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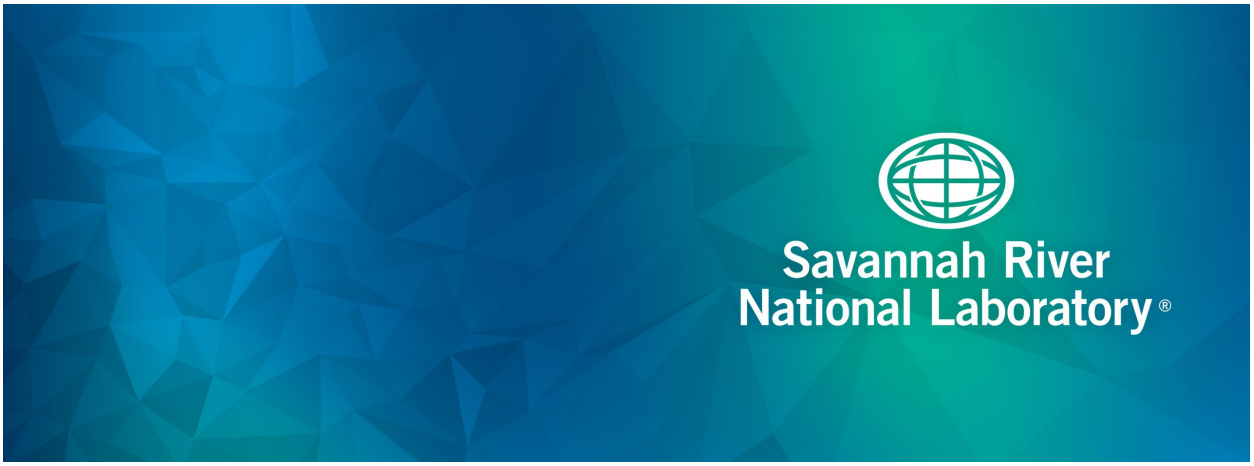

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Product Consistency Test Results for the LAW Phase 5 Rerun Leachates

M. C. Hsieh

July 2023

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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 Phase 5 (LP5) 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 (NC_i). NC_i of several elements was computed for both the target and measured glass compositions. The majority 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.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BDL	below detection limit
DF	dilution factor
DOE	Department of Energy
ICP-OES	inductively coupled plasma – optical emission spectroscopy
ID	identifier
LAW	low-activity waste
LP5	Low-Activity Waste Phase 5
LRM	low-activity reference material
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]

The Low-Activity Waste Phase 5 (LP5) glasses were previously analyzed and the leaching results reported.[3] Those results identified certain analytes in the references/standards and blanks that were unexpected and not in conformance for reporting per ASTM. To assess those inconsistencies, a subset of 14 glasses identical in composition to the previous study glasses were prepared and tested at Pacific Northwest National Laboratory (PNNL). The data reported here are from that subset of glasses with compositions identical to those previously reported.[3]

This report provides the chemical analysis of the Product Consistency Test (PCT) leachates from the Low-Activity Waste Phase 5 (LP5) glasses, a series of simulated nuclear waste glasses designed and fabricated at PNNL. The PCT leachates were from quenched (Q) glasses. The glasses were part of a broader study to evaluate the influence of glass composition on chemical durability, sulfur retention, and other properties.[4] 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.[5] SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.[6] Laboratory data for this study were recorded in the SRNL Electronic Laboratory Notebook system, experiment L6390-00441-02. 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 a leach test in accordance with ASTM C1285 PCT Method A[7] on quenched versions of each of the study glasses. The low-activity reference material (LRM) glass was included in the PCT-A but no blanks were included. 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).

Table 2-1. Identifiers for the PCT Leachates

PNNL Solution ID	Lab ID	PNNL Solution ID	Lab ID
LP5-01-Q-PCT-A-TI-197	S-15122	LP5-19-Q-PCT-C-TI-197	S-15148
LP5-01-Q-PCT-B-TI-197	S-15123	LP5-20-Q-PCT-A-TI-197	S-15149
LP5-01-Q-PCT-C-TI-197	S-15124	LP5-20-Q-PCT-B-TI-197	S-15150
LP5-02-Q-PCT-A-TI-197	S-15125	LP5-20-Q-PCT-C-TI-197	S-15151
LP5-02-Q-PCT-B-TI-197	S-15126	LP5-22-Q-PCT-A-TI-197	S-15152
LP5-02-Q-PCT-C-TI-197	S-15127	LP5-22-Q-PCT-B-TI-197	S-15153
LP5-06-mod1-Q-PCT-A-TI-197	S-15128	LP5-22-Q-PCT-C-TI-197	S-15154
LP5-06-mod1-Q-PCT-B-TI-197	S-15129	LP5-23-Q-PCT-A-TI-197	S-15155
LP5-06-mod1-Q-PCT-C-TI-197	S-15130	LP5-23-Q-PCT-B-TI-197	S-15156
LP5-08-Q-PCT-A-TI-197	S-15131	LP5-23-Q-PCT-C-TI-197	S-15157
LP5-08-Q-PCT-B-TI-197	S-15132	LP5-24-Q-PCT-A-TI-197	S-15158
LP5-08-Q-PCT-C-TI-197	S-15133	LP5-24-Q-PCT-B-TI-197	S-15159
LP5-10-Q-PCT-A-TI-197	S-15134	LP5-24-Q-PCT-C-TI-197	S-15160
LP5-10-Q-PCT-B-TI-197	S-15135	LP5-25-Q-PCT-A-TI-197	S-15161
LP5-10-Q-PCT-C-TI-197	S-15136	LP5-25-Q-PCT-B-TI-197	S-15162
LP5-13-Q-PCT-A-TI-197	S-15137	LP5-25-Q-PCT-C-TI-197	S-15163
LP5-13-Q-PCT-B-TI-197	S-15138	LRM-STD1-PCT-A-TI-197	S-15164
LP5-13-Q-PCT-C-TI-197	S-15139	LRM-STD1-PCT-B-TI-197	S-15165
LP5-15-Q-PCT-A-TI-197	S-15140	LRM-STD1-PCT-C-TI-197	S-15166
LP5-15-Q-PCT-B-TI-197	S-15141	LRM-STD2-PCT-A-TI-197	S-15167
LP5-15-Q-PCT-C-TI-197	S-15142	LRM-STD2-PCT-B-TI-197	S-15168
LP5-16-mod1-Q-PCT-A-TI-197	S-15143	LRM-STD2-PCT-C-TI-197	S-15169
LP5-16-mod1-Q-PCT-B-TI-197	S-15144	LRM-STD3-PCT-A-TI-197	S-15170
LP5-16-mod1-Q-PCT-C-TI-197	S-15145	LRM-STD3-PCT-B-TI-197	S-15171
LP5-19-Q-PCT-A-TI-197	S-15146	LRM-STD3-PCT-C-TI-197	S-15172
LP5-19-Q-PCT-B-TI-197	S-15147		

2.3 PCT Leachate Analysis

The PCT leachate samples were analyzed by inductively coupled plasma – optical emission spectroscopy (ICP-OES)[8] according to the analytical study plan designed to statistically randomize the measurements.[9] High purity multi-element custom ICP solution standards[b] (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[10] glass compositions.

3.0 Results and Discussion

JMP® version 16.0.0 (SAS Institute, Inc.)[11] was used to support these analyses.

3.1 Measured Compositions of the PCT Leachates

Table A-1 in Appendix A list the elemental concentration, in mg/L, for the LP5 PCT leachates, LRM standard glass and multi-element custom standard solutions as measured by ICP-OES in analytical sequence. Table A-1 provides the measurements after dilution correction, using a dilution factor (DF) of 5, provided by PNNL.

[b] 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 and Si concentrations were in agreement with published LRM leachate value ranges[12]. The measured Na concentration in one LRM leachate was higher than the published range.

Following the guidance in ASTM C1285,[7] 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, 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 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 Al, B, Li, Na, and Si for each of the test glasses following the expression given in ASTM C1285,[7]

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

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}.[c] NC_i was computed using both the target and average measured compositions.[10]

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[10]). Note that the symbols in this second equation were kept consistent with those used in ASTM C1285,[7] but the units of measurement differ.

Table B-1 in Appendix B provides the normalized PCT responses for the Q 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 detection limit

[c] 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.

(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.

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

- The measured glass compositions for the study glasses[10] were close to target values; therefore, little difference (≤6%) was seen when evaluating the normalized release using the target or measured glass compositions. For one glass, LP5-25, a 22% difference in the NC_{Li} is attributed to the small amount of Li detected in the glass.
- Most of the glasses exceeded the WTP NC_B, NC_{Na}, and/or NC_{Si} 4 g/L constraints.[d]
    - The following glasses exceeded the NC_B and NC_{Na} constraints
        - LP5-01, LP5-08, LP5-10, LP5-13, LP5-15, LP5-16-mod1, LP5-19, LP5-20, and LP5-22.
    - The following glasses also exceeded the NC_{Si} constraint:
        - LP5-01, LP5-10, LP5-13, LP5-20, and LP5-22.

4.0 Summary

The elemental release for the study glasses is reported as normalized concentration NC_i. NC_i of several elements and was computed for both the target and measured glass compositions. Most 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. One of the reference glasses that was included with the study glasses had an Na concentration slightly higher than expected. The unexpected analyte concentrations in the reference glass were insignificant with respect to the reported NC_i values and are noted for completeness.

5.0 References

1. C.E. Lonergan, "Low-activity Waste (LAW) Glass Testing Phase 5: Expansion of LAW Glass Composition Boundaries," Pacific Northwest National Laboratory, Richland, WA, EWG-TP-0135, Revision 1.0, 2021.

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.

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4. 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.

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

7. 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.

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

8. "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.

9. M.C. Hsieh, "An Analytical Plan for Measuring the Rerun PCT Solutions of the LAW Phase 5 Study Glasses," Savannah River National Laboratory, Aiken, SC, SRNL-L3310-2022-00024, Rev. 0, 2022.

10. M.C. Hsieh, "Composition Measurements of the LAW Phase 5 Glasses," Savannah River National Laboratory, Aiken, SC, SRNL-STI-2021-00409, Revision 0, 2021.

11. JMP® Version 16.0.0, SAS Institute Inc., Cary, NC, 2021.

12. 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. Measurement Data for the LP5 PCT Leachates

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

PNNL Solution ID	Block	Seq	Lab ID	Al	B	Cr	K	Li	Na	Si	Zr
std-1	1	1	std-11	3.91	19.2	<1.00	9.27	9.94	73.1	48.6	<1.00
LP5-24-Q-PCT-A-TI-197	1	2	S-15158	13.5	33.7	<5.00	<5.00	<5.00	188	61.0	<5.00
LP5-08-Q-PCT-A-TI-197	1	3	S-15131	66.0	148	<5.00	107	<5.00	1050	151	<5.00
LP5-01-Q-PCT-A-TI-197	1	4	S-15122	8.00	3310	123	2400	<5.00	14500	2080	<5.00
LP5-22-Q-PCT-A-TI-197	1	5	S-15152	<5.00	2070	5.70	53.0	<5.00	7100	2250	<5.00
LP5-10-Q-PCT-A-TI-197	1	6	S-15134	9.60	545	15.8	412	<5.00	4300	680	<5.00
LRM-STD2-PCT-A-TI-197	1	7	S-15167	16.7	27.9	<5.00	<5.00	<5.00	162	86.5	<5.00
std-1	1	8	std-12	4.11	20.3	<1.00	10.3	10.7	79.9	51.8	<1.00
LP5-25-Q-PCT-A-TI-197	1	9	S-15161	<5.00	25.9	<5.00	<5.00	10.7	98.0	77.0	<5.00
LP5-19-Q-PCT-A-TI-197	1	10	S-15146	8.60	835	13.1	765	<5.00	3630	560	<5.00
LP5-02-Q-PCT-A-TI-197	1	11	S-15125	8.50	44.1	<5.00	25.9	<5.00	785	117	<5.00
LRM-STD1-PCT-A-TI-197	1	12	S-15164	16.7	26.8	<5.00	<5.00	<5.00	158	83.0	<5.00
LRM-STD3-PCT-A-TI-197	1	13	S-15170	16.3	26.3	<5.00	<5.00	<5.00	159	83.5	<5.00
LP5-23-Q-PCT-A-TI-197	1	14	S-15155	8.80	22.6	<5.00	21.9	<5.00	565	190	<5.00
std-1	1	15	std-13	4.14	20.4	<1.00	10.5	11.0	83.7	51.9	<1.00
LP5-15-Q-PCT-A-TI-197	1	16	S-15140	47.0	173	<5.00	93.0	<5.00	860	94.0	<5.00
LP5-20-Q-PCT-A-TI-197	1	17	S-15149	<5.00	2550	39.4	560	<5.00	8100	1410	<5.00
LP5-16-mod1-Q-PCT-A-TI-197	1	18	S-15143	24.8	197	8.50	22.7	<5.00	1420	211	<5.00
LP5-06-mod1-Q-PCT-A-TI-197	1	19	S-15128	29.1	51.5	<5.00	27.7	<5.00	318	77.5	<5.00
LP5-13-Q-PCT-A-TI-197	1	20	S-15137	<5.00	3710	77.5	1480	<5.00	13100	1430	<5.00
std-1	1	21	std-14	4.25	20.4	<1.00	10.7	11.0	78.7	52.3	<1.00
std-2	2	1	std-21	4.10	20.3	<1.00	9.99	10.3	82.0	50.0	<1.00
LP5-15-Q-PCT-B-TI-197	2	2	S-15141	45.2	167	<5.00	85.0	<5.00	855	88.0	<5.00
LP5-06-mod1-Q-PCT-B-TI-197	2	3	S-15129	28.8	50.0	<5.00	24.2	<5.00	315	74.5	<5.00
LP5-24-Q-PCT-B-TI-197	2	4	S-15159	13.4	32.5	<5.00	<5.00	<5.00	193	58.0	<5.00
LP5-22-Q-PCT-B-TI-197	2	5	S-15153	<5.00	2100	5.60	51.5	<5.00	7300	2440	<5.00
LRM-STD1-PCT-B-TI-197	2	6	S-15165	16.0	26.2	<5.00	<5.00	<5.00	161	81.0	<5.00

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

PNNL Solution ID	Block	Seq	Lab ID	Al	B	Cr	K	Li	Na	Si	Zr
LP5-02-Q-PCT-B-TI-197	2	7	S-15126	8.10	41.9	<5.00	22.6	<5.00	745	109	<5.00
std-2	2	8	std-22	3.98	19.9	<1.00	9.60	10.1	80.6	49.6	<1.00
LP5-20-Q-PCT-B-TI-197	2	9	S-15150	<5.00	2530	37.6	595	<5.00	8300	1490	<5.00
LP5-16-mod1-Q-PCT-B-TI-197	2	10	S-15144	24.1	192	8.15	19.5	<5.00	1390	203	<5.00
LP5-10-Q-PCT-B-TI-197	2	11	S-15135	9.45	540	15.0	388	<5.00	4360	715	<5.00
LRM-STD3-PCT-B-TI-197	2	12	S-15171	16.1	26.6	<5.00	<5.00	<5.00	166	80.5	<5.00
LP5-13-Q-PCT-B-TI-197	2	13	S-15138	<5.00	3840	72.5	1630	<5.00	14000	1490	<5.00
LP5-25-Q-PCT-B-TI-197	2	14	S-15162	<5.00	25.6	<5.00	<5.00	9.20	95.5	78.0	<5.00
std-2	2	15	std-23	4.05	20.3	<1.00	9.90	10.3	82.1	50.2	<1.00
LP5-19-Q-PCT-B-TI-197	2	16	S-15147	8.75	870	13.1	865	<5.00	3910	610	<5.00
LRM-STD2-PCT-B-TI-197	2	17	S-15168	16.9	28.1	<5.00	<5.00	<5.00	178	83.0	<5.00
LP5-08-Q-PCT-B-TI-197	2	18	S-15132	63.0	145	<5.00	104	<5.00	910	141	<5.00
LP5-01-Q-PCT-B-TI-197	2	19	S-15123	8.10	3220	123	2400	<5.00	14300	2150	<5.00
LP5-23-Q-PCT-B-TI-197	2	20	S-15156	8.40	22.4	<5.00	19.4	<5.00	510	181	<5.00
std-2	2	21	std-24	3.97	19.9	<1.00	9.54	9.94	79.4	49.2	<1.00
std-3	3	1	std-31	3.91	19.7	<1.00	9.58	9.13	81.0	48.9	<1.00
LP5-19-Q-PCT-C-TI-197	3	2	S-15148	8.55	860	12.4	830	<5.00	3900	600	<5.00
LP5-25-Q-PCT-C-TI-197	3	3	S-15163	<5.00	25.0	<5.00	<5.00	7.00	96.5	72.5	<5.00
LP5-06-mod1-Q-PCT-C-TI-197	3	4	S-15130	27.9	49.8	<5.00	23.9	<5.00	319	73.0	<5.00
LP5-02-Q-PCT-C-TI-197	3	5	S-15127	7.70	40.6	<5.00	21.6	<5.00	700	104	<5.00
LRM-STD3-PCT-C-TI-197	3	6	S-15172	15.6	26.1	<5.00	<5.00	<5.00	166	78.0	<5.00
LRM-STD2-PCT-C-TI-197	3	7	S-15169	15.9	26.4	<5.00	<5.00	<5.00	168	80.0	<5.00
std-3	3	8	std-32	3.94	19.8	<1.00	9.56	9.25	81.9	49.0	<1.00
LRM-STD1-PCT-C-TI-197	3	9	S-15166	15.8	25.0	<5.00	<5.00	<5.00	159	75.0	<5.00
LP5-20-Q-PCT-C-TI-197	3	10	S-15151	<5.00	2440	36.0	550	<5.00	8400	1440	<5.00
LP5-10-Q-PCT-C-TI-197	3	11	S-15136	9.50	530	14.9	375	<5.00	4580	705	<5.00
LP5-22-Q-PCT-C-TI-197	3	12	S-15154	<5.00	2020	5.20	49.1	<5.00	7250	2380	<5.00

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

PNNL Solution ID	Block	Seq	Lab ID	Al	B	Cr	K	Li	Na	Si	Zr
LP5-16-mod1-Q-PCT-C-TI-197	3	13	S-15145	24.4	193	7.90	19.7	<5.00	1380	202	<5.00
LP5-23-Q-PCT-C-TI-197	3	14	S-15157	8.25	21.8	<5.00	19.4	<5.00	535	178	<5.00
std-3	3	15	std-33	3.92	19.8	<1.00	9.39	9.13	81.0	48.8	<1.00
LP5-24-Q-PCT-C-TI-197	3	16	S-15160	13.6	34.0	<5.00	<5.00	<5.00	205	59.0	<5.00
LP5-01-Q-PCT-C-TI-197	3	17	S-15124	7.30	3060	117	2350	<5.00	14300	2450	<5.00
LP5-13-Q-PCT-C-TI-197	3	18	S-15139	<5.00	3820	75.0	1510	<5.00	13500	1560	<5.00
LP5-15-Q-PCT-C-TI-197	3	19	S-15142	45.9	172	<5.00	86.5	<5.00	870	95.5	<5.00
LP5-08-Q-PCT-C-TI-197	3	20	S-15133	69.0	158	<5.00	118	<5.00	1030	156	<5.00
std-3	3	21	std-34	4.17	20.7	<1.00	10.7	10.1	88.4	51.5	<1.00

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

PNNL Solution ID	Lab ID	B	Na	Si
LRM-STD1-PCT-A-TI-197	S-15164	26.8	158	83.0
LRM-STD1-PCT-B-TI-197	S-15165	26.2	161	81.0
LRM-STD1-PCT-C-TI-197	S-15166	25.0	159	75.0
LRM-STD2-PCT-A-TI-197	S-15167	27.9	162	86.5
LRM-STD2-PCT-B-TI-197	S-15168	28.1	178	83.0
LRM-STD2-PCT-C-TI-197	S-15169	26.4	168	80.0
LRM-STD3-PCT-A-TI-197	S-15170	26.3	159	83.5
LRM-STD3-PCT-B-TI-197	S-15171	26.6	166	80.5
LRM-STD3-PCT-C-TI-197	S-15172	26.1	166	78.0

Ranges of Expected Test Results for LRM[c]
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.

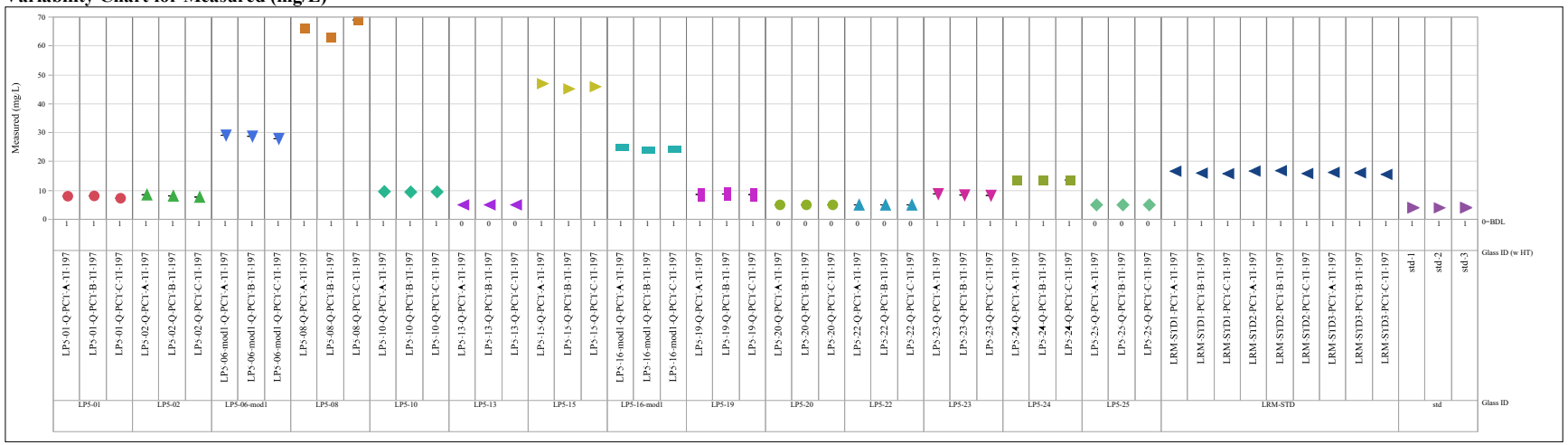
[c] W.L. Ebert and S.F. Wolf, "Round-Robin Testing of a Reference Glass for Low-Activity Waste Forms," Argonne National Laboratory, Argonne, IL, ANL-99/22, Revision 0, 1999

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

Analytical Block	Q-1	Q-2	Q-3	Reference Values (mg/L)
Mean (Al (mg/L))	4.10	4.03	3.99	4.00
Mean (B (mg/L))	20.1	20.1	20.0	20.0
Mean (K (mg/L))	10.2	9.76	9.81	10.0
Mean (Li (mg/L))	10.7	10.2	9.4	10.0
Mean (Na (mg/L))	78.9	81.0	83.1	81.0
Mean (Si (mg/L))	51.2	49.8	49.6	50.0
% relative bias, Al	2.56	0.62	-0.38	<10% per ASTM C1285
% relative bias, B	0.37	0.50	0.00	
% relative bias, K	1.92	-2.42	-1.92	
% relative bias, Li	6.60	1.60	-5.97	
% relative bias, Na	-2.65	0.03	2.56	
% relative bias, Si	2.30	-0.50	-0.90	
Standard Deviation (Al (mg/L))	0.14	0.06	0.12	
Standard Deviation (B (mg/L))	0.59	0.23	0.47	
Standard Deviation (K (mg/L))	0.64	0.22	0.60	
Standard Deviation (Li (mg/L))	0.50	0.17	0.47	
Standard Deviation (Na (mg/L))	4.39	1.28	3.58	
Standard Deviation (Si (mg/L))	1.71	0.44	1.30	
%RSD (Al)	3.46	1.52	3.11	<10% per ASTM C1285
%RSD (B)	2.92	1.15	2.35	
%RSD (K)	6.24	2.26	6.13	
%RSD (Li)	4.69	1.72	4.98	
%RSD (Na)	5.56	1.58	4.30	
%RSD (Si)	3.35	0.89	2.63	

Exhibit A-1. PCT Measurements by Glass ID

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



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

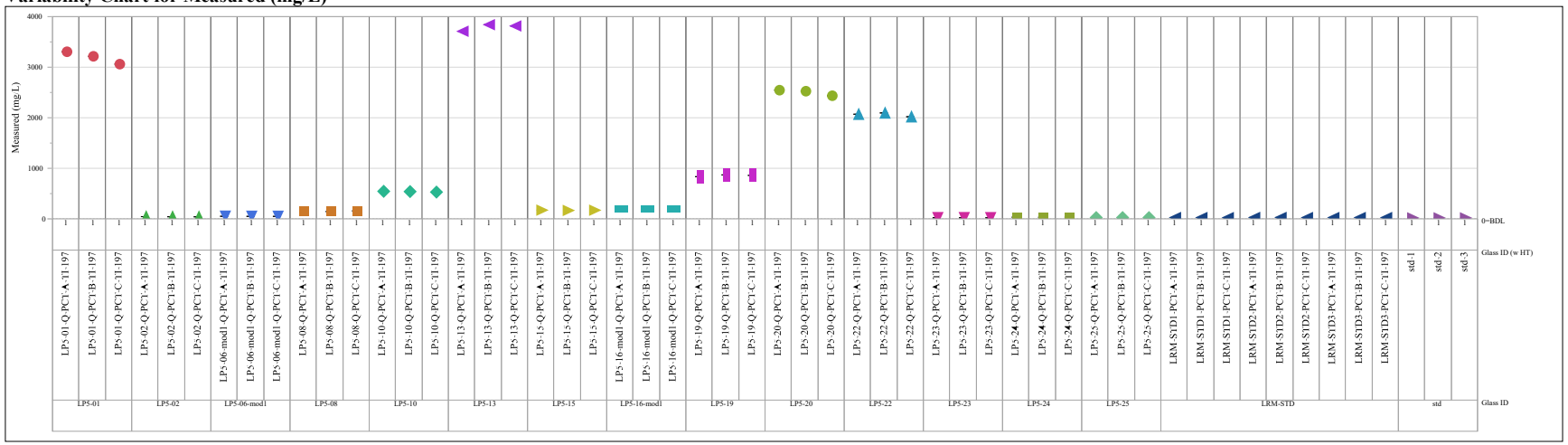
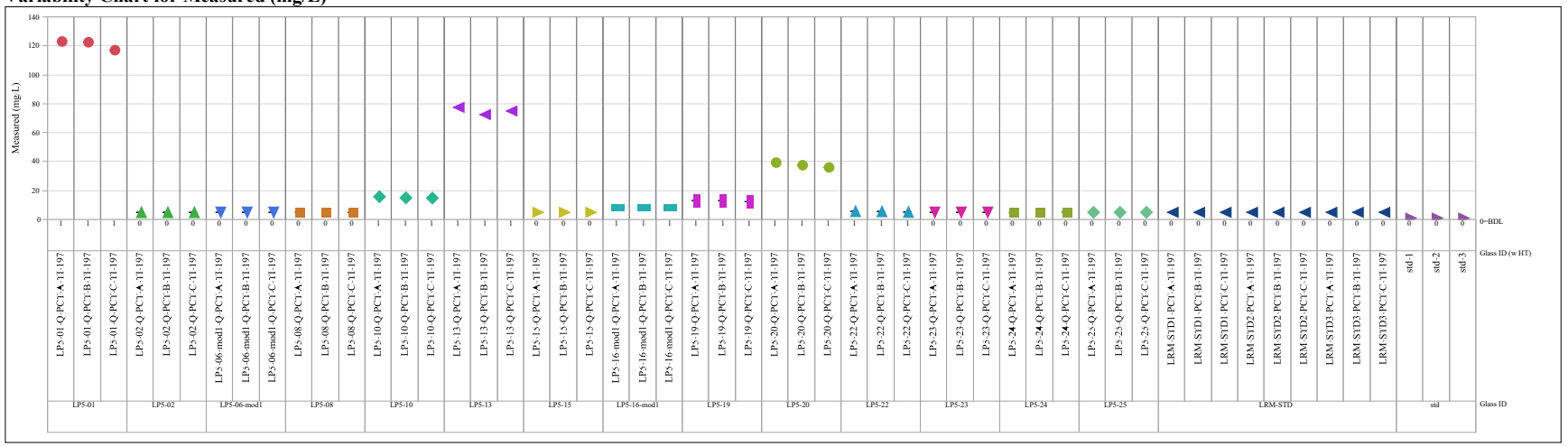


Exhibit A-1. PCT Measurements by Glass ID (continued)

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



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

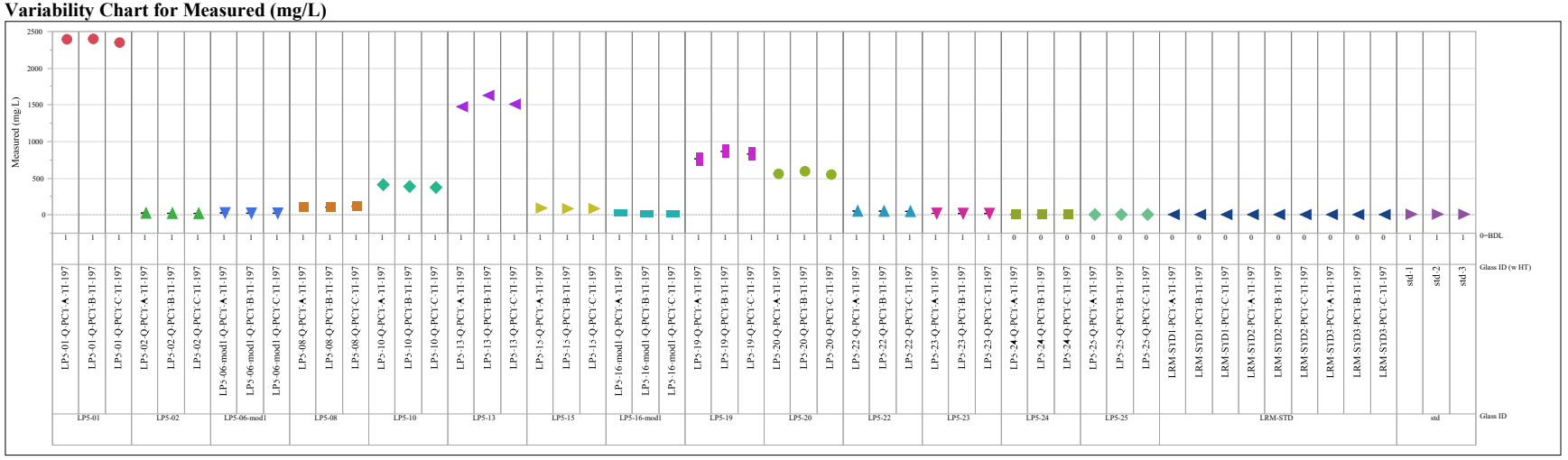
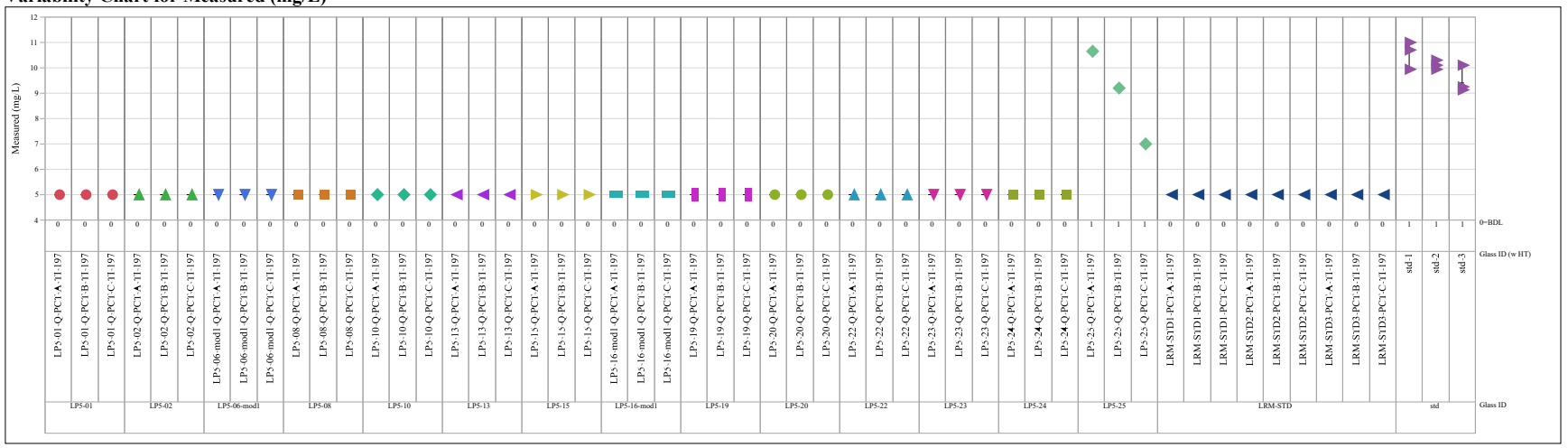


Exhibit A-1. PCT Measurements by Glass ID (continued)

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



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

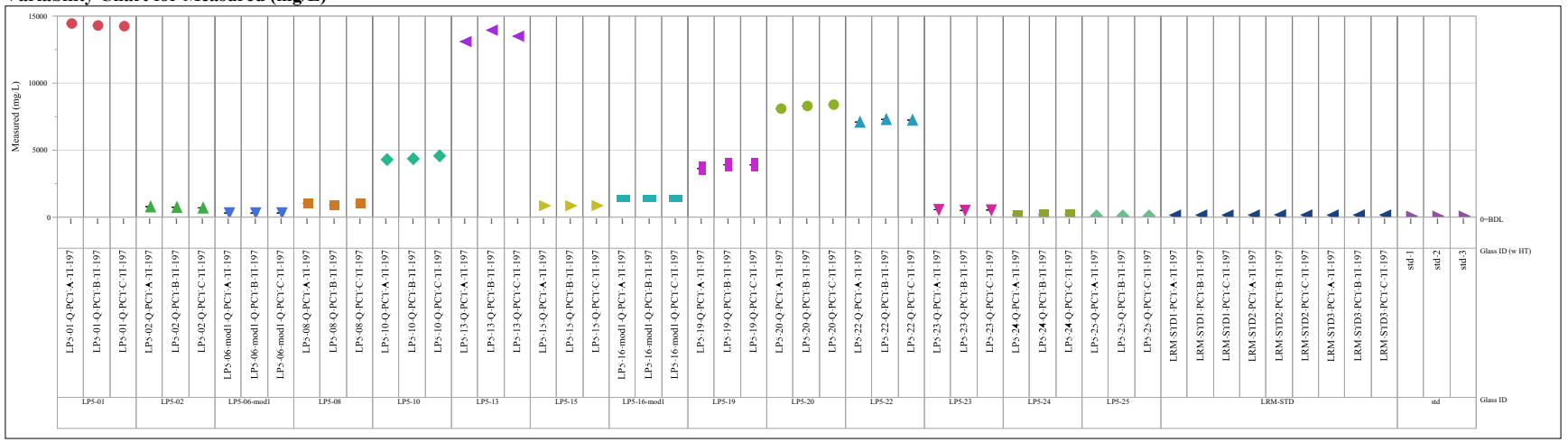
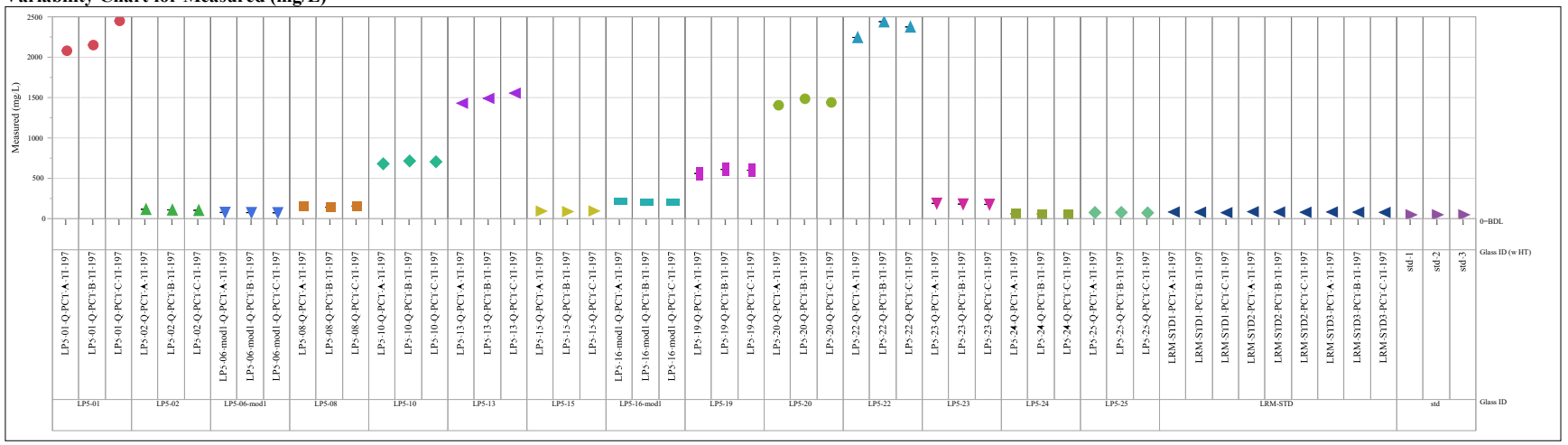
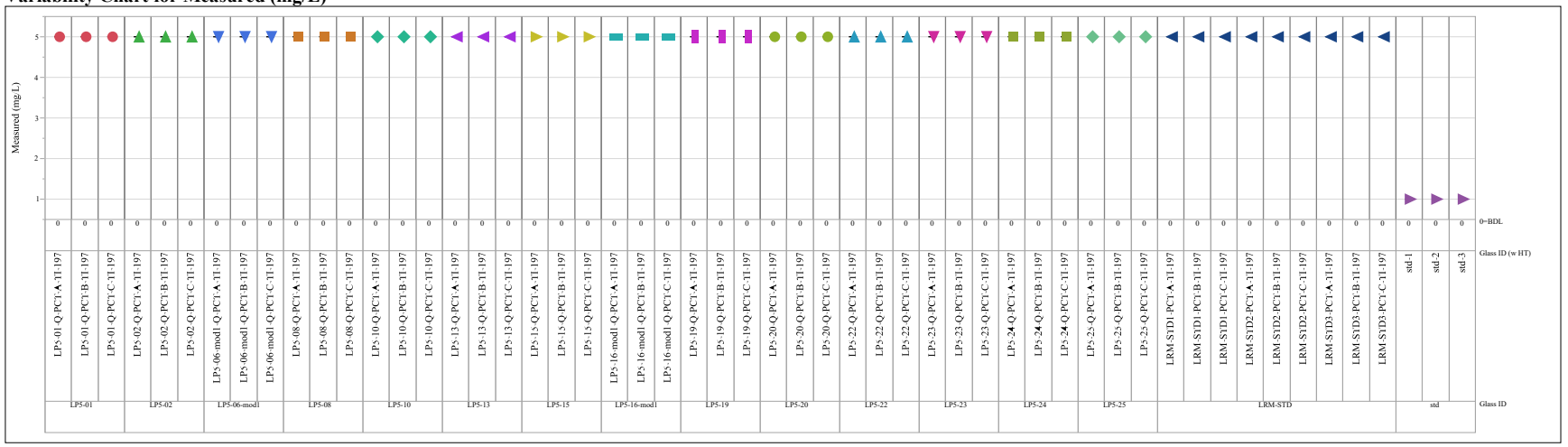


Exhibit A-1. PCT Measurements by Glass ID (continued)

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



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



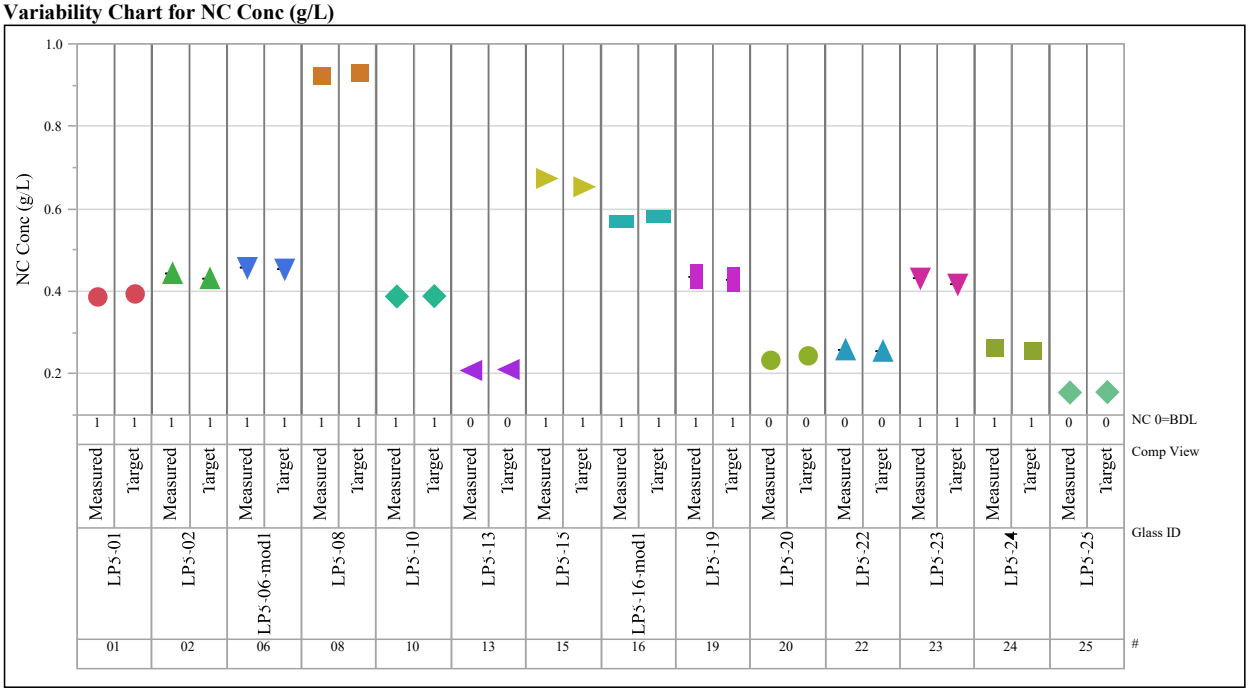
Appendix B. Normalized LP5 PCT Results

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

Glass ID	Comp View	Sample ID	NC Al	NC B	NC Li	NC Na	NC Si
LP5-01	Target	LP5-01-Q-TI-197	0.394	95.2	NA	73.5	14.1
LP5-01	Measured	LP5-01-Q-TI-197	0.386	90.9	NA	75.8	13.8
LP5-02	Target	LP5-02-Q-TI-197	0.431	2.02	NA	3.86	0.678
LP5-02	Measured	LP5-02-Q-TI-197	0.443	2.01	NA	4.00	0.669
LP5-06-mod1	Target	LP5-06-mod1-Q-TI-197	0.454	2.03	NA	1.94	0.477
LP5-06-mod1	Measured	LP5-06-mod1-Q-TI-197	0.458	1.94	NA	1.93	0.453
LP5-08	Target	LP5-08-Q-TI-197	0.930	5.10	NA	4.98	0.924
LP5-08	Measured	LP5-08-Q-TI-197	0.923	4.92	NA	4.94	0.896
LP5-10	Target	LP5-10-Q-TI-197	0.388	28.2	NA	22.1	4.15
LP5-10	Measured	LP5-10-Q-TI-197	0.388	27.6	NA	22.5	4.11
LP5-13	Target	LP5-13-Q-TI-197	<0.210	94.5	NA	68.7	9.35
LP5-13	Measured	LP5-13-Q-TI-197	<0.208	93.1	NA	70.1	9.33
LP5-15	Target	LP5-15-Q-TI-197	0.653	6.06	NA	4.47	0.587
LP5-15	Measured	LP5-15-Q-TI-197	0.674	5.78	NA	4.61	0.552
LP5-16-mod1	Target	LP5-16-mod1-Q-TI-197	0.581	8.64	NA	7.46	1.31
LP5-16-mod1	Measured	LP5-16-mod1-Q-TI-197	0.569	8.39	NA	7.80	1.27
LP5-19	Target	LP5-19-Q-TI-197	0.428	26.5	NA	23.0	3.65
LP5-19	Measured	LP5-19-Q-TI-197	0.435	26.2	NA	23.1	3.58
LP5-20	Target	LP5-20-Q-TI-197	<0.243	59.7	NA	43.7	7.96
LP5-20	Measured	LP5-20-Q-TI-197	<0.233	56.7	NA	44.7	7.76
LP5-22	Target	LP5-22-Q-TI-197	<0.255	52.7	NA	39.4	10.5
LP5-22	Measured	LP5-22-Q-TI-197	<0.258	52.3	NA	39.7	10.3
LP5-23	Target	LP5-23-Q-TI-197	0.417	1.12	NA	3.04	0.798
LP5-23	Measured	LP5-23-Q-TI-197	0.432	1.12	NA	3.00	0.796
LP5-24	Target	LP5-24-Q-TI-197	0.255	1.13	NA	1.14	0.327
LP5-24	Measured	LP5-24-Q-TI-197	0.262	1.13	NA	1.17	0.323
LP5-25	Target	LP5-25-Q-TI-197	<0.156	0.813	0.756	0.905	0.348
LP5-25	Measured	LP5-25-Q-TI-197	<0.155	0.789	0.922	0.905	0.339
LRM-STD	Reference	LRM-STD1-TI-197	0.321	1.06	<9.79	1.07	0.314
LRM-STD	Reference	LRM-STD2-TI-197	0.327	1.12	<9.79	1.14	0.328
LRM-STD	Reference	LRM-STD3-TI-197	0.317	1.08	<9.79	1.10	0.318

Exhibit B-1. Normalized PCT Results by Glass ID by Composition View for Selected Elements

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



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

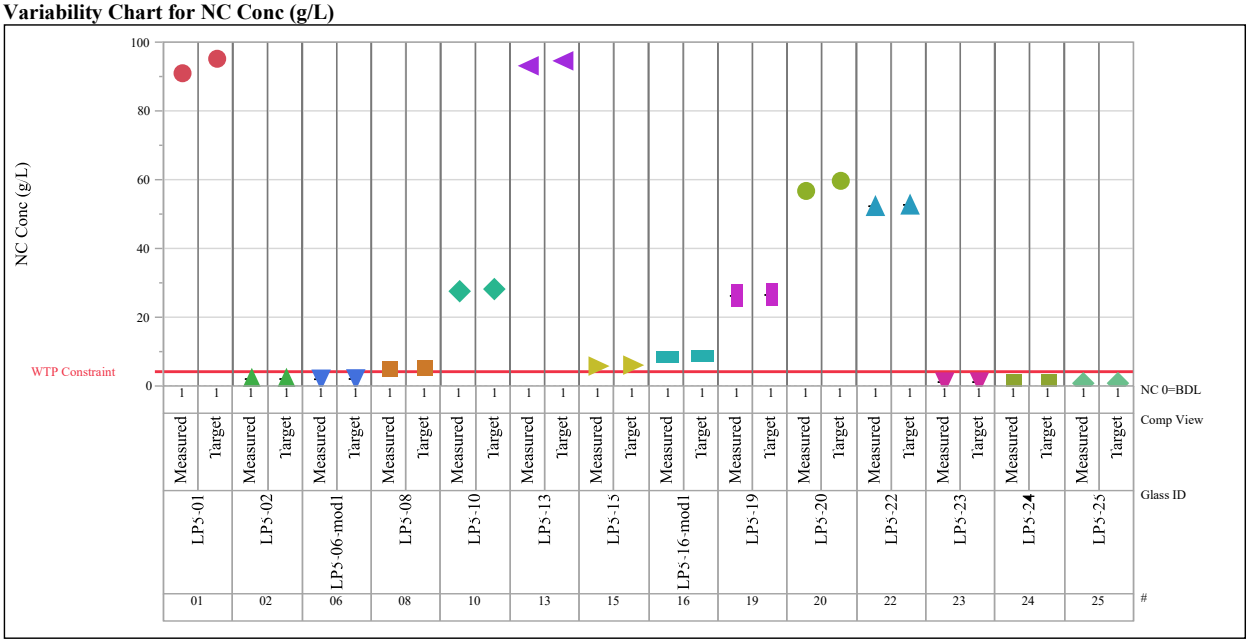
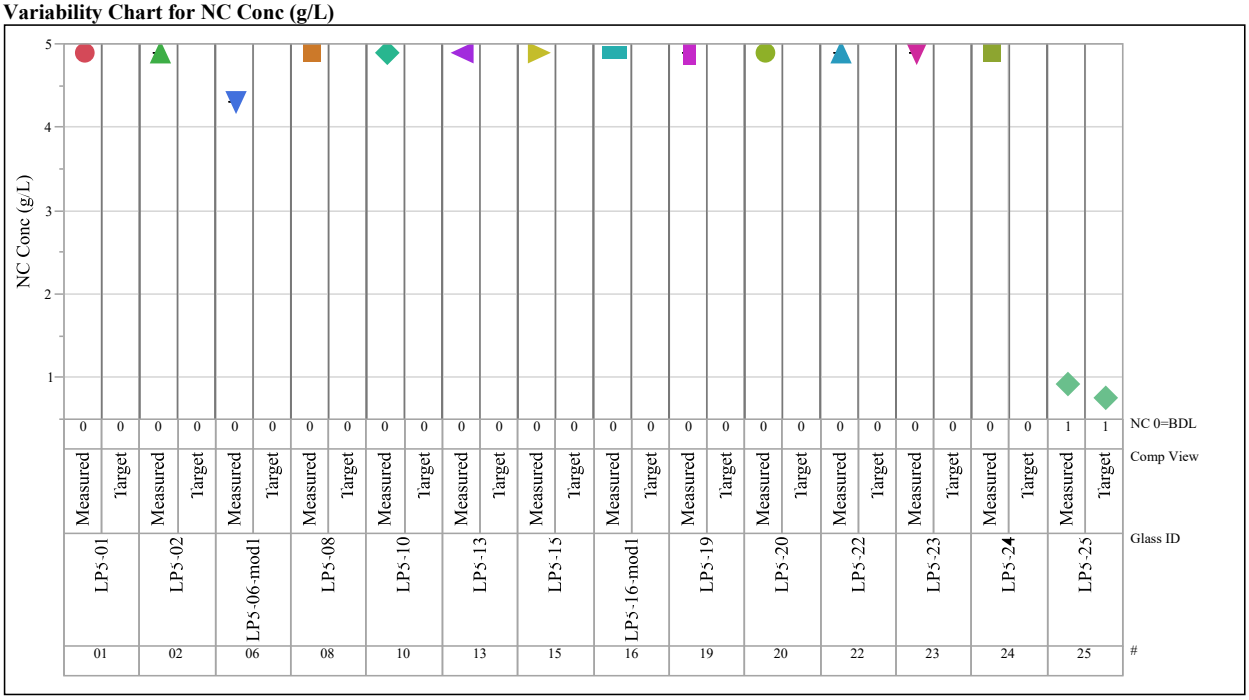


Exhibit B-1. Normalized PCT Results by Glass ID by Composition View for Selected Elements (continued)

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



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

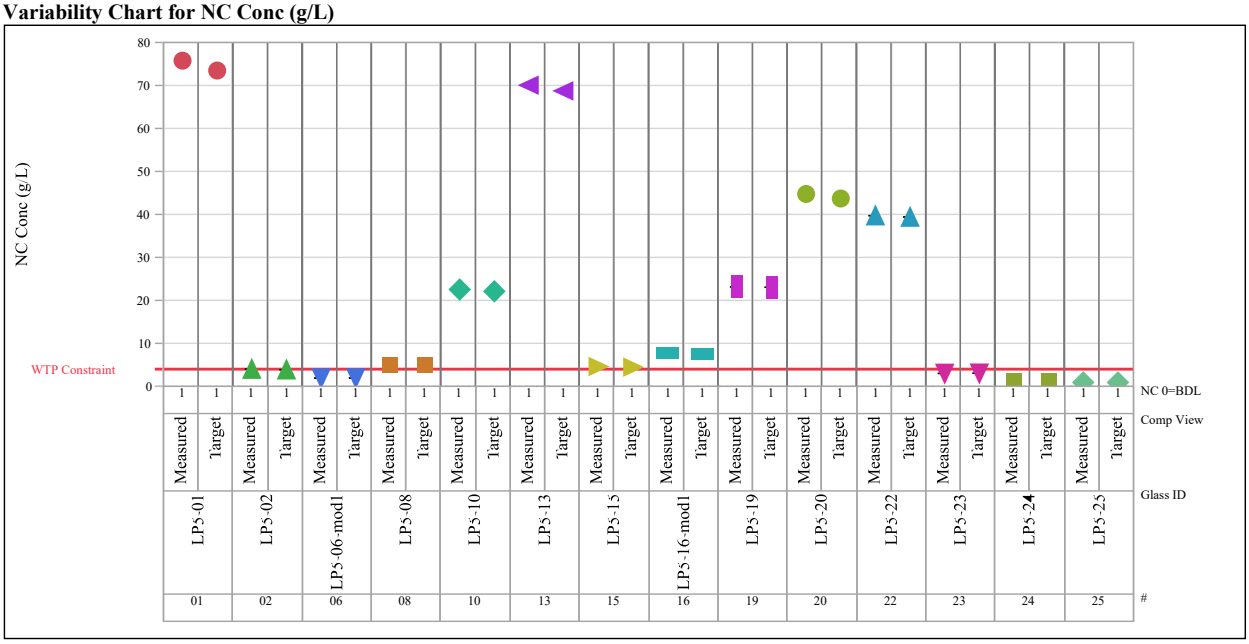
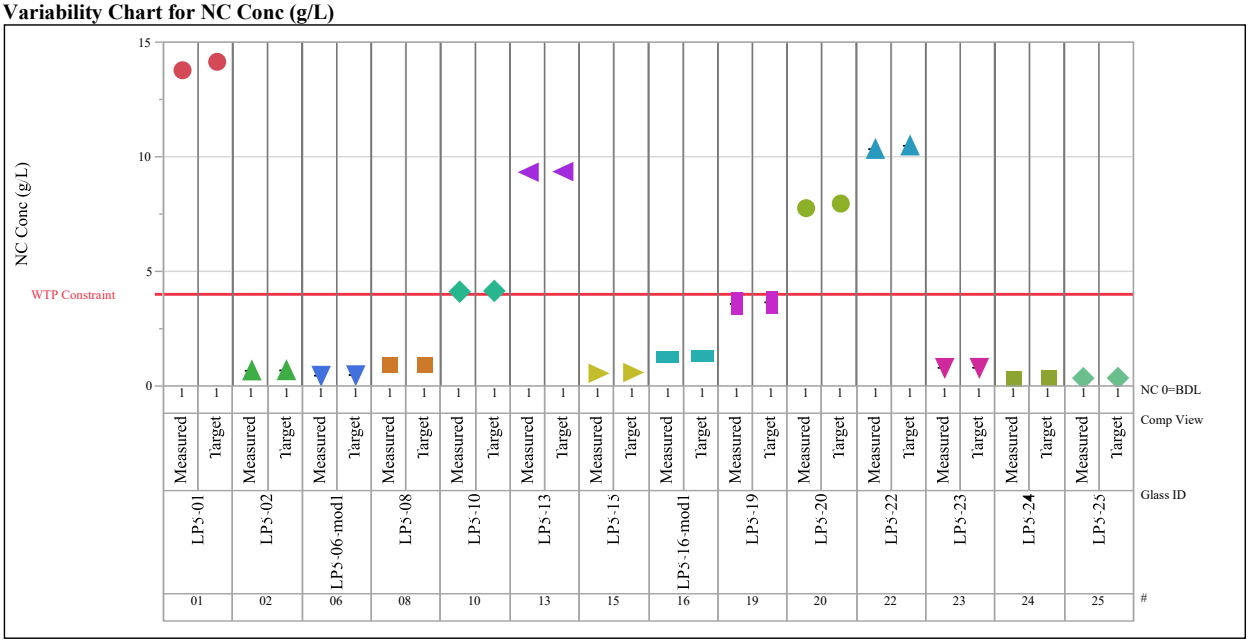


Exhibit B-1. Normalized PCT Results by Glass ID by Composition View for Selected Elements (continued)

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



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