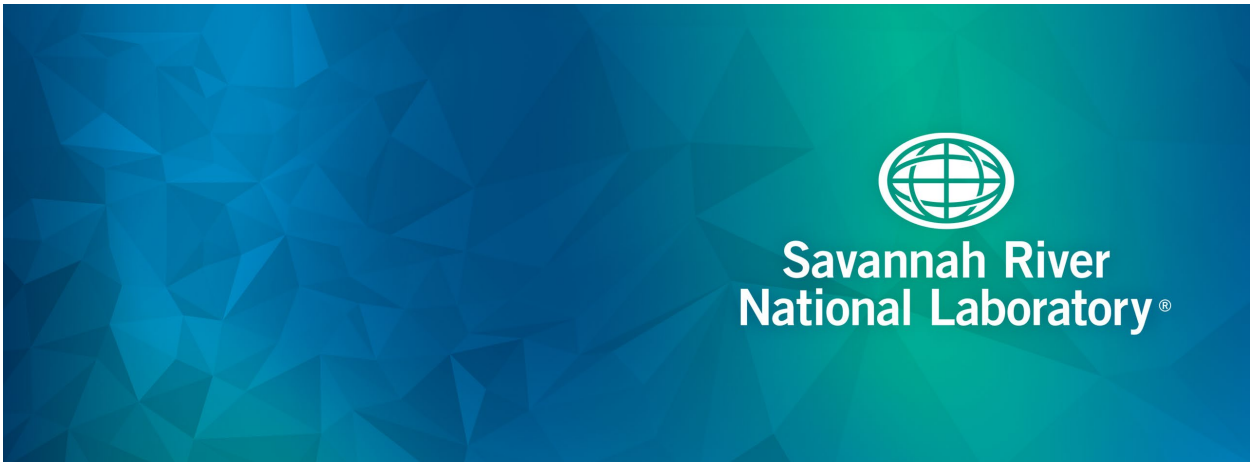
Contract No:

This document was prepared in conjunction with work accomplished under Contract No. 89303321CEM000080 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

Disclaimer:



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

Product Consistency Test Results for the LAW ML1 Glasses

M. C. Hsieh

July 2023

SRNL-STI-2023-00281, Revision 0

DISCLAIMER

Printed in the United States of America

Prepared for
U.S. Department of Energy

SRNL-STI-2023-00281
Revision 0

Keywords: *Hanford, WTP, low-activity waste, durability*

Retention: *Lifetime*

Product Consistency Test Results for the LAW ML1 Glasses

M. C. Hsieh

July 2023

Savannah River National Laboratory is operated by Battelle Savannah River Alliance for the U.S. Department of Energy under Contract No. 89303321CEM000080.

REVIEWS AND APPROVALS

AUTHORS:

_____

M. C. Hsieh, Applied Materials Research Date

TECHNICAL REVIEW:

_____

A. N. Stanfield, Applied Materials Research, Reviewed per E7 2.60 Date

APPROVAL:

_____

J. Manna, Division Director, Environmental and Legacy Management Date

ACKNOWLEDGEMENTS

The author would like to thank Matthew Alexander, Daniel Jones, Josh Kitchings, and Whitney Riley at the Savannah River National Laboratory for their skilled assistance with the sample analysis described in this report. The author also thanks Viviana Gervasio at the Pacific Northwest National Laboratory for helpful discussions and review of these data and the report. Funding from the U. S. Department of Energy Contract Work Authorization HAN-M0SRV00101 as managed by Albert A. Kruger is gratefully acknowledged.

EXECUTIVE SUMMARY

This report summarizes the chemical analysis of Product Consistency Test (PCT) leachates received from Pacific Northwest National Laboratory (PNNL). The leachates are from a series of quenched simulated nuclear waste glasses designated Low-Activity Waste Machine Learning (LAW ML1) glasses that were designed and fabricated at PNNL. The reported data will be used in the development, validation, and implementation of enhanced property/composition models for waste glass vitrification at Hanford.

The elemental release for the study glasses is reported as normalized concentration *NCi*. *NCi* of several elements was computed for both the target and measured glass compositions, which were similar, resulting in no significant differences. Several of the glasses exhibited NC_B, NC_{Na}, and/or NC_{Si} values that were greater than the Waste Treatment Plant (WTP) low-activity waste constraint of 4 g/L. All reference glasses included with the study glasses had measurements that fell within the expected ranges.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BDL	below detection limit
CCC	canister centerline cooled
DF	dilution factor
DOE	Department of Energy
ICP-OES	inductively coupled plasma – optical emission spectroscopy
ID	identifier
LAW	low-activity waste
LRM	low-activity reference material
ML1	Machine Learning
NCi	normalized concentration of element "i"
ORP	Office of River Protection
PCT	Product Consistency Test
PNNL	Pacific Northwest National Laboratory
Q	quenched
%RSD	percent relative standard deviation
seq.	sequence
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
std	High Purity Standards ICP multi-element custom solution SM-744-013
TTQAP	Task Technical and Quality Assurance Plan
wt.%	weight percent
WTP	Waste Treatment and Immobilization Plant

1.0 Introduction

The U.S. Department of Energy (DOE) is responsible for building the Waste Treatment and Immobilization Plant (WTP) at the Hanford site in Washington state to remediate 56 million gallons of radioactive waste historically 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 chemical analysis of the Product Consistency Test (PCT) leachates from the Low-Activity Waste Machine Learning (LAW ML1) glasses, a series of simulated nuclear waste glasses designed and fabricated at the Pacific Northwest National Laboratory (PNNL). The PCT leachates were from both quenched (Q) and canister centerline cooled (CCC)[b] glasses. The glasses were part of a broader study to evaluate 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 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 Savannah River Site (SRS) 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, Rev. 2.[5] Laboratory data for this study were recorded in the SRNL Electronic Laboratory Notebook system, experiment L6390-00441-07. The leachates were provided by PNNL following a Task Plan.[1]

2.2 Glasses Selected for Study

The glass compositions referred to in this study were selected and fabricated by PNNL. PNNL subsequently performed the ASTM C1285 PCT Method A[6] on Q and CCC versions of each of the study glasses. The low-activity reference material (LRM) glasses were included in the PCT. The resulting PCT leachates were analyzed at 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).
[b] Memorandum, Canister Centerline Cooling Data, Revision 1, CCN: 074851, RPP-WTP, October 29, 2003.

Table 2-1. Identifiers for the PCT Leachates

PNNL Solution ID	Lab ID	PNNL Solution ID	Lab ID
LAWML1-05-Q-PCT-A	S-15037	LAWML1-05-CCC-PCT-A	S-15063
LAWML1-05-Q-PCT-B	S-15038	LAWML1-05-CCC-PCT-B	S-15064
LAWML1-05-Q-PCT-C	S-15039	LAWML1-05-CCC-PCT-C	S-15065
LAWML1-09-Q-PCT-A	S-15040	LAWML1-09-CCC-PCT-A	S-15066
LAWML1-09-Q-PCT-B	S-15041	LAWML1-09-CCC-PCT-B	S-15067
LAWML1-09-Q-PCT-C	S-15042	LAWML1-09-CCC-PCT-C	S-15068
LAWML1-10-Q-PCT-A	S-15043	LAWML1-10-CCC-PCT-A	S-15069
LAWML1-10-Q-PCT-B	S-15044	LAWML1-10-CCC-PCT-B	S-15070
LAWML1-10-Q-PCT-C	S-15045	LAWML1-10-CCC-PCT-C	S-15071
LAWML1-11-Q-PCT-A	S-15046	LAWML1-11-CCC-PCT-A	S-15072
LAWML1-11-Q-PCT-B	S-15047	LAWML1-11-CCC-PCT-B	S-15073
LAWML1-11-Q-PCT-C	S-15048	LAWML1-11-CCC-PCT-C	S-15074
LAWML1-12-Q-PCT-A	S-15049	LAWML1-12-CCC-PCT-A	S-15075
LAWML1-12-Q-PCT-B	S-15050	LAWML1-12-CCC-PCT-B	S-15076
LAWML1-12-Q-PCT-C	S-15051	LAWML1-12-CCC-PCT-C	S-15077
LAWML1-13-Q-PCT-A	S-15052	LAWML1-13-CCC-PCT-A	S-15078
LAWML1-13-Q-PCT-B	S-15053	LAWML1-13-CCC-PCT-B	S-15079
LAWML1-13-Q-PCT-C	S-15054	LAWML1-13-CCC-PCT-C	S-15080
LAWML1-17-Q-PCT-A	S-15055	LAWML1-17-CCC-PCT-A	S-15081
LAWML1-17-Q-PCT-B	S-15056	LAWML1-17-CCC-PCT-B	S-15082
LAWML1-17-Q-PCT-C	S-15057	LAWML1-17-CCC-PCT-C	S-15083
LRM-STD-PCT-A	S-15058	LRM STD-1-PCT-A	S-15084
LRM-STD-PCT-B	S-15059	LRM STD-1-PCT-B	S-15085
LRM-STD-PCT-C	S-15060	LRM STD-1-PCT-C	S-15086
MQ WATER BLANK-A	S-15061	MQ WATER BLANK-A	S-15087
MQ WATER BLANK-B	S-15062	MQ WATER BLANK-B	S-15088

2.3 PCT Leachate Analysis

The PCT leachate samples were analyzed by inductively coupled plasma – optical emission spectroscopy (ICP-OES)[7] according to the analytical study plan designed to statistically randomize the measurements.[8] High purity multi-element custom ICP solution standards[c] (std) were prepared at SRNL and included in the analytical study plan as a check of the accuracy of the instrument used for these measurements. The analytical measurements were adjusted based on the dilution provided by PNNL. Normalized elemental release values were calculated for each glass based on the target and measured[9] glass compositions.

3.0 Results and Discussion

JMP® version 16.0.0 (SAS Institute, Inc.)[10] was used to support these analyses.

3.1 Measured Compositions of the PCT Leachates

Table A-1 in Appendix A lists the elemental concentration, in mg/L, for the LAW ML1 PCT leachates, blanks, LRM glass standards, and multi-element custom standard solutions as measured by ICP-OES in analytical sequence. Table A-1 in Appendix A provides the measurements after dilution correction, using a dilution factor (DF) of 5, provided by PNNL.

[c] ICP-multi-element custom solution, product number SM-744-013, High Purity Standards, North Charleston, SC.

Table A-2 in Appendix A lists the measured elemental concentrations in the leachates from the LRM glass included in the PCT. The measured B, Na, and Si concentrations were all in agreement with published LRM leachate value ranges[11].

Following the guidance in ASTM C1285,[6] the mean, standard deviation, and percent relative standard deviation (%RSD) were determined for six elements (Al, B, K, Li, Na, and Si) measured in the multi-element solution standard for each analytical block. As shown in Table A-3 in Appendix A, the mean measured concentration 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 of the measured elements. The analytical results are acceptable per the criteria in ASTM C1285,[6] which indicates no significant issues with the analytical outcomes from the measurements of the PCT leachates.

Exhibit A-1 in Appendix A provides linear plots of the blanks, standards, and triplicate leachate concentrations by the glass 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

Elemental release as measured by the PCT was computed as normalized concentration NC_i for B, Li, Na, and Si for each of the test 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}.[d] NC_i was computed using both the target and average measured compositions.[9]

NC_i values were calculated using the units of measurement provided with the analytical results for this study. To accommodate the triplicate leachate measurements for each of the study glasses, the common logarithm of the normalized concentration for each element "*i*" (NC_i) for each of the study glasses was determined using the equation:

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

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 target 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[9]). Note that the symbols in this second equation were kept consistent with those used in ASTM C1285,[6] but the units of measurement differ.

Table B-1 in Appendix B provides the normalized PCT responses for the Q and CCC versions for each of the study glasses as well as the responses for the LRM reference glasses. The results are grouped by Glass ID. Note that a less than symbol (<) is provided as part of this table to show results involving below

[d] 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.

detection limit (BDL) values. The plots of Exhibit B-1 in Appendix B provide a graphical comparison between the PCT responses for the target and measured compositions and reference values.

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

- The measured glass compositions for the study glasses[9] above detection limits were close to target values; therefore, little difference (≤4%) was seen when evaluating the normalized release using the target or measured glass compositions.
- In all glasses, heat treated samples had lower NC_i values. Most notably, LAWML1-12 NC_B, NC_{Na}, and NC_{Si} values decreased by an average of 75% based on measured composition values.
- Several of the glasses exceeded the WTP NC_B, NC_{Na}, and/or NC_{Si} 4 g/L constraints.[e]
    - The following glasses exceeded the NC_B constraint:
        - LAWML1-09-CCC and -Q, LAWML1-10-CCC and -Q, LAWML1-11-CCC and -Q, LAWML1-12-Q, LAWML1-17-CCC and -Q.
    - The following glasses exceeded the NC_{Na} constraint:
        - LAWML1-10-CCC and -Q, LAWML1-11-CCC and -Q, LAWML1-12-Q, LAWML1-17-CCC and -Q.
    - The following glasses also exceeded the NC_{Si} constraint:
        - LAWML1-11-Q and LAWML1-17-Q.

4.0 Conclusions

The elemental release for the study glasses is reported as normalized concentration *NCi*. *NCi* of several elements was computed for both the target and measured glass compositions, which were similar, resulting in no significant differences. Several of the glasses exhibited NC_B, NC_{Na}, and/or NC_{Si} values that were greater than the WTP low-activity waste constraint of 4 g/L. All reference glasses included with the study glasses had measurements that fell within the expected ranges.

5.0 References

1. V. Gervasio, "Experimental Verification of the ML Paradigm for LAW Glass Optimization Matrix," Pacific Northwest National Laboratory, Richland, WA, EWG-TP-200, Rev. 0, 2022.

2. J.W. Amoroso, "Task Technical and Quality Assurance Plan for Hanford Waste Glass Development and Characterization," Savannah River National Laboratory, Aiken, SC, SRNL-RP-2013-00692, Revision 2, 2023.

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. 22, 2023.

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.

[e] 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 LAW ML1 Study Glasses," Savannah River National Laboratory, Aiken, SC, SRNL-L3310-2022-00021, 2022.

9. M.C. Hsieh, "Composition Measurements of the LAW ML1 Glasses," Savannah River National Laboratory, Aiken, SC, SRNL-STI-2023-00277, Revision 0, 2023.

10. JMP(R) Version 16.0.0, SAS Institute Inc., Cary, NC, 2021.

11. W.L. Ebert and S.F. Wolf, "Round-Robin Testing of a Reference Glass for Low-Activity Waste Forms," Argonne National Laboratory, Argonne, IL, ANL-99/22, Revision 0, 1999.

Appendix A. Tables and Exhibits Containing the Measurement Data for the LAW ML1 PCT Leachates

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

PNNL ID	Block	Seq.	Lab ID	Al	B	Cr	K	Li	Na	Si	Zr
std	1	1	std-11	4.05	20.3	<1.00	9.95	9.98	81.9	48.6	<1.00
LAWML1-11-Q-PCT-A	1	2	S-15046	<5.00	735	<5.00	240	11.5	3320	1430	<5.00
LAWML1-10-Q-PCT-A	1	3	S-15043	<5.00	257	<5.00	<5.00	<5.00	985	477	<5.00
LAWML1-05-CCC-PCT-B	1	4	S-15064	<5.00	30.3	<5.00	<5.00	17.0	85.5	81.0	<5.00
LRM STD-1-PCT-B	1	5	S-15085	14.9	29.9	<5.00	<5.00	<5.00	166	79.5	<5.00
LAWML1-17-Q-PCT-A	1	6	S-15055	<5.00	605	<5.00	28.5	6.35	2510	1070	<5.00
LAWML1-13-Q-PCT-A	1	7	S-15052	<5.00	31.5	<5.00	<5.00	18.0	167	102	<5.00
std	1	8	std-12	3.92	20.1	<1.00	9.83	9.93	81.5	47.6	<1.00
WATER BLANK-B	1	9	S-15088	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
LAWML1-12-CCC-PCT-B	1	10	S-15076	<5.00	57.5	<5.00	<5.00	<5.00	299	145	<5.00
LAWML1-17-CCC-PCT-B	1	11	S-15082	<5.00	432	<5.00	21.8	<5.00	1810	790	<5.00
LAWML1-11-CCC-PCT-B	1	12	S-15073	<5.00	435	<5.00	145	6.80	1830	875	<5.00
LRM-STD-PCT-A	1	13	S-15058	13.4	30.0	<5.00	<5.00	<5.00	168	79.5	<5.00
LAWML1-09-CCC-PCT-B	1	14	S-15067	<5.00	127	<5.00	<5.00	<5.00	520	159	<5.00
std	1	15	std-13	3.93	20.0	<1.00	9.47	9.59	78.7	47.5	<1.00
LAWML1-12-Q-PCT-A	1	16	S-15049	<5.00	319	<5.00	<5.00	<5.00	1370	422	<5.00
LAWML1-09-Q-PCT-A	1	17	S-15040	<5.00	178	<5.00	<5.00	<5.00	700	194	<5.00
LAWML1-05-Q-PCT-A	1	18	S-15037	<5.00	32.2	<5.00	<5.00	18.6	92.5	83.5	<5.00
LAWML1-10-CCC-PCT-B	1	19	S-15070	<5.00	179	<5.00	<5.00	<5.00	720	365	<5.00
LAWML1-13-CCC-PCT-B	1	20	S-15079	<5.00	24.6	<5.00	<5.00	14.8	136	82.0	<5.00
std	1	21	std-14	3.93	19.8	<1.00	9.72	9.85	80.8	47.7	<1.00
std	2	1	std-21	3.92	19.9	<1.00	9.52	9.84	78.7	48.3	<1.00
LRM-STD-PCT-B	2	2	S-15059	14.0	29.9	<5.00	<5.00	<5.00	168	77.0	<5.00
LAWML1-05-Q-PCT-B	2	3	S-15038	<5.00	34.1	<5.00	<5.00	20.6	96.5	87.5	<5.00
LAWML1-17-Q-PCT-B	2	4	S-15056	<5.00	595	<5.00	27.3	7.00	2450	1060	<5.00
LAWML1-05-CCC-PCT-C	2	5	S-15065	<5.00	30.0	<5.00	<5.00	17.2	81.5	84.5	<5.00
LRM STD-1-PCT-C	2	6	S-15086	14.3	30.6	<5.00	<5.00	<5.00	168	79.0	<5.00
LAWML1-10-CCC-PCT-C	2	7	S-15071	<5.00	180	<5.00	<5.00	<5.00	735	375	<5.00
std	2	8	std-22	3.99	20.1	<1.00	9.77	10.2	81.4	48.8	<1.00
LAWML1-17-CCC-PCT-C	2	9	S-15083	<5.00	430	<5.00	21.6	5.05	1840	815	<5.00
WATER BLANK-B	2	10	S-15062	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
LAWML1-12-Q-PCT-B	2	11	S-15050	<5.00	315	<5.00	<5.00	<5.00	1380	429	<5.00
LAWML1-10-Q-PCT-B	2	12	S-15044	<5.00	256	<5.00	<5.00	<5.00	1030	472	<5.00

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

PNNL ID	Block	Seq.	Lab ID	Al	B	Cr	K	Li	Na	Si	Zr
LAWML1-09-CCC-PCT-C	2	13	S-15068	<5.00	128	<5.00	<5.00	<5.00	530	162	<5.00
LAWML1-12-CCC-PCT-C	2	14	S-15077	<5.00	58.0	<5.00	<5.00	<5.00	294	147	<5.00
std	2	15	std-23	3.85	19.7	<1.00	9.12	9.47	76.5	47.5	<1.00
LAWML1-11-Q-PCT-B	2	16	S-15047	<5.00	710	<5.00	233	11.4	3310	1410	<5.00
LAWML1-11-CCC-PCT-C	2	17	S-15074	<5.00	421	<5.00	150	7.10	1800	870	<5.00
LAWML1-09-Q-PCT-B	2	18	S-15041	<5.00	174	<5.00	<5.00	<5.00	695	198	<5.00
LAWML1-13-CCC-PCT-C	2	19	S-15080	<5.00	28.1	<5.00	<5.00	17.0	144	92.0	<5.00
LAWML1-13-Q-PCT-B	2	20	S-15053	<5.00	32.8	<5.00	<5.00	19.1	171	103	<5.00
std	2	21	std-24	3.95	20.1	<1.00	9.29	9.64	78.0	48.5	<1.00
std	3	1	std-31	3.99	20.4	<1.00	9.76	10.3	82.1	49.7	<1.00
LAWML1-09-Q-PCT-C	3	2	S-15042	<5.00	174	<5.00	<5.00	<5.00	720	198	<5.00
LRM-STD-PCT-C	3	3	S-15060	14.9	29.7	<5.00	<5.00	<5.00	173	81.0	<5.00
LAWML1-10-CCC-PCT-A	3	4	S-15069	<5.00	189	<5.00	<5.00	<5.00	765	392	<5.00
LAWML1-12-CCC-PCT-A	3	5	S-15075	<5.00	59.0	<5.00	<5.00	<5.00	315	153	<5.00
LAWML1-12-Q-PCT-C	3	6	S-15051	<5.00	328	<5.00	<5.00	<5.00	1480	446	<5.00
LAWML1-11-CCC-PCT-A	3	7	S-15072	<5.00	456	<5.00	163	7.65	2010	935	<5.00
std	3	8	std-32	4.06	20.8	<1.00	10.1	10.7	85.2	51.1	<1.00
LRM STD-1-PCT-A	3	9	S-15084	14.5	29.6	<5.00	<5.00	<5.00	172	80.5	<5.00
LAWML1-13-Q-PCT-C	3	10	S-15054	<5.00	37.5	<5.00	<5.00	21.4	193	114	<5.00
WATER BLANK-A	3	11	S-15087	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
LAWML1-17-CCC-PCT-A	3	12	S-15081	<5.00	437	<5.00	21.1	5.25	1910	840	<5.00
LAWML1-05-Q-PCT-C	3	13	S-15039	<5.00	36.0	<5.00	<5.00	21.8	105	94.5	<5.00
LAWML1-09-CCC-PCT-A	3	14	S-15066	<5.00	136	<5.00	<5.00	<5.00	570	172	<5.00
std	3	15	std-33	4.13	20.9	<1.00	10.2	10.7	85.6	51.5	<1.00
LAWML1-05-CCC-PCT-A	3	16	S-15063	<5.00	30.3	<5.00	<5.00	18.6	88.5	83.5	<5.00
LAWML1-17-Q-PCT-C	3	17	S-15057	<5.00	620	<5.00	28.2	6.85	2620	1130	<5.00
LAWML1-11-Q-PCT-C	3	18	S-15048	<5.00	770	<5.00	261	12.4	3350	1550	<5.00
LAWML1-10-Q-PCT-C	3	19	S-15045	<5.00	274	<5.00	74.5	<5.00	1070	515	<5.00
LAWML1-13-CCC-PCT-A	3	20	S-15078	<5.00	30.2	<5.00	<5.00	18.8	165	99.0	<5.00
WATER BLANK-A	3	21	S-15061	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
std	3	22	std-34	4.10	21.3	<1.00	10.5	10.9	87.9	51.8	<1.00

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

PNNL Solution ID	Lab ID	B	Na	Si
LRM STD-1-PCT-A	S-15084	29.6	172	80.5
LRM STD-1-PCT-B	S-15085	29.9	166	79.5
LRM STD-1-PCT-C	S-15086	30.6	168	79.0
LRM-STD-PCT-A	S-15058	30.0	168	79.5
LRM-STD-PCT-B	S-15059	29.9	168	77.0
LRM-STD-PCT-C	S-15060	29.7	173	81.0

Ranges of Expected Test Results for LRM[f]

Boron: 19.5 – 33.9 mg/L (26.7 ± 7.20 mg/L)
Sodium: 147 – 173 mg/L (160 ± 13.0 mg/L)
Silicon: 69.3 – 94.7 mg/L (82.0 ± 12.7 mg/L)
Values that fall outside of the reference ranges are shaded gray.

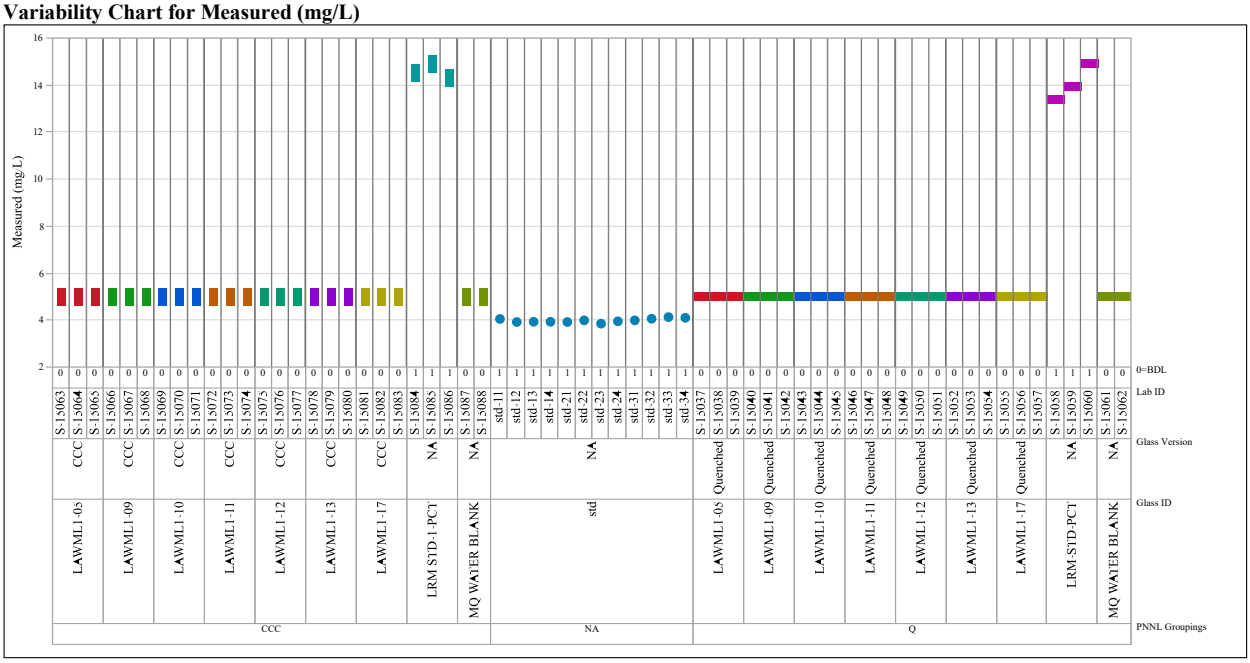
[f] W.L. Ebert and S.F. Wolf, "Round-Robin Testing of a Reference Glass for Low-Activity Waste Forms," Argonne National Laboratory, Argonne, IL, ANL-99/22, Revision 0, 1999

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))	3.96	3.93	4.07	4.00
Mean (B (mg/L))	20.1	20.0	20.9	20.0
Mean (K (mg/L))	9.74	9.43	10.1	10.0
Mean (Li (mg/L))	9.84	9.79	10.7	10.0
Mean (Na (mg/L))	80.7	78.7	85.2	81.0
Mean (Si (mg/L))	47.9	48.3	51.0	50.0
% relative bias, Al	-1.06	-1.81	1.75	<10% per ASTM C1285
% relative bias, B	0.25	-0.25	4.25	
% relative bias, K	-2.58	-5.75	1.40	
% relative bias, Li	-1.62	-2.13	6.50	
% relative bias, Na	-0.34	-2.90	5.19	
% relative bias, Si	-4.30	-3.45	2.05	
Standard Deviation (Al (mg/L))	0.06	0.06	0.06	
Standard Deviation (B (mg/L))	0.21	0.19	0.37	
Standard Deviation (K (mg/L))	0.20	0.28	0.31	
Standard Deviation (Li (mg/L))	0.17	0.31	0.25	
Standard Deviation (Na (mg/L))	1.42	2.05	2.38	
Standard Deviation (Si (mg/L))	0.51	0.56	0.93	
%RSD (Al)	1.56	1.5	1.49	<10% per ASTM C1285
%RSD (B)	1.04	0.96	1.77	
%RSD (K)	2.1	3.0	3.01	
%RSD (Li)	1.76	3.21	2.36	
%RSD (Na)	1.76	2.61	2.8	
%RSD (Si)	1.06	1.15	1.82	

Exhibit A-1. PCT Measurements by Glass ID by PNNL Groupings

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



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

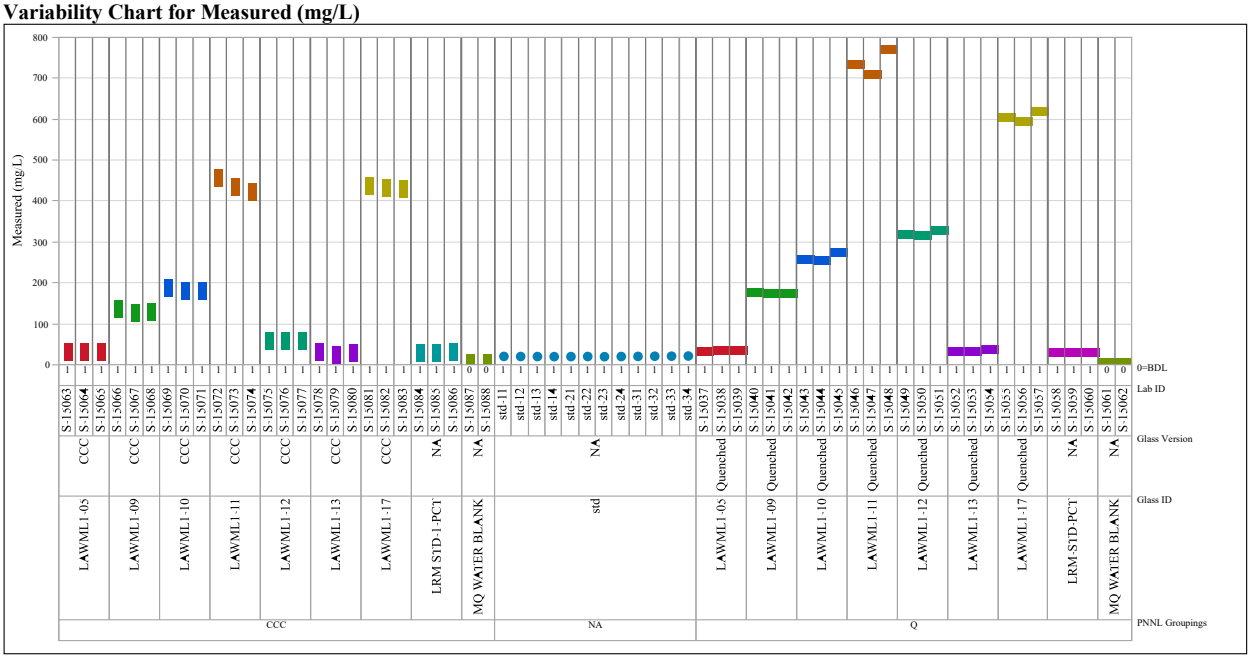
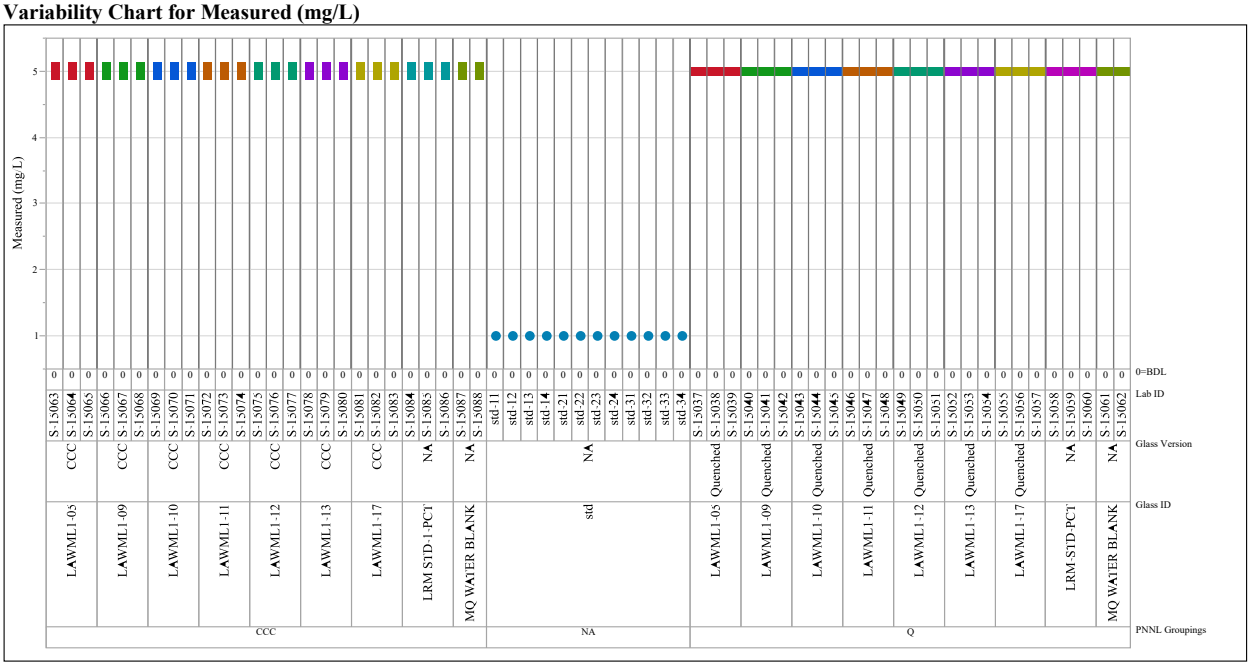


Exhibit A-1. PCT Measurements by Glass ID by PNNL Groupings (continued)

Analyte=Cr
Variability Chart for Measured (mg/L)



Analyte=K
Variability Chart for Measured (mg/L)

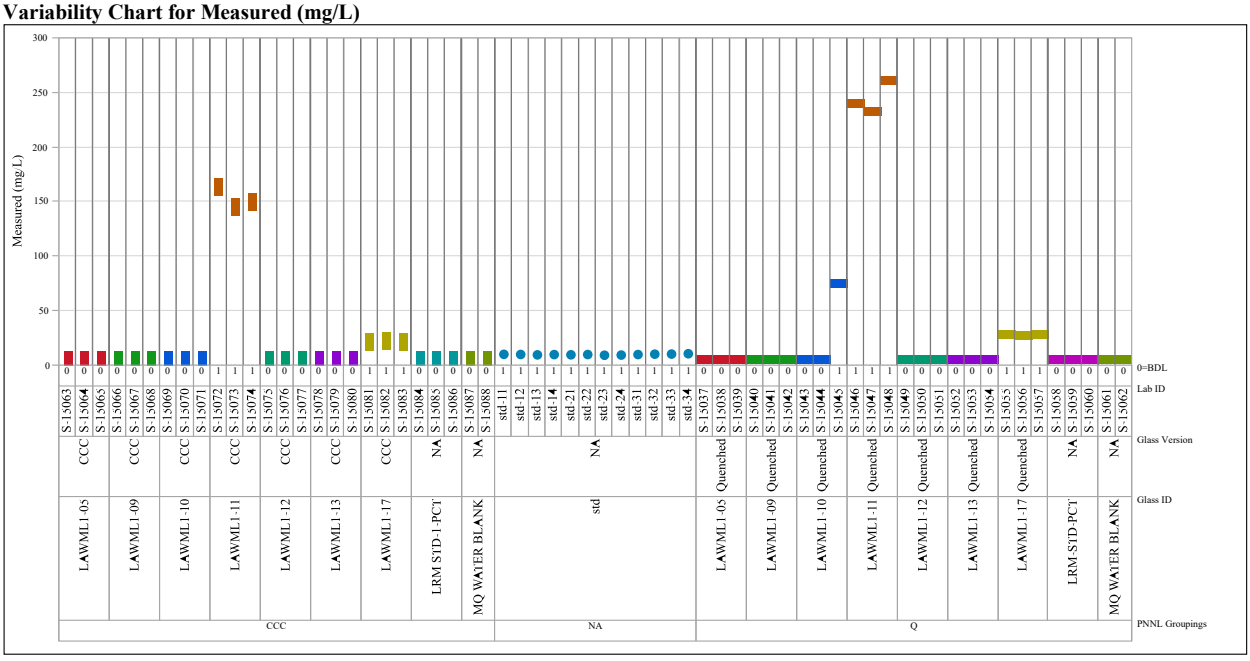
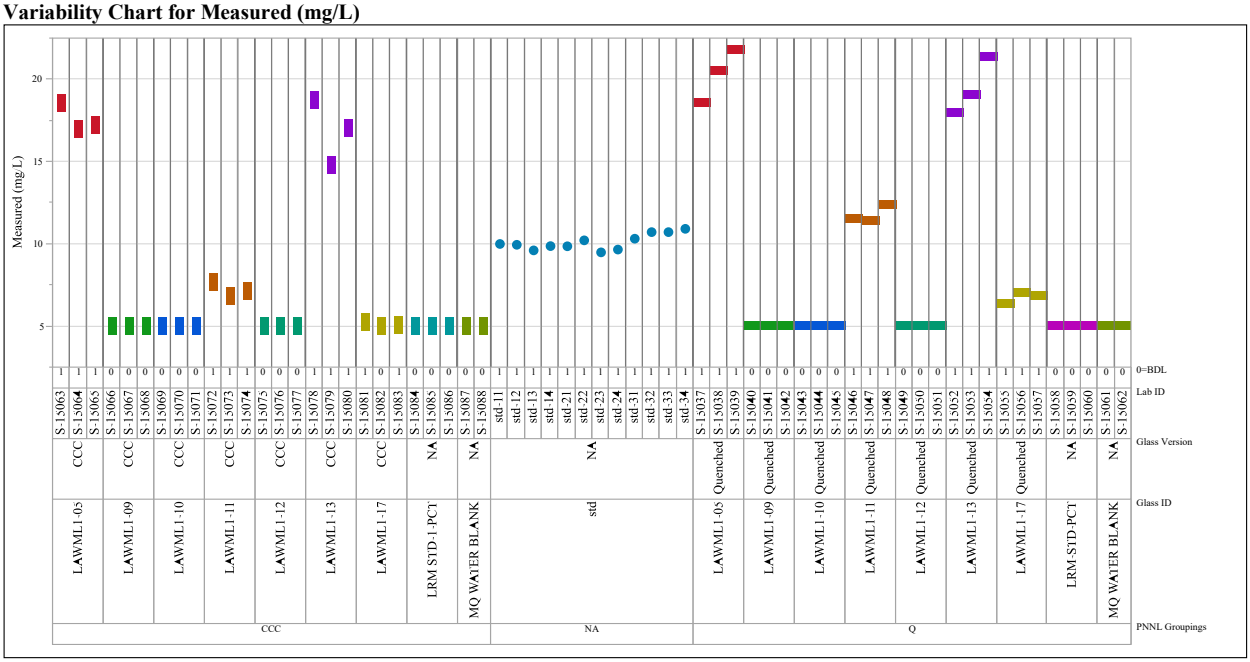


Exhibit A-1. PCT Measurements by Glass ID by PNNL Groupings (continued)

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



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

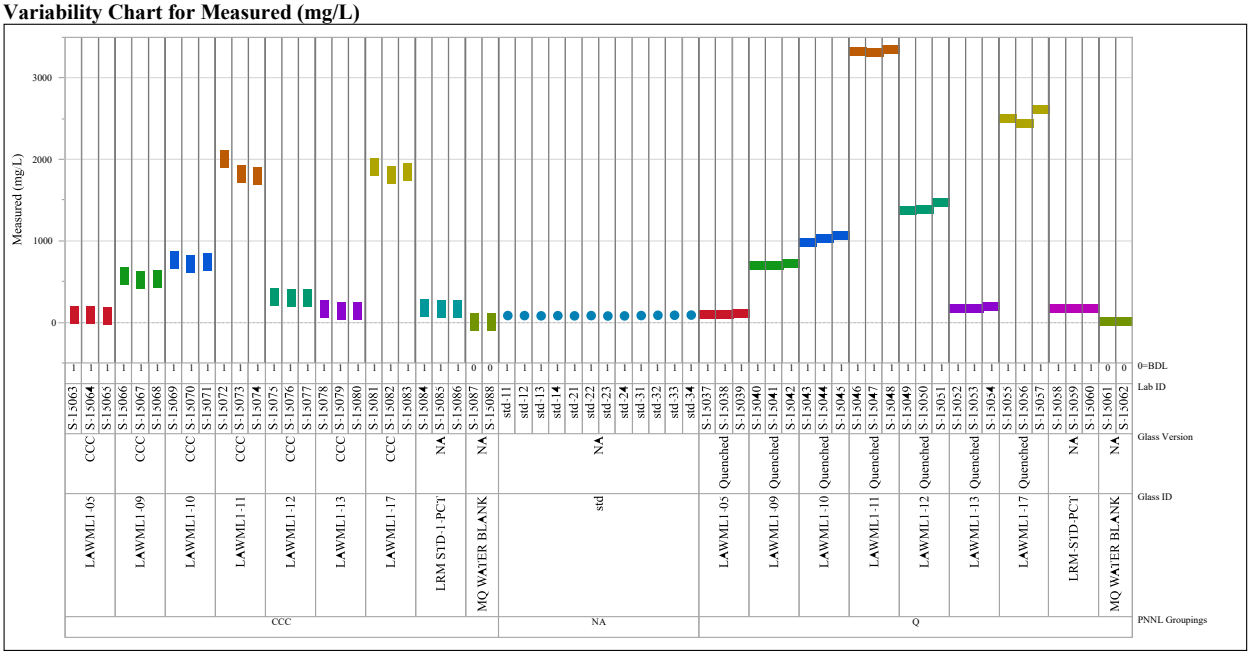
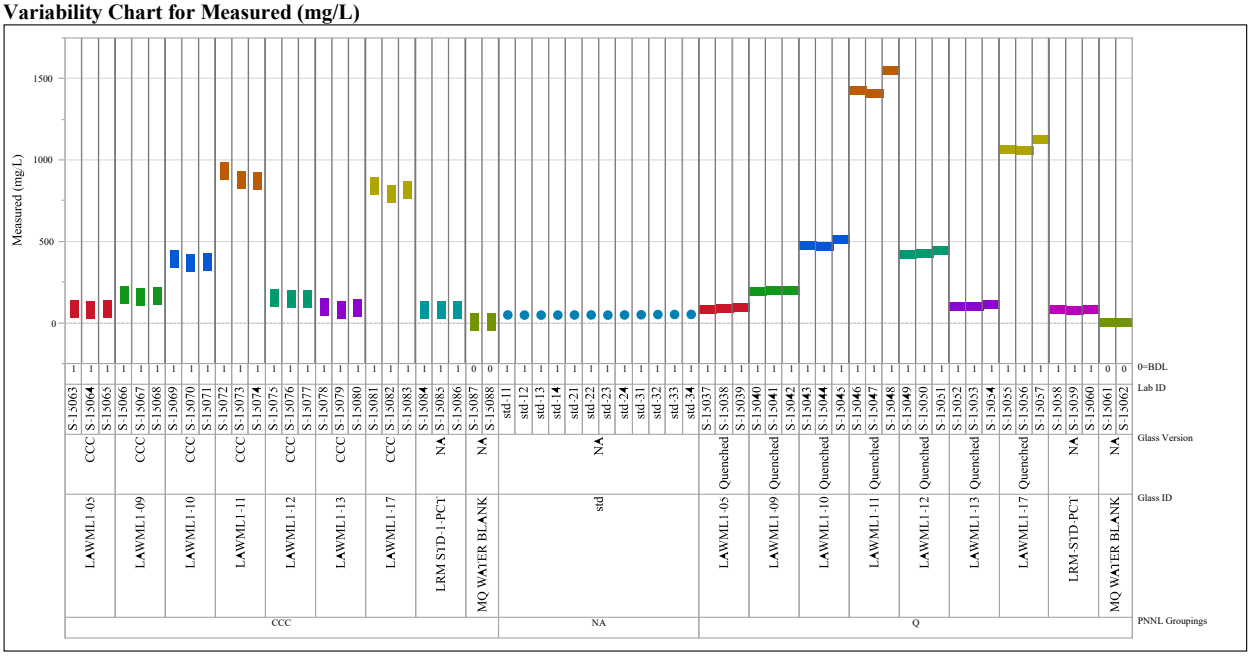
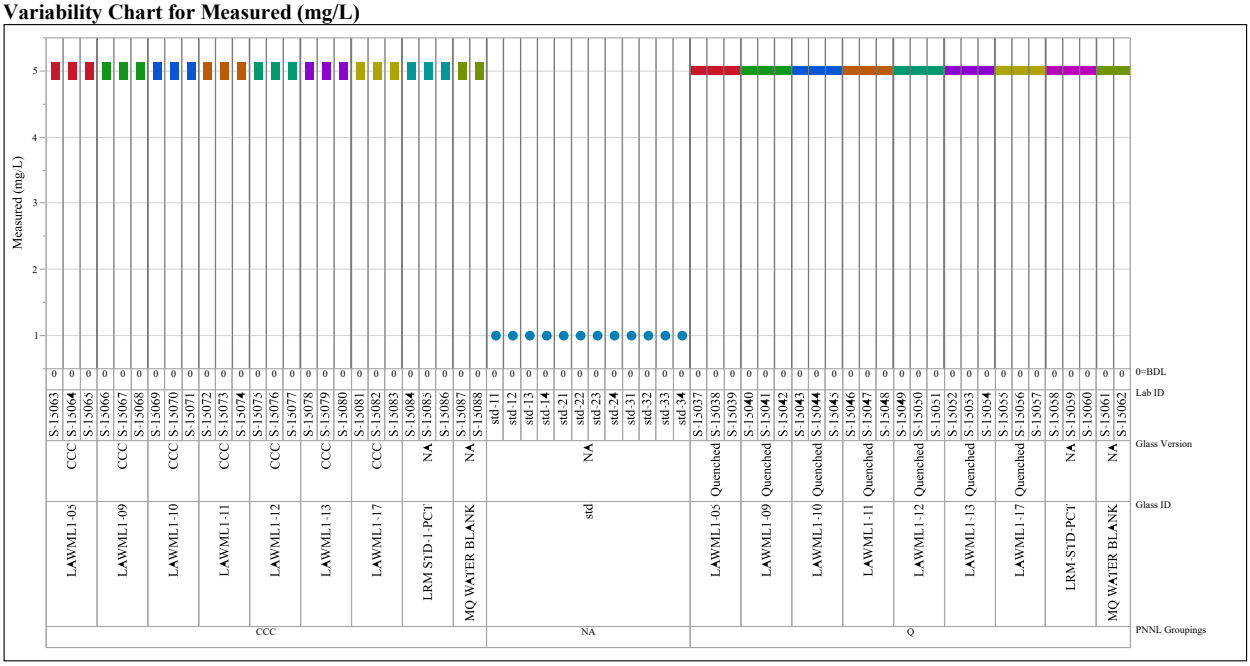


Exhibit A-1. PCT Measurements by Glass ID by PNNL Groupings (continued)

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



Analyte=Zr
Variability Chart for Measured (mg/L)



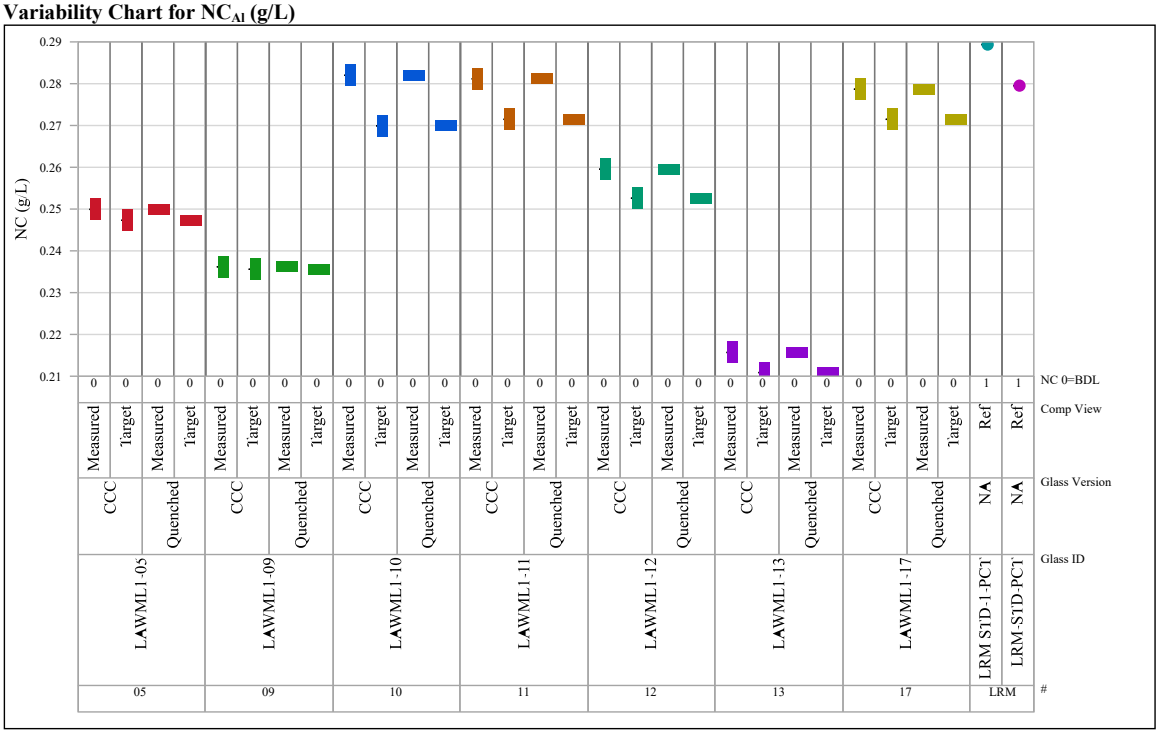
Appendix B. Normalized PCT Results

Table B-1. Normalized PCT Results (g/L) for Selected Elements

Sample ID	Heat Treatment	Comp View	NC B	NC Li	NC Na	NC Si
LAWML1-05-CCC-PCT	CCC	Target	0.943	1.20	1.10	0.374
LAWML1-05-CCC-PCT	CCC	Measured	0.962	1.17	1.05	0.372
LAWML1-05-Q-PCT	Quenched	Target	1.06	1.38	1.27	0.398
LAWML1-05-Q-PCT	Quenched	Measured	1.08	1.35	1.21	0.396
LAWML1-09-CCC-PCT	CCC	Target	4.07	<9.44	2.99	0.820
LAWML1-09-CCC-PCT	CCC	Measured	4.11	<9.20	2.93	0.824
LAWML1-09-Q-PCT	Quenched	Target	5.47	<9.44	3.91	0.981
LAWML1-09-Q-PCT	Quenched	Measured	5.52	<9.20	3.83	0.986
LAWML1-10-CCC-PCT	CCC	Target	5.54	<8.75	4.09	1.62
LAWML1-10-CCC-PCT	CCC	Measured	5.7	<8.22	4.05	1.65
LAWML1-10-Q-PCT	Quenched	Target	7.95	<8.75	5.66	2.09
LAWML1-10-Q-PCT	Quenched	Measured	8.19	<8.22	5.61	2.13
LAWML1-11-CCC-PCT	CCC	Target	15.1	11.7	10.9	3.93
LAWML1-11-CCC-PCT	CCC	Measured	15.6	12.2	10.9	4.00
LAWML1-11-Q-PCT	Quenched	Target	25.5	19.2	19.3	6.43
LAWML1-11-Q-PCT	Quenched	Measured	26.4	19.9	19.2	6.54
LAWML1-12-CCC-PCT	CCC	Target	1.93	<59.5	2.07	0.747
LAWML1-12-CCC-PCT	CCC	Measured	1.98	<9.97	2.02	0.758
LAWML1-12-Q-PCT	Quenched	Target	10.7	<59.5	9.63	2.18
LAWML1-12-Q-PCT	Quenched	Measured	10.9	<9.97	9.39	2.21
LAWML1-13-CCC-PCT	CCC	Target	1.01	1.32	1.34	0.432
LAWML1-13-CCC-PCT	CCC	Measured	1.03	1.29	1.37	0.437
LAWML1-13-Q-PCT	Quenched	Target	1.24	1.53	1.61	0.505
LAWML1-13-Q-PCT	Quenched	Measured	1.27	1.50	1.64	0.511
LAWML1-17-CCC-PCT	CCC	Target	13.4	<10.1	10.4	3.62
LAWML1-17-CCC-PCT	CCC	Measured	13.7	<10.1	10.3	3.67
LAWML1-17-Q-PCT	Quenched	Target	18.8	13.3	14.2	4.82
LAWML1-17-Q-PCT	Quenched	Measured	19.1	<13.3	14.0	4.88
LRM STD-1-PCT	NA	Ref	1.23	<9.79	1.13	0.314
LRM-STD-PCT	NA	Ref	1.22	<9.79	1.14	0.312

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

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



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

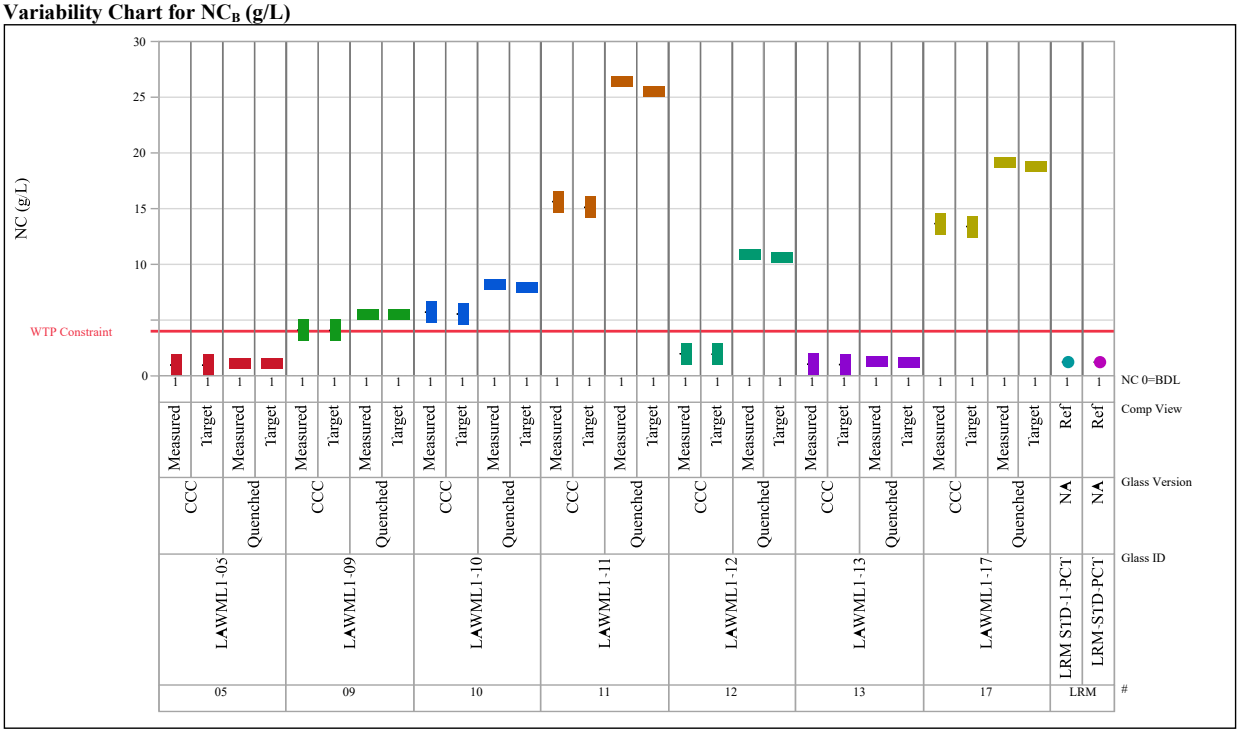
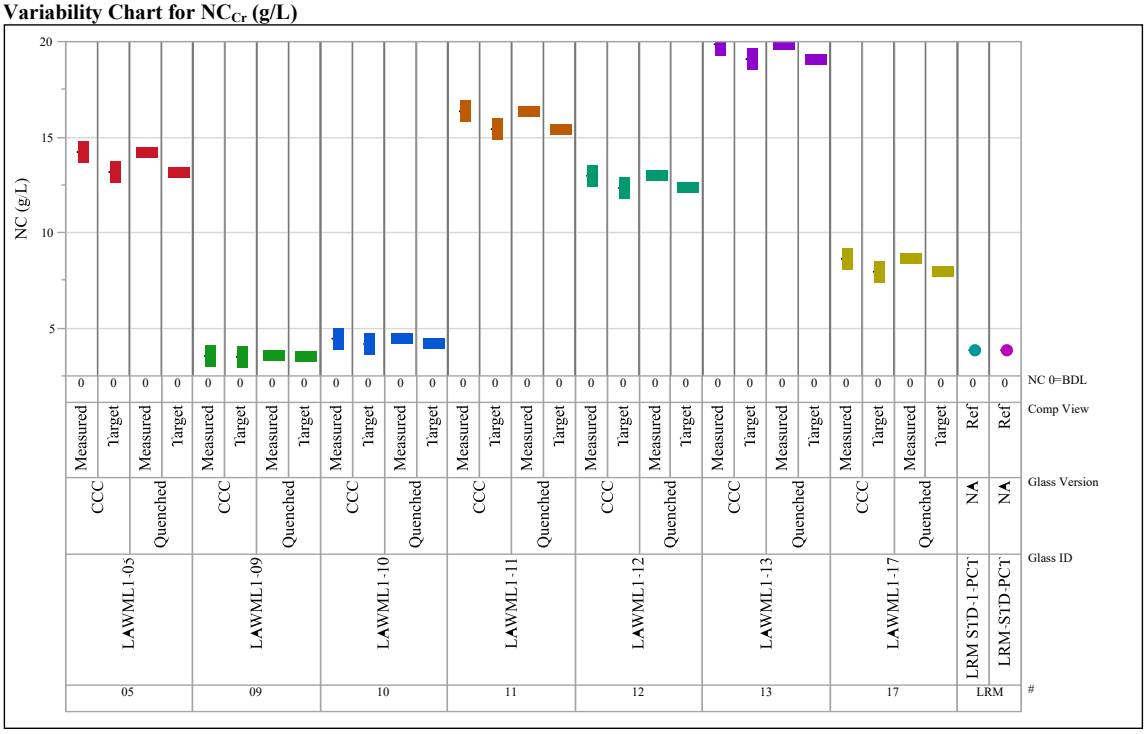


Exhibit B-1. Normalized PCT Results by Glass Version by Compositional View for Each Glass (continued)

Analyte=Cr
Variability Chart for NC_{Cr} (g/L)



Analyte=K
Variability Chart for NC_{K} (g/L)

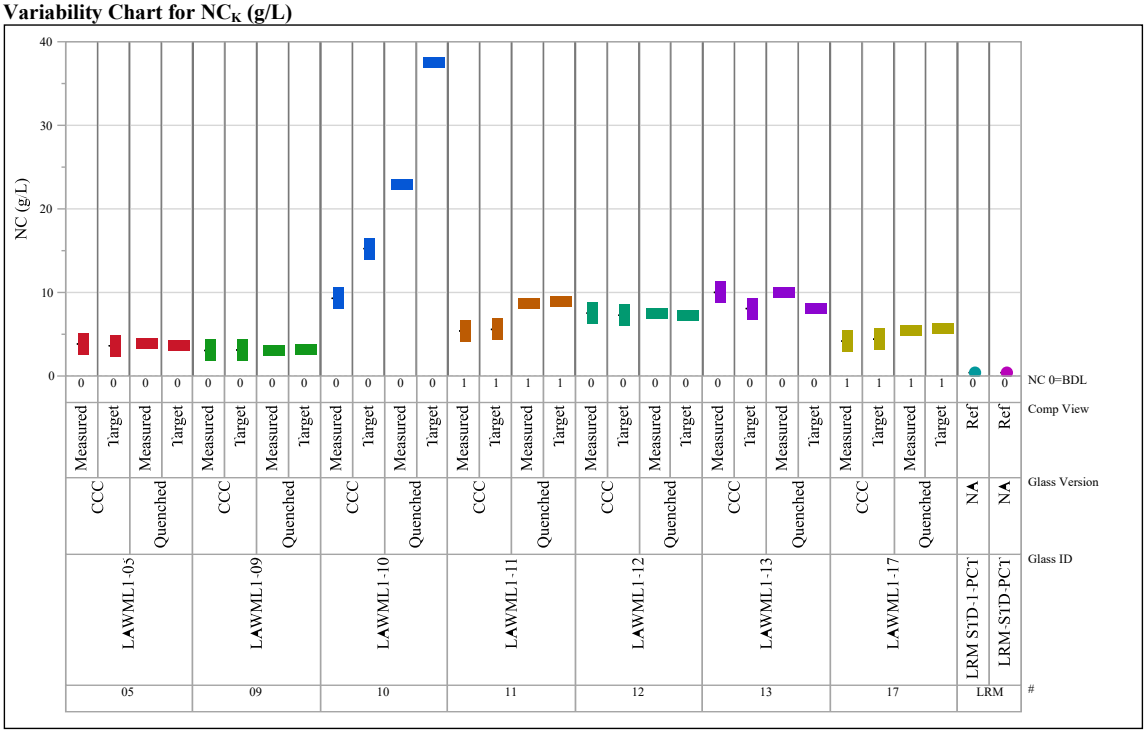
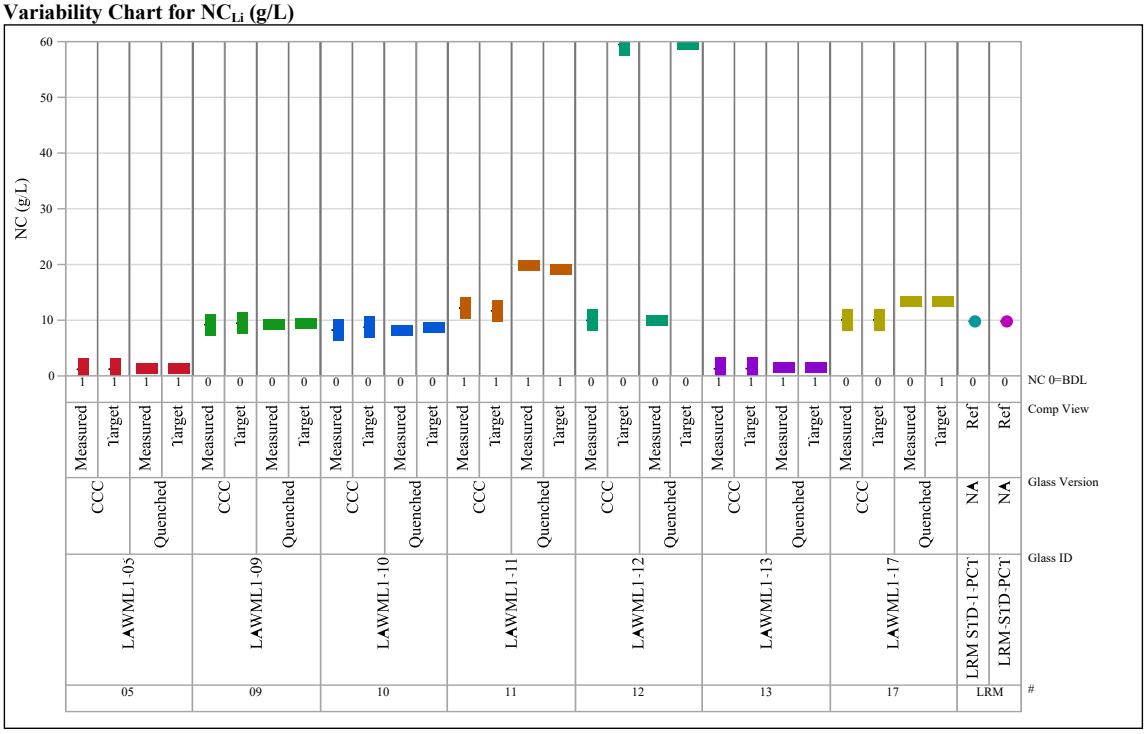


Exhibit B-1. Normalized PCT Results by Glass Version by Compositional View for Each Glass (continued)

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



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

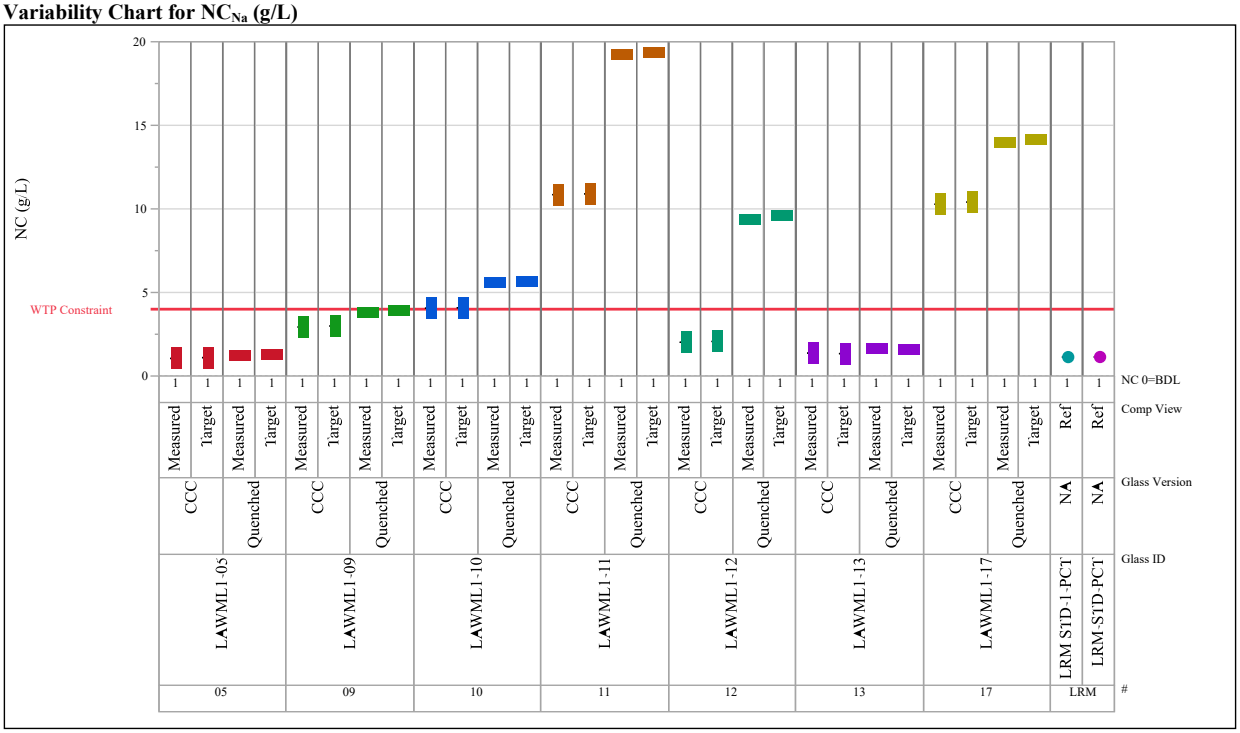
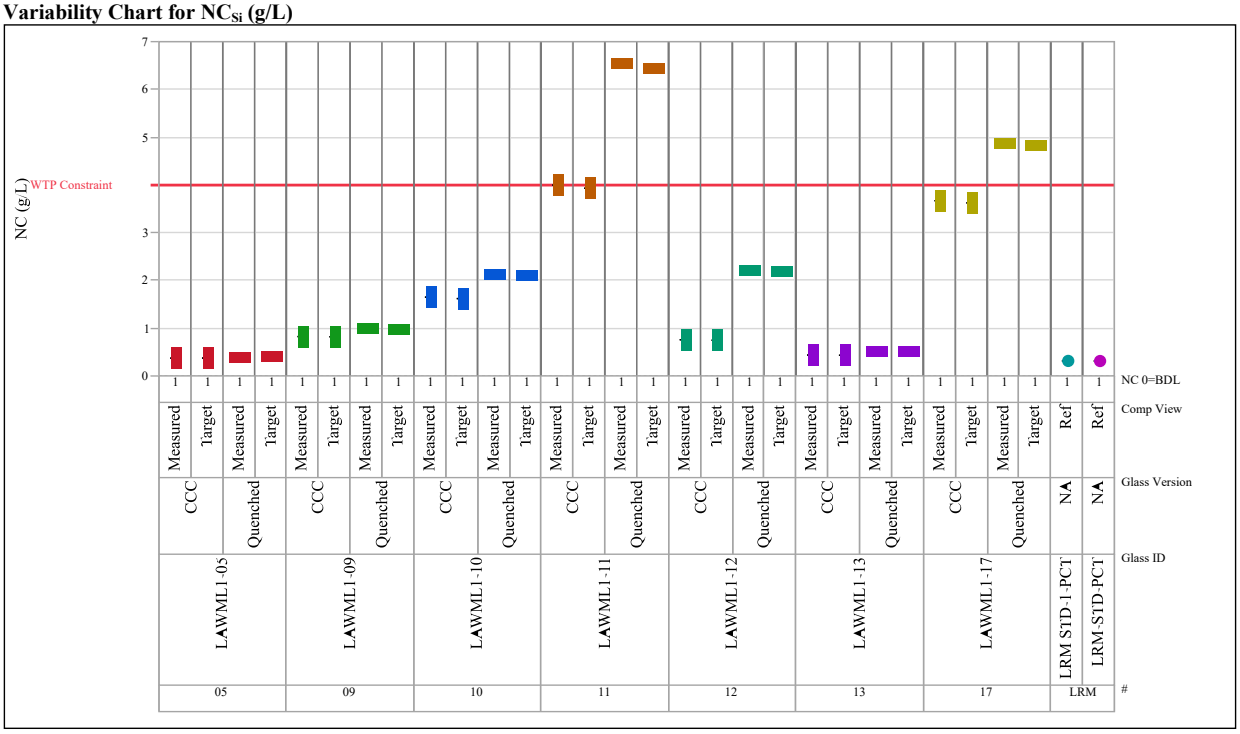
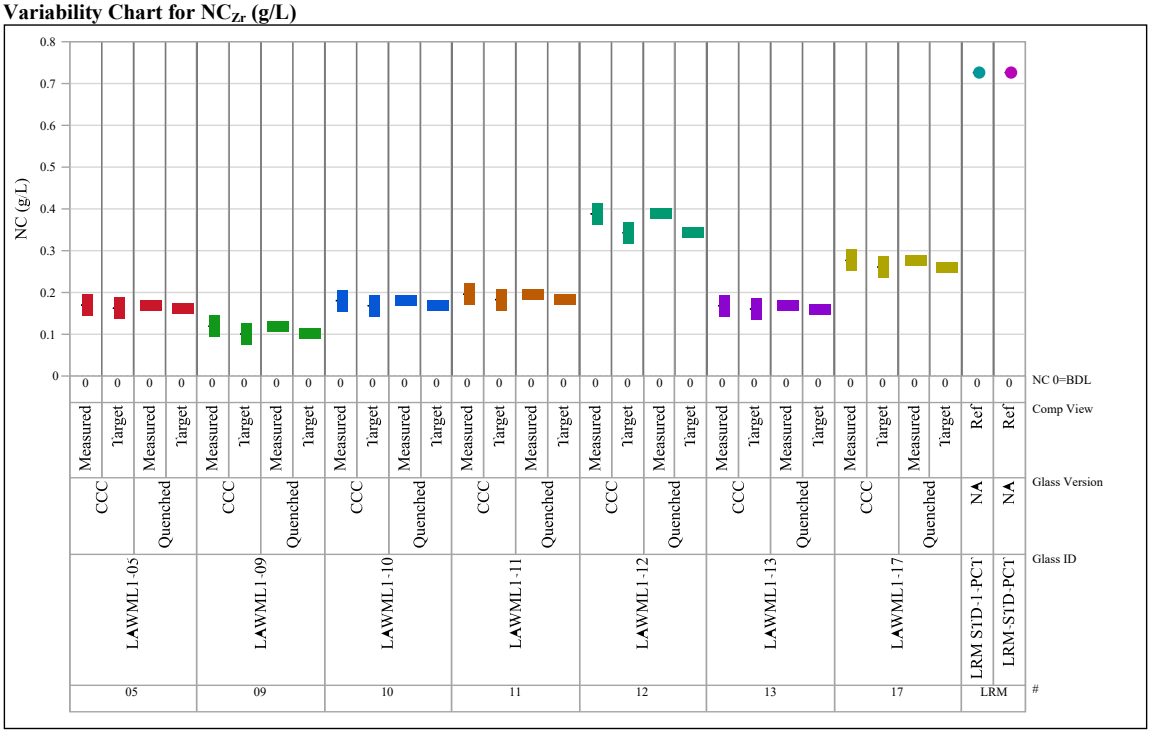


Exhibit B-1. Normalized PCT Results by Glass Version by Compositional View for Each Glass (continued)

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



Analyte=Zr
Variability Chart for NC_{Zr} (g/L)



Distribution:

Jake.Amoroso@srnl.doe.gov
CJ.Bannochie@srnl.doe.gov
Alex.Cozzi@srnl.doe.gov
Charles.Crawford@srnl.doe.gov
Elaine_N_Diaz@orp.doe.gov
William.C.Eaton@pnnl.gov
Vivianaluxa.Gervasio@pnnl.gov
Holly.Hall@srnl.doe.gov
Erich.Hansen@srnl.doe.gov
Connie.Herman@srnl.doe.gov
Anthony.Howe@srnl.doe.gov
Madison.Hsieh@srnl.doe.gov
Fabienne.Johnson@srnl.doe.gov
Albert_A_Kruger@orp.doe.gov
Christine.Langton@srnl.doe.gov
Brady.Lee@srnl.doe.gov
Xiaonan.Lu@pnnl.gov
Joseph.Manna@srnl.doe.gov
Daniel.McCabe@srnl.doe.gov
Gregg.Morgan@srnl.doe.gov
James.Neeway@pnnl.gov
Frank.Pennebaker@srnl.doe.gov
William.Ramsey@srnl.doe.gov
Whitney.Riley@srnl.doe.gov
Renee.Russell@pnnl.gov
Eric.Skidmore@srnl.doe.gov
Anna.Stanfield@srnl.doe.gov
Michael.Stone@srnl.doe.gov
John.Vienna@pnnl.gov
Boyd.Wiedenman@srnl.doe.gov
Richard.Wyrwas@srnl.doe.gov
Records Administration (EDWS)