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Product Consistency Test Results for the Environmental Management Headquarters (EMHQ) Low-Activity Waste (LAW) Glasses

M. C. Hsieh

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EXECUTIVE SUMMARY

This report provides the results of the Product Consistency Test leachates from the Environmental Management Headquarters Low-Activity Waste glasses, a series of simulated nuclear waste glasses designed and fabricated at the Pacific Northwest National Laboratory. The series included quenched versions of the glasses. These data will be used in the development, validation, and implementation of enhanced property/composition models for waste glass vitrification at Hanford.

The measured concentrations of the analytes in the test blank samples were below detection limits. The measured concentrations of B, Li, Na, and Si in the Approved Reference Material-1 samples included with the Product Consistency Tests fell within control chart values indicating proper test performance. The measured glass compositions for the study glasses were close to target values: therefore, little difference was seen when evaluating the normalized values using the targeted or measured glass compositions. The NC_B, NC_{Na}, and NC_{Si} values were less than the Hanford Tank Waste Treatment and Immobilization Plant low-activity waste constraint of 4 g/L for all glasses.

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LIST OF ABBREVIATIONS

ARM-1	Approved Reference Material-1
ASTM	American Society for Testing and Materials
BDL	below detection limit
DF	dilution factor
DOE	Department of Energy
EMHQ	Environmental Management Headquarters
ICP-OES	inductively coupled plasma – optical emission spectroscopy
ID	identifier
LAW	low-activity waste
NC_i	normalized concentration of element "*i*"
ORP	Office of River Protection
PCT	Product Consistency Test
PNNL	Pacific Northwest National Laboratory
%RSD	percent relative standard deviation
seq	sequence
SRNL	Savannah River National Laboratory
std	High Purity Standards ICP multi-element custom solution SM-744-013
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) 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 the results of the Product Consistency Test (PCT) leachates from the Environmental Management Headquarters (EMHQ) Low-Activity Waste (LAW) glasses, a series of simulated nuclear waste glasses designed and fabricated at the Pacific Northwest National Laboratory (PNNL). The series included quenched versions of the glasses. 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] These data will be used in the development, validation, and implementation of enhanced property/composition models for waste glass vitrification at Hanford.[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 leachates were provided by PNNL 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. American Society for Testing and Materials (ASTM) C1285 PCT Method A[6] was performed on each of the study glasses. The resulting PCT leachates were sent to SRNL for chemical analysis. Identifiers (ID) for the PCT leachates 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 PCT Leachates

PNNL Solution ID	Lab ID
EMHQ-LBE-01-PCT-A	S-13384
EMHQ-LBE-01-PCT-B	S-13385
EMHQ-LBE-01-PCT-C	S-13386
EMHQ-LBE-02-PCT-A	S-13387
EMHQ-LBE-02-PCT-B	S-13388
EMHQ-LBE-02-PCT-C	S-13389
EMHQ-LBE-03-PCT-A	S-13390
EMHQ-LBE-03-PCT-B	S-13391
EMHQ-LBE-03-PCT-C	S-13392
EMHQ-LBE-04-PCT-A	S-13393
EMHQ-LBE-04-PCT-B	S-13394
EMHQ-LBE-04-PCT-C	S-13395
EMHQ-LBE-05-PCT-A	S-13396
EMHQ-LBE-05-PCT-B	S-13397
EMHQ-LBE-05-PCT-C	S-13398
EMHQ-LBE-06-PCT-A	S-13399
EMHQ-LBE-06-PCT-B	S-13400
EMHQ-LBE-06-PCT-C	S-13401
EMHQ-LBE-07-PCT-A	S-13402
EMHQ-LBE-07-PCT-B	S-13403
EMHQ-LBE-07-PCT-C	S-13404
EMHQ-LBE-08-PCT-A	S-13405
EMHQ-LBE-08-PCT-B	S-13406
EMHQ-LBE-08-PCT-C	S-13407
EMHQ-LBE-09-PCT-A	S-13408
EMHQ-LBE-09-PCT-B	S-13409
EMHQ-LBE-09-PCT-C	S-13410
EMHQ-LBE-10-PCT-A	S-13411
EMHQ-LBE-10-PCT-B	S-13412
EMHQ-LBE-10-PCT-C	S-13413
EMHQ-LBE-STD-PCT-A	S-13414
EMHQ-LBE-STD-PCT-B	S-13415
EMHQ-LBE-STD-PCT-C	S-13416
EMHQ-LBE-BLANK-PCT-1	S-13417
EMHQ-LBE-BLANK-PCT-2	S-13418

2.3 PCT Leachate Analysis

The PCT leachate samples were analyzed by inductively coupled plasma – optical emission spectroscopy (ICP-OES)[7] under the auspices of an analytical study plan.[8] Samples of High Purity Standards ICP multi-element custom solution SM-744-013 (std) were also included in the analytical plan as a check of the accuracy of the instrument used for these measurements. PNNL provided the dilution factor (DF) used in preparing the PCT leachates for analyses. The leachate measurements were adjusted using the provided DF of 5 as described further below. Normalized release values were calculated for each glass based on the targeted and measured[9] glass compositions.

3.0 Results and Discussion

JMP® Version 14.3.0 (SAS Institute, Inc.)[10] was used to support these analyses.

3.1 Measured Compositions of the PCT Leachates

Table A-1 in Appendix A provides the elemental concentration measurements in mg/L for the PCT leachates and standard solutions as measured by ICP-OES in analytical sequence. These values are shown as received from the analytical laboratory and after using the provided DF of 5 to correct for dilutions performed at PNNL. Note that the measured concentrations of the analytes in the test blank samples were below detection limits (BDL) and denoted by a less than symbol (<).

Table A-2 in Appendix A provides measurements for the samples of the approved reference material (ARM-1) reference glass included in the PCTs after using the provided DF of 5 to correct for dilutions performed at PNNL. Note that measured concentrations of the analytes fell within control chart values indicating proper test performance.[11]

Following the guidance in ASTM C1285,[6] the mean, standard deviation, and percent relative standard deviation (%RSD) were determined for each element present in the solution standard for each analytical block. As shown in Table A-3 in Appendix A, the mean value for each analytical block was found to be less than 10% from the reference value (i.e., a percent relative bias less than 10%), and the %RSD was less than 10% for each element. Thus, these analytical results are acceptable per the criteria in ASTM C1285[6], which indicates no significant issues with the analytical outcomes for the measurements of the PCT leachates.

Exhibit A-1 in Appendix A provides linear plots of the triplicate leachate concentrations by the solution ID. Plotting the data in this format allows for the assessment of the repeatability of the measurements for each glass.

3.2 Normalization of PCT Data

The PCT leachate data were used to determine normalized concentrations for each element of interest using both the targeted and average measured compositions[9] of the glasses following the expression given in ASTM C1285.[6]

$$NC_i = \frac{c_i\left(sample\right)}{f_i}$$

where NC_i is the normalized concentration in units of $g_{waste\ form}/L_{leachant}$, $c_i(sample)$ is the concentration of element "*i*" in the leachate in units of g_i/L (corrected for the dilutions performed at PNNL), and f_i is the mass fraction of element "*i*" in the unleached glass in units of g_i/g_{glass}.[b]

An equation was developed to allow for calculation of the NC_i values using the units of measurement provided with the analytical results for this study and to accommodate the triplicate leachate measurements for each of the study glasses. Note that the symbols in this second equation were kept consistent with those used in ASTM C1285,[6] but the units of measurement differ. The common logarithm of the normalized concentration for each element "*i*" (NC_i) for each of the study glasses was determined using the equation:

$$\log_{10}\left(NC_i\right) = \overline{\log_{10} c_i} - \left[1 + \log_{10} f_i\right]$$

[b] Note that the waste forms in this study were assumed to be of similar density. The PCT-A reference volume of leachant to sample mass ratio was used, and the 100 to 200 mesh reference particle size was used. Thus, no adjustment for the density of the glasses was made in normalizing the PCT results. Data provided in the appendices of this report allow for the calculation of normalized elemental mass loss (NL_i) if glass densities are measured at a later date.

where NC_i remains in units of $g_{waste\ form}/L_{leachant}$, $\overline{\log_{10} c_i}$ is the average of the common logarithms of the measured concentrations of element "*i*" in the triplicate leachates in units of mg/L (corrected for the dilutions performed at PNNL as discussed in Section 3.1), and $\log_{10} f_i$ is either the common logarithm of the targeted concentration of element "*i*" in the glass in units of weight percent (wt.%) or the common logarithm of the average measured concentration of element "*i*" in the glass in units of wt.% (reported previously[1]).

Table B-1 in Appendix B provides the normalized PCT responses for selected elements, Al, B, Li, Na, and Si, for each of the study glasses as well as the responses for the ARM-1 reference glass[12]. The results are grouped by compositional view. Note that an indicator (<) is provided as part of these plots to show results involving BDL values. The plots of Exhibit B-1 in Appendix B provide a graphical comparison between the PCT responses for the targeted and measured compositions of each study glass.

A review of the PCT data resulted in the following observations:

- The measured glass compositions for the study glasses[9] were close to target values; therefore, little difference was seen when evaluating the normalized values using the targeted or measured glass compositions.
- The NC_B, NC_{Na}, and NC_{Si} values fell below 4 g/L for all glasses, meeting the WTP constraints.[c]

4.0 Summary

The measured concentrations of the analytes in the test blank samples were below detection limits. The measured concentrations of B, Li, Na, and Si of the ARM-1 reference glass samples fell within control chart values indicating proper test performance. The measured glass compositions for the study glasses were close to target values; therefore, little difference was seen when evaluating the normalized values using the targeted or measured glass compositions. The NC_B, NC_{Na}, and NC_{Si} values were less than the WTP low-activity waste constraint of 4 g/L for all glasses.

5.0 References

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2. K.M. Fox, "Task Technical and Quality Assurance Plan for Hanford Waste Glass Development and Characterization," Savannah River National Laboratory, Aiken, SC, SRNL-RP-2013-00692, Revision 1, 2016.

3. D.K. Peeler, D.S. Kim, J.D. Vienna, M.J. Schweiger, and G.F. Piepel, "Office of River Protection Advanced Low-Activity Waste Glass Research and Development Plan," Pacific Northwest National Laboratory, Richland, WA, PNNL-24883, EWG-RPT-008, Revision 0, 2015.

4. "Technical Reviews," Savannah River Site, Aiken, SC, Manual E7, Procedure 2.60, Rev. 20, 2021.

5. "Savannah River National Laboratory Technical Report Design Check Guidelines," Westinghouse Savannah River Company, Aiken, SC, WSRC-IM-2002-00011, Rev. 2, 2004.

6. ASTM, "Standard Test Methods for Determining Chemical Durability of Nuclear, Hazardous, and Mixed Waste Glasses and Multiphase Glass Ceramics: The Product Consistency Test (PCT)," ASTM International, West Conshohocken, PA, C1285 - 21, 2021.

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

7. "Calibration, Verification, and Operation of the Agilent 5110 ICP-OES Inductively Coupled Plasma-Optical Emission Spectrometer," Savannah River National Laboratory, Aiken, SC, Manual L33, Procedure 0242, Rev. 1, 2021.

8. M.C. Hsieh, "An Analytical Plan for Measuring the PCT Solutions of the EMHQ LAW Glasses," Savannah River National Laboratory, Aiken, SC, SRNL-L3310-2021-00014, Revision 0, 2021.

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12. G.B. Mellinger and J.L. Daniel, "Approved Reference and Testing Materials for Use in Nuclear Waste Management Research and Development Programs," Pacific Northwest Laboratory, Richland, WA, PNL-4955-2, Revision 0, 1984.

Appendix A. Tables Containing the Measurement Data for the EMHQ LAW PCT Leachates

Table A-1. PCT Leachate Measurements (mg/L) Measured by ICP-OES

				As Received Measurements									Dilution-Corrected Measurements							
PNNL Solution ID	Block	Seq	Lab ID	Al	B	Ca	Li	Na	S	Si	V	DF	Al	B	Ca	Li	Na	S	Si	V
PCT std	1	1	std-11	3.99	19.9	<1.00	10.1	76	<1.00	51.3	<1.00	1	3.99	19.9	<1.00	10.1	76.0	<1.00	51.3	<1.00
EMHQ-LBE-01-PCT-A	1	2	S-13384	<1.00	20.7	<1.00	<1.00	83	3.6	29.8	11.6	5	<5.00	104	<5.00	<5.00	415	18.0	149	58.0
EMHQ-LBE-STD-PCT-A	1	3	S-13414	1	3.4	<1.00	2.93	7.03	<1.00	12.5	<1.00	5	5.00	17.0	<5.00	14.7	35.2	<5.00	62.5	<5.00
ICPBlank	1	4	Blank-11	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
EMHQ-LBE-BLANK-PCT-1	1	5	S-13417	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	5	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
EMHQ-LBE-02-PCT-A	1	6	S-13387	<1.00	24.4	<1.00	<1.00	93.5	4.3	32.4	13.6	5	<5.00	122	<5.00	<5.00	468	21.5	162	68.0
EMHQ-LBE-06-PCT-A	1	7	S-13399	<1.00	7.74	3.72	1.93	18.6	1.64	18.1	3.9	5	<5.00	38.7	18.6	9.65	93.0	8.20	90.5	19.5
EMHQ-LBE-03-PCT-A	1	8	S-13390	<1.00	25.1	<1.00	<1.00	98.9	4.32	32.2	14.3	5	<5.00	126	<5.00	<5.00	495	21.6	161	71.5
PCT std	1	9	std-12	3.93	19.1	<1.00	9.78	74.4	1.27	48.9	<1.00	1	3.93	19.1	<1.00	9.78	74.4	1.27	48.9	<1.00
EMHQ-LBE-09-PCT-A	1	10	S-13408	2.72	6.15	<1.00	<1.00	55.7	1	15.1	<1.00	5	13.6	30.8	<5.00	<5.00	279	5.00	75.5	<5.00
EMHQ-LBE-07-PCT-A	1	11	S-13402	2.56	6.63	<1.00	<1.00	58.9	1.04	15.5	<1.00	5	12.8	33.2	<5.00	<5.00	295	5.20	77.5	<5.00
EMHQ-LBE-04-PCT-A	1	12	S-13393	<1.00	6.99	3.97	1.77	16.8	1.74	17.5	3.51	5	<5.00	35.0	19.9	8.85	84.0	8.70	87.5	17.6
ICPBlank	1	13	Blank-12	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
EMHQ-LBE-10-PCT-A	1	14	S-13411	2.74	5.8	<1.00	<1.00	57	<1.00	15.1	<1.00	5	13.7	29.0	<5.00	<5.00	285	<5.00	75.5	<5.00
EMHQ-LBE-05-PCT-A	1	15	S-13396	<1.00	6.45	3.89	1.61	15.4	2.05	16.4	3.39	5	<5.00	32.3	19.5	8.05	77.0	10.3	82.0	17.0
EMHQ-LBE-08-PCT-A	1	16	S-13405	3.04	7.6	<1.00	<1.00	74.5	<1.00	17.3	<1.00	5	15.2	38.0	<5.00	<5.00	373	<5.00	86.5	<5.00
PCT std	1	17	std-13	3.77	18.5	<1.00	9.66	73.5	<1.00	48	<1.00	1	3.77	18.5	<1.00	9.66	73.5	<1.00	48.0	<1.00
PCT std	2	1	std-21	3.98	19.6	<1.00	10.1	77.1	<1.00	50.4	<1.00	1	3.98	19.6	<1.00	10.1	77.1	<1.00	50.4	<1.00
EMHQ-LBE-07-PCT-B	2	2	S-13403	2.57	6.5	<1.00	<1.00	59.8	<1.00	15.4	<1.00	5	12.9	32.5	<5.00	<5.00	299	<5.00	77.0	<5.00
EMHQ-LBE-03-PCT-B	2	3	S-13391	<1.00	22.7	<1.00	<1.00	93.5	3.65	30.2	12.9	5	<5.00	114	<5.00	<5.00	468	18.3	151	64.5
ICPBlank	2	4	Blank-21	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
EMHQ-LBE-02-PCT-B	2	5	S-13388	<1.00	24	<1.00	<1.00	97.7	3.86	32.2	13.4	5	<5.00	120	<5.00	<5.00	489	19.3	161	67.0
EMHQ-LBE-10-PCT-B	2	6	S-13412	2.85	5.89	<1.00	<1.00	59.5	<1.00	15.3	<1.00	5	14.3	29.5	<5.00	<5.00	298	<5.00	76.5	<5.00
EMHQ-LBE-01-PCT-B	2	7	S-13385	<1.00	19.6	<1.00	<1.00	84.1	3.04	29.8	10.9	5	<5.00	98.0	<5.00	<5.00	421	15.2	149	54.5
EMHQ-LBE-08-PCT-B	2	8	S-13406	3.07	7.34	<1.00	<1.00	75.6	<1.00	17.7	<1.00	5	15.4	36.7	<5.00	<5.00	378	<5.00	88.5	<5.00
PCT std	2	9	std-22	3.94	19.1	<1.00	9.99	76	<1.00	48.8	<1.00	1	3.94	19.1	<1.00	9.99	76.0	<1.00	48.8	<1.00
EMHQ-LBE-BLANK-PCT-2	2	10	S-13418	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	5	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
EMHQ-LBE-06-PCT-B	2	11	S-13400	<1.00	7.59	3.84	1.97	18.8	1.1	18.2	3.88	5	<5.00	38.0	19.2	9.85	94.0	5.50	91.0	19.4
EMHQ-LBE-STD-PCT-B	2	12	S-13415	<1.00	3	<1.00	2.83	6.39	<1.00	11.2	<1.00	5	<5.00	15.0	<5.00	14.2	32.0	<5.00	56.0	<5.00
ICPBlank	2	13	Blank-22	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
EMHQ-LBE-04-PCT-B	2	14	S-13394	<1.00	7.26	4.37	1.93	18.9	<1.00	18.9	3.76	5	<5.00	36.3	21.9	9.65	94.5	<5.00	94.5	18.8
EMHQ-LBE-05-PCT-B	2	15	S-13397	<1.00	5.84	4.42	1.6	15	1.08	14.9	3.05	5	<5.00	29.2	22.1	8.00	75.0	5.40	74.5	15.3
EMHQ-LBE-09-PCT-B	2	16	S-13409	2.47	5.66	<1.00	<1.00	54.1	<1.00	13.7	<1.00	5	12.4	28.3	<5.00	<5.00	271	<5.00	68.5	<5.00
PCT std	2	17	std-23	3.88	18.9	<1.00	9.87	75.9	<1.00	48.8	<1.00	1	3.88	18.9	<1.00	9.87	75.9	<1.00	48.8	<1.00
PCT std	3	1	std-31	3.98	19.3	<1.00	9.99	76.2	<1.00	50.5	<1.00	1	3.98	19.3	<1.00	9.99	76.2	<1.00	50.5	<1.00
EMHQ-LBE-07-PCT-C	3	2	S-13404	2.65	6.94	<1.00	<1.00	63.3	<1.00	16.4	<1.00	5	13.3	34.7	<5.00	<5.00	317	<5.00	82.0	<5.00
EMHQ-LBE-08-PCT-C	3	3	S-13407	3.08	7.86	<1.00	<1.00	76.6	<1.00	18.5	<1.00	5	15.4	39.3	<5.00	<5.00	383	<5.00	92.5	<5.00
ICPBlank	3	4	Blank-31	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
EMHQ-LBE-04-PCT-C	3	5	S-13395	<1.00	7.28	4.29	1.83	17.6	1.34	18.9	3.61	5	<5.00	36.4	21.5	9.15	88.0	6.70	94.5	18.1
EMHQ-LBE-03-PCT-C	3	6	S-13392	<1.00	21	<1.00	<1.00	88.1	3.9	29.6	11.7	5	<5.00	105	<5.00	<5.00	441	19.5	148	58.5
EMHQ-LBE-02-PCT-C	3	7	S-13389	<1.00	23.8	<1.00	<1.00	97.7	4.46	32.9	13.4	5	<5.00	119	<5.00	<5.00	489	22.3	165	67.0
EMHQ-LBE-STD-PCT-C	3	8	S-13416	1.01	3.5	<1.00	3.03	7.18	<1.00	13	<1.00	5	5.05	17.5	<5.00	15.2	35.9	<5.00	65.0	<5.00
PCT std	3	9	std-32	3.94	19.5	<1.00	10.3	77.3	<1.00	50	<1.00	1	3.94	19.5	<1.00	10.3	77.3	<1.00	50.0	<1.00
EMHQ-LBE-06-PCT-C	3	10	S-13401	<1.00	7.31	3.61	1.91	18.4	1.4	17.8	3.67	5	<5.00	36.6	18.1	9.55	92.0	7.00	89.0	18.4
EMHQ-LBE-09-PCT-C	3	11	S-13410	2.37	5.11	<1.00	<1.00	50	<1.00	13.5	<1.00	5	11.9	25.6	<5.00	<5.00	250	<5.00	67.5	<5.00
EMHQ-LBE-05-PCT-C	3	12	S-13398	<1.00	6.27	3.98	1.53	14.8	<1.00	16.3	3.19	5	<5.00	31.4	19.9	7.65	74.0	<5.00	81.5	16.0
ICPBlank	3	13	Blank-32	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
EMHQ-LBE-01-PCT-C	3	14	S-13386	<1.00	18.9	<1.00	<1.00	81.4	3.00	28.4	10.4	5	<5.00	94.5	<5.00	<5.00	407	15.0	142	52.0
EMHQ-LBE-10-PCT-C	3	15	S-13413	2.87	5.91	<1.00	<1.00	57.3	<1.00	15.6	<1.00	5	14.4	29.6	<5.00	<5.00	287	<5.00	78.0	<5.00
PCT std	3	16	std-33	3.92	19.4	<1.00	9.96	75.5	<1.00	50.7	<1.00	1	3.92	19.4	<1.00	9.96	75.5	<1.00	50.7	<1.00

Table A-2. Dilution-Corrected ARM-1 Leachate Measurements (mg/L)

PNNL Solution ID	Lab ID	B	Li	Na	Si
EMHQ-LBE-STD-PCT-A	S-13414	17.0	14.7	35.2	62.5
EMHQ-LBE-STD-PCT-B	S-13415	15.0	14.2	32.0	56.0
EMHQ-LBE-STD-PCT-C	S-13416	17.5	15.2	35.9	65.0

Ranges of Expected Test Results for ARM-1[d]
Boron: 12.89 – 22.65 mg/L (17.7 ± 4.89 mg/L)
Lithium: 10.80 – 16.32 mg/L (13.6 ± 2.76 mg/L)
Sodium: 28.86 – 43.58 mg/L (36.2 ± 7.36 mg/L)
Silicon: 49.03 – 73.43 mg/L (61.2 ± 12.2 mg/L)
Values that fall outside of the reference ranges are shaded grey.

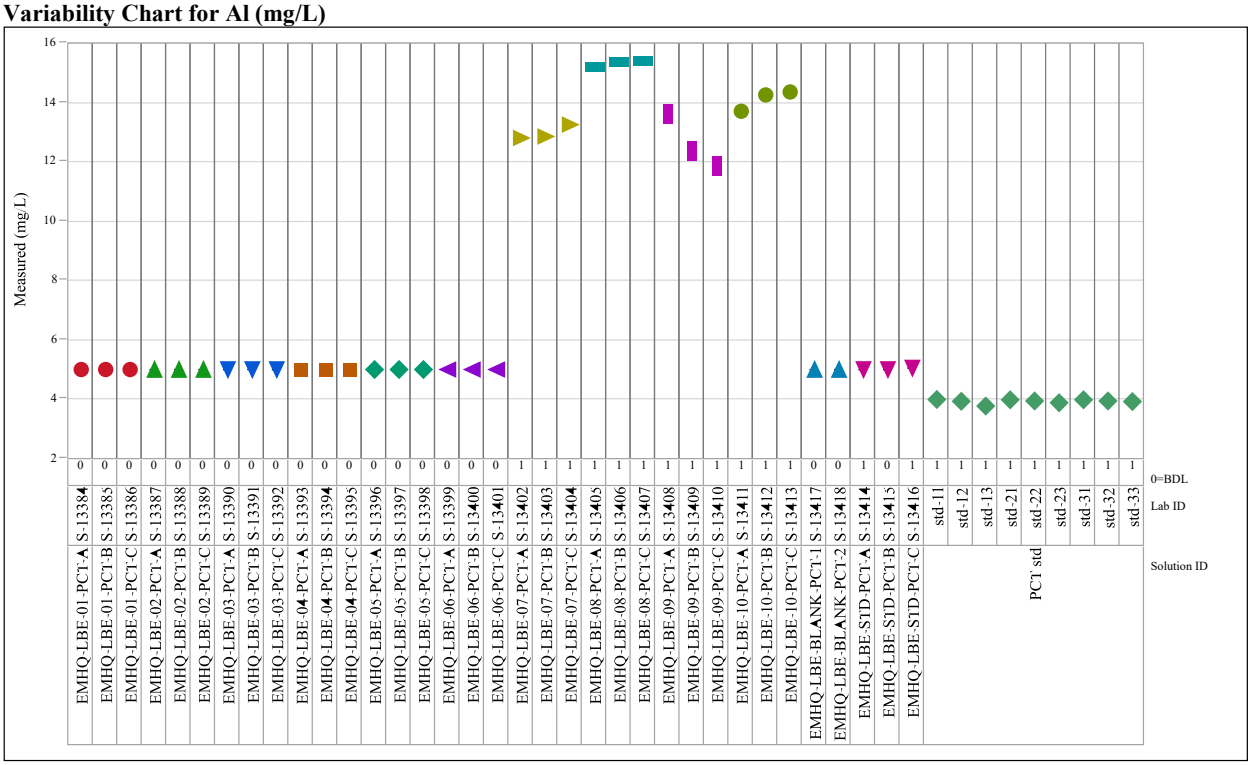
[d] C.M. Jantzen, J.B. Pickett, K.G. Brown, T.B. Edwards, and D.C. Beam, "Process/Product Models for the Defense Waste Processing Facility (DWPF): Part I. Predicting Glass Durability from Composition Using a Thermodynamic Hydration Energy Reaction Model (THERMO)," Westinghouse Savannah River Company, Aiken, SC, WSRC-TR-93-672, Rev. 1, 1995.

Table A-3. Results from Samples of the Multi-Element Solution Standard Included with the PCT Leachates

Analytical Block	1	2	3	Reference Values (mg/L)
Mean (Al (mg/L))	3.9	3.93	3.95	4.00
Mean (B (mg/L))	19.2	19.2	19.4	20.0
Mean (Li (mg/L))	9.85	9.99	10.1	10.0
Mean (Na (mg/L))	74.6	76.3	76.3	81.0
Mean (Si (mg/L))	49.4	49.3	50.4	50.0
% relative bias, Al	-2.6	-1.7	-1.3	
% relative bias, B	-4.2	-4.0	-3.0	<10% per ASTM C1285
% relative bias, Li	-1.5	-0.1	0.8	
% relative bias, Na	-7.9	-5.8	-5.8	
% relative bias, Si	-1.2	-1.3	0.8	
Standard Deviation (Al (mg/L))	0.11	0.05	0.03	
Standard Deviation (B (mg/L))	0.70	0.36	0.10	
Standard Deviation (Li (mg/L))	0.23	0.12	0.19	
Standard Deviation (Na (mg/L))	1.27	0.67	0.91	
Standard Deviation (Si (mg/L))	1.71	0.92	0.36	
%RSD (Al)	2.9	1.3	0.8	
%RSD (B)	3.7	1.9	0.5	<10% per ASTM C1285
%RSD (Li)	2.3	1.2	1.9	
%RSD (Na)	1.7	0.9	1.2	
%RSD (Si)	3.5	1.9	0.7	

Exhibit A-1. PCT Measurements by Solution ID

Analyte=Al
Variability Chart for Al (mg/L)



Analyte=B
Variability Chart for B (mg/L)

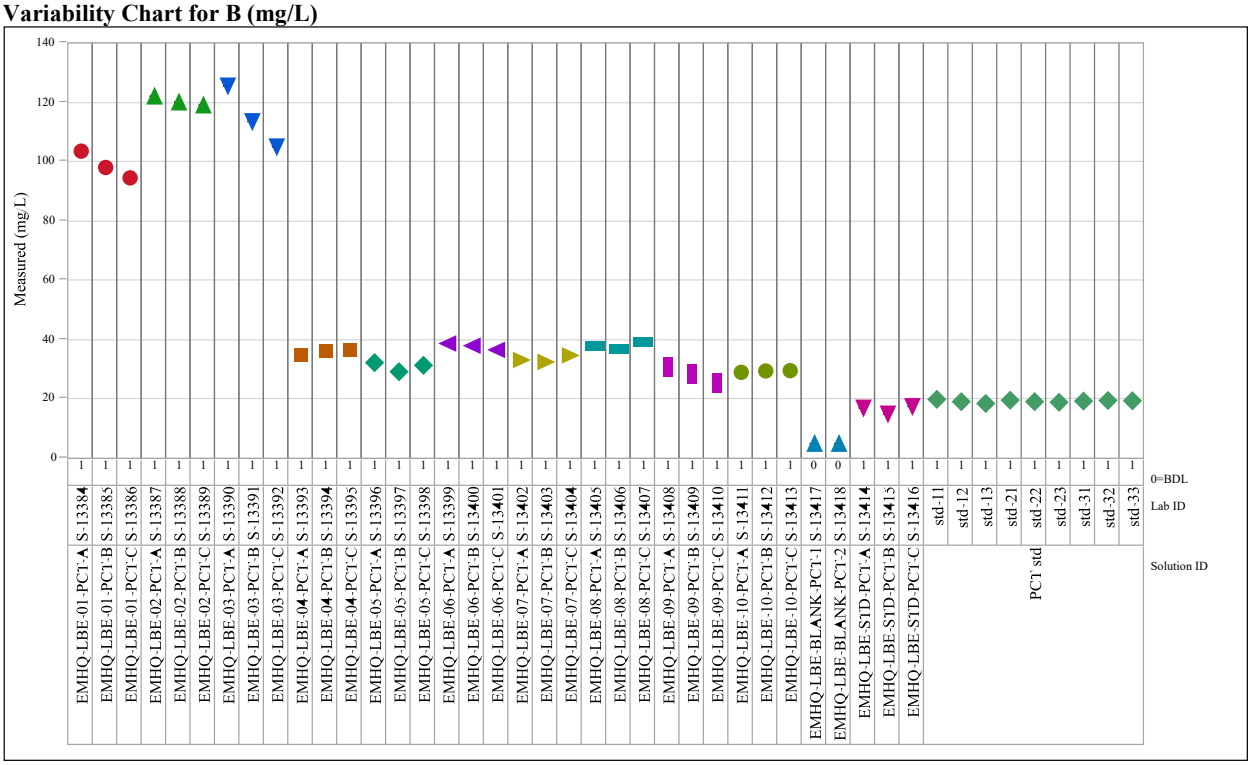
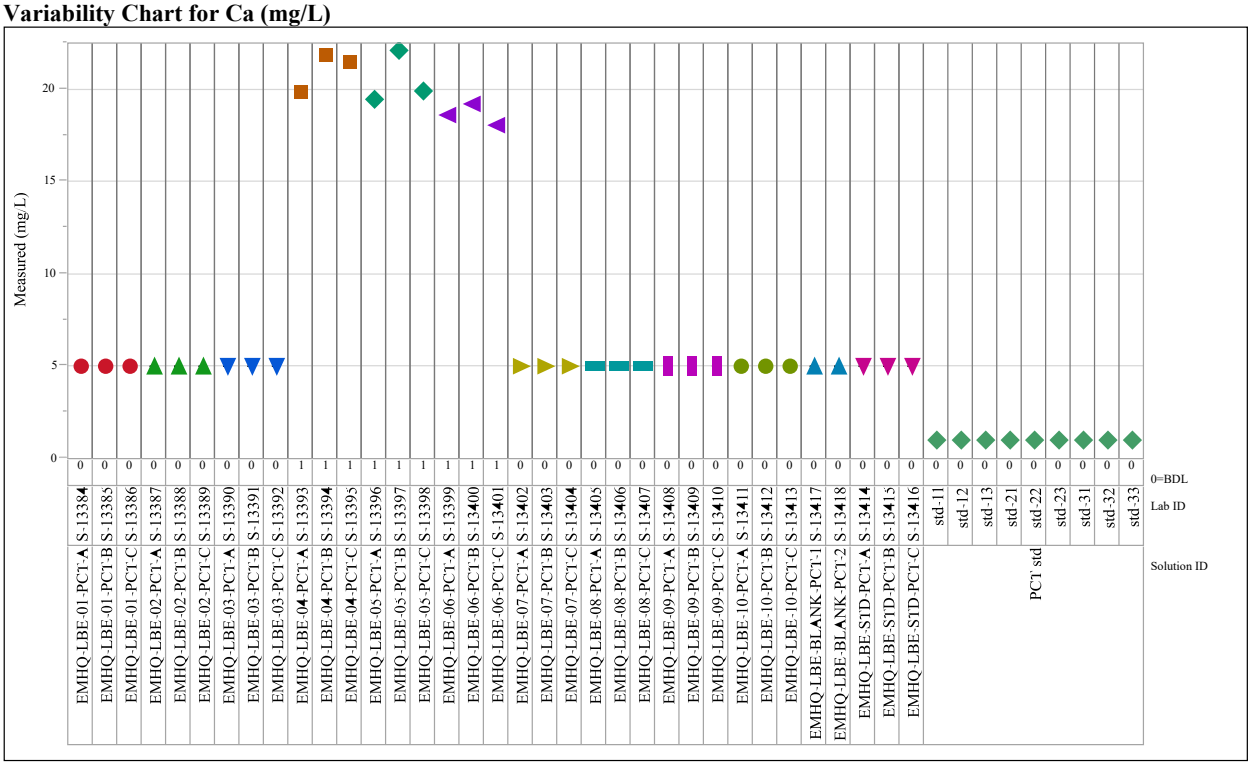


Exhibit A-1. PCT Measurements by Solution ID (continued)

Analyte=Ca
Variability Chart for Ca (mg/L)



Analyte=Li
Variability Chart for Li (mg/L)

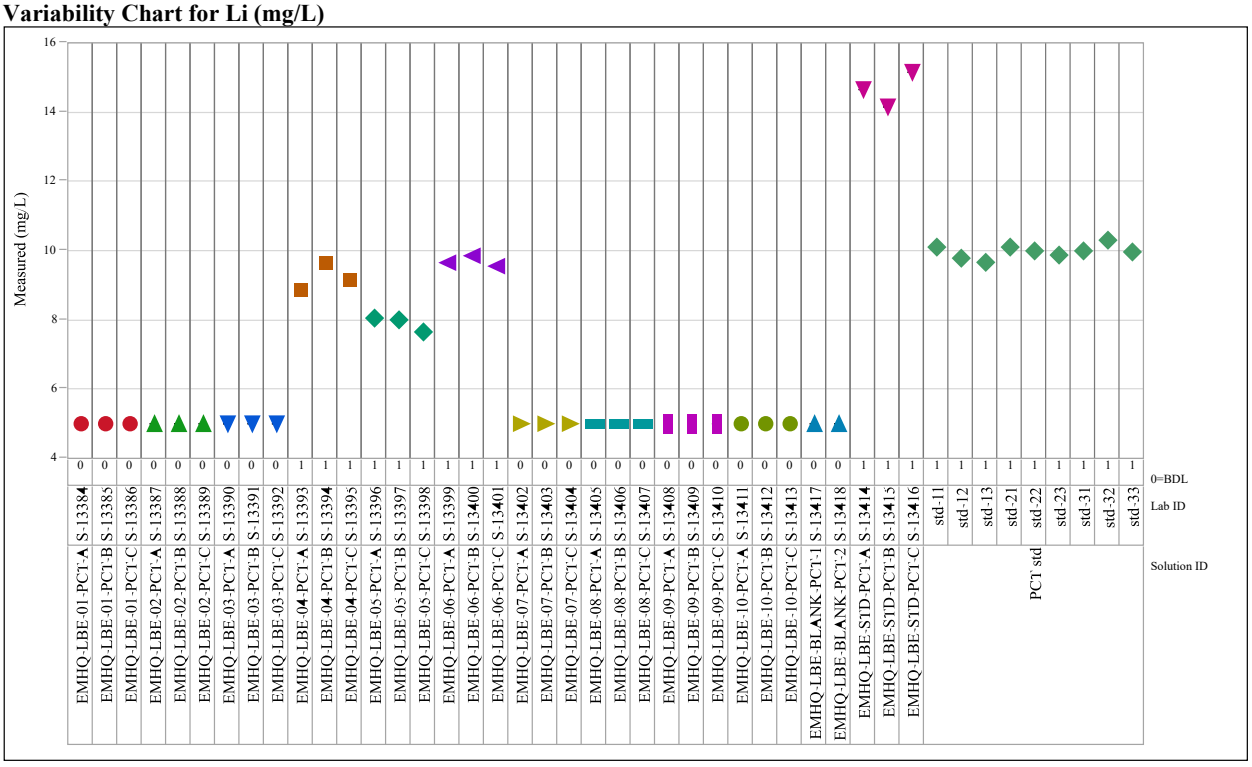
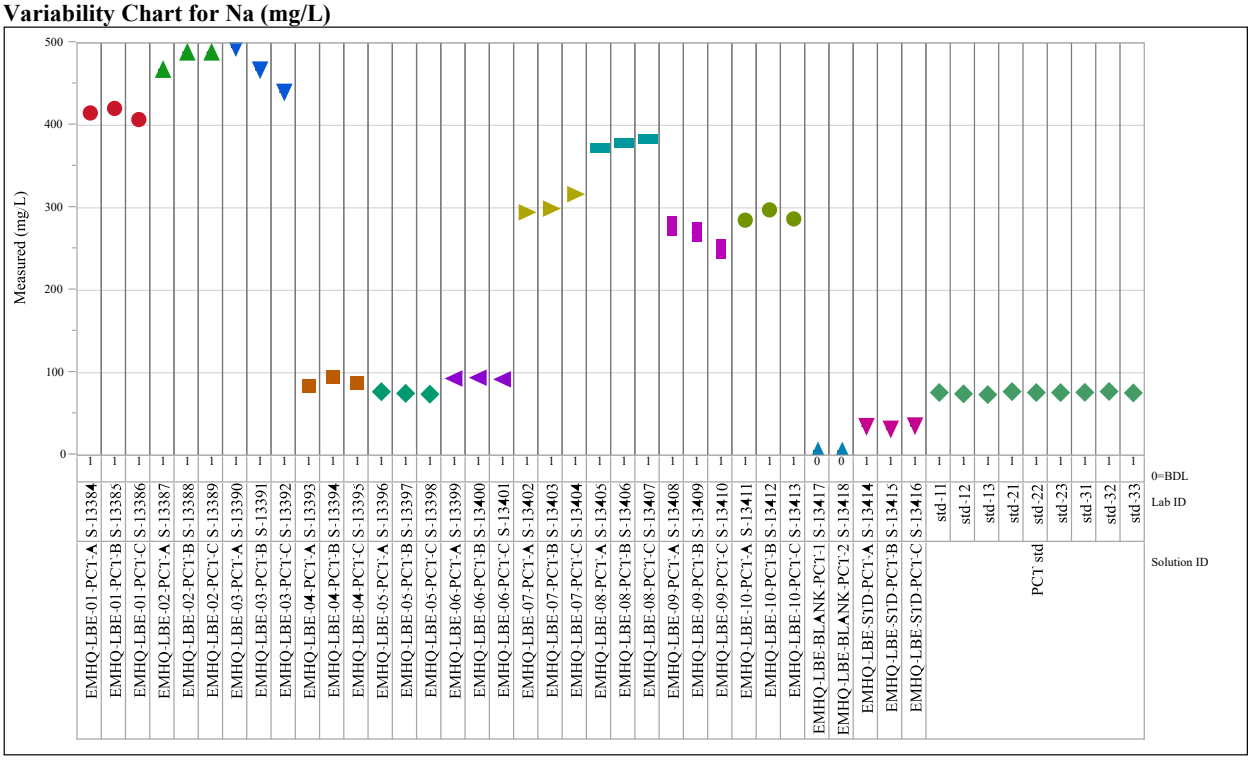


Exhibit A-1. PCT Measurements by Solution ID (continued)

Analyte=Na
Variability Chart for Na (mg/L)



Analyte=S
Variability Chart for S (mg/L)

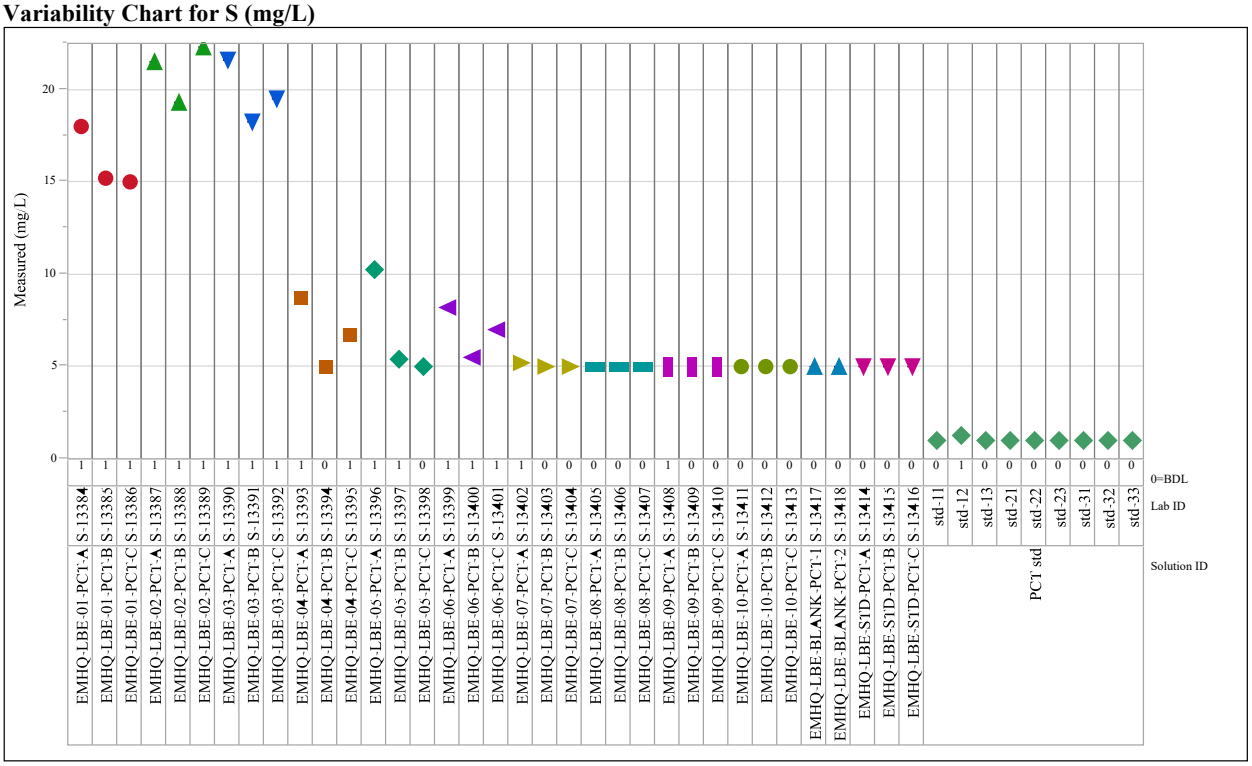
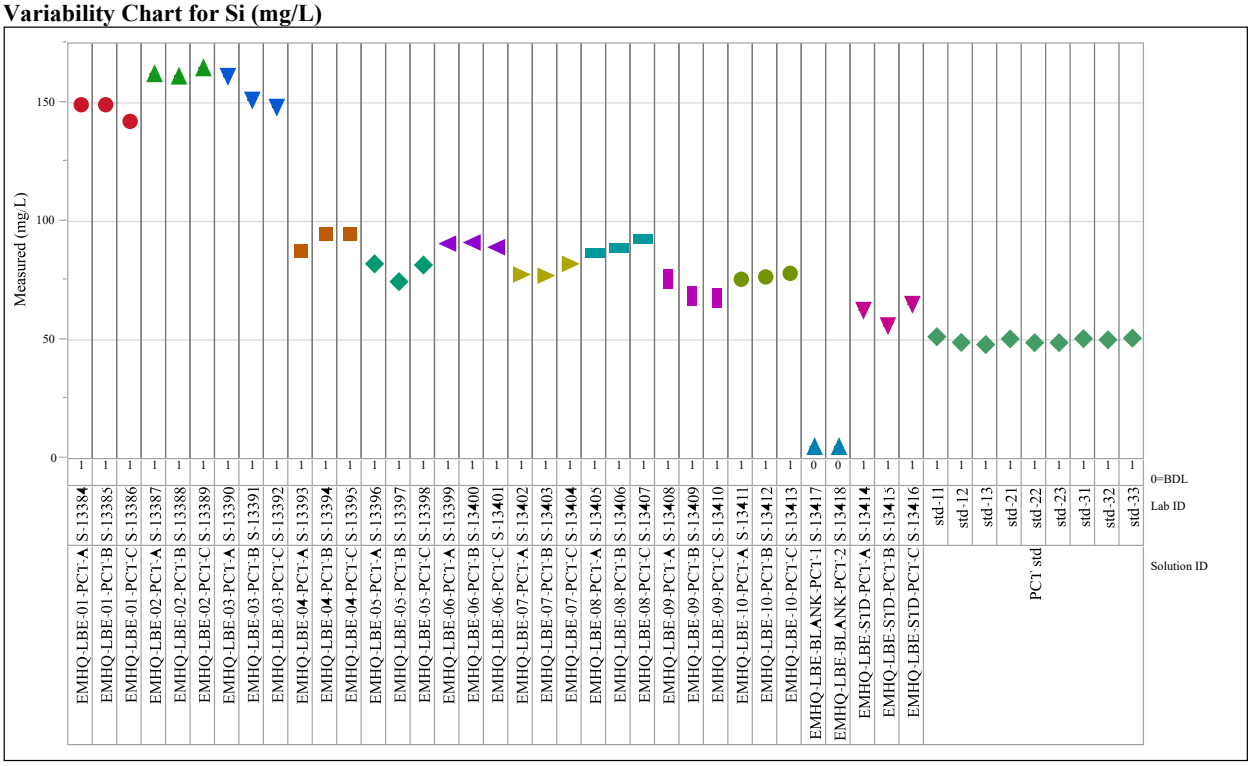
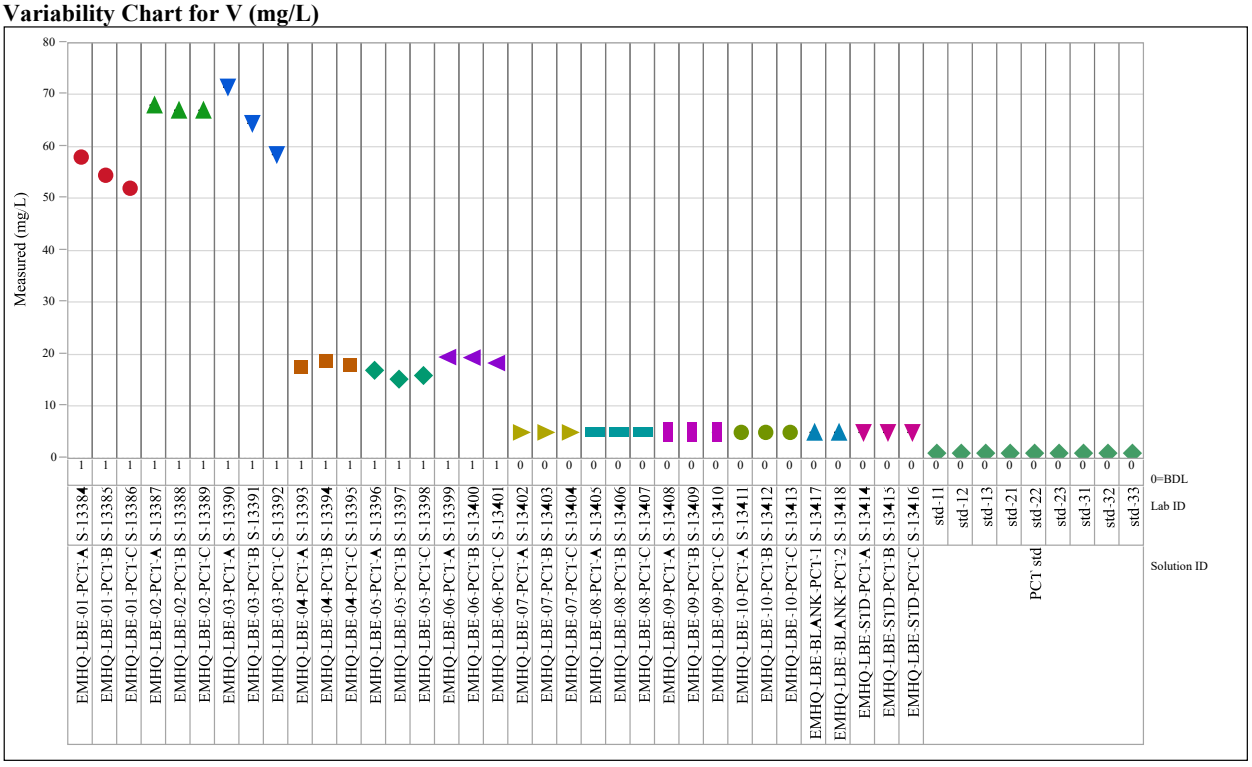


Exhibit A-1. PCT Measurements by Solution ID (continued)

Analyte=Si
Variability Chart for Si (mg/L)



Analyte=V
Variability Chart for V (mg/L)



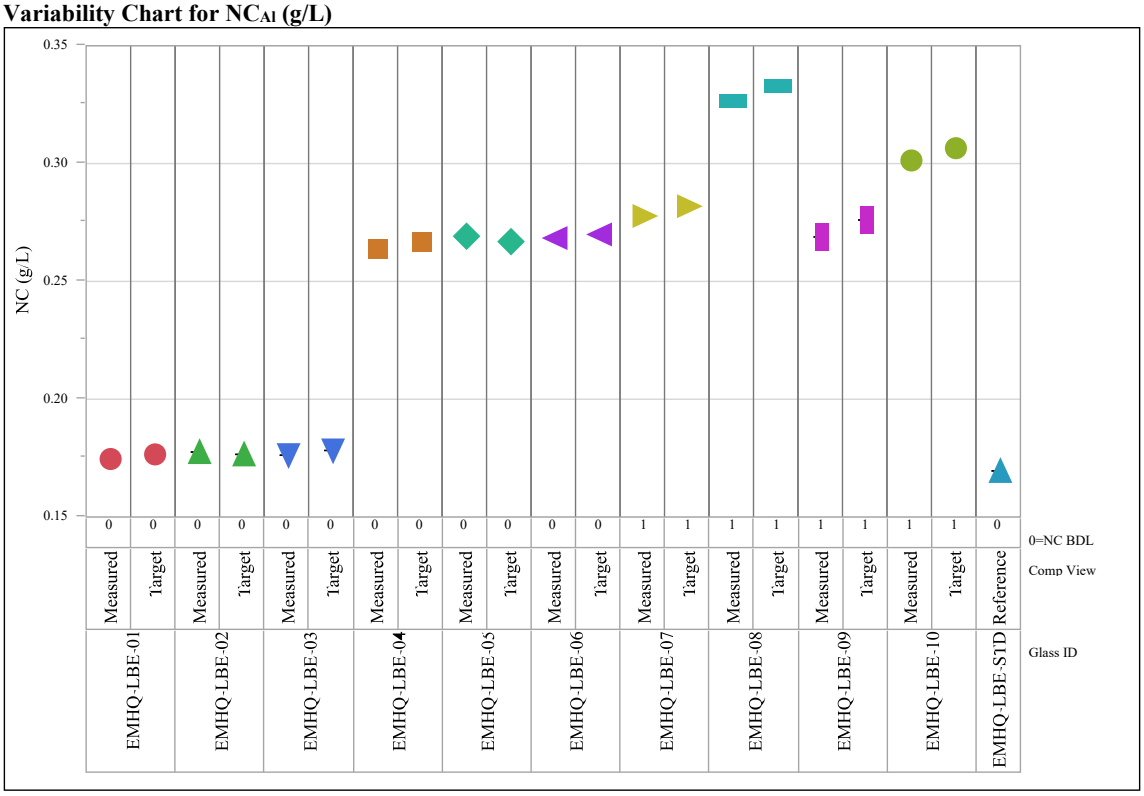
Appendix B. Normalized PCT Results

Table B-1. Normalized PCT Results for Selected Elements

Glass ID	Comp. View	NC_{Al} (g/L)	NC_{B} (g/L)	NC_{Li} (g/L)	NC_{Na} (g/L)	NC_{Si} (g/L)
EMHQ-LBE-01	Target	<0.177	2.46	NA	2.88	0.759
EMHQ-LBE-01	Measured	<0.175	2.69	<5.01	2.72	0.782
EMHQ-LBE-02	Target	<0.177	3.00	NA	3.34	0.842
EMHQ-LBE-02	Measured	<0.178	3.28	<5.01	3.23	0.873
EMHQ-LBE-03	Target	<0.178	2.90	NA	3.28	0.801
EMHQ-LBE-03	Measured	<0.176	3.15	<5.01	3.12	0.826
EMHQ-LBE-04	Target	<0.267	0.856	1.19	1.22	0.397
EMHQ-LBE-04	Measured	<0.264	0.932	1.07	1.04	0.412
EMHQ-LBE-05	Target	<0.267	0.737	1.02	1.04	0.342
EMHQ-LBE-05	Measured	<0.269	0.816	0.939	0.883	0.358
EMHQ-LBE-06	Target	<0.270	0.906	1.27	1.29	0.393
EMHQ-LBE-06	Measured	<0.268	0.988	1.15	1.11	0.405
EMHQ-LBE-07	Target	0.282	1.25	NA	1.76	0.428
EMHQ-LBE-07	Measured	0.278	1.34	<5.01	1.78	0.437
EMHQ-LBE-08	Target	0.333	1.42	NA	2.20	0.484
EMHQ-LBE-08	Measured	0.327	1.53	<5.01	2.24	0.490
EMHQ-LBE-09	Target	0.276	1.06	NA	1.56	0.386
EMHQ-LBE-09	Measured	0.269	1.14	<5.01	1.59	0.390
EMHQ-LBE-10	Target	0.307	1.09	NA	1.68	0.416
EMHQ-LBE-10	Measured	0.301	1.19	<5.01	1.70	0.425
EMHQ-LBE-STD	Reference	<0.170	0.469	0.621	0.478	0.281

Exhibit B-1. Normalized PCT Results by Glass ID by Compositional View for Each Glass

Variability Chart for NC_{Al} (g/L)



Variability Chart for NC_{B} (g/L)

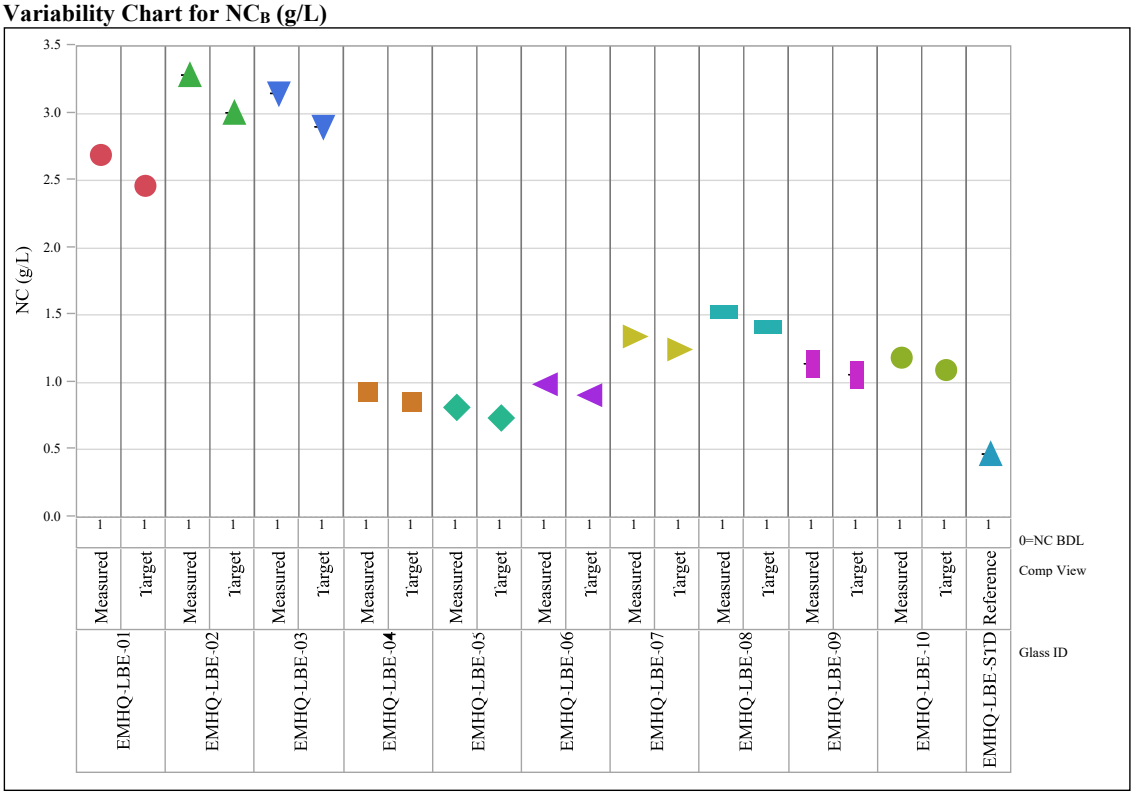
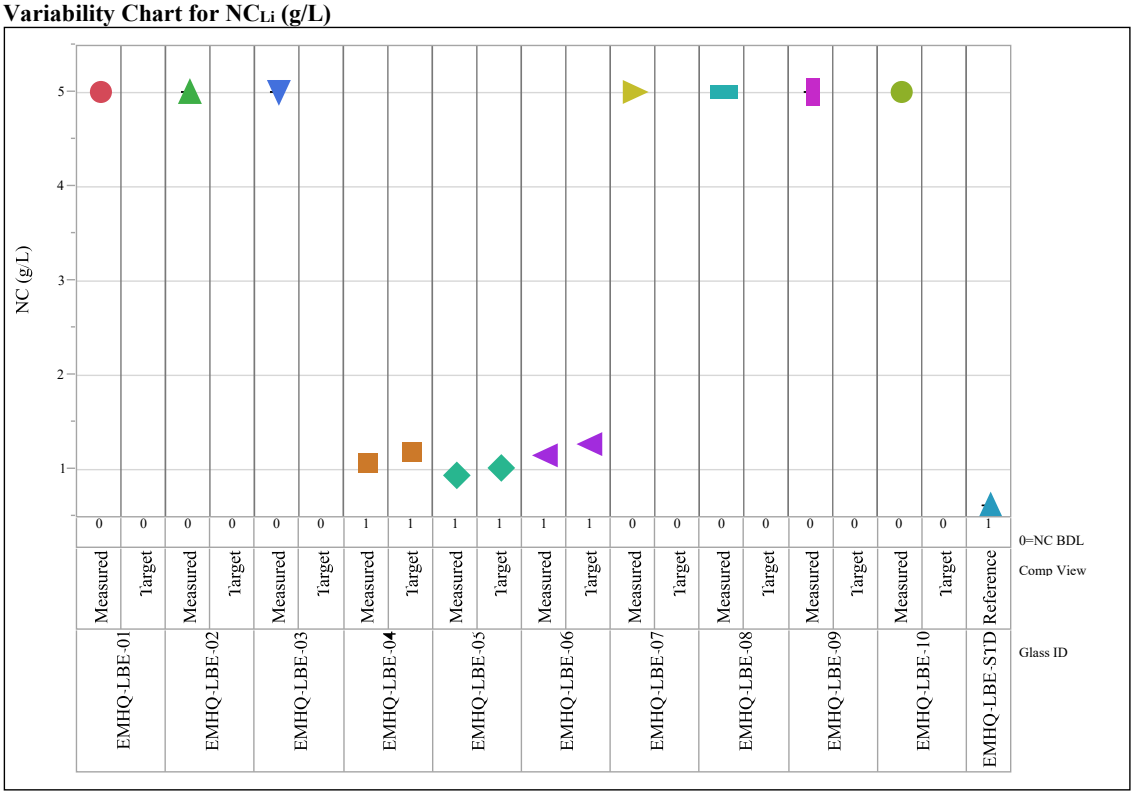


Exhibit B-1. Normalized PCT Results by Glass ID by Compositional View for Each Glass (continued)

Variability Chart for NC_{Li} (g/L)



Variability Chart for NC_{Na} (g/L)

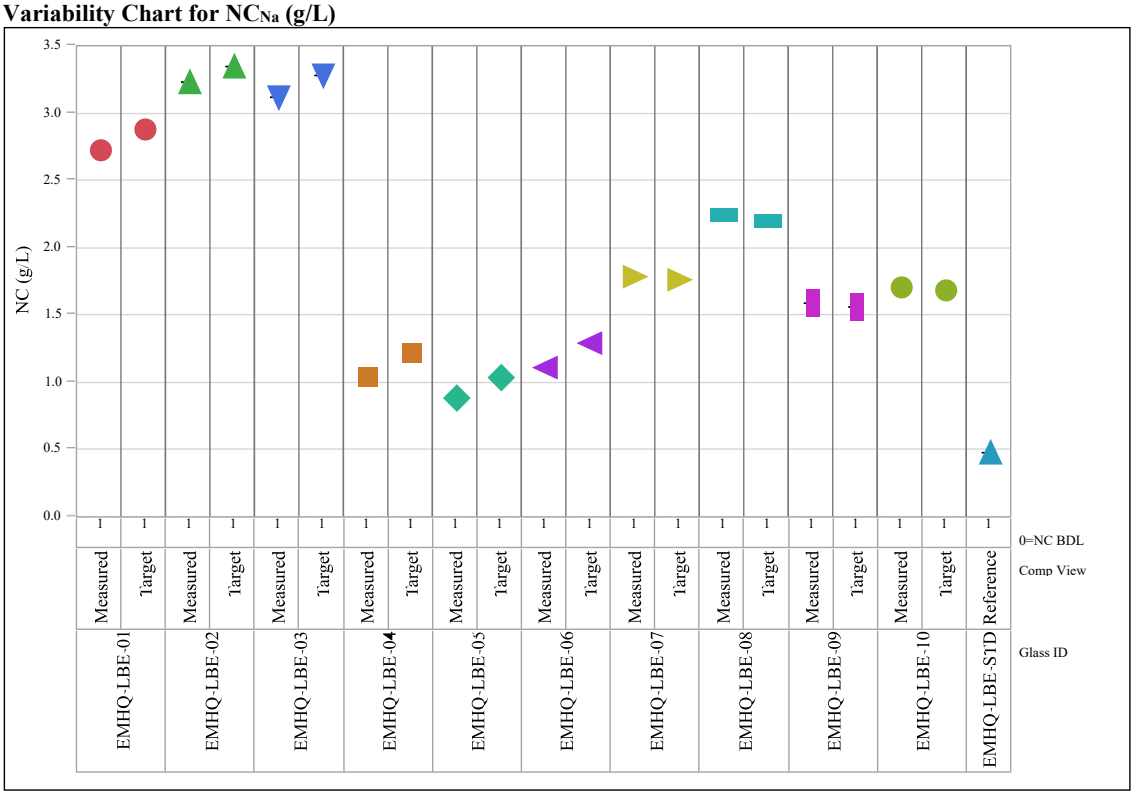
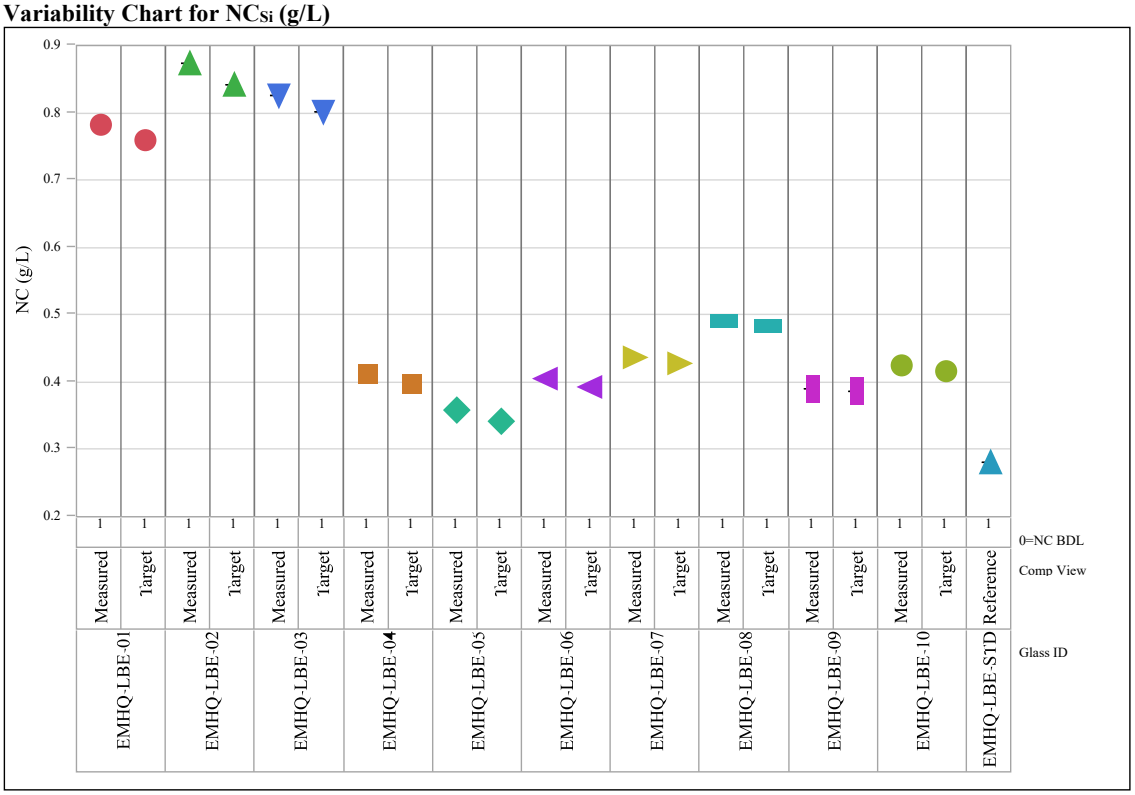


Exhibit B-1. Normalized PCT Results by Glass ID by Compositional View for Each Glass (continued)

Variability Chart for NC_{Si} (g/L)



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