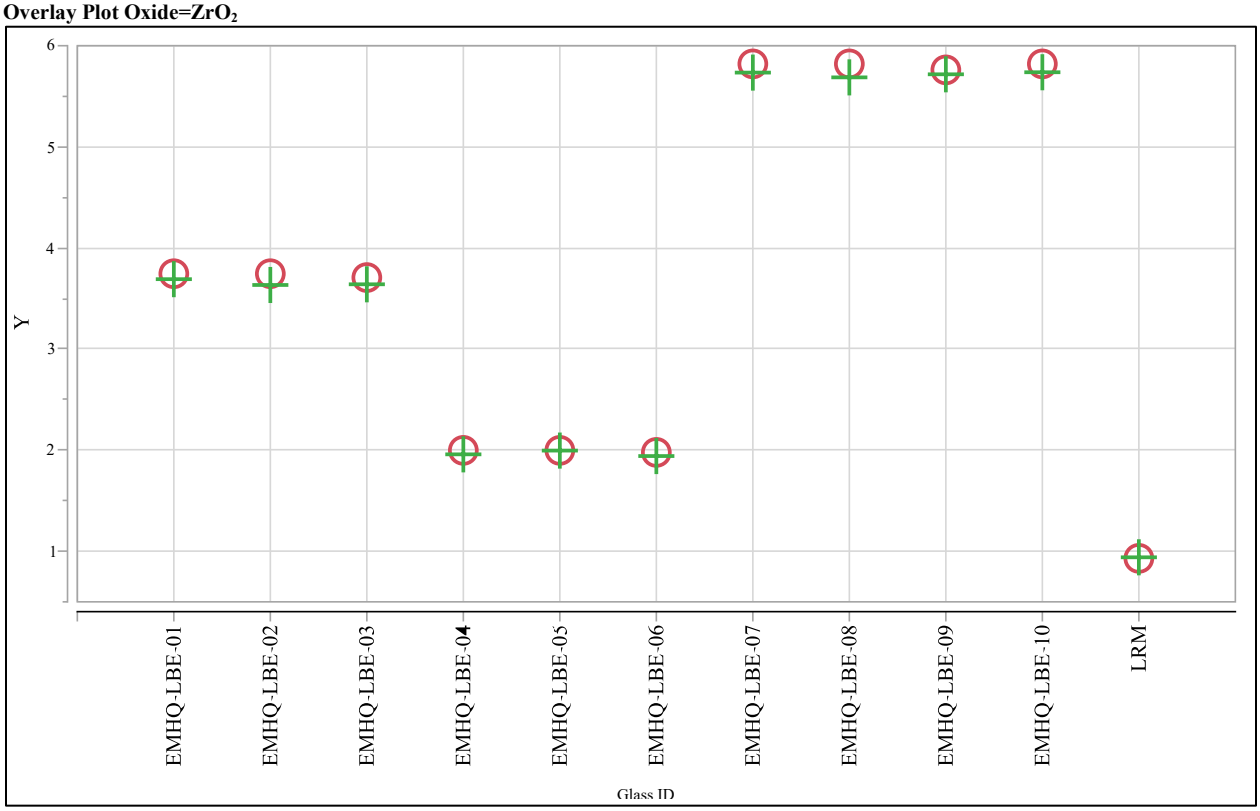
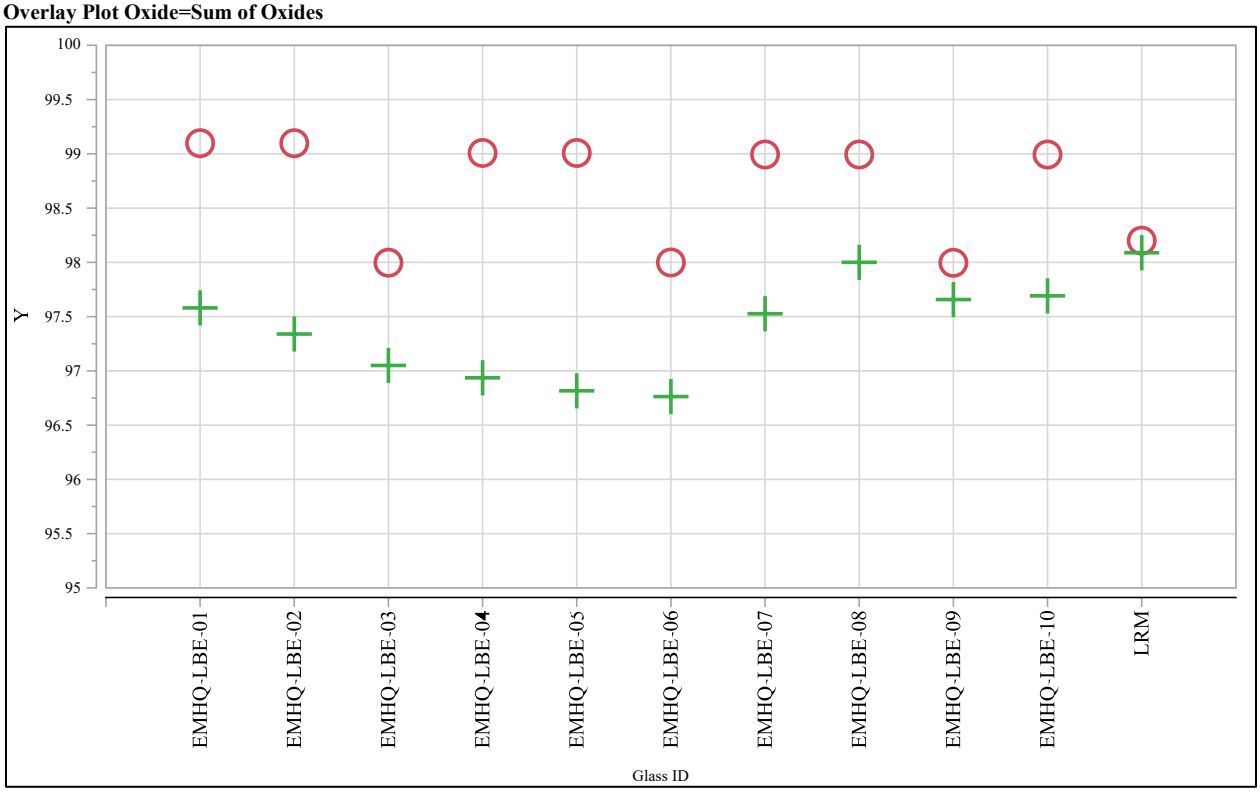


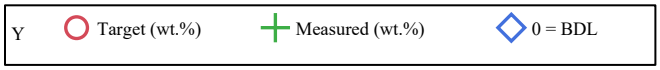
Exhibit A-3. Measured versus Target Concentrations by Glass ID by Oxide (continued)

Overlay Plot Oxide=ZrO_2



Overlay Plot Oxide=Sum of Oxides





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