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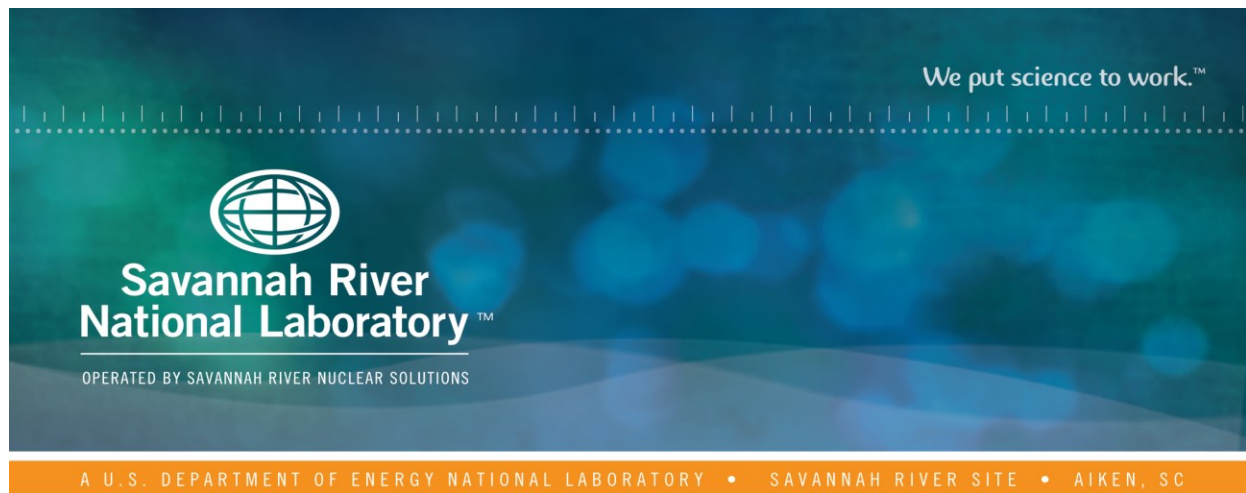
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Analysis of Hanford Cast Stone Supplemental LAW using Composition Adjusted SRS Tank 50 Salt Solution

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April 2017

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EXECUTIVE SUMMARY

Vitrification is the primary disposition path for Low Activity Waste (LAW) at the Department of Energy (DOE) Hanford Site. A cementitious waste form is one of the alternatives being considered for the supplemental immobilization of the LAW that will not be treated by the primary vitrification facility. Washington River Protection Solutions (WRPS) has been directed to generate and collect data on cementitious or pozzolanic waste forms such as Cast Stone.

This report documents work done to support supplemental immobilization efforts by performing testing on actual salt wastes immobilized in Cast Stone. The actual waste used in testing was a Savannah River Site (SRS) salt solution from Tank 50 H-area Tank Farm that was chemically adjusted with aluminum hydroxide, ammonium phosphate, and ammonium sulfate to represent Hanford salt waste. Radioactive Tc-99 and natural iodide-127 were also added to match previous simulant Tc-99 spike studies and to provide enough iodide for detection in the aqueous leachates. Using a chemically adjusted SRS salt waste avoided sampling, transportation and permitting issues, which would have been required for actual Hanford tank waste, while providing a readily available and representative sample for testing.

Chemical adjustment of the SRS Tank 50 sample was verified by analysis showing targeted concentrations were achieved. Duplicate 2" x 4" 'baseline' monoliths were made using the adjusted Tank 50 salt solution and dry blend materials (premix) of ordinary portland cement (OPC), Class F fly ash (FA) and ground, granulated blast furnace slag (GGBFS) for a free water to premix ratio of 0.55. Three other sets of monoliths were made using various getters that included Potassium Metal Sulfide (KMS)-2 ($K_2MgSn_2S_6$), tin apatite ($Sn_2Ca_8(PO_4)_6Cl_2$) and silver zeolite ($Ag_{84}Na_2[(AlO_2)_{86}(SiO_2)_{106}] \cdot xH_2O$). The getters replaced mass from the premix, mass for mass, maintaining the effective premix ratio of 0.55. Monoliths were leach tested in reagent water using the Environmental Protection Agency (EPA) Method 1315 which is designed to provide mass transfer rates (release rates) of inorganic analytes contained in monolithic material under diffusion controlled release conditions as a function of leaching time. All initial species monolith concentrations used in the reported leachability index (LI) values are based on as-batched concentrations, i.e., no actual dissolution and characterization was performed on the monolithic cast stone matrix. As-batched species concentrations in the monoliths were based on analyzed adjusted Tank 50 supernate, previous analysis of premix components and calculated getter concentrations that are based on simple getter empirical formulas.

Chemical adjustment of the SRS Tank 50 salt solution by the addition of Al, sulfate, phosphate and Tc-99 species, as well as natural iodide, met target levels as determined by chemical and radiochemical analysis. Monolith leach tests indicate no significant differences in the observed diffusivities (D_{obs}) for these tests on the getter-containing monoliths versus the baseline monoliths. The only exception observed was the increased retention of iodide and decreased retention in Cr and Tc-99 in the silver zeolite (Ag-Z) monolith leach test. Leach index (LI) values are in similar ranges for two groups of analytes for all monoliths. For the first group (Cr, Al and Ca), the LI values for Cr were in the range of 12.5 to 12.6 except for the Ag-Z samples that were lower at 10.6, the Al and Ca LI values were similar in magnitude at about 11. For the second group (S, Na, NO_2 , NO_3 , K and I) the LI values were similar in the range of 7.6 to 8.8. The LI values for Tc-99 were similar for the baseline (10.9) and the samples made with Tc getters (10.3 and 10.1). The Ag-Z samples showed lower retention of Tc-99 with LI of 9.3. These data obtained from monoliths prepared with actual radioactive waste and leached in ultrapure water ($> 18 M\Omega cm$) are consistent with previous results from Pacific Northwest National Laboratory (PNNL) using spiked simulants leached in deionized water indicating that the Tc getters KMS-2 and Sn-A are not effective at retaining Tc-99 relative to baseline samples when leached in either of these reagent waters. It should be noted that previous work using spiked simulants with similar getters in Cast Stone monoliths that were leached in Hanford vadose zone pore water (VZPW) did show significant effective retention of Tc.

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LIST OF ABBREVIATIONS

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
D _{obs}	Observed Diffusivity
dpm	Disintegrations per minute
EPA	Environmental Protection Agency
ES	Engineering Scale
FA	Fly Ash
GGBFS or BFS	Ground, Granulated Blast Furnace Slag
IC	Ion Chromatography
ICP-MS	Inductively Coupled Plasma – Mass Spectroscopy
ICP-OES	Inductively Coupled Plasma – Optical Emission Spectroscopy
KMS	Potassium Metal Sulfide
LAW	Low Activity Waste
LI	Leachability Index
mg/L	Milligrams per liter
OPC	Ordinary Portland Cement
PNNL	Pacific Northwest National Laboratory
ppt	Parts per trillion
QAP	Quality Assurance Program
SRNL	Savannah River National Laboratory
TTQAP	Task Technical and Quality Assurance Plan
VZPW	Vadose Zone Pore Water
WAC	Waste Acceptance Criteria
WRPS	Washington River Protection Solutions

1.0 Introduction

The Department of Energy – Office of River Protection has directed WRPS to generate and collect data on cementitious or pozzolanic waste forms such as Cast Stone. A cementitious waste form is one of the alternatives being considered for Supplemental Immobilization of Hanford LAW, along with vitrification, bulk vitrification, and fluidized bed steam reforming. The goal of this project for WRPS was to obtain data on the performance of the Cast Stone waste form and process for immobilizing LAW.

A testing program was developed to obtain additional information on the Cast Stone option.¹ Screening tests were conducted in 2013 to examine expected ranges in waste composition, waste concentration, dry materials sources, and free water (in the waste liquid)-to-dry blend mix ratios.²

An engineering scale demonstration (ES Demo) with nonradioactive LAW simulants was initiated in October 2013. The primary objectives were to increase the Technology Readiness Level (TRL) (per DOE Office of Environmental Management Technology Readiness Assessment (TRA)/Technology Maturation Plan (TMP) Process Implementation Guide)³ of the Cast Stone process/technology for immobilizing Hanford LAW and to demonstrate equivalent performance between waste forms produced at the laboratory, bench and engineering pilot plant scales.⁴ The TRL protocols are in place to provide a systematic approach to prevent premature, large capital expenditures on under-developed technologies. A primary benchmark of technology maturity or demonstration, i.e., TRL 6, is integrated system testing in a relevant environment. Examples include testing a prototype with real waste and a range of simulants.³ The Scaled Continuous Processing Facility at Savannah River National Laboratory (SRNL) was used to fill a container with simulated Cast Stone grout to demonstrate the ability to operate a process to immobilize a simulated LAW salt solution in a cementitious waste form. A report has been issued⁵ that describes the core sampling and leach testing of monolithic samples that were obtained during April 2014 and March 2015 from the Cast Stone ES Demo. An important objective of the ES Demo was to generate data that correlate back to laboratory scale tests with simulants. In a similar manner, laboratory/bench scale testing with real waste was conducted to provide ties back to laboratory tests of Cast Stone made with simulants.

This report describes the preparation, analysis and results of Cast Stone formulated with SRS LAW. The purpose of this test was to provide confirmation that the results observed with simulants in the screening and formulation development testing, including tests of Cast Stone spiked with Tc and I getters, are representative of what is expected with actual wastes. A sample of SRS LAW salt solution retrieved from SRS Tank 50 in the first quarter of 2013⁶ was chemically adjusted to approximate the Hanford Tank Waste Operations Simulator 5M Na Overall Average LAW composition in reference 7. Chemical adjustments included addition of Al, phosphate, sulfate and I chemicals as well as Tc-99.

2.0 Experimental Procedure

Adjustment of SRS Tank 50 and leach testing activities performed on monoliths fabricated using the adjusted Tank 50 salt solution are described in a Task Technical and Quality Assurance Plan (TTQAP).⁸ Section 2.1.3 of that plan explains the approach for adjusting the chemical composition and analysis of the Tank 50 actual waste sample, leach testing of monoliths made using the adjusted Tank 50 salt solution and specific getters added to retain Tc-99 and/or iodide.

2.1 Adjustment and Analysis of Tank 50 Salt Solution

A glass container, fitted with a heating wrap and a condenser, was situated on a stir plate and used for the chemical adjustment activities. Figure 1 depicts the setup used during water mockup test runs. The temperature of the solution was monitored using a K-type thermocouple and heating was controlled by a regulated power supply. A maximum nominal temperature of 90 °C was targeted to stay below the boiling point of water. The condenser was used to condense any evaporative losses and was designed to

use either chilled water or flowing air. The 1-Liter adjusted Tank 50 salt solution was analyzed via Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES) for metals and Ion Chromatography (IC) for anions. Radiochemical counting techniques were applied to determine the Tc-99 concentration after separation of the Tc-99 from interfering nuclides in the Tank 50 salt solution. Tc-99m was used as a tracer, gamma pulse height analysis was used for tracer yield determination, and liquid scintillation counting was used for Tc-99 determination. Inductively Coupled Plasma – Mass Spectroscopy (ICP-MS) was used to analyze the iodide concentration in the adjusted salt solution.

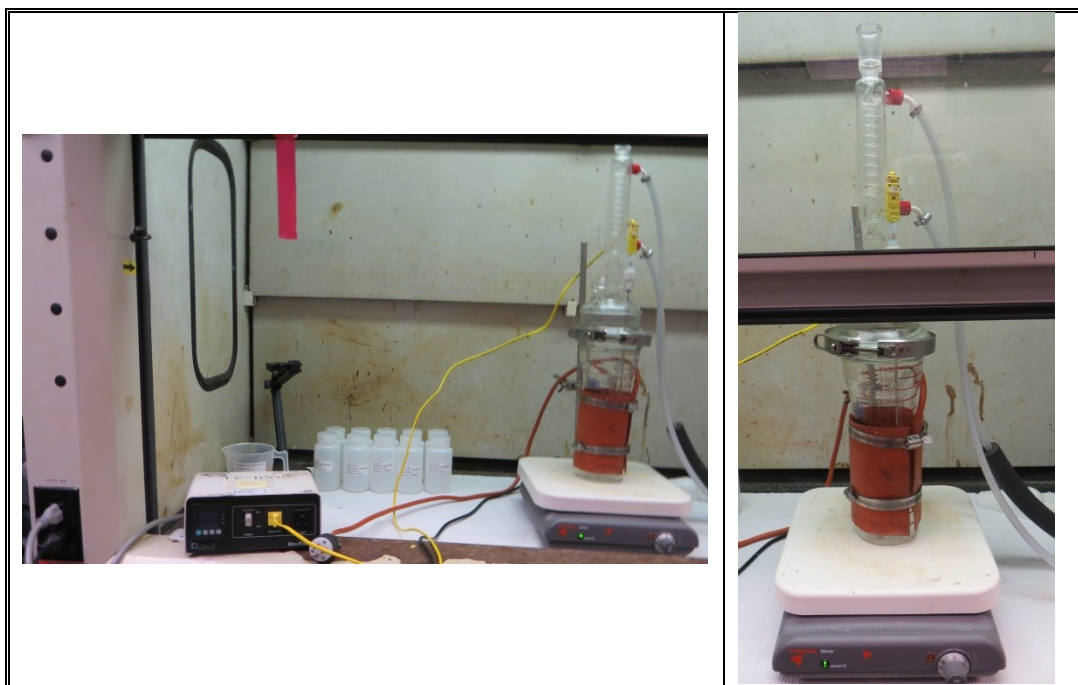


Figure 1. Apparatus for Mixing and Heating/Condensing of Adjusted Tank 50 Sample

2.2 Addition of Getters and Monolith Preparation

Getter chemicals were added to the adjusted Tank 50 salt solution before the monoliths were prepared. The getter chemicals KMS-2 and tin-apatite (Sn-A) were used to target Tc-99 retention. Silver zeolite (Ag-Z) was used to target iodine retention. The KMS-2 was substituted for pore modifier Xypex to incorporate additional getters tested at PNNL after the original task plan was approved.⁸ Further details regarding these getter materials including their sources and applications can be found in recent PNNL reports and references cited therein, describing fabrication and leach testing of simulant samples spiked with Tc-99.^{9,10} It should be noted that the previous study used both reagent water and a Hanford VZPW eluent¹⁰ whereas this present work with actual waste samples used only reagent water as eluent. The KMS-2 used in the present study was fabricated with a hydrothermal synthesis and was supplied to SRNL from PNNL,¹⁰ whereas the recent PNNL study used KMS-2 fabricated with a solid state synthesis, hence referred to as KMS-2-SS.¹¹ The Sn-A was also supplied by PNNL personnel and the Ag-Z was obtained from Sigma-Aldrich. Both the KMS-2 and the Sn-A were used as received. The Ag-Z was received as +20 mesh (+0.841 mm) granular material and was used as received with no further size reduction or crushing. Monoliths were prepared in duplicate using nominally 250

mL of the adjusted Tank 50 salt solution for each pair. A baseline, or control pair, of monoliths was prepared with no getter additives. Table 1 depicts the amounts of materials used in the monolith preparations. Water amounts were calculated from the adjusted salt solution using the averaged measured total wt% solids value of 27.99 wt%. For the Sn-A/Ag-Z system the Sn-A was added to the salt solution first and mixed for four days prior to adding the Ag-Z. This system was mixed overnight before monoliths were made. For the KMS-2/Ag-Z system the KMS-2 was added to the salt solution first and mixed for 48 hours followed by filtration of the solids through a 0.2 μ m nylon filter. These filtered solids were set aside to be added back in the final monolith preparation. The Ag-Z was then added and the system mixed overnight before monolith formation. The Ag-Z only system added Ag-Z directly to the premix dry materials. Premix dry materials for the monoliths consisted of 8 wt% OPC, 45 wt% Class F FA and 47 wt% GGBFS. For the formulation of the final grouts, the mass of getters was included in the premix in determining the free water to premix ratio. Grout slurries were prepared by slowly adding the pre-mixed dry materials into the solution such that a slight vortex was maintained during and after solids addition. After all the premix was added, the mixing continued for 10 additional minutes. Mixing was controlled using a variable speed mixer with a shaft/impeller that was previously used to support similar grout mixing efforts.¹² Photographs of the various 250-mL solutions after getter additions and prepared grouts are shown in Figure 2. Well mixed final slurries were poured directly into 2" x 4" plastic molds. The grouts were allowed to cure for 28 days in sealed polybags containing a damp cloth, resulting in monoliths for leach testing. The masses and volumes of final cured monoliths are provided in Table 1 for two monoliths obtained from the batched materials. The dry mass of each monolith was calculated using an extrapolated moisture content (26.57 wt%) determined from 105 °C drying tests that were previously performed on benchtop monolith samples at a 0.4 (mix number 2, Random run order 11) to 0.6 (mix number 35(20a), random run order 24) water-to-dry blend solids ratio.² These data were used to calculate a dry basis sample density as shown in Table 1.

Table 1. Summary of Mixes Used in Batch and Resulting Monoliths

Additive/Property		System and Sample Identification			
		Baseline	Sn-A and Ag-Z	KMS-2 and Ag-Z	Ag-Z
		BS1/BS2	Sn1/Sn2	KM1/KM2	Ag1/Ag2
Batched Materials quantities	Adjusted Tank 50 Salt Solution (g)	304.0	303.9	305.5	305.5
	Free Water in adjusted Tank 50 soln. (g)	218.9	218.8	220.0	220.0
	Free water/(premix+getter) ratio	0.55	0.55	0.55	0.55
	Premix (g)	398.0	375.8	384.7	358.3
	Getters (g)	0.0	(13.8) + (8.3) = 22.1	(6.9) + (8.4) = 15.3	41.7
	Total Mass (g)	701.9	701.8	705.4	705.6
Cured Monoliths Properties	Cured mass (g)	328.3 / 338.1	319.6 / 320.8	328.8 / 322.4	328.2 / 323.8
	Calculated Dry Mass (g)	241.1 / 248.2	234.7 / 235.5	241.5 / 236.8	241.0 / 237.7
	Measured Volume (cm ³)	181.0 / 188.2	173.4 / 174.4	177.8 / 170.1	191.8 / 188.9
	Calculated Dry Density (g/cm ³)	1.33 / 1.32	1.35 / 1.35	1.36 / 1.39	1.26 / 1.26
	Cured Density (g/cm ³)	1.81 / 1.80	1.84 / 1.84	1.85 / 1.90	1.71 / 1.71

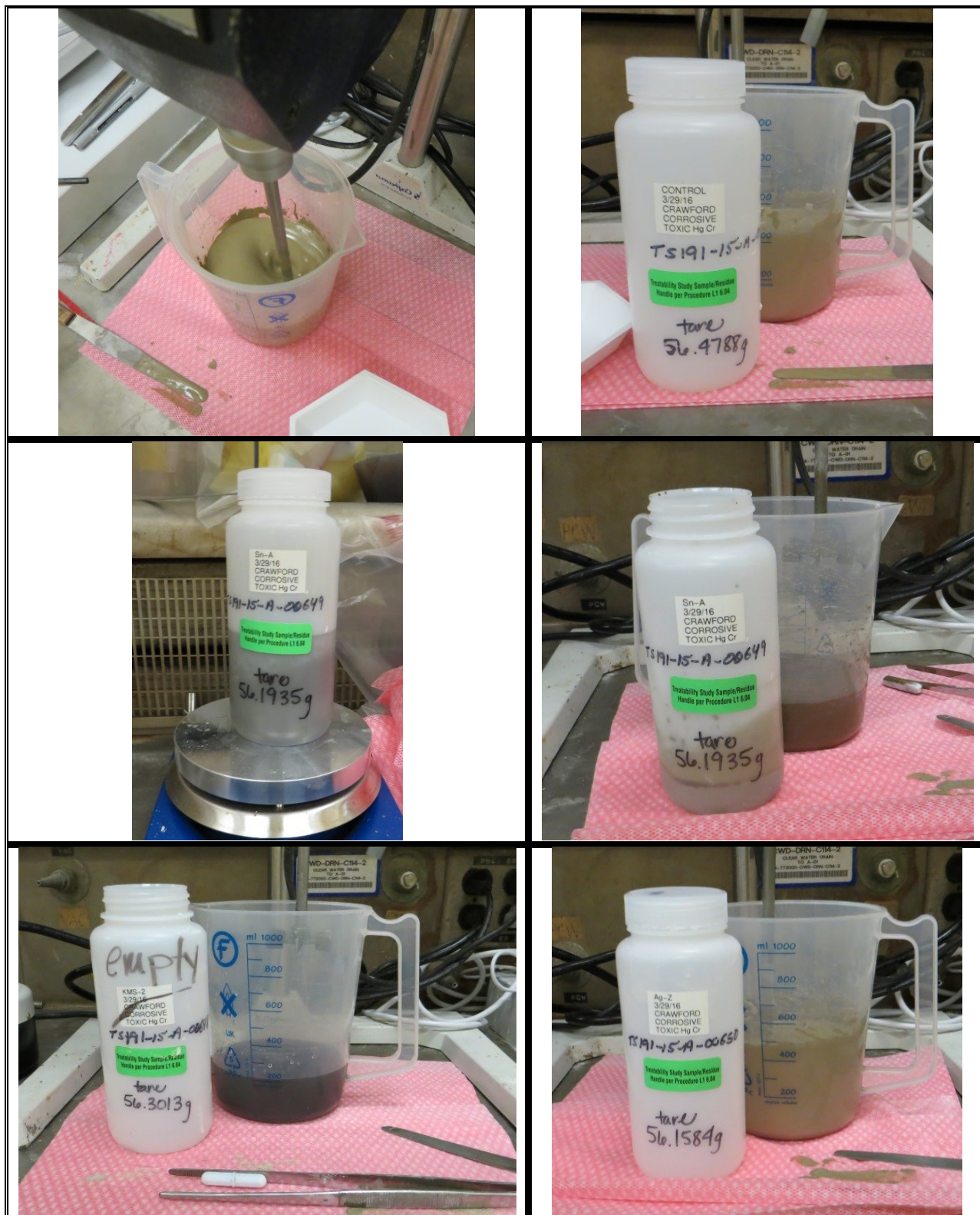


Figure 2. Photographs of System, Solutions, and Grout Preparation. Upper photographs show grout preparation with the Baseline slurry with no getters added. Middle photographs show the Sn-A samples. Lower photographs show the KMS-2 solution (left) and the Ag-Z slurry.

2.3 Leach Testing

Monolith samples were analyzed using the United States EPA Manual SW-846 Method 1315 leach test.¹³ Leachability indices (LI) were calculated based on the D_{obs} equation shown below as presented in Section 12.2.5 of Reference 13. Throughout this report the use of D_{obs} is equivalent to the EPA reference use of D^{obs} .

$$D_i^{obs} = \pi \left[\frac{M_{t_i}}{2\rho C_0 (\sqrt{t_i} - \sqrt{t_{i-1}})} \right]^2$$

Where:

D_i^{obs} = observed diffusivity of a COPC for leaching interval i (m^2/s)

M_{t_i} = mass released during leaching interval i (mg/m^2)

t_i = cumulative contact time at the end of the current leaching interval, i (s)

t_{i-1} = cumulative contact time at the end of the previous leaching interval, i-1 (s)

ρ = sample density (dry basis) ($kg\text{-}dry/m^3$)

C_0 = initial leachable content (i.e., available release potential) (mg/kg)

The LI is not part of the SW-846 Method 1315 procedure, but derives from an earlier form of the monolithic leach test as described by American National Standards Institute (ANSI) 16.1.¹⁴ The LI can be calculated as $(-)\log(D_{obs})$.¹⁴ The LI values for a given sample and analyte represent a single value that can be used to classify or rank the material.¹⁴ Leach tests were started 28 days after monolith preparation and were conducted in ultrapure water as the eluent with a resistivity $> 18 M\Omega\text{cm}$ (Barnstead Nanopure Infinity Ultrapure Water System). The EPA Method 1315 specifies the use of ‘reagent water’ as the eluent, with reagent water defined as free from constituents of potential concern, i.e., interferents.¹³ Eluents other than reagent water are also allowed.¹³ The leachates were analyzed via ICP-OES for aluminum, calcium, sodium, potassium and chromium with respective detection limits of 0.05 mg/L, 0.34 mg/L, 0.056 mg/L, 0.33 mg/L and 0.018 mg/L. Ion Chromatography was used to analyze for sulfate, nitrate and nitrite anions with a detection limit of 10 mg/L for each. The Tc-99 concentrations were determined by radiochemical counting methods with a nominal detection limit of ~ 5 disintegrations per minute dpm/mL or $1.33E-04$ mg/L. Natural iodide (I-127) was analyzed following the method of Zhang et al.¹⁵ Briefly, this method involves the quantification of 4-iodo-N,N-dimethylaniline which is formed by iodinating N,N-dimethylaniline and using 2,4,6-tribromoaniline as an internal standard. The analysis by Gas Chromatography-Mass Spectroscopy allows for distinguishing between stable I-127 and radioiodine (I-129). The nominal detection limit from this method is $\sim 1E-03$ mg/L. To reduce overall expense the I-127 and Tc-99 methods were only applied to a single set of leachates from each duplicate monolith set that was tested. Initial leachate concentration analyses showed mostly undetectable levels of Cr from ICP-OES and all Tc-99 values were below detection. Thus leachates from the last four leach intervals were re-analyzed via ICP-MS for both Cr and Tc-99. D_{obs} values were calculated based on the calculated as-batched analyte concentrations in the monoliths. Previous SRNL analyses of cement, slag and FA as detailed by Westsik et al. were used for the premix.² Calculated chemical compositions determined from their empirical formulas were used for the getters.

2.4 Quality Assurance

The SRNL work scope was performed in accordance with a Quality Assurance Program (QAP) that meets the Quality Assurance criteria specified in DOE Order 414.1D, Quality Assurance; 10 CFR 830, ‘Nuclear

Safety Management,” Subpart A, “Quality Assurance Requirements,” paragraph 830.122; and also meets the requirements of American Society of Mechanical Engineers (ASME) NQA-1-2004, Quality Assurance Requirements for Nuclear Facility Applications, including NQA-1a-2005 and NQA-1b-2007 Addenda, or later version. The SRNL work scope was performed in accordance with Savannah River Site Manual 1Q, QAP 2-3 (Control of Research and Development Activities). Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.

3.0 Results and Discussion

3.1 Adjusted Tank 50 Salt Solution

Table 2 shows the amounts of chemical additives used in the adjustment of the Tank 50 sample. These amounts were based on previous testing as described in the Task Technical and Quality Assurance Plan.⁸ Heating and mixing of the solution was required to get the added Al to dissolve. It was assumed that the aluminum hydroxide chemical reagent used was a hydrated form ($\text{Al}(\text{OH})_3 \cdot 3\text{H}_2\text{O}$). The ammonium salts of the sulfate and phosphate were used in place of more common sodium salts to prevent significant increase of the Na concentration of the original Tank 50 sample. These compounds were added after Al dissolution. It was assumed that the ammonium cation of these added salts would deprotonate and the ammonia could be evolved from solution. The potassium iodide and ammonium pertechnetate were added last.

Table 2. Chemicals and Masses Used in the Adjustment of the Tank 50 Sample

Chemical Name	Chemical Formula	Mass (g)
Aluminum hydroxide	$\text{Al}(\text{OH})_3 \cdot n\text{H}_2\text{O}$	18.69
Ammonium sulfate	$(\text{NH}_3)_2\text{SO}_4$	5.81
Diammonium phosphate	$(\text{NH}_3)_2\text{HPO}_4$	5.97
Potassium iodide	KI	0.118
Ammonium pertechnetate	NH_4TcO_7	0.37 mL of 0.5 mCi/mL solution

Table 3 lists the time increments, set temperature and measured temperature for the heating and stirring cycle of the adjusted Tank 50 salt solution. Complete dissolution of the aluminum hydroxide was observed near the end of the second heating cycle. The solution remained clear after cooling to ambient temperature. Table 4 provides the results from the metals, anion analysis, and radiochemical counting of the adjusted Tank 50 salt solution. Key species and concentrations from this table are listed in Table 5 and compared to the original Tank 50 salt solution and the targeted compositions. Both the elemental sulfur and phosphorus shown in Table 4 yield higher calculated values of either sulfate or phosphate than are shown for the actual anion analysis by IC. These differences likely indicate P and S containing species in the waste other than phosphate or sulfate. The IC-Anions values of phosphate and sulfate were used for calculated adjustments reported in Table 5.

Table 3. Data from Heating Cycles

Set Temperature (°C)	Measured Temperature (°C)	Time
30	19	09:45 (11-11-15)
30	30	10:00
30	31	12:00
40	31	12:00
40	40	12:15
40	40	14:00
50	40	14:00
50	49	14:15
50	50	15:00
50	50	15:35
18	50	15:35
18	47	15:50
30	26	06:07 (11-12-15)
30	26	06:07
30	30	06:15
50	31	07:00
50	40	07:07
50	50	07:22
60	50	08:00
60	60	08:23
65	60	08:30
65	65	08:52
70	65	09:00
70	70	09:23
75	70	09:30
80	75	10:00
85	80	10:30
90	85	11:00
90	89*	11:30
90	90*	12:00
50	90	12:30
Cool to ambient with stirring		

*Visual observation of clear solution indicating complete dissolution of the hydrated $\text{Al}(\text{OH})_3$

Table 4. Adjusted Tank 50 Analysis

Species	Concentration (mg/L)	Species	Concentration (mg/L)
Ag	< 2.2	S	4,290
Al	10,900	Sb	< 34.8
B	47	Si	61.8
Ba	0.1	Sn	< 22.1
Be	< 0.11	Sr	< 0.09
Ca	7.11	Th	< 6.27
Cd	< 1.6	Ti	< 9.35
Ce	< 13.1	U	< 51.3
Co	< 1.26	V	< 0.71
Cr	36.4	Zn	7.33
Cu	< 1.17	Zr	< 0.41
Fe	5.79	Fluoride	< 100
Gd	< 1.44	Formate	< 100
K	349	Chloride	< 100
La	< 0.72	Nitrite	21,500
Li	11.5	Bromide	< 500
Mg	0.72	Nitrate	129,000
Mn	< 0.42	Phosphate	3,280
Mo	< 3.55	Sulfate	9,020
Na	125,000	Oxalate	198
Ni	< 11.2	Iodide	85
P	1,820	Tc-99	2.46
Pb	< 17.1	--	--

Table 5. Comparison of Adjusted Tank 50 to Targets

Species	Tank 50 1QCY13 (WAC), mg/L	Tank 50, Adjusted		
		Avg. 5M Target, mg/L	Avg. Measured mg/L	Percent of Measured to Target
Aluminum	3,860	8,283	10,900	131.6
Phosphate	427	4,654	3280	70.5
Potassium	276	1,282	349	27.2
Sodium	120,236	114,949	125,000	108.7
Sulfate	4,050	8,261	9020	109.2
Nitrate	113,000	100,572	129,000	128.3
Nitrite	14,200	25,989	21,500	82.7
Iodide	~ 0.08*	100**	85**	85.0
Tc-99	1.22	2.44	2.46	100.8

*Calculated from the trace radioactive I-129 present in the 1QCY13 Waste Acceptance Criteria (WAC) sample

**As natural iodide (I-127)

3.2 Calculated Getters Additions

The calculated quantities of KMS-2 and Sn-A getters from Table 1 were determined using the analyzed Tank 50 adjusted composition, the reported reference reduction capacity of each getter and a multiplication factor of 100X (as compared to initial multiplication factors of only 10X reported in the TTQAP⁸). This increase from 10 to 100 was a decision made by WRPS. A reduction capacity of 7.88 millimol e⁻ / g KMS-2 was used to determine 7.16 g KMS-2 required for 250 mL of Tank 50 adjusted salt solution. This reduction capacity value supplied by WRPS to SRNL is within the range measured and that reported by Neeway et al. of 7.4 +/- 0.6 mequiv/g.¹¹ Equations 1 through 4 of the TTQAP were used, substituting KMS-2 for Sn-A.

The TTQAP⁸ calculation yielded a value of 4.06 g/L Sn-A targeted for Tc-99, using a PNNL measured reduction capacity of 7.53 mol e⁻ / mol Sn-A and a multiplication factor of 10X. The reduction capacity value was measured using the Ce(IV) methodology referenced by Neeway et al.¹¹ The same calculation method using; 1) the actual Tc-99 concentration from Table 4, 2) a lower reduction capacity of 4.00 millimol e⁻ / g Sn-A based on the Ce(IV) methodology measured value reported by Asmussen et al.,¹⁶ and 3) a multiplication factor of 100X yielded a value of 54.3 g/L Sn-A. The lower reduction capacity is likely due to oxidation of the Sn-A material over time as discussed by Asmussen et al.¹⁶ For 250 mL of Tank 50 adjusted salt solution, 13.58 g of Sn-A was required and 13.8 g of Sn-A was used. Based on the assumed reduction capacities of KMS-2 and Sn-A, roughly twice the amount of Sn-A was required as compared to KMS-2. Neeway et al. report a higher reduction capacity for KMS-2-SS (20 ± 3 mequiv/g) vs. KMS-2 (7.4 ± 0.6 mequiv/g) so use of the KMS-2-SS would require lower amounts of getter material (KMS-2-SS and Sn-A). Various reduction capacity values for the KMS-2 and the Sn-A are shown in Table 6.

The Ag-Z addition was calculated using equation 5 of the TTQAP and the measured value of natural I-127 from Table 4. Equation 5 of the TTQAP indicates that the molar amount of Ag from the Ag-Z getter material is targeted to match the summation of I⁻, Cl⁻ and F⁻ anions. The radioactive I-129 in Tank 50 was not used in this calculation since it was three orders of magnitude lower in concentration than the added I-127. This calculation yielded 33.1 g/L Ag-Z or 8.3 g Ag-Z for 250 mL of Tank 50 salt solution. This targeted concentration was for the Sn-A/Ag-Z and KMS-2/Ag-Z systems. For the Ag-Z system, WRPS determined that approximately 10% of the premix would contain Ag-Z, which is approximately five times the amount used in the Sn-A/Ag-Z and KMS-2/Ag-Z samples. Total premix mass was 400 grams, whereas 41.7 grams of Ag-Z was used for the Ag-Z sample.

Table 6. Comparison of Various Reduction Capacities for KMS-2 and Ag-Z

Getter	Grams/mole.	mol e ⁻ / mol X	mol e ⁻ / g X	mmol e ⁻ / g X
KMS-2	532.28	4.20	7.88E-03 ^a	7.88
Sn-A	1199.2	7.53	6.28E-03 ^b	6.28
Sn-A	1199.2	4.8	4.00E-03 ^c	4.00

a) Measured value supplied by PNNL, similar to reported value from Neeway et al.¹¹

b) Value referenced in TTQAP⁸ as initially measured and reported by PNNL in April 2015.

c) Value measured by Asmussen et al. for Sn-A reported in November 2016.¹⁶

3.3 Calculated Chemical Composition of Monoliths

The chemical composition of the monoliths was calculated using the measured Tank 50 adjusted salt solution (Table 4), the previously analyzed chemical compositions of the premix additives² and the chemical composition calculated based on the empirical formulae of the getters. These compositions are shown in Appendix A. Table 7 shows the overall calculated chemical composition of each monolith formulation.

Table 7. Calculated Chemical Composition of the Monolith

Species	Baseline (wt%)	Sn-A and Ag-Z (wt%)	KMS-2 and Ag-Z (wt%)	Ag-Z (wt%)
Ag	0	0.005	0.005	0.026
Al	4.49	4.26	4.33	4.07
Ba	0.14	0.13	0.13	0.12
Ca	12.52	11.82	12.04	11.23
Cr	0.01	0.01	0.01	0.01
Fe	1.28	1.21	1.23	1.15
K	0.42	0.39	0.40	0.37
Mg	1.36	1.29	0.39	1.22
Mn	0.06	0.05	0.05	0.05
Na	5.08	5.04	5.06	5.02
P	1.06	0.07	0.06	0.06
S	0.75	0.72	0.73	0.69
Si	10.72	10.12	10.31	9.60
Sn	0.00	0.002	0.004	0.00
Sr	0.09	0.08	0.08	0.08
Ti	0.19	0.18	0.08	0.17
Zn	0.01	0.01	0.01	0.01
Zr	0.01	0.01	0.01	0.01
NO ₃ ⁻	4.54	4.54	4.54	4.54
NO ₂ ⁻	0.76	0.76	0.76	0.76
Cl ⁻	<0.001	0.001	<0.001	<0.001
C ₂ O ₄ ²⁻	0.01	0.01	0.01	0.01
I	3.0E-03	3.0E-03	3.0E-03	3.0E-03
Tc-99	8.67E-05	8.66E-05	8.66E-05	8.66E-05

3.4 Leach Testing

Initial Leachate Analyses

Leachate concentrations from leach testing the monoliths are shown in Appendix B. D_{obs} values were calculated for ten species using EPA Method 1315, Section 12.2.5 and are tabulated in Appendix B. The Cr leachate concentrations were below the method detection limit for all of the baseline, the KMS-2/Ag-Z and the Sn-A/Ag-Z samples. Some detectable Cr concentrations were observed for the Ag-Z sample leachates (T4 and T6 time intervals for Ag-Z 1 and T4, T5, T6, T8 and T9 for Ag-Z 2). Ag-Z is used as a getter for iodide by formation of the highly insoluble AgI. Currently there is no explanation as to why the Ag-Z only samples (41.7 g Ag-Z per duplicate monolith) would show lower retention of Cr than the other samples containing Ag-Z (Sn-A and KMS-2 with 8.4 g Ag-Z per duplicate monolith) or the baseline monoliths with no Ag-Z. All the Tc-99 concentrations were below the method detection limit of nominally 5 dpm/mL, or about 0.0001 milligram per liter (mg/L).

It was decided through consultation with WRPS to reanalyze the last four time interval leachates using ICP-MS for both Cr and Tc-99 due to the lower detection limit of nominally 10 parts per trillion (ppt). All Cr and mass Tc-99 values were detectable. The results are shown in Appendix C and are discussed later in this section.

Plots of the ten analyte D_{obs} values from all the initial leachate analyses are shown in Figure 3 through Figure 12. Figure 3 shows some higher D_{obs} values for the Ag-Z matrix with few detectable Cr values but overall the other three matrix sets (BS, KM and Sn-A) are all grouped together as no Cr was detected in these leachates. Comparison of the various D_{obs} values for each getter-containing monolith sets for iodide in Figure 12 indicates significantly better retention for iodide in the Ag-Z sample. The incremental D_{obs} values plotted in Figure 11 used Tc-99 values that were below detection limit so no conclusions could be made on the getter effectiveness from these initial leachate analyses that used radiochemical counting methods.

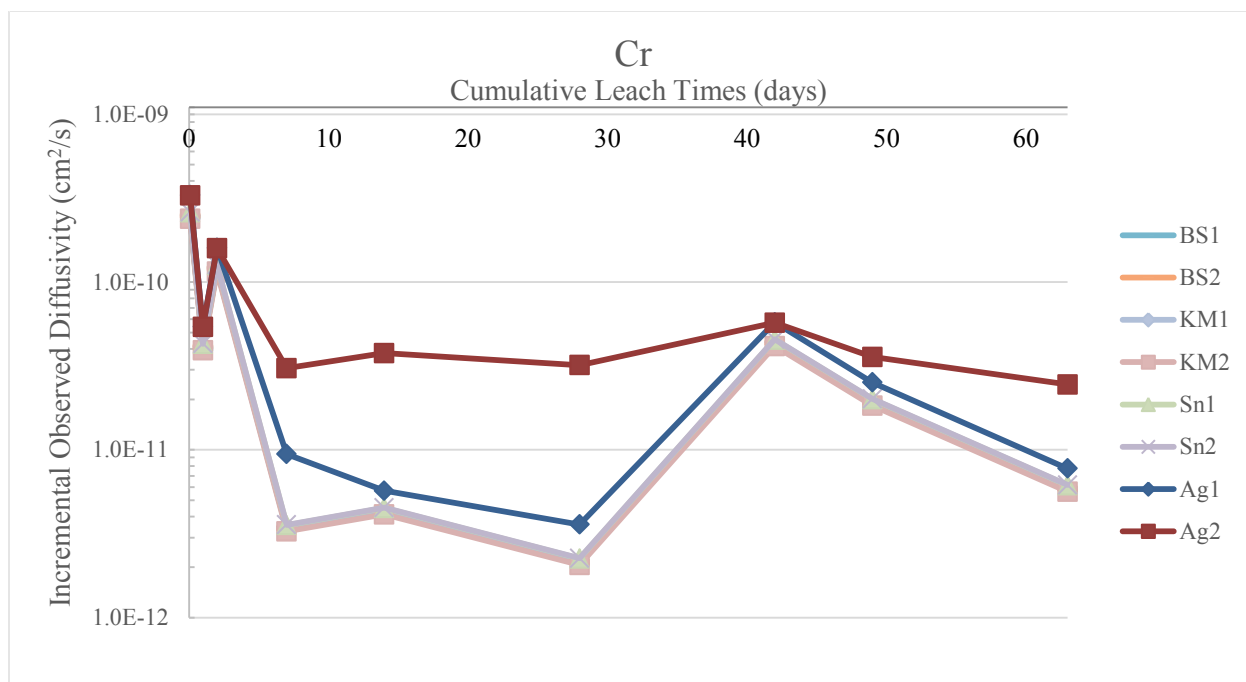


Figure 3. Chromium Observed Diffusivities.

The baseline, KM and Sn-A leachates are all less than detection limits. Some detectable Cr values are present for the Ag-Z sample leachates – see text.

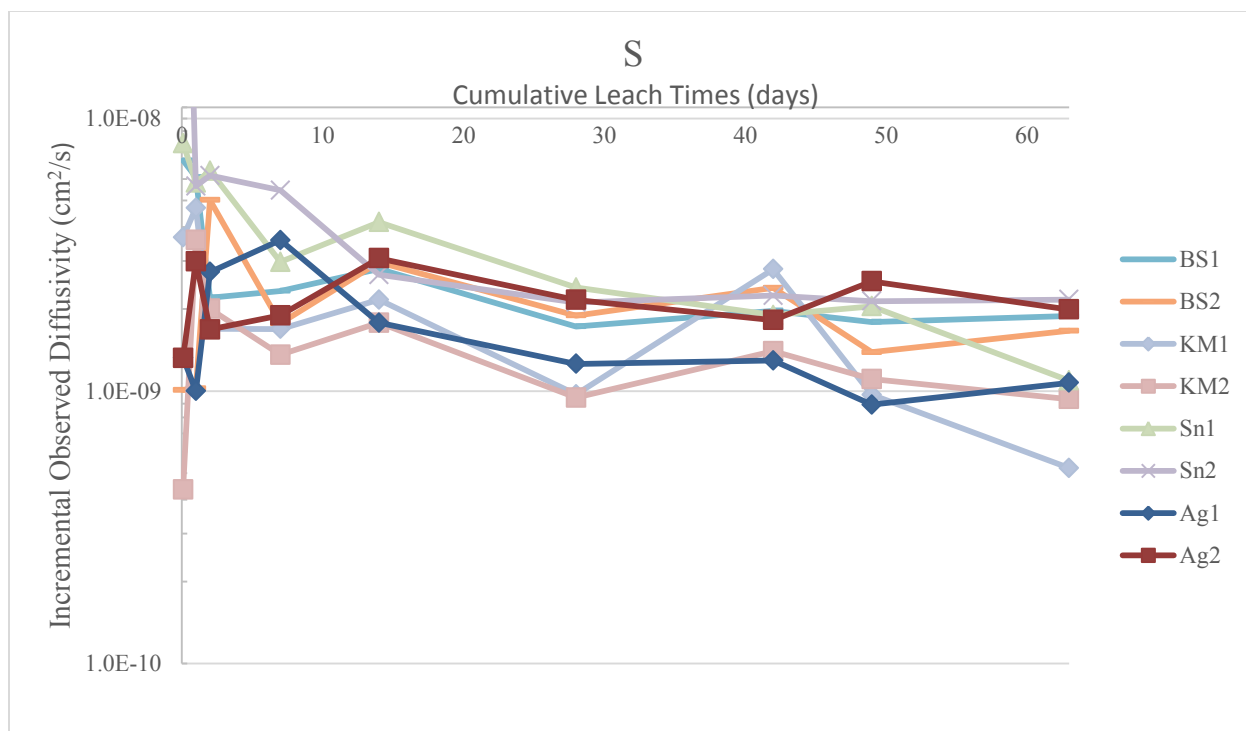


Figure 4. Sulfur Observed Diffusivities

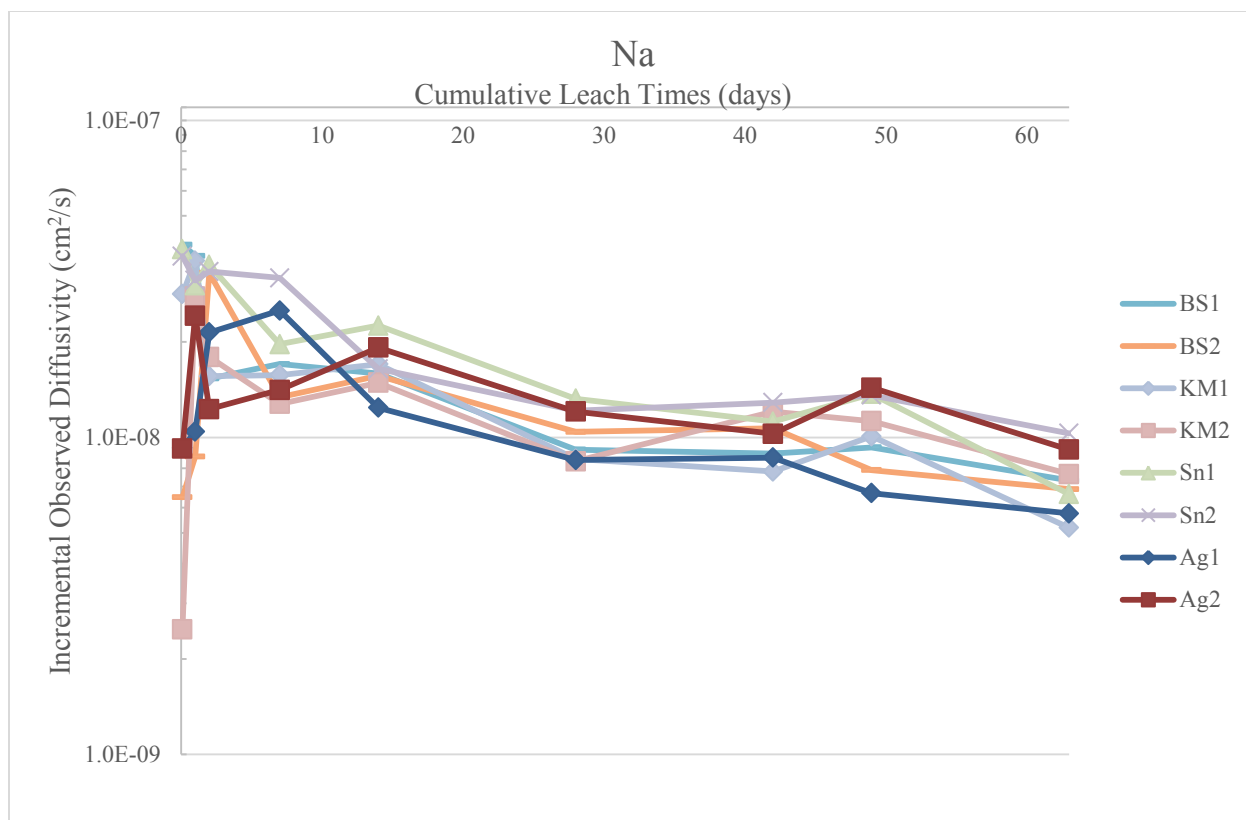


Figure 5. Sodium Observed Diffusivities

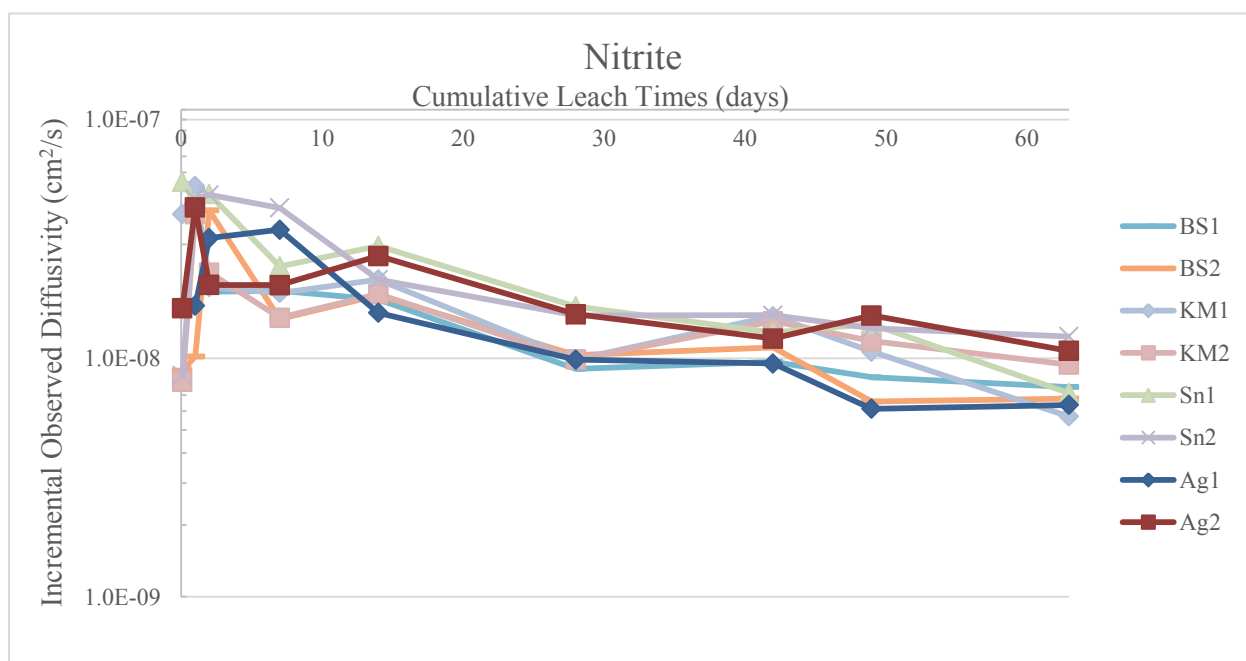


Figure 6. Nitrite Observed Diffusivities

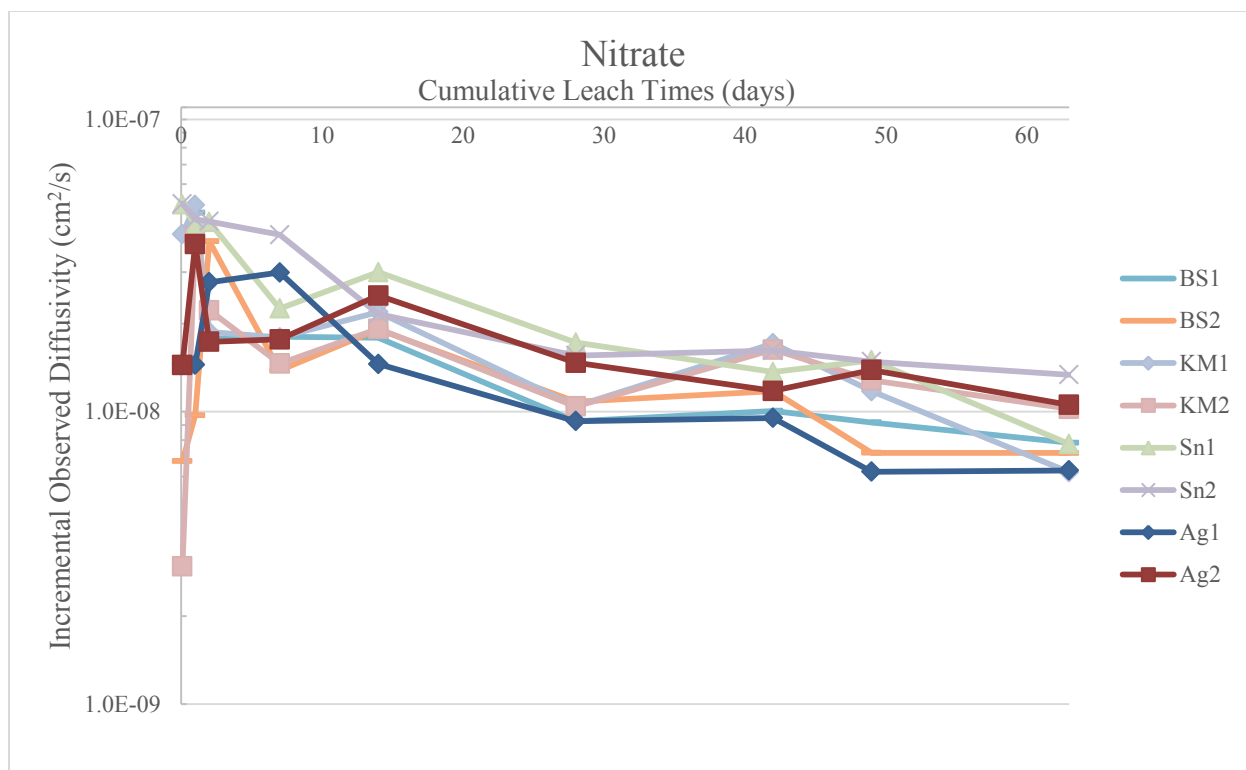


Figure 7. Nitrate Observed Diffusivities

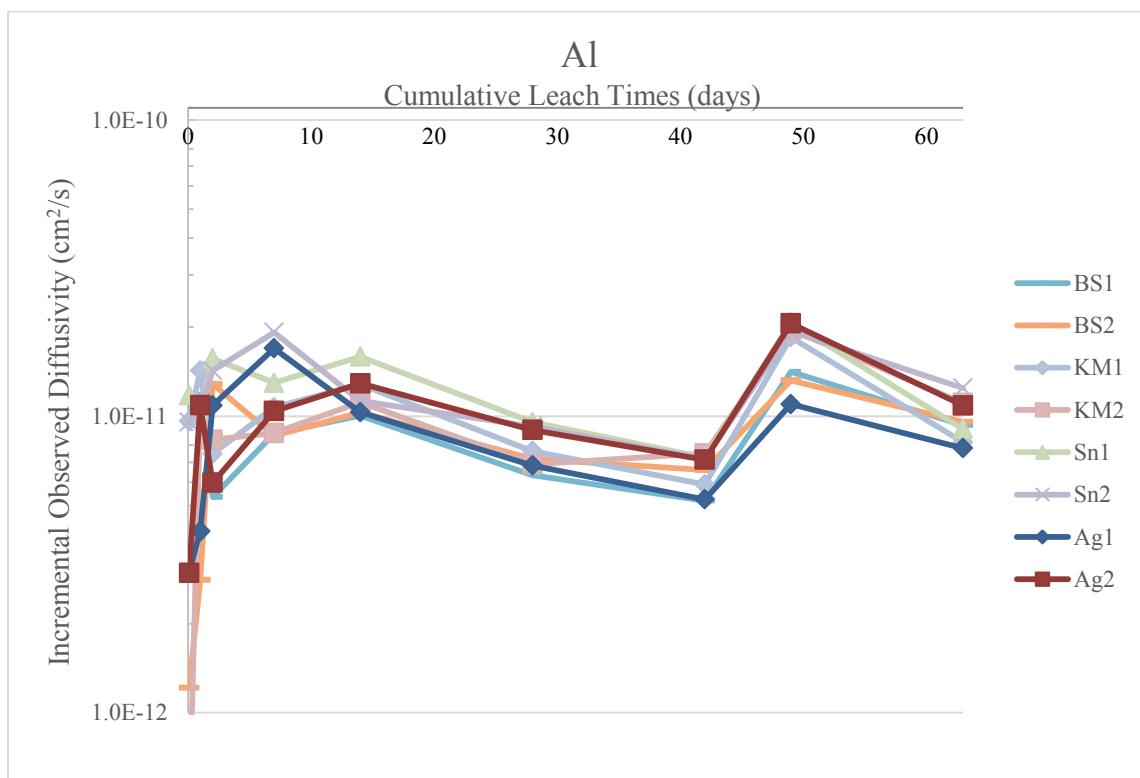


Figure 8. Aluminum Observed Diffusivities

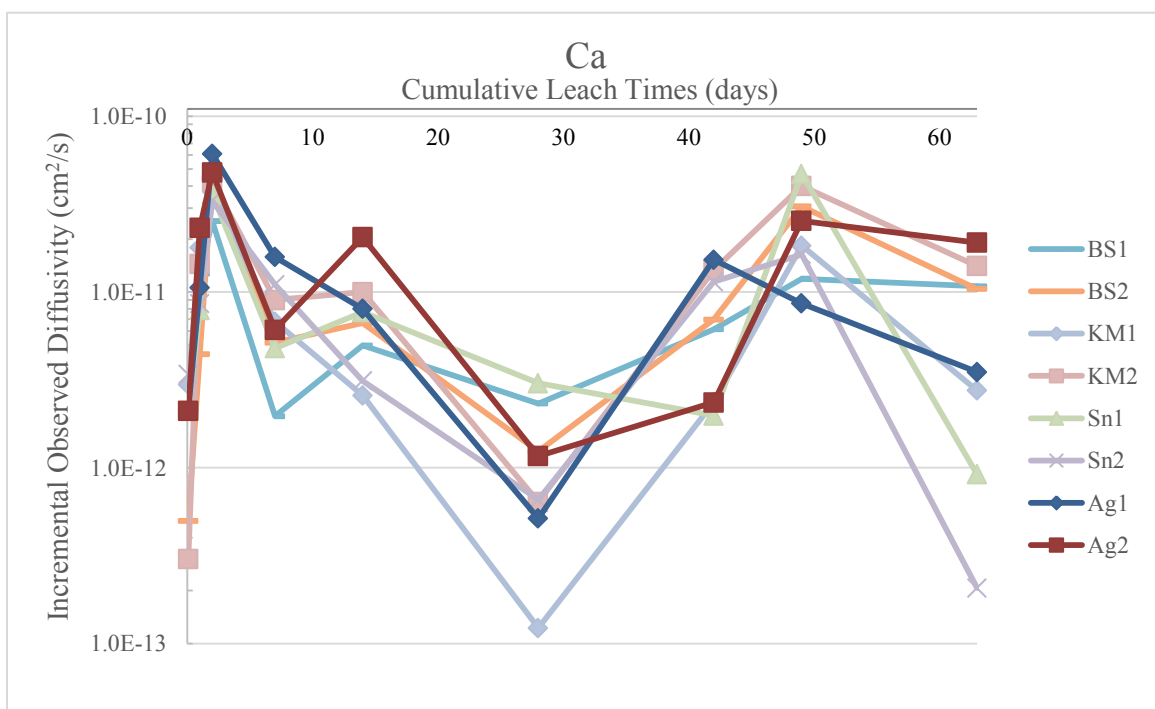


Figure 9. Calcium Observed Diffusivities

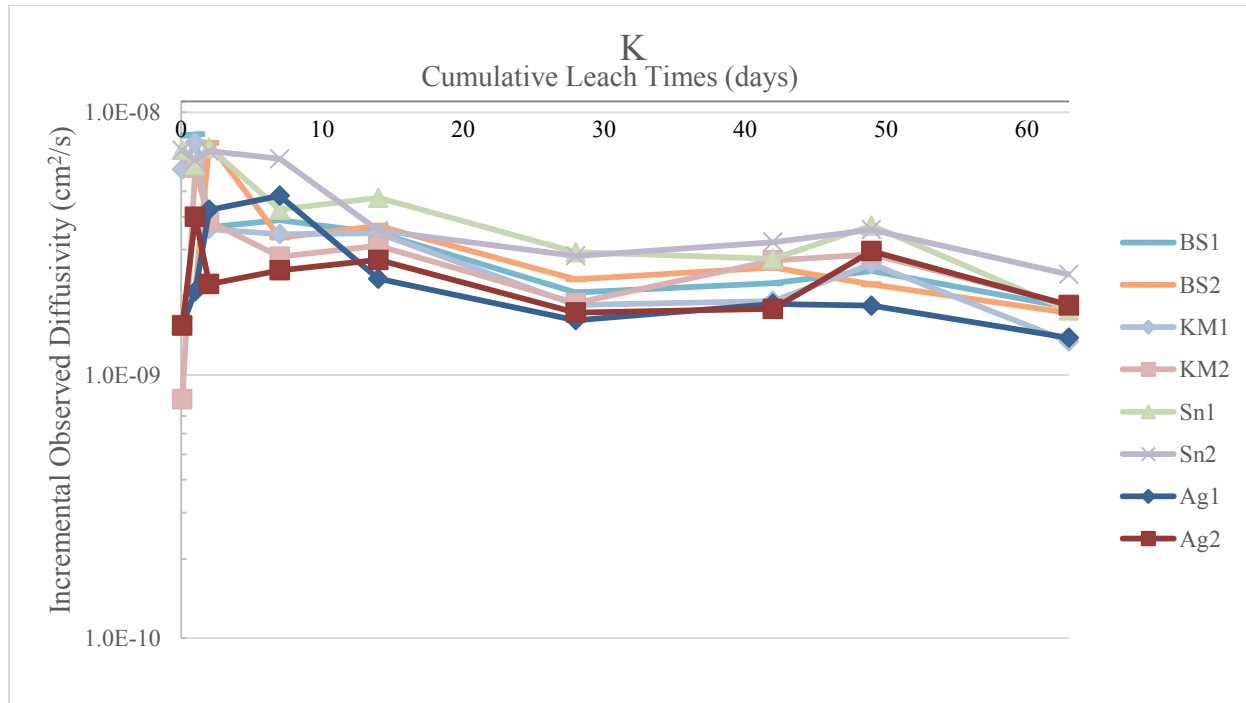


Figure 10. Potassium Observed Diffusivities

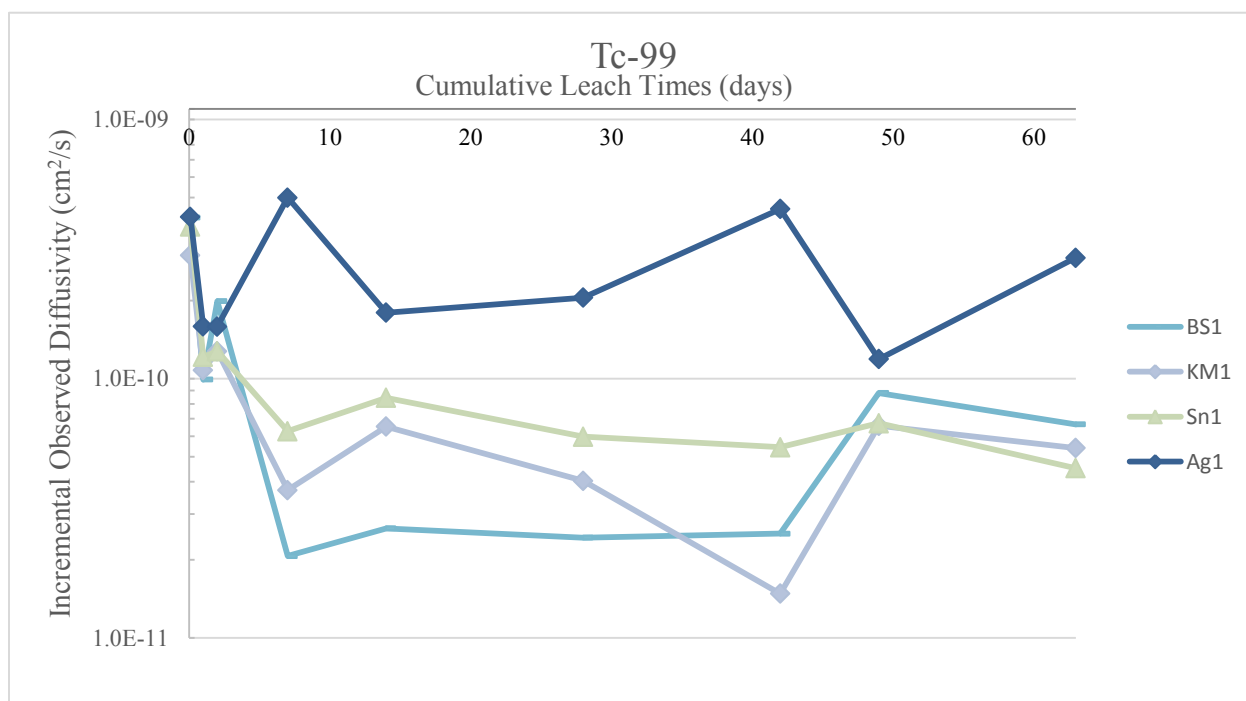


Figure 11. Tc-99 Observed Diffusivities based on less than detect Tc-99 leachate concentrations

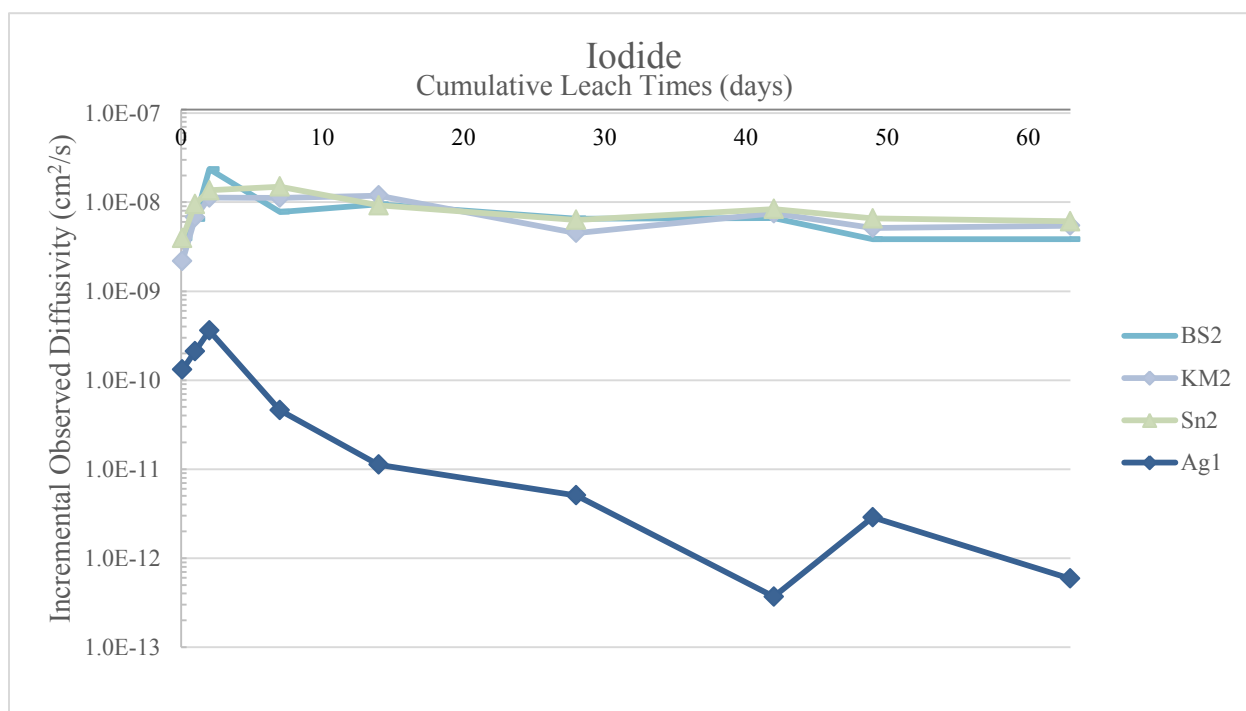


Figure 12. I-127 Observed Diffusivities

Leachates were measured for pH and conductivity after each leach interval. These data are tabulated in Table 8 and Table 9. As noted in Appendix B, the leachate sample from Sn-A#2 was inadvertently acidified prior to analyses so no pH or conductivity data are shown for this sample. Similarly the leachate sample from Ag-Z#1 was inadvertently discarded prior to any analysis.

Table 8. pH Data

Interval	Cumulative Time (days)	BS1	BS2	KM1	KM2	Sn1	Sn2	Ag1	Ag2	Blank
T01	0.08	10.61	10.4	10.62	10.18	10.95	NA	NA	10.48	6.69
T02	1	11.28	10.97	11.14	11.17	11.22	11.23	11.14	11.32	7.77
T03	2	10.97	11.06	10.84	10.88	11.06	11.06	11.14	11.01	6.98
T04	7	11.54	11.76	11.59	11.47	11.92	11.74	11.8	11.88	6.63
T05	14	11.1	10.98	11	11.1	11.1	11.06	10.98	11.08	7.35
T06	28	11.06	11.09	11.04	10.96	11.18	11.11	10.95	11.11	6.94
T07	42	10.93	10.92	10.8	10.99	10.9	10.95	10.8	10.82	6.88
T08	49	10.52	10.45	10.48	10.7	10.47	10.63	10.45	10.75	6.32
T09	63	10.9	10.86	11.04	11.18	11.05	11.2	11.3	11.23	8.32

Table 9. Conductivity Data ($\mu\text{S}/\text{cm}$)

Interval	Cumulative Time (days)	BS1	BS2	KM1	KM2	Sn1	Sn2	Ag1	Ag2	Blank
T01	0.08	770	426	845	286.6	1009	NA	NA	577	2.13
T02	1	2565	1323	2433	2182	2205	2339	1411	1763	2.67
T03	2	1091	1495	1114	1150	1498	1456	1140	858	2.24
T04	7	2593	3020	2694	2527	3590	3730	3050	2483	3.28
T05	14	2646	2546	2456	2612	2732	2607	2268	2450	2
T06	28	2801	2769	2359	2538	2961	2920	2384	2801	1.03
T07	42	2095	2139	1965	2383	2231	2507	1943	2016	1.01
T08	49	980	974	953	1146	1219	1164	852	1159	0.92
T09	63	1244	1450	1406	1729	1419	1539	1305	1450	1.49

Plots of the leachate pH are shown in Figure 13 and plots of the conductivity are shown in Figure 14. These plots show the individual interval values T01 through T09 as a function of the monolith types. The overall pH range for these leachates is between pH 10.2 and 11.9, with an average pH of 11. The pH measurements of the ultrapure water blanks were on average 7.1 ± 0.6 . Leachate conductivity values varied across all time intervals for all the samples and are all below 4,000 $\mu\text{S}/\text{cm}$. Conductivity measurements on the ultrapure blank water solutions averaged 2 ± 1 $\mu\text{S}/\text{cm}$. Two of the conductivity data points for the T01 (2 hour samples) interval show as zero values in Figure 14. These two sample leachates were not able to be measured due to an inadvertent nitric acid spike (sample 6) and a leachate discard before analysis (sample 7). Similar leachate pH ranges and conductivity ranges were also measured for previous 2014 ES Demo leach testing.⁵

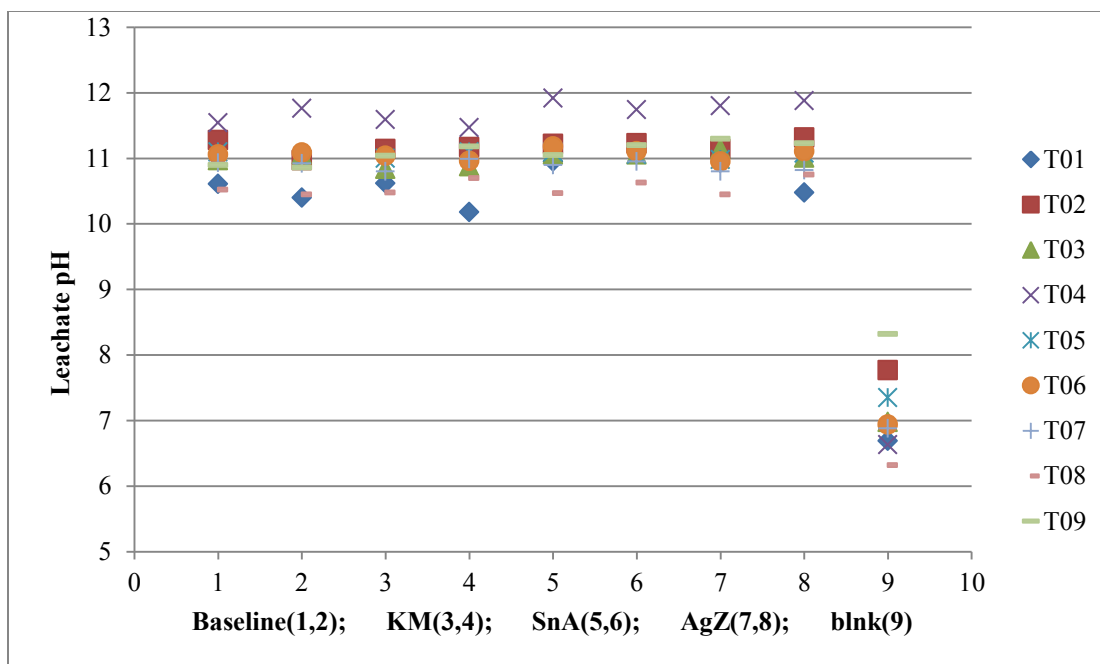


Figure 13. Leachate pH as Function of Monolith Type

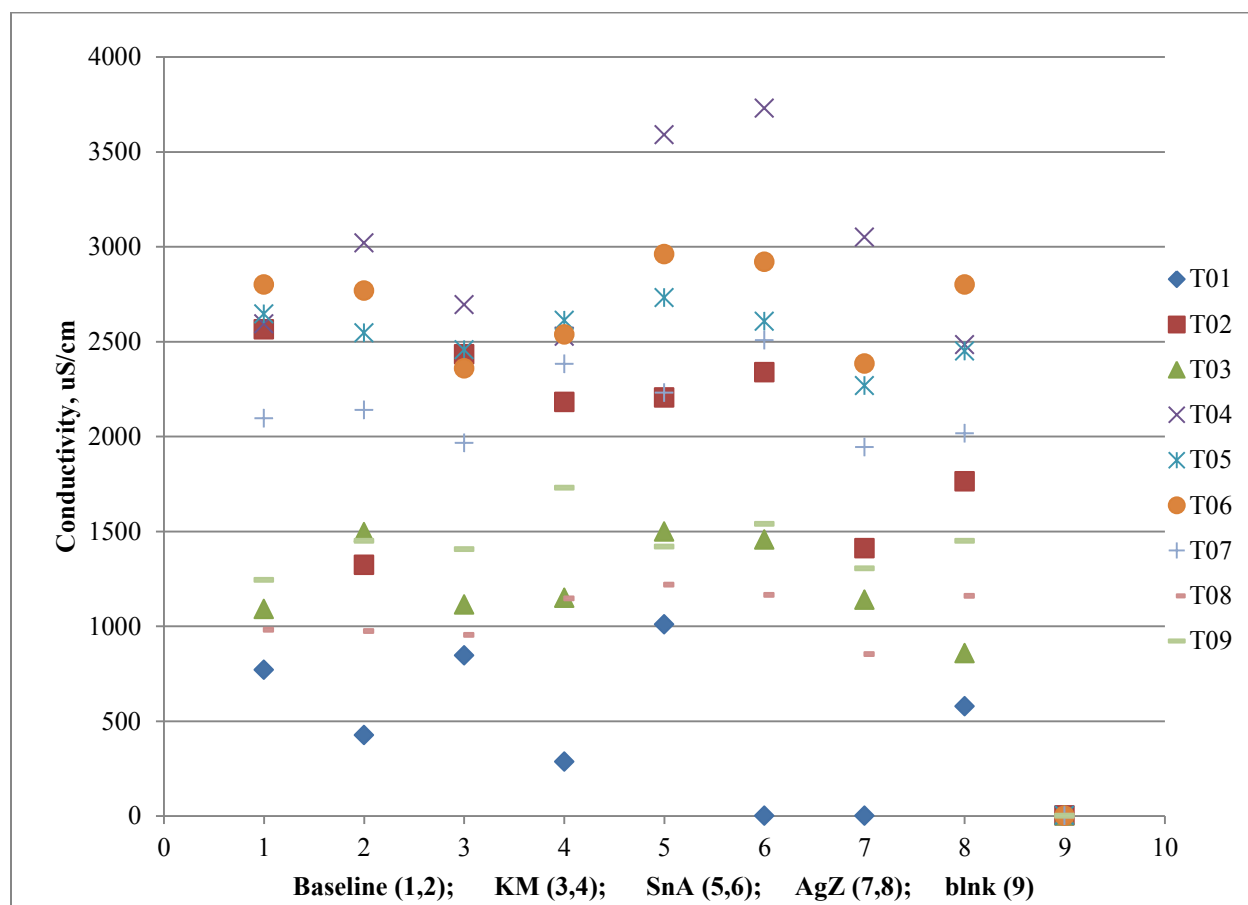


Figure 14. Leachate Conductivity as Function of Monolith Type

The average LI values were determined using the D_{obs} values for the ten analytes shown in Figure 3 through Figure 12. These values are shown in Table 10. For each replicate the average LI was computed for each analyte by summing the individual LI values at each time interval and dividing by the total number of time intervals (9). The two average LI values for the replicate pair were then averaged and are shown in Appendix D. The average (D_{obs}) for Cr in the Ag-Z system is shown as a \geq value in Table 10 since only seven of the original eighteen leachate values were above detection limits for these ICP-OES analyses. Reanalysis of the last four interval leachates by ICP-MS yielded detectable Cr values for all leachates and these data are discussed below.

Only single leachate sets were analyzed for both Tc-99 and I-127. The average LI values indicate similar magnitudes for all the analytes for each set of monoliths. One exception is the higher LI for I-127 in the Ag-Z sample. The LI values for Al and Ca were similar in magnitude of about 11 and the LI values for S, Na, NO_2 , NO_3 , K and I were similar in the range of 7.6 to 8.8. One exception to this observation is the higher LI of 10.9 for the Ag-Z monolith for iodide, indicating a much lower leach rate than the other monoliths. Thus, as recommended from previous testing at PNNL, the addition of 5X amount of Ag-Z into the premix (vs. the 1X addition of Ag-Z into salt solution for either KMS-2/Ag-Z or Sn-A/Ag-Z) can improve the retention of iodide. No detectable Tc-99 was observed in any of the leachates so these LI values are reported as 'greater than' values. No detectable Tc-99 was measured in any of the leachates which yields LI (Tc-99) values of > 9.6 to > 10.2 . Reanalysis of the last four interval leachates by ICP-MS gave detectable Tc-99 values for all leachates and these data are discussed below.

Table 10. Average Leachability Index Values

Species	Average Leach Index Values For Each Monolith Type			
	BS	KMS-2/Ag-Z	Sn-A/Ag-Z	Ag-Z
Cr	>10.8	>10.8	>10.7	$\geq 10.4^*$
S	8.6	8.8	8.4	8.8
Na	7.9	7.9	7.7	7.9
NO_2	7.9	7.8	7.7	7.8
NO_3	7.9	7.8	7.6	7.8
Al	11.1	11.1	10.9	11.1
Ca	11.2	11.2	11.3	11.1
K	8.5	8.6	8.4	8.7
Tc-99	>10.2	>10.2	>10.1	>9.6
I-127	8.2	8.2	8.1	10.9

*seven of the original eighteen leachates analyzed by ICP-OES gave detectable values for Cr

Reanalysis of Last Four Leach Time Interval Leachates for Cr and Tc-99

As discussed above in the initial leachate analyses, the last four time interval leachates were reanalyzed using non-diluted leachates with ICP-MS. All of these Cr and Tc-99 data were analyzed as detectable species and Appendix C shows the measured concentrations and calculated D_{obs} values. Average LI values calculated from these D_{obs} values are shown in Table 11 and compared to the LI values determined

from the last four time intervals for the original analyses. The lower detectable ICP-MS values for Cr in the reanalysis resulted in LI values that are ~ 1.5 units higher than the original analyses using less than detectable ICP-OES values for the baseline, KMS-2 and Sn-A samples. Similar LI (Cr) values are obtained for Ag-Z with the reanalyzed Cr concentrations compared to the initial analyses where limited detectable Cr values were obtained. The ICP-MS data for Tc-99 show that the samples containing Tc getters (KMS-2 and Sn-A) are not effective in suppressing the leachability of Tc-99 in the pure water leachant. Addition of Ag-Z directly into the premix solids at the levels used for these tests appears to increase the leachability of both Cr and Tc-99, even though it significantly reduces the iodide release. One explanation for this observation could be that the added Ag-Z expends some of the reducing capacity of the GGBFS in the premix. Varying the relative amounts of Ag-Z and GGBFS in the premix could also be performed for further testing..

Table 11. Comparison of LI Values Calculated from Last Four Leach Intervals

Analyses-Intervals	Species	Average Leach Index Values For Each Monolith Type			
		BS	KMS-2/Ag-Z	Sn-A/Ag-Z	Ag-Z
Initial – Last Four	Cr	>11.0	>11.0	>11.0	≥10.8*
Reanalysis – Last Four	Cr	12.6	12.4	12.5	10.6
Initial – Last Four	Tc-99	>10.4	>10.4	>10.3	>9.6
Reanalysis – Last Four	Tc-99	10.9	10.3	10.1	9.3

*four of the eight original leachates analyzed gave detectable values for Cr

The reanalyzed D_{obs} values of the last four time intervals are compared to previous studies using monoliths prepared with radionuclide spiked simulants with similar getter materials and leached in deionized water from PNNL.¹⁰ Table 12 shows the various averaged D_{obs} values for the baseline, KMS-2 and Sn-A. As mentioned earlier, the PNNL studies used KMS-2-SS synthesized from solid state methods versus the KMS-2 material synthesized from hydrothermal methods that were used in this study. All averaged D_{obs} values shown in Table 12 for Tc-99 and Cr in the shaded cells are calculated from only the final four time intervals for direct comparison. All other D_{obs} values shown are averages of all nine time intervals. Comparison of these values shows that the spiked PNNL simulants and the actual radioactive material used at SRNL yielded similar leachability data for the baseline as well as for the two systems with either the Sn-A plus Ag-Z or KMS-2 plus Ag-Z getters for the radioactive species.

Table 12. Comparison of D_{obs} from Samples Made with Real Waste and Simulated Waste and Leached in Water*

System	Species	SRNL D_{obs}	PNNL D_{obs}
Baseline	Tc	1.2E-11	2.7E-11
	Cr	2.4E-13	2.0E-13
	Na	1.5E-08	4.8E-09
	NO ₂ ⁻	1.8E-08	5.3E-09
	NO ₃ ⁻	1.7E-08	4.9E-09
	I	8.0E-09	8.0E-09
Sn-A	Tc	7.7E-11	1.8E-11
	Cr	3.4E-13	1.9E-13
	Na	2.2E-08	5.2E-09
	NO ₂ ⁻	2.6E-08	5.9E-09
	NO ₃ ⁻	2.8E-08	5.4E-09
	I	8.7E-09	4.0E-09
KMS-2	Tc	5.0E-11	2.0E-11
	Cr	4.4E-13	2.1E-13
	Na	1.4E-08	4.4E-09
	NO ₂ ⁻	1.9E-08	5.0E-09
	NO ₃ ⁻	1.9E-08	4.2E-09
	I	7.3E-09	4.9E-09

*SRNL eluent used ultrapure water (> 18 MΩcm), PNNL eluent used deionized building water.¹⁰
Shaded cells indicate D_{obs} calculated from final four leach intervals

EPA Method 1315 states that the release of chemical species is likely being controlled by a diffusion controlled process if a plot of the logarithm of the cumulative release of the species versus the logarithm of leaching time yields a trend line with a slope in the range of 0.35 to 0.65 (EPA Method 1315, Section 12.2.5) over the complete range of the data set. Plots for logarithm of the cumulative release of the species release from one of the replicate monoliths of the four different types of monoliths versus the logarithm of leaching time studied in this work are presented in Appendix E and are fitted with a linear equation. Equations for the best linear fit including the R^2 values are shown on each plot. The slopes from these plots, as well as the other duplicate in each monolith pair, indicate that all the species are within the 0.35 to 0.65 range. Plots for Cr and Tc-99 are not applicable since only data for the last four time intervals data are available. Table E-1 shows the slopes tabulated for all species and all monoliths with overall monolith species averages in the range of 0.35 to 0.69. The one slope value of 0.69 for Ca in one of the KM monoliths is the only sample outside of the 0.35 to 0.65 range. If each duplicate monolith set of slopes are averaged, then the slope ranges are from 0.43 to 0.59.

4.0 Conclusions and Recommendations for Further Work

Successful chemical adjustment of an actual SRS Tank 50 radioactive salt solution to mimic a Hanford salt solution was performed. Preparation of the radioactive salt solution was followed by getter additions (KMS-2, Sn-A, Ag-Z), generation of monoliths and subsequent leach testing in reagent water. The following conclusions can be made from this report:

- Chemical adjustment of the SRS Tank 50 radioactive salt solution by the addition of aluminum, sulfate, phosphate, Tc-99, and natural iodide met target levels as determined by chemical/radiochemical analysis. Elemental analysis for both P and S from the adjusted salt solution gave higher calculated levels of phosphate and sulfate from IC-anions analysis suggesting that other P and S containing species are present in the waste.
- Monolith leach tests conducted in reagent water indicate no significant differences in D_{obs} values for the getter-containing monoliths versus the baseline monoliths. The only exception observed was the increased retention of iodide in the Ag-Z monolith leach test. Initial analysis of leachates using ICP-OES for Cr and radiochemical counting methods for Tc-99 provided less than detectable results for these two analytes with the exception of some detectable values for Cr in the Ag-Z system.
- LI values are in similar ranges for two groups of analytes consisting of Cr, Al, Ca and S, Na, NO_2 , NO_3 , K and I. The LI values for Cr were in the range of 12.5 to 12.6 except for the Ag-Z samples that were lower at 10.6 and the LI values for Al and Ca were similar in magnitude of about 11. The LI values for S, Na, NO_2 , NO_3 , K and I were in the range of 7.6 to 8.8. The lower LI values indicate approximately 3 orders of magnitude higher D_{obs} values for the 2nd group of analytes.
- Reanalysis of the last four leach interval leachates for Cr and Tc-99 via ICP-MS with no dilution of the samples yielded detectable quantities of both Cr and Tc-99. These data showed that the LI values for neither Cr nor Tc-99 show improved retention in the KMS-2/Ag-Z or Sn-A/Ag-Z samples when leached in reagent water relative to baseline non-getter containing samples. The LI values are in the range of 12.5 to 12.6. The LI values for Cr for the Ag-Z sample was 10.6, clearing indicating it was releasing a lot more Cr relative to the other samples. The LI values for Tc-99 indicated that the baseline sample retained Tc-99 better than any of the samples, with the Ag-Z having the lowest LI value.
- The Ag-Z samples that used five times the amount of Ag-Z versus the KMS-2/Ag-Z or Sn-A/Ag-Z sample showed increased retention of iodide with an average LI of 10.9 and lower retention for both Cr and Tc-99 when compared to either the baseline samples or the mixed getter samples containing KMS-2/Ag-Z or Sn-A/Ag-Z. It is possible that the added Ag-Z substituted at 10 wt% of the required premix expends some of the reduction capacity of the GGBFS in the premix.

Recommendations for Further Work

- These studies intentionally used natural iodide (I-127) spike additions of nominally 100 mg/L to ensure detectable iodide was present in the leachates. However, this level of iodide concentration is orders of magnitude higher than the actual 12 pCi/mL, or 0.07 mg/L of I-129 present in SRS Tank 50 salt solution.⁶ Subsequent studies could target either lower levels of natural iodide or increased levels of radioactive I-129 to investigate iodide release in the presence of getters.

- The only significant reduction in release of natural iodide observed in this study was for the Ag-Z system which incorporated relatively high amounts of Ag-Z (5.9 wt% of the total batch per Table 1). The KMS-2/Ag-Z and Sn-A/Ag-Z samples were fabricated with relatively lower (1.1 wt% of total monolith) amounts of Ag-Z added into the salt solution. These two systems did not show iodide retention over that of the baseline. Future testing could characterize the effects on iodide retention as a function of reduced Ag-Z additions below the 5.9 wt% level down to the 1.1 wt% level used in the solution additions, and as a function of either solution or premix additive strategy. Varying the relative amounts of Ag-Z and GGBFS in the premix could also be performed.
- Previous work by PNNL has shown significant retention of Tc-99 using the KMS-2 and Sn-A getters in Cast stone monolithic samples prepared from spiked simulants that were leached in Hanford VZPW.¹⁰ Lower measured Hanford VZPW eluent pHs vs. the pHs of reagent water eluent and the subsequent effects of pH on the Tc redox state was cited as an explanation for the better performance of the Cast Stone containing getters when leached in Hanford VZPW vs. reagent water. Thus it would be informative to repeat these bench scale studies at SRNL using Cast Stone monoliths fabricated from real waste and leached in Hanford VZPW to provide a tieback to that work.

5.0 References

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Appendix A. Elemental Concentrations of Premix and Getters

Table A-1. Previously Measured Premix Dry Chemical Compositions (wt%) – See Reference 2

Component	Cement		Slag		Flyash	
Al	2.56	2.55	6.78	6.67	8.58	8.63
Ba	0.039	0.039	0.034	0.038	0.481	0.487
Ca	45.1	45.1	30.1	30.7	9.32	9.25
Cr	0.021	0.020	<0.010	<0.010	0.030	0.017
Fe	2.47	2.50	0.391	0.430	4.15	4.15
K	0.269	0.272	0.269	0.291	1.25	1.24
Mg	0.406	0.404	2.54	2.49	2.65	2.65
Mn	0.059	0.057	0.146	0.160	0.048	0.047
Na	0.239	0.241	0.147	0.158	2.47	2.47
S	1.66	1.58	1.57	1.71	0.333	0.345
Si	9.62	9.60	15.5	15.3	24.2	24.2
Sr	0.137	0.140	0.056	0.060	0.256	0.259
Ti	0.149	0.148	0.220	0.240	0.473	0.479
Zn	0.139	0.139	<0.010	<0.010	0.011	0.011
Zr	0.030	0.017	0.018	0.019	0.043	0.024

Table A-2. Elemental Composition of Getter Compounds (wt%) Calculated from Empirical Formula

Getter	Species	wt%
Ag-Z	Ag	44.10
	Na	0.22
	Al	11.29
	Si	14.49
	O	29.90
Sn-A	Ca	26.75
	Sn	19.80
	PO ₄	47.53
	Cl	5.92
KMS-2	K	14.69
	Mg	4.57
	Sn	44.60
	S	36.14

Appendix B. Leachate Concentrations and Observed Diffusivities

Table B-1. Leachate Concentrations (mg/L)

Sample	Interval ID	Cr	S	Na	NO2	NO3	Al	Ca	K	Tc-99	I-127
BS1	T1	<0.018	8.9	145	25	143	2.1	2.7	5.3	<2.5E-04	NA
	T2	<0.018	20.4	343	60	347	5.4	15.6	13.2	<3.0E-04	NA
	T3	<0.018	7.1	128	21	123	2.1	12.8	5.1	<2.5E-04	NA
	T4	<0.009	21.8	401	63	369	8.0	10.6	15.7	<2.4E-04	NA
	T5	<0.009	21.3	345	54	327	7.7	15.0	13.2	<2.4E-04	NA
	T6	<0.009	23.7	370	55	333	8.6	14.5	14.4	<3.3E-04	NA
	T7	<0.031	19.4	280	43	266	6.0	18.1	11.5	<2.5E-04	NA
	T8	<0.009	8.1	125	18	111	4.3	11.0	5.3	<2.1E-04	NA
	T9	<0.009	15.0	200	30	185	6.3	18.9	8.2	<3.3E-04	NA
BS2	T1	<0.018	<3.3	57	10	53	0.7	1.2	2.4	NA	0.03
	T2	<0.018	8.3	164	26	155	2.6	9.1	6.6	NA	0.08
	T3	<0.018	10.7	186	31	179	3.2	16.8	7.3	NA	0.09
	T4	<0.009	18.9	352	55	320	7.9	17.0	14.4	NA	0.16
	T5	<0.009	21.7	339	55	335	7.7	17.2	13.5	NA	0.16
	T6	<0.009	24.5	391	58	356	9.1	10.5	15.1	NA	0.18
	T7	<0.031	21.2	304	46	285	6.7	19.1	12.2	NA	0.14
	T8	<0.009	7.0	114	16	98	4.1	17.5	5.0	NA	0.05
	T9	<0.009	13.9	192	28	176	6.3	18.4	7.9	NA	0.08
KM1	T1	<0.018	9.4	123	22	132	2.0	3.0	6.1	<2.2E-04	NA
	T2	<0.018	26.4	342	62	365	6.0	18.1	17.0	<3.2E-04	NA
	T3	<0.018	9.2	131	22	129	2.5	15.3	6.8	<2.0E-04	NA
	T4	<0.009	27.4	391	64	375	9.0	19.3	19.7	<3.3E-04	NA
	T5	<0.009	27.6	362	61	369	8.8	10.6	17.6	<3.8E-04	NA
	T6	<0.009	26.1	363	58	360	9.6	3.3	18.2	<4.3E-04	NA
	T7	<0.031	34.0	266	55*	354*	6.5	11.0	14.2	<2.0E-04	NA
	T8	<0.009	8.7	132	20	128	5.0	13.4	7.3	<1.8E-04	NA
	T9	<0.009	11.6	171	27	168	6.0	9.4	9.4	<3.0E-04	NA
KM2	T1	<0.018	<3.3	37	10	37	0.4	1.0	2.3	NA	0.02
	T2	<0.018	23.6	308	55	331	5.3	16.7	15.6	NA	0.09
	T3	<0.018	10.3	144	24	144	2.7	16.7	7.2	NA	0.07
	T4	<0.009	25.2	361	58	347	8.4	22.8	18.3	NA	0.20
	T5	<0.009	25.6	347	58	354	8.4	21.4	17.1	NA	0.18
	T6	<0.009	26.4	369	60	369	9.3	7.7	18.8	NA	0.16
	T7	<0.031	24.7	339	55	354	7.5	26.8	17.4	NA	0.16
	T8	<0.009	9.6	143	22	137	5.3	20.3	7.8	NA	0.06
	T9	<0.009	15.9	213	35	221	7.2	21.7	11.3	NA	0.11
Sn1	T1	<0.018	9.3	144	26	148	2.2	2.6	4.8	<2.4E-04	NA
	T2	<0.018	19.4	311	57	335	5.1	12.3	11.1	<3.4E-04	NA
	T3	<0.018	11.8	195	35	198	3.6	15.3	7.0	<2.0E-04	NA
	T4	<0.009	24.0	435	72	419	9.7	16.6	15.8	<4.2E-04	NA
	T5	<0.009	25.2	414	71	430	9.6	18.7	14.8	<4.3E-04	NA
	T6	<0.009	27.1	449	75	461	10.5	16.6	16.5	<5.2E-04	NA
	T7	<0.031	18.5	317	51	315	7.0	10.3	12.3	<3.8E-04	NA
	T8	<0.009	8.4	153	23	144	5.2	21.9	6.2	<1.8E-04	NA
	T9	<0.009	11.0	192	30	187	6.2	5.5	7.7	<2.7E-04	NA

*Sample leachate inadvertently spiked with nitric acid that prohibited accurate analysis of nitrate and nitrite. These “missing” values were set equal to the replicate KMS-2 sample 4 to facilitate calculation of interval D_{obs} values.

NA – Not Analyzed

Table B-1. Leachate Concentrations (mg/L), continued

Sample	Interval ID	Cr	S	Na	NO2	NO3	Al	Ca	K	Tc-99	I-127
Sn2	T1	<0.018	9.3*	140	10	148*	2.2	2.6	4.8	NA	0.03
	T2	<0.018	19.0	316	58	343	5.1	12.8	11.3	NA	0.10
	T3	<0.018	11.6	190	34	198	3.4	14.6	6.9	NA	0.07
	T4	<0.013	32.4	552	96	559	11.8	25.1	19.7	NA	0.22
	T5	<0.009	20.2	353	60	364	8.0	11.9	12.8	NA	0.16
	T6	<0.009	25.4	429	72	437	10.3	7.7	16.2	NA	0.18
	T7	<0.031	20.0	339	55	342	7.0	24.7	13.2	NA	0.16
	T8	<0.009	8.5	152	23	143	5.0	12.9	6.1	NA	0.06
	T9	<0.009	15.5	239	39	245	7.2	2.6	9.0	NA	0.11
Ag1	T1**	<0.018	<3.3	65	13	73	1.1	2.2	2.0	<2.4E-04	0.005
	T2	<0.018	7.1	169	32	180	3.2	12.0	5.6	<3.6E-04	0.014
	T3	<0.018	6.9	141	26	145	3.0	16.8	4.7	<2.1E-04	0.011
	T4	0.024	23.4	454	80	448	11.1	25.4	14.8	<1.1E-03	0.012
	T5	<0.009	14.7	284	48	278	7.7	16.1	9.2	<5.9E-04	0.005
	T6	0.010	17.5	332	54	314	8.9	5.8	10.8	<8.9E-04	0.005
	T7	<0.031	13.6	257	41	244	6.0	24.1	8.9	<1.0E-03	<0.001
	T8	<0.009	4.9	99	14	87	3.8	7.9	3.9	<2.3E-04	0.001
	T9	<0.009	9.8	166	26	157	5.8	9.1	6.1	<6.5E-04	<0.001
Ag2	T1	<0.018	<3.3	65	13	73	1.1	2.2	2.0	NA	NA
	T2	<0.018	12.4	258	52	290	5.2	17.8	7.8	NA	NA
	T3	<0.018	5.4	107	21	115	2.2	14.9	3.4	NA	NA
	T4	0.024	17.1	341	62	345	8.7	15.8	10.7	NA	NA
	T5	0.023	19.3	354	63	365	8.6	25.8	10.0	NA	NA
	T6	0.030	22.9	397	67	396	10.2	8.7	11.2	NA	NA
	T7	<0.031	16.2	281	46	272	7.0	9.5	8.7	NA	NA
	T8	0.011	8.3	145	22	129	5.2	13.6	4.9	NA	NA
	T9	0.016	13.3	209	34	203	6.8	21.3	7.0	NA	NA
Blank***	T1	<0.018	<3.3	<0.056	<10	<10	<0.05	<0.34	<0.33	<0.0001	<0.0010
	T2	<0.018	<3.3	<0.056	<10	<10	<0.05	<0.39	<0.33	<0.0001	<0.0010
	T3	<0.018	<3.3	<0.056	<10	<10	<0.05	<0.49	<0.33	<0.0001	<0.0010
	T4	<0.061	<3.3	<0.056	<10	<10	<0.05	<0.72	<0.33	<0.0001	<0.0010
	T5	<0.009	<3.3	<0.056	<10	<10	<0.05	<0.07	<0.33	<0.0001	<0.0010
	T6	<0.009	<3.3	<0.056	<10	<10	<0.05	<0.01	<0.33	<0.0001	<0.0010
	T7	<0.031	<3.3	<0.508	<10	<10	<0.08	<0.03	<0.59	<0.0001	<0.0010
	T8	<0.009	<3.3	<0.056	<10	<10	<0.05	<0.03	<0.33	<0.0001	<0.0010
	T9	<0.009	<3.3	<0.056	<10	<10	<0.05	<0.01	<0.33	<0.0001	<0.0010

*An inadvertent nitric acid spike was delivered to this leachate prior to analysis. The nitrate concentration was thus set equal to the replicate Sn-A sample. Examination of the IC Anion chromatogram indicated also a significantly high concentration of sulfate for this leachate. It was concluded that likely traces of sulfuric acid were also in with the nitric acid that was inadvertently added to this leachate. The sulfate concentration was thus set equal to the replicate Sn-A sample.

** This T1 interval leachate was inadvertently discarded before it could be analyzed. All leachate concentrations were set equal to the replicate T1 interval Ag-Z leachate concentrations for sample 8 (Ag2).

*** Ultrapure water blanks were prepared and analyzed for all nine sampling intervals.

NA – Not Analyzed

Table B-2. EPA Observed Diffusivities (cm²/s) for Adjusted Tank 50 Monoliths

Sample	Species	D(i)T1	D(i)T2	D(i)T3	D(i)T4	D(i)T5	D(i)T6	D(i)T7	D(i)T8	D(i)T9
BS1	Cr	<2.43E-10	<4.01E-11	<1.18E-10	<3.34E-12	<4.22E-12	<2.11E-12	<4.25E-11	<1.88E-11	<5.77E-12
	S	7.01E-09	6.09E-09	2.20E-09	2.33E-09	2.81E-09	1.73E-09	1.97E-09	1.79E-09	1.89E-09
	Na	4.05E-08	3.74E-08	1.53E-08	1.70E-08	1.59E-08	9.15E-09	8.90E-09	9.31E-09	7.31E-09
	NO ₂	5.35E-08	5.07E-08	1.90E-08	1.91E-08	1.76E-08	9.02E-09	9.64E-09	8.32E-09	7.57E-09
	NO ₃	4.94E-08	4.79E-08	1.77E-08	1.81E-08	1.79E-08	9.29E-09	1.01E-08	9.19E-09	7.84E-09
	Al	1.10E-11	1.18E-11	5.35E-12	8.74E-12	1.01E-11	6.33E-12	5.19E-12	1.41E-11	9.34E-12
	Ca	2.30E-12	1.27E-11	2.53E-11	1.96E-12	4.96E-12	2.32E-12	6.14E-12	1.19E-11	1.08E-11
	K	8.16E-09	8.24E-09	3.65E-09	3.89E-09	3.47E-09	2.07E-09	2.24E-09	2.49E-09	1.81E-09
	Tc-99	<4.18E-10	<9.93E-11	<1.99E-10	<2.07E-11	<2.65E-11	<2.44E-11	<2.53E-11	<8.81E-11	<6.66E-11
	I-127	NA	NA	NA	NA	NA	NA	NA	NA	NA
BS2	Cr	<2.48E-10	<4.08E-11	<1.20E-10	<3.41E-12	<4.30E-12	<2.15E-12	<4.33E-11	<1.91E-11	<5.88E-12
	S	1.01E-09	1.02E-09	5.02E-09	1.77E-09	2.97E-09	1.89E-09	2.39E-09	1.39E-09	1.67E-09
	Na	6.47E-09	8.70E-09	3.30E-08	1.34E-08	1.57E-08	1.04E-08	1.07E-08	7.89E-09	6.87E-09
	NO ₂	8.86E-09	1.02E-08	4.16E-08	1.46E-08	1.83E-08	1.03E-08	1.11E-08	6.58E-09	6.78E-09
	NO ₃	6.78E-09	9.74E-09	3.83E-08	1.38E-08	1.92E-08	1.08E-08	1.18E-08	7.24E-09	7.23E-09
	Al	1.21E-12	2.81E-12	1.28E-11	8.60E-12	1.03E-11	7.19E-12	6.59E-12	1.32E-11	9.58E-12
	Ca	4.98E-13	4.43E-12	4.44E-11	5.15E-12	6.65E-12	1.24E-12	6.96E-12	3.07E-11	1.04E-11
	K	1.66E-09	2.08E-09	7.66E-09	3.33E-09	3.70E-09	2.31E-09	2.57E-09	2.22E-09	1.72E-09
	Tc-99	NA	NA	NA	NA	NA	NA	NA	NA	NA
	I-127	3.93E-09	6.44E-09	2.35E-08	7.77E-09	9.46E-09	6.54E-09	6.62E-09	3.83E-09	3.83E-09
KM1	Cr	<2.50E-10	<4.12E-11	<1.21E-10	<3.43E-12	<4.33E-12	<2.17E-12	<4.36E-11	<1.93E-11	<5.92E-12
	S	3.66E-09	4.70E-09	1.69E-09	1.69E-09	2.16E-09	9.72E-10	2.80E-09	9.70E-10	5.22E-10
	Na	2.83E-08	3.61E-08	1.56E-08	1.57E-08	1.70E-08	8.55E-09	7.80E-09	1.01E-08	5.19E-09
	NO ₂	4.01E-08	5.26E-08	1.98E-08	1.88E-08	2.14E-08	9.86E-09	1.50E-08	1.06E-08	5.70E-09
	NO ₃	4.05E-08	5.10E-08	1.88E-08	1.80E-08	2.19E-08	1.04E-08	1.71E-08	1.18E-08	6.22E-09
	Al	9.62E-12	1.43E-11	7.47E-12	1.07E-11	1.28E-11	7.64E-12	5.89E-12	1.85E-11	8.18E-12
	Ca	2.98E-12	1.78E-11	3.76E-11	6.77E-12	2.58E-12	1.23E-13	2.36E-12	1.83E-11	2.75E-12
	K	6.06E-09	7.67E-09	3.60E-09	3.44E-09	3.46E-09	1.85E-09	1.91E-09	2.65E-09	1.34E-09
	Tc-99	<3.00E-10	<1.08E-10	<1.28E-10	<3.71E-11	<6.53E-11	<4.03E-11	<1.48E-11	<6.58E-11	<5.40E-11
	I-127	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table B-2. EPA Observed Diffusivities (cm²/s) for Adjusted Tank 50 Monoliths, continued

Sample	Species	D(i)T1	D(i)T2	D(i)T3	D(i)T4	D(i)T5	D(i)T6	D(i)T7	D(i)T8	D(i)T9
KM2	Cr	<2.38E-10	<3.92E-11	<1.15E-10	<3.27E-12	<4.12E-12	<2.06E-12	<4.15E-11	<1.84E-11	<5.63E-12
	S	4.35E-10	3.58E-09	2.00E-09	1.36E-09	1.78E-09	9.46E-10	1.40E-09	1.11E-09	9.35E-10
	Na	2.48E-09	2.78E-08	1.79E-08	1.28E-08	1.49E-08	8.41E-09	1.21E-08	1.13E-08	7.66E-09
	NO ₂	7.96E-09	4.01E-08	2.28E-08	1.48E-08	1.86E-08	9.87E-09	1.43E-08	1.18E-08	9.40E-09
	NO ₃	2.96E-09	3.99E-08	2.22E-08	1.46E-08	1.92E-08	1.04E-08	1.63E-08	1.28E-08	1.02E-08
	Al	4.47E-13	1.06E-11	8.34E-12	8.79E-12	1.12E-11	6.89E-12	7.50E-12	1.96E-11	1.11E-11
	Ca	3.02E-13	1.45E-11	4.26E-11	8.99E-12	9.99E-12	6.38E-13	1.33E-11	4.00E-11	1.40E-11
	K	8.11E-10	6.14E-09	3.85E-09	2.82E-09	3.11E-09	1.88E-09	2.73E-09	2.88E-09	1.86E-09
	Tc-99	NA	NA	NA	NA	NA	NA	NA	NA	NA
	I-127	2.17E-09	6.75E-09	1.13E-08	1.12E-08	1.19E-08	4.51E-09	7.49E-09	5.15E-09	5.45E-09
Sn1	Cr	<2.59E-10	<4.27E-11	<1.26E-10	<3.56E-12	<4.50E-12	<2.25E-12	<4.53E-11	<2.00E-11	<6.15E-12
	S	8.12E-09	5.82E-09	6.44E-09	2.98E-09	4.17E-09	2.40E-09	1.90E-09	2.05E-09	1.09E-09
	Na	3.93E-08	3.02E-08	3.50E-08	1.97E-08	2.25E-08	1.32E-08	1.12E-08	1.37E-08	6.62E-09
	NO ₂	5.47E-08	4.46E-08	4.87E-08	2.42E-08	2.95E-08	1.65E-08	1.28E-08	1.39E-08	7.14E-09
	NO ₃	5.12E-08	4.32E-08	4.46E-08	2.26E-08	3.00E-08	1.73E-08	1.37E-08	1.50E-08	7.76E-09
	Al	1.18E-11	1.05E-11	1.57E-11	1.30E-11	1.59E-11	9.57E-12	7.26E-12	2.07E-11	9.06E-12
	Ca	2.17E-12	7.89E-12	3.60E-11	4.79E-12	7.68E-12	3.03E-12	1.98E-12	4.69E-11	9.18E-13
	K	7.19E-09	6.31E-09	7.33E-09	4.26E-09	4.72E-09	2.94E-09	2.77E-09	3.70E-09	1.76E-09
	Tc-99	<3.86E-10	<1.21E-10	<1.28E-10	<6.27E-11	<8.43E-11	<5.97E-11	<5.44E-11	<6.73E-11	<4.52E-11
	I-127	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sn2	Cr	<2.60E-10	<4.29E-11	<1.27E-10	<3.58E-12	<4.52E-12	<2.26E-12	<4.55E-11	<2.01E-11	<6.18E-12
	S	8.12E-09	5.65E-09	6.17E-09	5.46E-09	2.67E-09	2.12E-09	2.24E-09	2.14E-09	2.17E-09
	Na	3.73E-08	3.13E-08	3.34E-08	3.18E-08	1.64E-08	1.21E-08	1.29E-08	1.36E-08	1.03E-08
	NO ₂	8.46E-09	4.65E-08	4.83E-08	4.26E-08	2.13E-08	1.51E-08	1.51E-08	1.34E-08	1.23E-08
	NO ₃	5.15E-08	4.55E-08	4.47E-08	4.03E-08	2.16E-08	1.56E-08	1.62E-08	1.49E-08	1.34E-08
	Al	9.55E-12	1.06E-11	1.43E-11	1.92E-11	1.13E-11	9.24E-12	7.19E-12	1.93E-11	1.25E-11
	Ca	3.40E-12	8.58E-12	3.29E-11	1.10E-11	3.12E-12	6.57E-13	1.14E-11	1.64E-11	2.07E-13
	K	7.16E-09	6.56E-09	7.11E-09	6.66E-09	3.55E-09	2.84E-09	3.21E-09	3.58E-09	2.41E-09
	Tc-99	NA	NA	NA	NA	NA	NA	NA	NA	NA
	I-127	3.94E-09	9.52E-09	1.36E-08	1.50E-08	9.23E-09	6.32E-09	8.39E-09	6.57E-09	6.09E-09

Table B-2. EPA Observed Diffusivities (cm²/s) for Adjusted Tank 50 Monoliths, continued

Sample	Species	D(i)T1	D(i)T2	D(i)T3	D(i)T4	D(i)T5	D(i)T6	D(i)T7	D(i)T8	D(i)T9
Ag1	Cr	<3.29E-10	<5.41E-11	<1.60E-10	9.42E-12	<5.70E-12	3.59E-12	<5.75E-11	<2.52E-11	<7.74E-12
	S	1.33E-09	1.00E-09	2.73E-09	3.58E-09	1.78E-09	1.26E-09	1.29E-09	8.91E-10	1.07E-09
	Na	9.26E-09	1.04E-08	2.14E-08	2.51E-08	1.24E-08	8.48E-09	8.63E-09	6.67E-09	5.76E-09
	NO ₂	1.63E-08	1.66E-08	3.18E-08	3.45E-08	1.55E-08	9.85E-09	9.49E-09	6.13E-09	6.37E-09
	NO ₃	1.45E-08	1.45E-08	2.77E-08	2.99E-08	1.46E-08	9.29E-09	9.52E-09	6.24E-09	6.30E-09
	Al	2.98E-12	4.09E-12	1.09E-11	1.70E-11	1.03E-11	6.82E-12	5.24E-12	1.10E-11	7.80E-12
	Ca	2.12E-12	1.06E-11	6.11E-11	1.58E-11	8.01E-12	5.15E-13	1.52E-11	8.60E-12	3.50E-12
	K	1.55E-09	2.08E-09	4.25E-09	4.81E-09	2.33E-09	1.62E-09	1.87E-09	1.84E-09	1.39E-09
	Tc-99	<4.21E-10	<1.59E-10	<1.59E-10	<5.00E-10	<1.80E-10	<2.05E-10	<4.52E-10	<1.19E-10	<2.93E-10
	I-127	1.31E-10	2.11E-10	3.61E-10	4.58E-11	1.12E-11	5.07E-12	3.68E-13	2.87E-12	5.89E-13
Ag2	Cr	<3.27E-10	<5.39E-11	<1.59E-10	3.07E-11	3.77E-11	3.20E-11	<5.72E-11	3.57E-11	2.45E-11
	S	1.32E-09	2.99E-09	1.68E-09	1.89E-09	3.07E-09	2.16E-09	1.82E-09	2.53E-09	1.99E-09
	Na	9.22E-09	2.42E-08	1.23E-08	1.41E-08	1.92E-08	1.21E-08	1.03E-08	1.43E-08	9.15E-09
	NO ₂	1.62E-08	4.28E-08	2.03E-08	2.02E-08	2.68E-08	1.53E-08	1.21E-08	1.51E-08	1.07E-08
	NO ₃	1.44E-08	3.75E-08	1.74E-08	1.77E-08	2.50E-08	1.47E-08	1.18E-08	1.39E-08	1.06E-08
	Al	2.96E-12	1.09E-11	5.97E-12	1.04E-11	1.29E-11	9.00E-12	7.14E-12	2.06E-11	1.09E-11
	Ca	2.11E-12	2.32E-11	4.78E-11	6.09E-12	2.05E-11	1.16E-12	2.35E-12	2.54E-11	1.91E-11
	K	1.54E-09	4.00E-09	2.22E-09	2.50E-09	2.74E-09	1.73E-09	1.79E-09	2.96E-09	1.84E-09
	Tc-99	NA	NA	NA	NA	NA	NA	NA	NA	NA
	I-127	NA	NA	NA	NA	NA	NA	NA	NA	NA

**Appendix C. Leachate Concentrations and Observed Diffusivities from Reanalysis of the Last Four
Leach Intervals for Cr and Tc-99**

Table C-1. Leachate Concentrations (mg/L) and D_{obs} for Reanalyzed Cr and Tc-99

Sample	Interval	Cr (mg/L)	Cr D_{obs} (cm ² /s)	Tc-99 (mg/L)	Tc-99 D_{obs} (cm ² /s)
	ID				
BS	T6	2.62E-03	1.82E-13	2.04E-04	9.80E-12
	T7	2.46E-03	2.73E-13	1.93E-04	1.49E-11
	T8	1.00E-03	2.37E-13	7.26E-05	1.10E-11
	T9	1.98E-03	2.84E-13	1.39E-04	1.24E-11
KM	T6	3.30E-03	2.77E-13	3.52E-04	2.62E-11
	T7	3.58E-03	5.55E-13	3.97E-04	5.65E-11
	T8	1.48E-03	4.94E-13	1.73E-04	5.61E-11
	T9	2.46E-03	4.22E-13	3.25E-04	6.08E-11
Sn-A	T6	2.49E-03	1.73E-13	4.97E-04	5.55E-11
	T7	3.57E-03	6.04E-13	4.66E-04	8.26E-11
	T8	1.12E-03	3.14E-13	3.67E-04	8.86E-11
	T9	1.90E-03	2.75E-13	3.67E-04	8.26E-11
Ag-Z	T6	2.79E-02	2.72E-11	1.42E-03	5.17E-10
	T7	2.00E-02	2.39E-11	1.03E-03	4.64E-10
	T8	9.59E-03	2.87E-11	4.49E-04	4.64E-10
	T9	1.63E-02	2.54E-11	7.75E-04	4.24E-10

Appendix D. Average Leach Index Values

Table D-1. Average Leach Index Values

Sample	Species	Avg.	St. Dev.	%RSD
BS	Cr	>10.8	--	--
	S	8.6	0.1	1.3
	Na	7.9	0.1	1.2
	NO ₂ ⁻	7.9	0.1	1.3
	NO ₃ ⁻	7.9	0.1	1.3
	Al	11.1	0.1	0.7
	Ca	11.2	0.0	0.1
	K	8.5	0.1	0.9
	Tc-99	>10.2	--	--
	I-127	8.2	--	--
KMS-2	Cr	>10.8	--	--
	S	8.8	0.1	1.0
	Na	7.9	0.1	0.9
	NO ₂ ⁻	7.8	0.1	0.7
	NO ₃ ⁻	7.8	0.1	1.1
	Al	11.1	0.1	1.0
	Ca	11.2	0.2	1.5
	K	8.6	0.1	0.7
	Tc-99	>10.2	--	--
	I-127	8.2	--	--

Table D-1. Average Leach Index Values, continued

Sample	Species	Avg.	St.Dev.	%RSD
Sn-A	Cr	>10.7	--	--
	S	8.4	0.2	1.8
	Na	7.7	0.0	0.3
	NO ₂ ⁻	7.7	0.0	0.4
	NO ₃ ⁻	7.6	0.0	0.4
	Al	10.9	0.0	0.0
	Ca	11.3	0.1	0.6
	K	8.4	0.0	0.2
	Tc-99	>10.1	--	--
	I-127	8.1	--	--
Ag-Z	Cr	>10.4	--	--
	S	8.8	0.1	1.2
	Na	7.9	0.1	0.8
	NO ₂ ⁻	7.8	0.1	1.1
	NO ₃ ⁻	7.8	0.1	1.1
	Al	11.1	0.1	0.5
	Ca	11.1	0.1	0.7
	K	8.7	0.0	0.1
	Tc-99	>9.6	--	--
	I-127	10.9	--	--

Appendix E. Logarithm of the Cumulative Release of the Species versus the Logarithm of Leaching Time

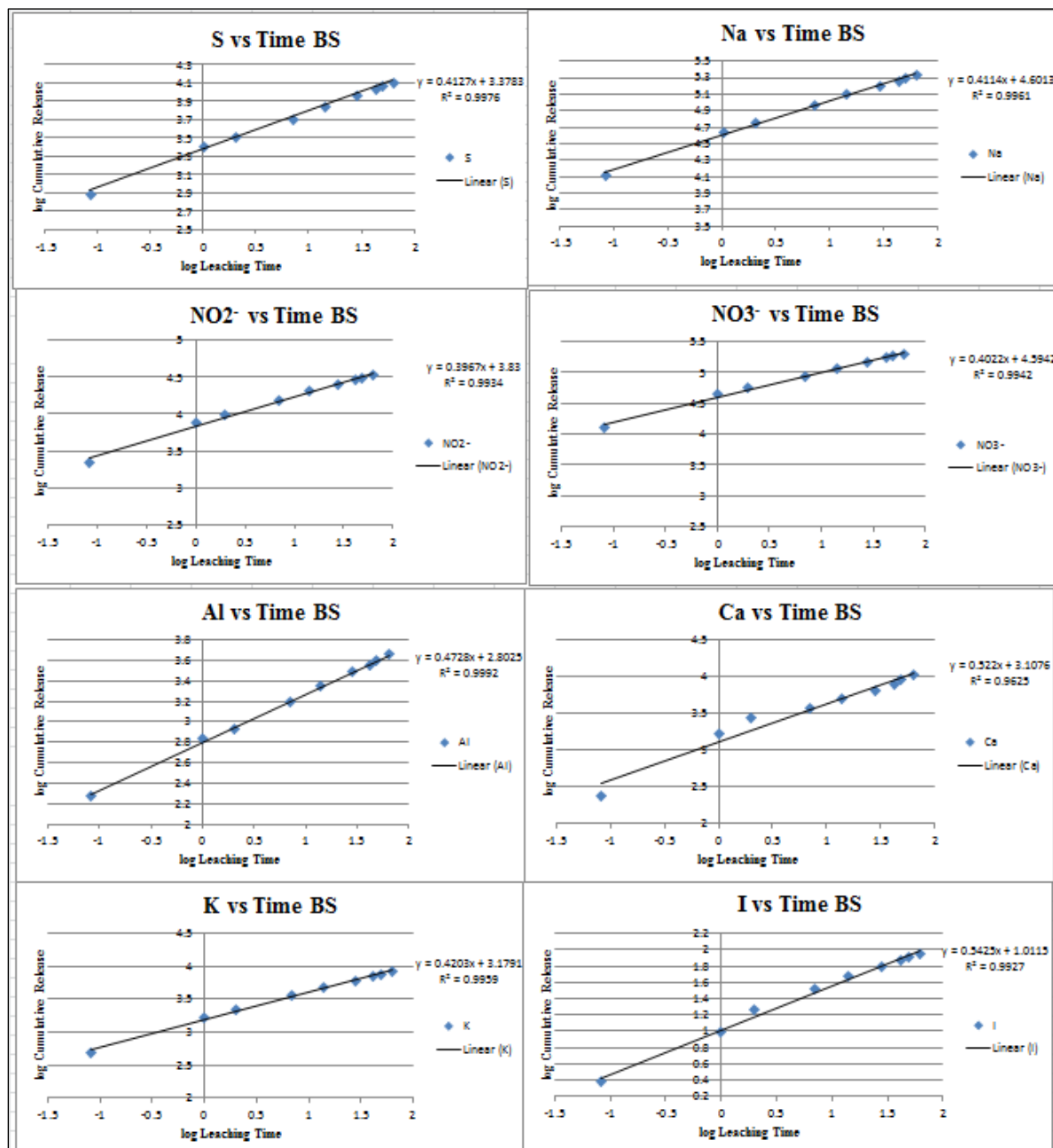


Figure E-1. Log – Log Plots for a Single Baseline Sample

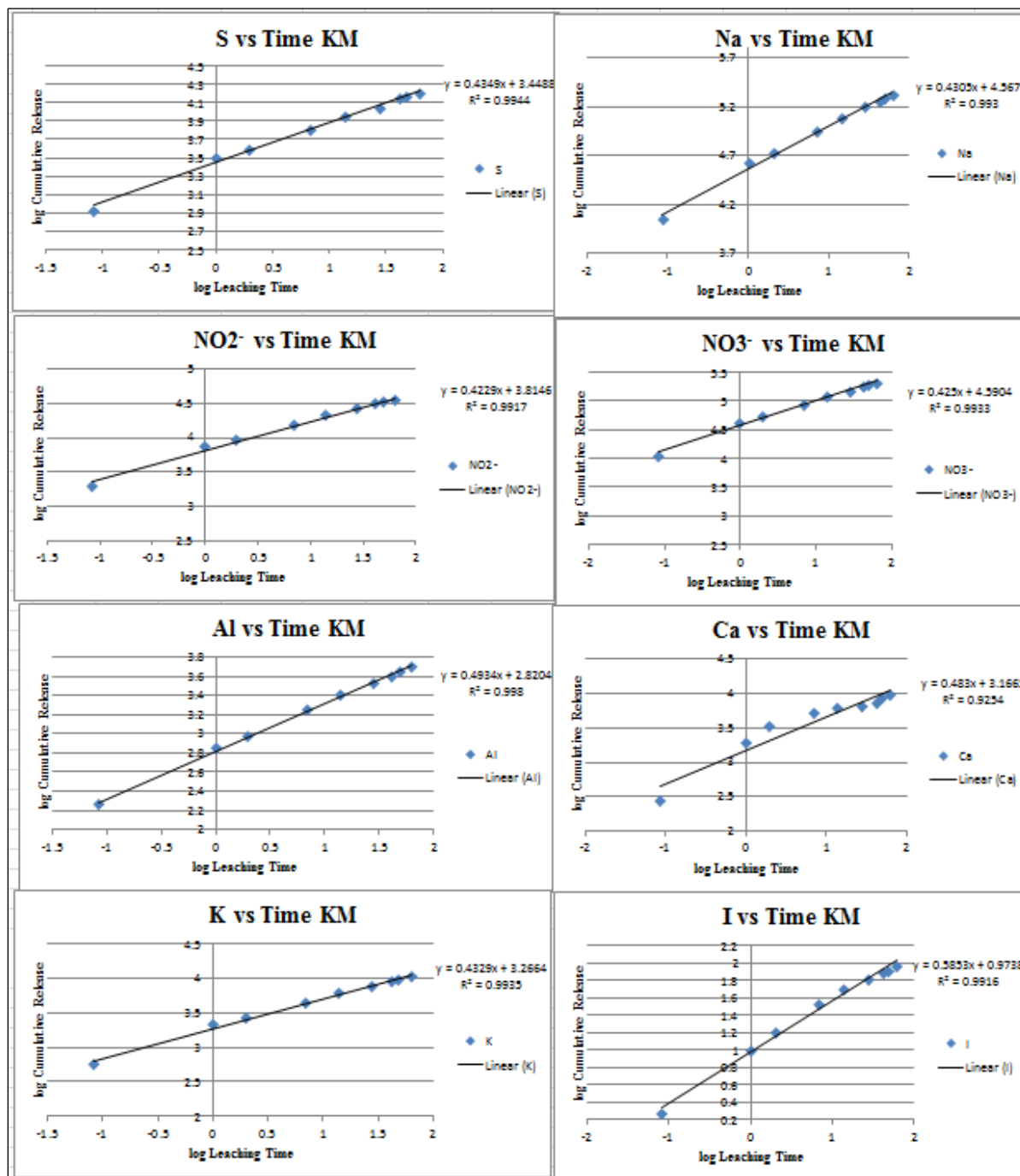


Figure E-2. Log – Log Plots for a Single KMS-2 Sample

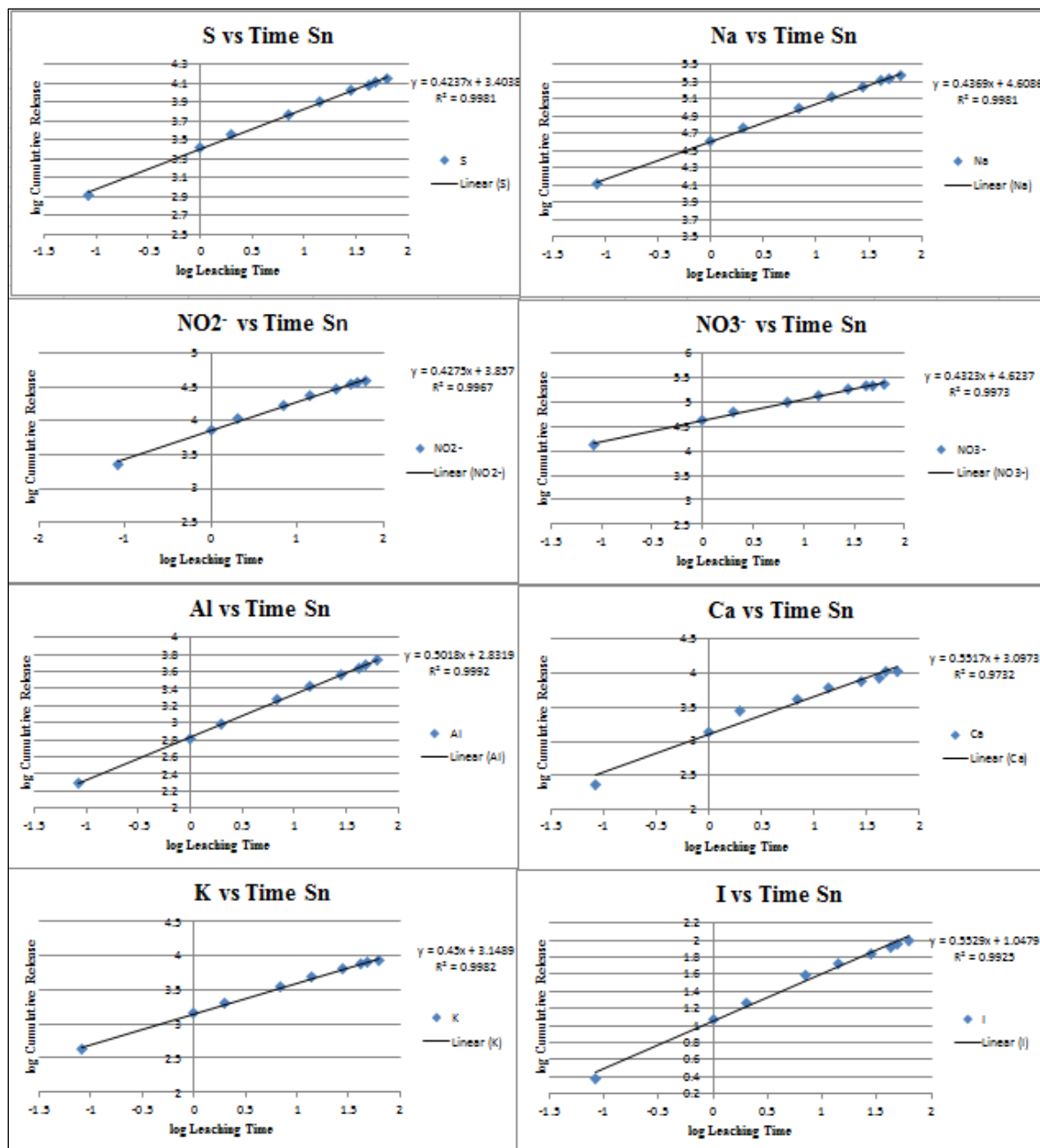


Figure E-3. Log – Log Plots for a Single Sn-A Sample

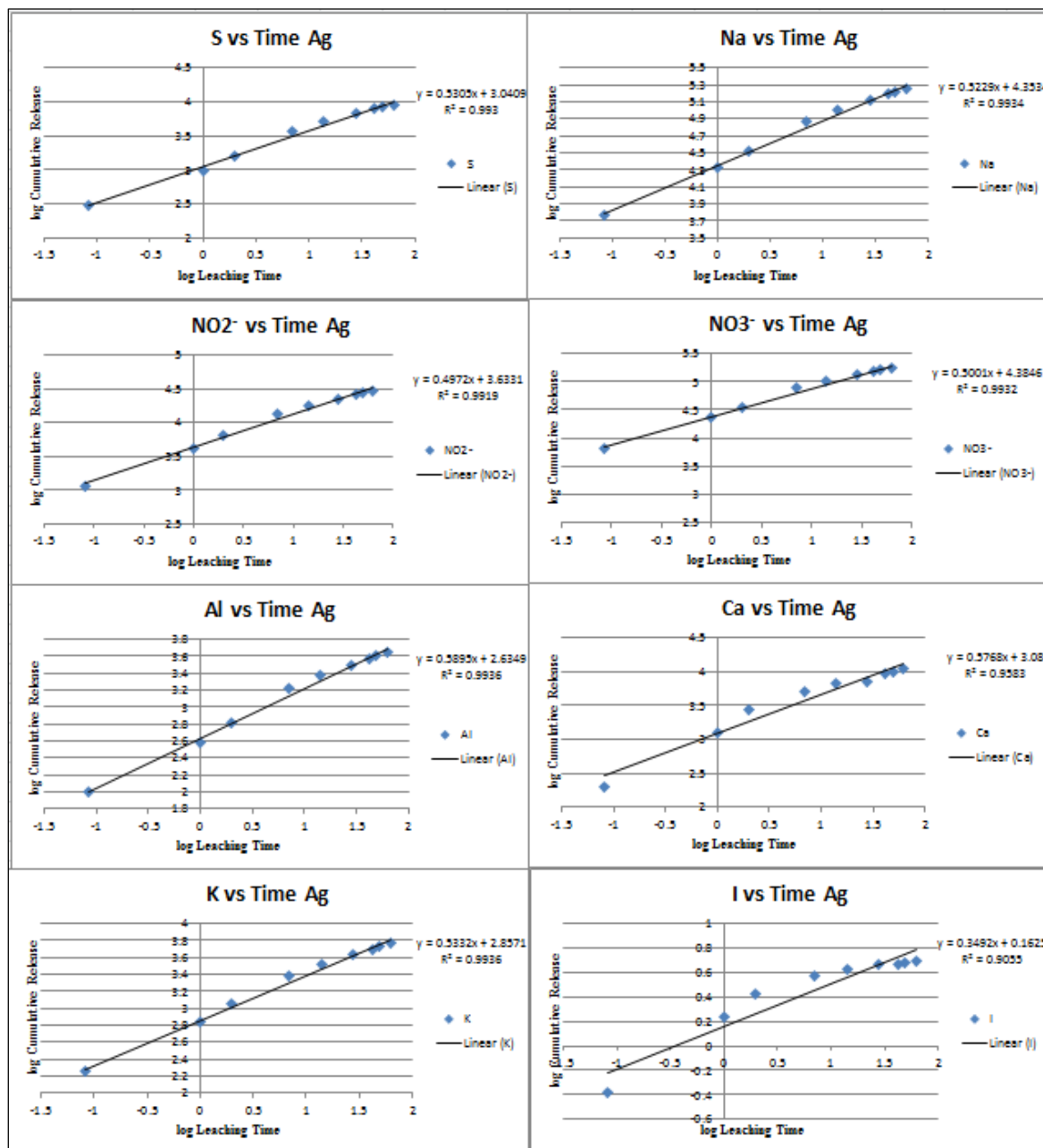


Figure E-4. Log – Log Plots for a Single Ag-Z Sample

Table E-1. Slopes of Log-Log Plots for All Samples

Species	Monolith				
	Sample	BS	KM	SN	AG
S	1	0.41	0.43	0.42	0.53
	2	0.56	0.55	0.43	0.53
	Avg.	0.49	0.49	0.43	0.53
Na	1	0.41	0.43	0.44	0.52
	2	0.55	0.58	0.45	0.52
	Avg.	0.48	0.51	0.44	0.52
NO ₂ ⁻	1	0.40	0.42	0.43	0.43
	2	0.53	0.52	0.55	0.55
	Avg.	0.46	0.47	0.49	0.49
NO ₃ ⁻	1	0.40	0.42	0.43	0.50
	2	0.55	0.58	0.44	0.50
	Avg.	0.48	0.50	0.44	0.50
Al	1	0.47	0.49	0.50	0.59
	2	0.64	0.68	0.52	0.58
	Avg.	0.56	0.59	0.51	0.58
Ca	1	0.52	0.48	0.55	0.58
	2	0.65	0.69	0.52	0.56
	Avg.	0.59	0.58	0.54	0.57
K	1	0.42	0.43	0.45	0.53
	2	0.54	0.56	0.46	0.51
	Avg.	0.48	0.49	0.45	0.52
I	1	0.54	0.59	0.55	0.35

Distribution:

T. B. Brown, 773-A
M. E. Cercy, 773-42A
D. A. Crowley, 773-43A
D. E. Dooley, 773-A
A. P. Fellingner, 773-42A
C. C. Herman, 773-A
D. T. Hobbs, 773-A
E. N. Hoffman, 999-W
J. E. Hyatt, 773-A
K. M. Kostelnik, 773-42A
B. B. Looney, 773-42A
D. A. McGuire, 773-42A
T. O. Oliver, 773-42A
F. M. Pennebaker, 773-42A
G. N. Smoland, 773-42A
B. J. Wiedenman, 773-42A
W. R. Wilmarth, 773-A
Records Administration (EDWS)
H. H. Burns, 773-41A
A. D. Cozzi, 999-W
S. D. Fink, 773-A
G. P. Flach, 773-42A
K. M. Fox, 999-W
E. K. Hansen, 999-W
K. A. Hill, 999-W
W. P. Kubilius, 999-W
C. A. Langton, 773-42A
D. J. McCabe, 773-42A
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M. R. Poirier, 773-42A
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