**Contract No:**

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

We put science to work.™

Savannah River National Laboratory®

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

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

# Solubility Testing to Support the Addition of Sodium Reactor Experiment Material to Sludge Batch 10


**C.J. Martino**

**C.J. Coleman**


August 2020


SRNL-STI-2020-00294, Revision 0


SRNL.DOE.GOV

**DISCLAIMER**



**Printed in the United States of America**

**Prepared for**
**U.S. Department of Energy**

SRNL-STI-2020-00294
Revision 0

**Keywords:** *Manganese, Uranium, DWPF, Nitric-Glycolic Acid Flowsheet*

**Retention:** *Permanent*

# Solubility Testing to Support the Addition of Sodium Reactor Experiment Material to Sludge Batch 10

C.J. Martino
C.J. Coleman

August 2020

Prepared for the U.S. Department of Energy under contract number DE-AC09-08SR22470.

# REVIEWS AND APPROVALS

AUTHORS:

______________________________________________________________________________
C.J. Martino, Chemical Flowsheet Development                                          Date

______________________________________________________________________________
C.J. Coleman, Analytical R&D Programs and Material Characterization          Date

TECHNICAL REVIEW:

______________________________________________________________________________
M.S. Williams, Chemical Flowsheet Development, Reviewed per E7 2.60          Date

APPROVAL:

______________________________________________________________________________
G.A. Morgan, Manager, Chemical Flowsheet Development                                Date

______________________________________________________________________________
S.D. Fink, Director, Chemical Processing Technology                                     Date

______________________________________________________________________________
T.L. Tice, Manager, H Canyon/Outside Facilities Engineering                           Date

______________________________________________________________________________
T.H. Huff, Manager, DWPF/Saltstone Facility Engineering                                Date

# EXECUTIVE SUMMARY

The Savannah River Site H-Canyon Facility is planning to discard dissolved Sodium Reactor Experiment (SRE) material into Tank 51 prior to Sludge Batch 10 (SB10). SB10 with the SRE material will be processed in the Defense Waste Processing Facility (DWPF) using the Nitric-Glycolic Acid (NGA) flowsheet. The DWPF Nuclear Criticality Safety Evaluation (NCSE) protects a 14:1 mass ratio of manganese to equivalent uranium-235 in both the solid and liquid phases during processing by requiring a 70:1 mass ratio in the feed. A concern was raised that freshly precipitated manganese in the SRE material will behave differently from the manganese in sludge during DWPF processing and potentially invalidate the criticality control. To mitigate risks to the DWPF criticality controls, the Savannah River National Laboratory (SRNL) performed a metals solubility test applicable to recently precipitated manganese and uranium, as would be expected with SRE transfers to SB10. The objective of this analysis is the tracking of partitioning of the primary fissile component (uranium-235) with the credited poison (manganese) between the aqueous and insoluble phases.

Acid was added to SB10 with SRE, consistent with the DWPF NGA flowsheet at 70%, 100%, and 140% Hsu acid stoichiometries. The mixtures were heated to 95 °C for 10 hours and filtrate was isolated for analyses. The following are the key results.

- Uranium percent soluble values exceeded the percent soluble values for manganese over the entire range tested, indicating that manganese poisoning in the solid phase will always be maintained. Thus, any increase in manganese solubility from the addition of SRE material to SB10 will not negatively impact the NCSE criticality control for manganese poisoning of equivalent uranium-235. Uranium solubility did not appear to be impacted by freshly precipitated sludge.

- Manganese percent soluble values were 2%, 65%, and 90% at the 70%, 100%, and 140% acid additions, respectively. For this specific SB10 and SRE mixture, the freshly precipitated manganese from SRE does not increase the manganese solubility to an extent that negatively impacts the ability of the manganese to poison the solid phase equivalent uranium-235.

- For the 100% and 140% acid additions, the mass ratios of manganese to equivalent uranium-235 were greater than the required 14:1 ratio in both liquid and solid phases.

- For the 70% acid addition, the mass ratio of manganese to equivalent uranium-235 in the liquid phase was 3.1:1 compared to the required 14:1. The low manganese to equivalent uranium-235 mass ratio in the liquid phase should not be a concern because the equivalent uranium-235 concentration in the liquid of 15.5 mg/L is significantly lower than the applicable American Nuclear Society standard 8.1 single parameter subcritical limit of 11600 mg/L. A similar trend in the liquid phase poison ratio was noted for an intermediate sample from half-way through the glycolic acid addition during Sludge Batch 9 qualification testing with the NGA flowsheet.

- Gadolinium percent soluble values closely mimicked the percent soluble values for manganese. Likewise, uranium percent soluble values exceeded the gadolinium percent soluble for all cases. These observations provide additional evidence that gadolinium may be a suitable replacement for manganese in the DWPF criticality control for poisoning enriched uranium in future sludge batches.

Savannah River Remediation requested anion analysis of the acid addition products to determine the level of nitrite and carbonate destruction. That information will be included in a separate document.

# TABLE OF CONTENTS

# LIST OF TABLES



# LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AFS | Alternate Feed Stock |
| ANS | American Nuclear Society |
| CPC | Chemical Process Cell |
| DI | deionized |
| DWPF | Defense Waste Processing Facility |
| IC | Ion Chromatography |
| ICP-ES | Inductively Coupled Plasma—Emission Spectroscopy |
| ICP-MS | Inductively Coupled Plasma—Mass Spectroscopy |
| KMA | Koopman Minimum Acid |
| m/z | mass divided by charge number |
| NCSE | Nuclear Criticality Safety Evaluation |
| REDOX | Reduction/Oxidation |
| RSD | Relative Standard Deviation |
| SB9 | Sludge Batch 9 |
| SB10 | Sludge Batch 10 |
| SME | Slurry Mix Evaporator |
| SRAT | Sludge Receipt and Adjustment Tank |
| SRE | Sodium Reactor Experiment |
| SRNL | Savannah River National Laboratory |
| SRS | Savannah River Site |
| TIC | Total Inorganic Carbon |
| TS | Total Solids |

## 1.0 Introduction

### 1.1 Background

The Savannah River Site (SRS) H-Canyon Facility is planning to discard dissolved Sodium Reactor Experiment (SRE) material into Tank 51 prior to Sludge Batch 10 (SB10).[1] The H-Canyon facility has previously transferred a portion of the SRE material to Sludge Batch 9 (SB9) and Alternate Feed Stock (AFS-2) into SB10.[2] The remaining SRE material is stored in H-Canyon Tanks 16.3 and 16.4. Due to the composition and relative volumes of Tanks 16.3 and 16.4 and Tank 51 material, additional manganese is required to assure a manganese to equivalent uranium-235[a] mass ratio of at least 70:1 in the blend. Prior to transfer to Tank 51, 50 wt% manganese nitrate solution will be added to the Tanks 16.3 and 16.4 material to provide manganese as a criticality control for the additional enriched uranium being transferred into SB10. The material will be pH adjusted to greater than 1.2 M free hydroxide, creating a slurry where the manganese and uranium are primarily insoluble.

SB10 with the SRE material will be processed in the Defense Waste Processing Facility (DWPF) using the Nitric-Glycolic Acid (NGA) flowsheet. The DWPF Nuclear Criticality Safety Evaluation (NCSE) protects a 14:1 mass ratio of manganese to equivalent uranium-235 (Mn:$^{235}$U(eq)) in both the solid and liquid phases through the DWPF Chemical Process Cell (CPC) processing by requiring 70:1 mass ratio of Mn:$^{235}$U(eq) in the Sludge Receipt and Adjustment Tank (SRAT) feed.[3] A concern was raised that the "freshly precipitated" manganese in the SRE material will initially form manganese hydroxide and will be more soluble than the manganese that has been stored in the waste tanks for decades. An increased solubility of freshly precipitated manganese has been seen experimentally when comparing manganese solubility of freshly precipitated simulants with waste samples at CPC conditions. Because the concern is an increase in manganese solubility with freshly precipitated simulant, the concern about Mn:$^{235}$U(eq) as an adequate criticality poison is in regard to the solid phase. The poisoning of uranium in the liquid phase is hypothesized to be enhanced due to introduction of freshly precipitated manganese and is thus bound by the previous analyses referenced in the DWPF NCSE. Thus, the focus is on the CPC conditions that challenge the Mn:$^{235}$U(eq) ratio in the solid phase. Additionally, the overall Mn and U content of the SB10 and SRE blend is less than concentrations experienced in previous sludge batches,[4-5] and thus does not challenge the historical basis of the solubility testing of the poisoning within the soluble phase.

To mitigate risks to the DWPF criticality controls outlined in the NCSE, SRNL performed a solubility test applicable to recently precipitated manganese and uranium, as would be expected with SRE transfers to SB10.[6-7] The objective of this analysis is the tracking of partitioning of the primary fissile component (uranium-235) with the credited poison (manganese) between the aqueous and insoluble phases. The conditions bracket the range of parameters applicable to the NGA flowsheet processing of SB10. The testing was performed with replicates and controls commensurate with the planned use of this data to support an existing NCSE requirement to meet 70:1 mass ratio of Mn:$^{235}$U(eq) the sludge feed to DWPF.

### 1.2 DWPF Solubility Testing

The basis of the NCSE control on the DWPF feed was an initial solubility test with nitric and formic acids prior to DWPF radioactive processing,[8] and was backed up with data collected during qualification testing for early sludge batches. The initial metals solubility test involved adding fixed amounts of acid to washed sludge, heating the mixtures to 95 °C for 6 hours, and measuring the pH and soluble metals in the filtrate.[9]

---

[a] As defined in the DWPF NCSE, the equivalent uranium-235 mass is the uranium-235 mass plus 1.4 times the uranium-233 mass.[3]

$$^{235}U(eq) = {}^{235}U + 1.4\ {}^{233}U$$

A portion of the previous testing was performed with simulants, where acid would be added to washed sludge simulant at 85 °C until the target pH is achieved.[10] There is a variation of this simulant testing where acid is added at 25 °C followed by heating to 85 °C. More recently, metals solubility testing for the NGA flowsheet started with SRAT product from a qualification test and involved adding additional glycolic acid at room temperature until a pH of 3 was reached, followed by adding nitric acid at room temperature to reach pH 2 and 1.[11-12] Through measuring the soluble metals in the filtrate, the tests covered bounding conditions in other portions of the DWPF process, such as the offgas condensate tanks, where the pH is routinely lower than of the SRAT.

The testing was a hybrid of the previous test protocols used as the basis for determining the effectiveness of manganese poisoning of uranium-235.[9] Small subsamples of washed sludge/SRE were blended with nitric and glycolic acid quantities corresponding to a range of plausible acid additions for the NGA flowsheet and heated to 90 to 95 °C for a specified period. This is similar to the other small-scale metals solubility testing where acid additions and a heating were performed without replicating a full SRAT cycle.[9] For this testing, three acid addition cases were utilized based on the NGA flowsheet acid calculation. The acid additions were approximately representative of low, moderate/nominal, and high regions of the expected processing range (for example, 70%, 100%, and 130 to 150% excess acid). The low and high excess acid cases were designed to bracket potential conditions and are expected to be outside of the optimal processing window. This acid addition range was not confirmed with simulant testing prior to the solubility test. Likewise, determination of the acid window for DWPF processing SB10 with SRE is outside of the scope of this solubility test.

Testing with adding additional acid to attain lower pH (e.g., 3, 2, and 1) was not necessary for SB10 with SRE based on the high uranium solubility noted at these excess acid conditions during SB9 testing with the NGA flowsheet.[12] Monosodium titanate was not included in this testing because it is considered separately in the existing NCSE.[3]

## 2.0 Experimental

### 2.1 SB10/SRE Blend

SRE material was prepared by addition of manganese nitrate solution to the samples of H-Canyon Tanks 16.3 and 16.4, followed by pH adjustment targeting 1.2 M free hydroxide.[13] The mass ratio of Tank 16.3 to 16.4 material used in the SRE blend was 2.136:1.[1] The blending of SRE material with Tank 51 sludge sample targeted 70:1 mass ratio of Mn:$^{235}$U(eq) in the final SB10/SRE slurry, noting that the conservative direction for a solubility test of poisoning is to be lower than the required 70:1 mass ratio and calculating the ratio in a manner consistent with DWPF. The sodium hydroxide addition was calculated based on the expected acid concentration in the Tank 16.3 and 16.4 solution and manganese nitrate solution, and the expected consumption of hydroxide by precipitation of aluminum, manganese, gadolinium, uranium, and thorium solids. The blending and subsequent washing was roughly based on the "No DUO and Min Mn w/o MST" column of Table 3 in the SB10 projection.[2] The nominal SRE to Tank 51 material blend on a volume basis was 0.0123:1. The amount of SRE per Tank 51 was increased by 20% to account for the uncertainty in previous SRE transfers into SB9. The insoluble solids concentration adjustment in the projection[2] was not used in this case because we had a measured insoluble solids concentration in the Tank 51 material used in testing. Analysis of the washed blend was performed prior to solubility testing to confirm $^{235}$U(eq), total uranium, and manganese content in the slurry and supernate. Additional details and observations on the blending of SRE with SB10 material and washing are included in Section 3.0.

### 2.2 Solubility Test

Previous solubility test results cover the information needed at lower pH (pH 3, 2, and 1) for the addition of SRE to SB10.[12] In that testing, uranium was seen to be fully soluble within measurement uncertainty at pH 3, 2, and 1.[12] The concern with the SRE addition is that it introduces "freshly precipitated" manganese, resulting in an expected increase in the manganese solubility and no expected impact on uranium solubility. Based on the previous results, even if manganese were to become fully soluble in the SB10/SRE mixture, the high uranium solubility at pH 3, 2, and 1 would still cause the manganese:U-235 to be greater than 14:1 in both phases to the degree that a test can differentiate.[12] Thus, additional testing specific to SB10 with SRE at the lower pH range (pH 3, 2, and 1) is not necessary based on the previous SB9 result.

Previous NGA flowsheet results were used as a basis for the necessary heating time for a SRAT cycle for metals solubility determination. The intermediate samples taken during the SB9 NGA flowsheet qualification test provides insight into the expectation of solubility trends.[12] The soluble manganese concentration remained relatively constant after acid addition and during boiling. The soluble uranium concentration, however, reduced by 78% between the end of acid addition and the first 10 hours of boiling. By comparison, soluble uranium concentration decreased by only 9% between 10 hours and 24 hours of boiling, which is within the analytical uncertainty. Because the challenge to the criticality control was expected to be maintaining the manganese poisoning of uranium in the solid phase, the metals solubility test timing should be sufficient to maximize manganese solubility and minimize uranium solubility. Thus, based on previous SB9 NGA testing, the heated period for metals solubility testing at SRAT conditions should be for at least 10 hours.

Three solubility tests were performed at varying acid additions of 70, 100, and 140% Hsu acid stoichiometry.[14] Solubility tests were conducted in polypropylene centrifuge tubes that were vented with a small hole in the cap to prevent over-pressurization when heated. The tubes were loaded with target masses of the SB10/SRE feed mixture, followed by the addition of pre-weighed aliquots of nitric acid and subsequently glycolic acid. A small amount of rinse water was used to assure the acid addition was complete. The tubes were capped and mixed with a vortex mixer after each acid addition. The three centrifuge tubes were heated to 95 °C and held for a total of 10 hours over a two-day period. Filtrate was prepared using syringe filters with 0.45 μm membranes. Additional details for the acid additions are contained in Section 3.0.

## 2.3 Analytical

### *2.3.1 Sample processing*

Samples were processed within the SRNL Shielded Cells. Some analyses required dilution and removal of aliquots from the Shielded Cells.

Aqua regia digestion preparation was used for test feed and product slurry elemental and isotopic analyses. Previous SB10 sample characterization that compared aqua regia and peroxide fusion digestions showed aqua regia to be adequate for the key components of interest in this study, including manganese, uranium, and gadolinium.[15] Additionally, the freshly precipitated SRE material would not be expected to contain solid phases that would challenge the aqua regia digestion preparation method. No remaining solids were noted after aqua regia digestion. Digested feed and product slurries were analyzed by Inductively Coupled Plasma—Emission Spectroscopy (ICP-ES) and Inductively Coupled Plasma—Mass Spectroscopy (ICP-MS).

Preparation of the soluble fraction of test products was by filtration through a 0.45-micron membrane. Product filtrates were diluted with 2 M nitric acid and analyzed by ICP-ES and ICP-MS.

Test feed and product slurries and supernatant or filtrate densities were determined gravimetrically from sample weights in vessels of known volume. Aliquots of slurry and supernate or filtrate were dried to a constant weight at 110 °C for determination of weight percent total solids (TS) and weight percent dissolved solids, respectively. Weight percent insoluble and soluble solids were calculated from the total and dissolved solids measurements.

Additional analysis of the feed material was needed to provide information for the DWPF NGA flowsheet acid calculation. Supernate was diluted with deionized (DI) water and analyzed by Ion Chromatography (IC) for anions and by Total Inorganic Carbon (TIC) for carbonate. Slurry was diluted with DI water and analyzed by titration for total base and by TIC.

Test product slurries were measured for pH within the Shielded Cells using a pH meter.

Averages and relative standard deviations (RSD) are reported for many of the analyses. RSD is not reported when the reported result average is a detection limit. Appendix A contains the individual results that were used in determining the averages and standard deviations. Individual results and averages are preceded by "<" when reported as the detection limit. Percent soluble results are preceded by "<" when the slurry concentration is a measured value and the supernate concentration is a detection limit. Percent soluble results are preceded by ">" when the slurry concentration is a detection limit and the supernate concentration is a measured value.

### *2.3.2 ICP-MS interpretation*

In some ICP-MS tables, the analytes are reported as "m/z" or "mass". The mass spectroscopy nomenclature "m/z" is the mass divided by the charge number, which for ICP-MS is usually reflective of the atomic weight of one or more isotopes. Various isotope and elemental concentrations can be attributed to individual, summed, or subtracted masses.[16-17] Often, the attribution of elemental concentrations requires an assumption to be made about the source of the material to disambiguate results from potential interfering isotopes. Table 2-1 contains a description of how isotope and elemental concentrations were determined from ICP-MS data and a summary of the assumptions made when necessary.

**Table 2-1. Interpretation and assumptions for converting ICP-MS data to element concentrations**

| |
|---|
| Cobalt is mass 59. This ignores the relatively smaller concentrations of radioactive cobalt isotopes. |
| Mass 88 is attributable to non-radioactive strontium but does not account for the entire strontium element concentration. |
| Technetium is mass 99. |
| Ruthenium is the sum of masses 101, 102, and 104. |
| Rhodium is mass 103. |
| Palladium is mass 105 multiplied by 1.663 to compensate for isotopes of other masses that cannot be disambiguated from other components in the mixture. |
| Silver is taken as the sum of masses 107 and 109 and potentially includes a minor interference from palladium. |
| Antimony is the sum of masses 121 and 123. |
| Tin is the sum of masses 117 through 120, 122, and 124. |
| Mass 133 is attributable to non-radioactive cesium but does not account for the entire cesium element concentration due to the presence of cesium-137. Cesium-135 and 137 cannot be disambiguated from barium-135 and 137 in the slurry. |
| Lanthanum is mass 139. |
| Neodymium is the sum of masses 143 through 146, 148, and 150. |
| Gadolinium is the sum of masses 155 through 158 and 160. For this analysis, masses 158 and 160 were not reported. Based on the measured ratio of 155 through 157, the main source of gadolinium was natural rather than a fission product. The sum of masses 155 through 157 was multiplied by 1.96 to yield an estimated elemental gadolinium concentration. |
| Thorium is mass 232. |
| Uranium is the sum of masses 233, 234, 235, 236 and 238. This ignores the very small fraction of mass 238 attributable to Plutonium-238. |
| Neptunium is mass 237. |
| Masses 239 and 240 are due to plutonium but do not account for the entire plutonium element concentration. |
| Masses 241 and 242 are a combination of plutonium and americium and cannot be disambiguated. |

## 2.4 Quality Assurance

Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60.[18] This document, including all calculations, was reviewed by Design Verification by Document Review. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.[19] Data are recorded in the electronic laboratory notebook system as experiment A6583-00142-28.

The SB10/SRE solubility tests were performed to determine the impacts of the SRE addition on the Nuclear Criticality Safety Evaluation (NCSE).[3] Data from the metals solubility test will be used to evaluate DWPF TSR SAC 5.8.2.11c (Nuclear Criticality Safety).[6] All work, analysis, and documentation was performed with quality assurance methods commensurate with the Safety Significant / Safety Class data requirements.

## 3.0 Results and Discussion

Table 3-1 lists the additions for the creation of the SB10/SRE feed material. The SRE material was blended by weighing target amounts of Tank 16.3 and 16.4 material, adding a pre-weighed portion of 50 wt% manganese nitrate solution and rinsing with about 5 grams of deionized (DI) water, shaking the material, adding a pre-weighed portion of 50 wt% sodium hydroxide and rinsing with about 5 grams of DI water, and shaking the material. The addition of the sodium hydroxide resulted in precipitation of solids. A portion of the solids appeared to exhibit fast settling and were relatively large particle size compared with the Tank 51 sludge. Thus, care was taken to assure the transfer of all precipitated SRE solids into the SB10 blend, through washing and visual observations.

The SRE slurry was combined with 102.93 g of SB10 Tank 51 sample. The Tank 51 sample used was the second subsample of the combined HTF-51-19-114 and HTF-51-20-15 qualification sample.[15] A wash solution was created to mimic the washing flowsheet anion concentration at the target wash endpoint of 0.85 M sodium with a single wash. The wash solution contained sodium nitrite and sodium hydroxide to account for the adjustments that will be needed in the Tank 51 washing to meet corrosion control program requirements. A portion of the wash water was used to rinse the SRE slurry into the blended material. After one day of settling, the supernate was decanted form the blended material and the resulting slurry was transferred to a smaller bottle. After several days of settling, additional supernate was transferred from the washed SB10/SRE blend, resulting in 80.595 g of feed for characterization and use in the solubility testing.

**Table 3-1. Parameters for blending the SRE and SB10/SRE mixtures**

| | |
|---|---|
| *SRE Slurry* | |
| Tank 16.4 sample | 0.415 g |
| Tank 16.3 sample | 0.920 g |
| 50 wt% $Mn(NO_3)_2$ | 0.359 g |
| 50 wt% NaOH | 1.128 g |
| DI $H_2O$ for rinsing | 10.0 g |
| *SB10/SRE Blend* | |
| SRE slurry | as above |
| SB10 Tank 51 slurry | 102.93 g |
| *Wash Solution* | |
| 50 wt% NaOH | 3.03 g |
| $NaNO_2$ | 5.78 g |
| DI $H_2O$ | 399.19 g |
| *Washed SB10/SRE Slurry* | |
| After supernate decant | 80.595 g |

**Table 3-2. SB10/SRE solubility test feed analysis**

| | wt% of slurry | wt% of TS | RSD |
|---|---|---|---|
| Al | 1.60E+00 | 1.15E+01 | 1.1% |
| Ba | 7.06E-03 | 5.1E-02 | 1.4% |
| Ca | 7.90E-02 | 5.7E-01 | 3.5% |
| Cd | 4.74E-04 | 3.4E-03 | 1.8% |
| Ce | 1.61E-02 | 1.2E-01 | 0.6% |
| Cr | 2.34E-02 | 1.7E-01 | 1.4% |
| Cu | 4.38E-03 | 3.2E-02 | 1.3% |
| Fe | 1.22E+00 | 8.8E+00 | 0.5% |
| Gd | 5.92E-03 | 4.3E-02 | 1.0% |
| La | 3.76E-03 | 2.7E-02 | 1.4% |
| Li | 1.66E-03 | 1.2E-02 | 4.0% |
| Mg | 2.96E-02 | 2.1E-01 | 1.5% |
| Mn | 2.95E-01 | 2.1E+00 | 1.0% |
| Na | 1.98E+00 | 1.43E+01 | 1.0% |
| Ni | 3.83E-02 | 2.8E-01 | 1.3% |
| S | 5.45E-02 | 3.9E-01 | 3.3% |
| Si | 4.91E-02 | 3.5E-01 | 1.5% |
| Sr | 3.07E-03 | 2.2E-02 | 1.6% |
| Th | 2.61E-01 | 1.9E+00 | 1.3% |
| Ti | 1.87E-03 | 1.3E-02 | 0.8% |
| U | 3.34E-01 | 2.4E+00 | 0.6% |
| Zn | 2.69E-03 | 1.9E-02 | 0.9% |
| Zr | 1.56E-02 | 1.1E-01 | 1.6% |
| $^{233}U$ | 9.44E-05 | 6.80E-04 | 0.8% |
| $^{234}U$ | 9.22E-05 | 6.64E-04 | 1.0% |
| $^{235}U$ | 4.47E-03 | 3.22E-02 | 1.0% |
| $^{236}U$ | 3.17E-04 | 2.29E-03 | 1.3% |
| $^{237}Np$ | 1.69E-04 | 1.22E-03 | 1.0% |
| $^{238}U$ | 3.23E-01 | 2.33E+00 | 0.3% |
| $^{239}Pu$ | 2.38E-03 | 1.72E-02 | 0.8% |
| $^{240}Pu$ | 1.81E-04 | 1.31E-03 | 0.6% |

Table 3-2 contains the key results from ICP-ES and ICP-MS for the SB10/SRE feed slurry mixture on the bases of wt% of slurry and wt% of TS. Additional results, including all replicates and detection limits, are available in Table A-1 through Table A-4. The washed slurry sodium concentration corresponds to 0.91 M in the slurry compared to the target sodium wash endpoint of 0.85 M. ICP-ES axial method was used to quantify sulfur in the SB10/SRE feed slurry to provide information useful in washing evaluations. Table 3-3 contains results for IC anions and TIC from supernate analysis, plus TIC and total base in the slurry. The TIC results are used to report carbonate in the supernate and slurry. All other results from IC anions were below the detectable level and are not reported. The total base in the slurry corresponded to 0.46 M. Several of the results in Table 3-3 are used in the acid calculation.

Based on the results in Table 3-2 for the SB10/SRE blend, the source of the manganese is 77% from Tank 51 and 23% from SRE, the source of the $^{235}U(eq)$ is 41% from Tank 51 and 59% from SRE, and the source of elemental uranium is 98% from Tank 51 and 2% from SRE.

**Table 3-3. Other results for the SB10/SRE supernate and slurry for acid calculation inputs**

| | mg/L supernate | M supernate | mg/L slurry | wt% of TS | RSD |
|---|---|---|---|---|---|
| Nitrate in supernate | 8.29E+03 | 1.34E-01 | 7.2E+03 | 5.2E+00 | 2.3% |
| Nitrite in supernate | 1.14E+04 | 2.49E-01 | 9.9E+03 | 7.2E+00 | 1.2% |
| Carbonate in supernate | 2.79E+03 | 4.64E-02 | 2.4E+03 | 1.7E+00 | 1.1% |
| Sulfate in supernate | 1.62E+03 | 1.69E-02 | 1.4E+03 | 1.0E+00 | 0.9% |
| Oxalate in supernate | 4.27E+02 | 4.85E-03 | 3.7E+02 | 2.7E-01 | 1.4% |
| Carbonate in slurry | -- | -- | 2.9E+03 | 2.1E+00 | -- |
| Total base in slurry | -- | -- | 7.8E+03 | -- | -- |

Table 3-4 summarizes the acid additions performed. Acid was prepared for 70, 100, and 130% acid addition on the Hsu acid stoichiometry basis targeting a Reduction/Oxidation (REDOX) of 0.1. The last slurry material to be prepared was the high acid condition, however, only 20.46 grams of the targeted 22 grams of SB10/SRE slurry material remained and was used in that test. Thus, the addition of the pre-prepared acid corresponded to a new Hsu acid stoichiometry of 140% and a REDOX target of 0.15. The pH measured after the conclusion of the heated test were as expected, with the low acid addition being slightly basic, the high acid addition approaching pH 4, and the moderate acid addition falling in-between the other values. This testing reasonably brackets the potential NGA flowsheet conditions for SB10. For comparison, Table 3-4 also reports the analogous Koopman Minimum Acid (KMA) stoichiometries.[20] Subsequent tables in this report and in the appendix reference the Hsu acid stoichiometry.

**Table 3-4. Acid addition details and pH results**

| | SB10/SRE Feed | Low Acid | Moderate Acid | High Acid |
|---|---|---|---|---|
| Hsu Acid Stoichiometry | 0% | 70% | 100% | 140% |
| Approximate KMA Stoichiometry | 0% | 65% | 92% | 129% |
| REDOX Target | -- | 0.10 | 0.10 | 0.15 |
| SB10/SRE Slurry | -- | 22.04 g | 22.05 g | 20.46 g |
| 50 wt% Nitric Acid | -- | 0.5065 g | 0.8957 g | 1.3220 g |
| 70 wt% Glycolic Acid | -- | 0.8530 g | 1.0655 g | 1.2544 g |
| pH | >13 estimated | 7.9 | 6.4 | 4.2 |

A total of approximately 1 gram of water was added for rinsing during acid additions for each test preparation. Similarly, approximately 1 gram of weight was lost during each heated test.

Figure 3-1 shows the SB10/SRE solubility test products in the SRNL Shielded Cells after heating and prior to filtration. No unexpected observations were noted during acid addition and sample heating. Within the Shielded Cells, the difficulty of visually observing the acidified sludge makes it impractical for confirming reduction of mercury.

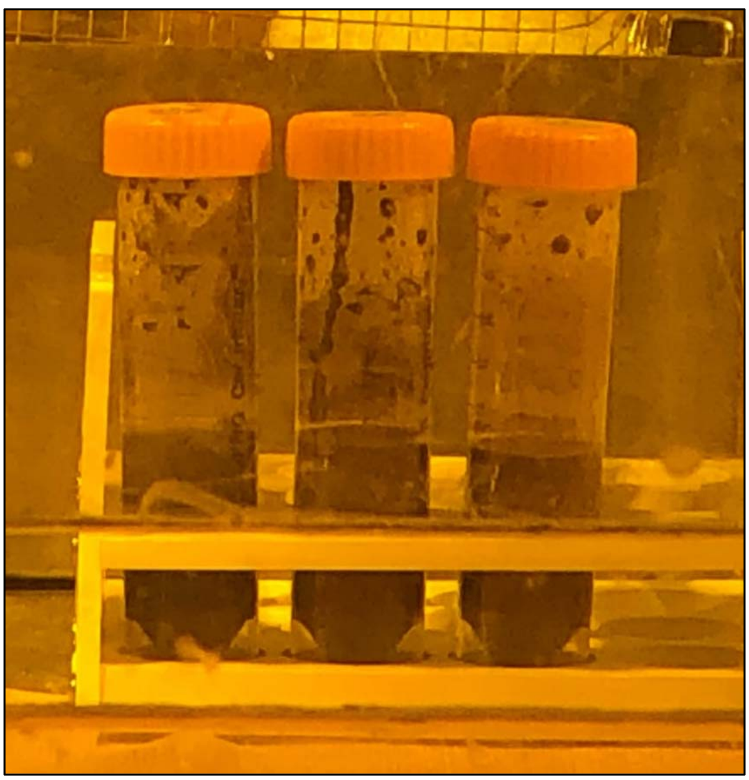

**Figure 3-1. SB10/SRE solubility test products**

The densities and solid content of the feed and product slurries are reported in Table 3-5. Slurry density and total solids increase with increasing acid addition for this testing, even without significant dewater. Supernate density and soluble solids concentration also increase with increasing acid addition, which is consistent with the dissolution of a portion of the solids in the original SB10/SRE mixture. The insoluble solids concentrations also decrease with increasing acid addition, consistent with the other data in indicating additional solids dissolution at higher acid addition levels.

Table 3-5 also reports the manganese poison ratio (the mass ratio of manganese to equivalent uranium-235) in the SB10/SRE feed mixture and in the product slurries from the three solubility tests. The ratios were measured as 64:1 for the feed slurry, the 70% acid addition slurry, and the 100% acid addition slurry; and 66:1 for the 140% acid addition slurry. These manganese poison ratio results are acceptable for the SB10/SRE solubility testing because it is conservative to test at a lower than 70:1 ratio to show that a 70:1 ratio is acceptable.

**Table 3-5. Physical results from the SB10/SRE solubility tests**

| | SB10/SRE Feed | | 70% Acid Additon | | 100% Acid Additon | | 140% Acid Additon | |
|---|---|---|---|---|---|---|---|---|
| | Average | RSD | Average | RSD | Average | RSD | Average | RSD |
| Slurry Density (g/mL slurry) | 1.060 | 0.5% | 1.126 | 0.5% | 1.138 | 0.6% | 1.141 | 0.1% |
| Supernate Density (g/mL supernate) | 1.054 | 0.5% | 1.044 | 0.1% | 1.063 | 0.3% | 1.064 | 0.03% |
| Total Solds (wt% slurry) | 13.9 | 2.7% | 14.6 | 0.9% | 15.2 | 0.5% | 16.3 | 0.4% |
| Dissolved Solids (wt% supernate) | 5.8 | 1.3% | 7.7 | 2.0% | 9.2 | 0.3% | 10.9 | 0.7% |
| Insoluble Solids (wt% slurry) | 8.5 | -- | 7.5 | -- | 6.6 | -- | 6.1 | -- |
| Soluble Solids (wt% slurry) | 5.3 | -- | 7.1 | -- | 8.5 | -- | 10.2 | -- |
| Mn:$^{235}$U(eq) in slurry | 64:1 | | 64:1 | | 64:1 | | 66:1 | |

The ICP-ES and ICP-MS results of the SB10/SRE solubility test feed and product slurries are reported in Table 3-6 and Table 3-7, respectively. Additional results for product slurries, including all replicates and detection limits, are available in Table A-5 though Table A-8.

The ICP-ES and ICP-MS results of the SB10/SRE solubility test product filtrates are reported in Table 3-8 and Table 3-9, respectively. Additional results for product filtrates, including all replicates and detection limits, are available in Table A-9 through Table A-12. Along with the test product slurry results, the test product filtrate results are used to calculate the percent soluble for each component.

**Table 3-6. ICP-ES results for the feed and product slurries from the SB10/SRE solubility tests**

| Analyte | Feed | | 70% Acid Addition | | 100% Acid Addition | | 140% Acid Addition | |
|---|---|---|---|---|---|---|---|---|
| | Average (wt% slurry) | RSD | Average (wt% slurry) | RSD | Average (wt% slurry) | RSD | Average (wt% slurry) | RSD |
| Ag | <1.1E-03 | -- | <8.0E-04 | -- | <7.9E-04 | -- | <8.0E-04 | -- |
| Al | 1.60E+00 | 1.1% | 1.50E+00 | 1.0% | 1.39E+00 | 5.2% | 1.39E+00 | 1.8% |
| B | <3.8E-04 | -- | <8.3E-04 | -- | <8.2E-04 | -- | <8.2E-04 | -- |
| Ba | 7.06E-03 | 1.4% | 6.89E-03 | 0.4% | 6.67E-03 | 3.3% | 6.58E-03 | 0.6% |
| Be | <5.4E-05 | -- | <2.8E-05 | -- | <2.8E-05 | -- | <2.8E-05 | -- |
| Ca | 7.90E-02 | 3.5% | 7.73E-02 | 0.3% | 7.48E-02 | 2.5% | 7.38E-02 | 0.4% |
| Cd | 4.74E-04 | 1.8% | <4.8E-04 | -- | <4.8E-04 | -- | <4.8E-04 | -- |
| Ce | 1.61E-02 | 0.6% | 1.55E-02 | 1.0% | 1.48E-02 | 2.7% | 1.48E-02 | 1.4% |
| Co | <5.7E-04 | -- | <6.0E-04 | -- | <5.9E-04 | -- | <5.9E-04 | -- |
| Cr | 2.34E-02 | 1.4% | 2.26E-02 | 0.7% | 2.21E-02 | 2.7% | 2.17E-02 | 0.3% |
| Cu | 4.38E-03 | 1.3% | 4.18E-03 | 1.0% | 4.08E-03 | 4.4% | 4.04E-03 | 1.0% |
| Fe | 1.22E+00 | 0.5% | 1.18E+00 | 0.0% | 1.14E+00 | 4.6% | 1.12E+00 | 0.5% |
| Gd | 5.92E-03 | 1.0% | 6.62E-03 | 0.2% | 6.33E-03 | 1.8% | 6.27E-03 | 0.8% |
| K | <6.3E-03 | -- | <9.3E-03 | -- | <9.2E-03 | -- | <9.2E-03 | -- |
| La | 3.76E-03 | 1.4% | 3.79E-03 | 1.6% | 3.73E-03 | 1.5% | 3.64E-03 | 1.7% |
| Li | 1.66E-03 | 4.0% | 1.65E-03 | 1.3% | 1.55E-03 | 5.4% | 1.59E-03 | 2.2% |
| Mg | 2.96E-02 | 1.5% | 2.90E-02 | 0.2% | 2.83E-02 | 2.5% | 2.77E-02 | 0.2% |
| Mn | 2.95E-01 | 1.0% | 2.84E-01 | 0.6% | 2.76E-01 | 2.1% | 2.70E-01 | 0.6% |
| Mo | <1.1E-03 | -- | <1.8E-03 | -- | <1.8E-03 | -- | <1.8E-03 | -- |
| Na | 1.98E+00 | 1.0% | 1.99E+00 | 0.8% | 1.94E+00 | 3.7% | 1.92E+00 | 0.3% |
| Ni | 3.83E-02 | 1.3% | 3.74E-02 | 0.4% | 3.66E-02 | 2.6% | 3.56E-02 | 1.2% |
| P | <7.4E-03 | -- | <7.2E-03 | -- | <7.1E-03 | -- | <7.2E-03 | -- |
| Pb | <2.5E-03 | -- | <4.0E-03 | -- | <4.0E-03 | -- | <4.0E-03 | -- |
| S | 5.45E-02 | 3.3% | <2.8E-01 | -- | <2.8E-01 | -- | <2.8E-01 | -- |
| Sb | <5.8E-03 | -- | <1.2E-02 | -- | <1.2E-02 | -- | <1.2E-02 | -- |
| Si | 4.91E-02 | 1.5% | 3.90E-02 | 3.6% | 3.73E-02 | 4.7% | 3.85E-02 | 0.5% |
| Sn | <1.6E-03 | -- | <3.5E-03 | -- | <3.5E-03 | -- | <3.5E-03 | -- |
| Sr | 3.07E-03 | 1.6% | 3.16E-03 | 0.4% | 3.07E-03 | 3.4% | 3.00E-03 | 1.0% |
| Th | 2.61E-01 | 1.3% | 2.41E-01 | 1.1% | 2.37E-01 | 7.7% | 2.32E-01 | 2.1% |
| Ti | 1.87E-03 | 0.8% | 1.72E-03 | 0.6% | 1.67E-03 | 3.3% | 1.64E-03 | 2.1% |
| U | 3.34E-01 | 0.6% | 3.18E-01 | 0.8% | 3.11E-01 | 2.4% | 3.03E-01 | 0.2% |
| V | <1.5E-04 | -- | <3.2E-04 | -- | <3.2E-04 | -- | <3.2E-04 | -- |
| Zn | 2.69E-03 | 0.9% | 2.60E-03 | 2.9% | 2.49E-03 | 2.6% | 2.45E-03 | 0.6% |
| Zr | 1.56E-02 | 1.6% | 1.43E-02 | 0.0% | 1.39E-02 | 3.6% | 1.36E-02 | 1.3% |

**Table 3-7. ICP-MS results for the feed and product slurries from the SB10/SRE solubility tests**

| Analyte | Feed | | 70% Acid Addition | | 100% Acid Addition | | 140% Acid Addition | |
|---|---|---|---|---|---|---|---|---|
| | Average (wt% slurry) | RSD | Average (wt% slurry) | RSD | Average (wt% slurry) | RSD | Average (wt% slurry) | RSD |
| Co | 3.47E-04 | 2.2% | 3.35E-04 | 0.2% | 3.30E-04 | 1.7% | 3.26E-04 | 0.9% |
| $^{88}Sr$ | 2.08E-03 | 1.0% | 2.06E-03 | 1.0% | 2.09E-03 | 2.6% | 1.97E-03 | 1.9% |
| $^{99}Tc$ | 2.46E-04 | 1.2% | 2.38E-04 | 1.4% | 2.30E-04 | 1.8% | 2.25E-04 | 1.6% |
| Ru | 5.44E-03 | 0.7% | 5.45E-03 | 1.0% | 5.29E-03 | 2.3% | 5.18E-03 | 1.8% |
| Rh | 1.11E-03 | 0.4% | 1.10E-03 | 0.6% | 1.06E-03 | 2.0% | 1.04E-03 | 1.2% |
| Pd | 2.32E-04 | 1.0% | 2.16E-04 | 3.8% | 2.17E-04 | 4.4% | 2.12E-04 | 4.8% |
| Ag | 8.93E-04 | 0.8% | 8.81E-04 | 0.8% | 8.45E-04 | 2.0% | 8.40E-04 | 1.8% |
| Sb | 3.65E-05 | 2.8% | 3.76E-05 | 1.8% | 3.62E-05 | 4.2% | 3.43E-05 | 5.6% |
| $^{133}Cs$ | 1.23E-04 | 0.6% | 1.18E-04 | 2.7% | 1.14E-04 | 1.5% | 1.12E-04 | 1.9% |
| La | 4.83E-03 | 0.3% | 4.84E-03 | 0.2% | 4.68E-03 | 2.0% | 4.61E-03 | 0.7% |
| Gd | 6.54E-03 | 0.7% | 6.69E-03 | 0.6% | 6.44E-03 | 2.2% | 6.32E-03 | 1.4% |
| $^{232}Th$ | 2.46E-01 | 1.1% | 2.29E-01 | 0.5% | 2.23E-01 | 7.9% | 2.18E-01 | 2.5% |
| $^{233}U$ | 9.44E-05 | 0.8% | 9.04E-05 | 3.4% | 8.80E-05 | 5.3% | 8.61E-05 | 1.1% |
| $^{234}U$ | 9.22E-05 | 1.0% | 8.06E-05 | 1.2% | 7.78E-05 | 2.1% | 7.58E-05 | 2.7% |
| $^{235}U$ | 4.47E-03 | 1.0% | 4.29E-03 | 0.9% | 4.16E-03 | 1.9% | 3.99E-03 | 0.9% |
| $^{236}U$ | 3.17E-04 | 1.3% | 3.27E-04 | 1.3% | 3.16E-04 | 0.7% | 3.09E-04 | 1.5% |
| $^{237}Np$ | 1.69E-04 | 1.0% | 1.68E-04 | 1.0% | 1.68E-04 | 3.6% | 1.58E-04 | 1.6% |
| $^{238}U$ | 3.23E-01 | 0.3% | 3.10E-01 | 0.4% | 3.01E-01 | 1.3% | 2.90E-01 | 1.0% |
| $^{239}Pu$ | 2.38E-03 | 0.8% | 2.18E-03 | 0.3% | 2.13E-03 | 3.6% | 2.07E-03 | 1.4% |
| $^{240}Pu$ | 1.81E-04 | 0.6% | 1.70E-04 | 0.4% | 1.67E-04 | 4.6% | 1.66E-04 | 2.7% |
| mass 241 | 4.41E-05 | 0.6% | 4.08E-05 | 7.7% | 3.90E-05 | 3.5% | 3.92E-05 | 7.9% |
| mass 242 | 1.40E-05 | 0.7% | 1.22E-05 | 2.4% | 1.28E-05 | 6.7% | 1.19E-05 | 8.1% |
| mass 243 | <3.9E-06 | -- | <3.3E-06 | -- | <3.3E-06 | -- | <3.3E-06 | -- |
| mass 244 | <3.9E-06 | -- | <3.3E-06 | -- | <3.3E-06 | -- | <3.3E-06 | -- |

**Table 3-8. ICP-ES results for the product filtrates from the SB10/SRE solubility tests**

| Analyte | 70% Acid Addition | | 100% Acid Addition | | 140% Acid Addition | |
|---|---|---|---|---|---|---|
| | Average (mg/L) | RSD | Average (mg/L) | RSD | Average (mg/L) | RSD |
| Ag | <5.7E+00 | -- | <5.9E+00 | -- | <5.9E+00 | -- |
| Al | 3.00E+01 | 5.0% | 5.45E+02 | 0.8% | 1.56E+03 | 0.4% |
| B | <8.2E+00 | -- | <8.4E+00 | -- | <8.5E+00 | -- |
| Ba | <2.9E+00 | -- | 3.12E+00 | 3.5% | <3.0E+00 | -- |
| Be | <2.3E+00 | -- | <2.4E+00 | -- | <2.4E+00 | -- |
| Ca | 1.83E+02 | 0.2% | 5.87E+02 | 3.6% | 6.81E+02 | 0.3% |
| Cd | <4.7E+00 | -- | <4.9E+00 | -- | <4.9E+00 | -- |
| Ce | <3.7E+01 | -- | <3.8E+01 | -- | <3.8E+01 | -- |
| Co | <5.9E+00 | -- | <6.1E+00 | -- | <6.1E+00 | -- |
| Cr | <9.9E+00 | -- | 1.06E+02 | 1.5% | 1.47E+02 | 0.2% |
| Cu | <1.4E+00 | -- | 3.93E+00 | 7.8% | 1.85E+01 | 0.5% |
| Fe | <4.6E+00 | -- | 1.34E+02 | 0.8% | 6.54E+02 | 0.2% |
| Gd | <4.0E+00 | -- | 4.12E+01 | 0.6% | 6.45E+01 | 0.3% |
| K | <9.2E+01 | -- | <9.5E+01 | -- | <9.5E+01 | -- |
| La | <1.5E+00 | -- | 6.23E+00 | 5.3% | 1.98E+01 | 0.6% |
| Li | <7.6E+00 | -- | <7.9E+00 | -- | 1.15E+01 | 3.9% |
| Mg | 7.16E+01 | 0.1% | 2.11E+02 | 0.6% | 2.68E+02 | 0.4% |
| Mn | 4.82E+01 | 0.2% | 2.04E+03 | 1.1% | 2.70E+03 | 0.3% |
| Mo | <1.8E+01 | -- | <1.9E+01 | -- | <1.9E+01 | -- |
| Na | 2.10E+04 | 0.2% | 2.18E+04 | 0.8% | 2.10E+04 | 0.5% |
| Ni | <2.9E+01 | -- | 9.82E+01 | 0.9% | 2.25E+02 | 0.8% |
| P | <3.5E+01 | -- | <3.6E+01 | -- | <3.6E+01 | -- |
| Pb | <4.0E+01 | -- | <4.1E+01 | -- | <4.2E+01 | -- |
| S | <2.0E+03 | -- | <2.0E+03 | -- | <2.1E+03 | -- |
| Sb | <1.2E+02 | -- | <1.3E+02 | -- | <1.3E+02 | -- |
| Si | <1.8E+01 | -- | 1.32E+02 | 0.9% | 2.50E+02 | 0.7% |
| Sn | <3.5E+01 | -- | <3.6E+01 | -- | <3.6E+01 | -- |
| Sr | 2.99E+00 | 0.8% | 1.34E+01 | 1.1% | 1.61E+01 | 0.1% |
| Th | <2.0E+01 | -- | 1.84E+02 | 1.2% | 3.79E+02 | 0.6% |
| Ti | <1.2E+00 | -- | <1.3E+00 | -- | <1.3E+00 | -- |
| U | 1.07E+03 | 0.7% | 3.19E+03 | 0.9% | 3.34E+03 | 0.5% |
| V | <3.2E+00 | -- | <3.3E+00 | -- | <3.3E+00 | -- |
| Zn | <3.4E+00 | -- | <3.5E+00 | -- | 6.53E+00 | 1.2% |
| Zr | <1.7E+00 | -- | 5.32E+00 | 3.7% | 1.86E+01 | 1.0% |

**Table 3-9. ICP-MS results for the product filtrates from the SB10/SRE solubility tests**

| Analyte | 70% Acid Addition | | 100% Acid Addition | | 140% Acid Addition | |
|---|---|---|---|---|---|---|
| | Average (mg/L) | RSD | Average (mg/L) | RSD | Average (mg/L) | RSD |
| Co | <1.6E-02 | -- | 7.12E-01 | 0.9% | 2.40E+00 | 0.5% |
| $^{88}Sr$ | 2.28E+00 | 2.1% | 9.60E+00 | 0.5% | 1.15E+01 | 0.4% |
| $^{99}Tc$ | 7.22E-01 | 2.2% | 9.28E-01 | 0.7% | 1.02E+00 | 0.3% |
| Ru | 5.60E+00 | 1.1% | 1.84E+01 | 0.4% | 2.92E+01 | 0.6% |
| Rh | 2.39E+00 | 1.0% | 5.84E+00 | 1.3% | 7.97E+00 | 0.6% |
| Pd | 6.42E-02 | 26.9% | 7.10E-02 | 21.1% | 5.10E-02 | 7.0% |
| Ag | <3.3E-02 | -- | 8.77E-02 | 11.1% | 5.66E-01 | 2.3% |
| Sb | <3.3E-02 | -- | 7.46E-02 | 7.4% | 1.73E-01 | 2.7% |
| $^{133}Cs$ | 8.82E-01 | 1.9% | 1.19E+00 | 0.5% | 1.15E+00 | 1.7% |
| La | 9.58E-02 | 2.7% | 7.85E+00 | 3.4% | 2.35E+01 | 0.6% |
| Gd | 8.47E-01 | 1.6% | 3.19E+01 | 2.3% | 5.76E+01 | 0.4% |
| $^{232}Th$ | 7.60E+00 | 1.3% | 1.60E+02 | 0.9% | 3.50E+02 | 0.5% |
| $^{233}U$ | 1.31E-01 | 1.7% | 4.48E-01 | 1.0% | 4.90E-01 | 0.7% |
| $^{234}U$ | 2.24E-01 | 5.9% | 7.08E-01 | 6.1% | 7.65E-01 | 1.6% |
| $^{235}U$ | 1.53E+01 | 0.6% | 4.19E+01 | 0.6% | 4.35E+01 | 0.3% |
| $^{236}U$ | 8.95E-01 | 1.4% | 3.00E+00 | 0.7% | 3.14E+00 | 1.1% |
| $^{237}Np$ | 1.05E-01 | 1.6% | 1.10E+00 | 0.8% | 1.29E+00 | 0.9% |
| $^{238}U$ | 1.04E+03 | 1.1% | 3.09E+03 | 1.2% | 3.21E+03 | 0.3% |
| $^{239}Pu$ | 1.46E-01 | 1.9% | 2.20E+00 | 0.6% | 9.25E+00 | 1.4% |
| $^{240}Pu$ | <1.6E-02 | -- | 1.42E-01 | 0.1% | 6.53E-01 | 0.4% |
| mass 241 | <1.6E-02 | -- | 5.31E-02 | 2.8% | 1.58E-01 | 0.2% |
| mass 242 | <1.6E-02 | -- | <1.7E-02 | -- | 2.61E-02 | 2.8% |
| mass 243 | <1.6E-02 | -- | <1.7E-02 | -- | <1.7E-02 | -- |
| mass 244 | <1.6E-02 | -- | <1.7E-02 | -- | <1.7E-02 | -- |

Table 3-10 contains the overall results summary for the solubility tests at the three acid additions. Additional information on analytes not contained in the Table 3-10 summary can be found in Table A-13 through Table A-16. All concentrations in these tables are on the same basis, wt% in the slurry, to calculate the percent soluble for each component. The percent soluble is calculated as the supernate concentration divided by the slurry concentration times 100%. The columns labelled "Total" represent the overall slurry concentrations from Table 3-6 and Table 3-7. The columns labelled "Liquid" represent the filtrate/soluble concentrations from Table 3-8 and Table 3-9 converted to wt% slurry basis. The columns labelled "Solid" are the difference between the corresponding "Total" and "Liquid" concentrations on a wt% slurry basis. The solid composition has additional uncertainty because it is a calculated value from two measurements. The solid concentration is not reported when the total or liquid concentration are below the detectable level. The percent soluble concentrations are calculated as the liquid concentration divided by the total concentration. Figure 3-2 contains a plot of percent solubility versus pH for some of the key fissile components (uranium and plutonium) and poisons (manganese, iron, and gadolinium).

Manganese showed relatively low (2%) soluble percent value at the 70% acid addition stoichiometry but had significantly higher soluble percent values (65% and 90%) at the 100% and 140% acid addition stoichiometries, respectively. It should not be a concern that manganese exceeded 80% soluble percent value in this testing due to the correspondingly high uranium solubility.

Elemental uranium and individual uranium isotopes showed similar results to each other. The uranium-233, 234, and 236 isotope results had more uncertainty than the other uranium results due to their relatively low concentrations. In general, elemental uranium and uranium isotopes were approximately 30%, 90%, and 96 to 98% soluble at the 70%, 100%, and 140% acid additions, respectively. The majority (59%) of the uranium-235 in the SB10/SRE mixture is from the SRE while only 2% of the elemental uranium is from the SRE. Thus, the similarity in the soluble percent values of uranium-235 and elemental uranium indicates that there is not an impact on uranium solubility from freshly precipitated SRE.

In all cases, the uranium percent soluble exceeded the manganese percent soluble. Because of this observation, it is not possible to have a deficit of manganese to poison the equivalent uranium-235 in the solid phase as long as the feed slurry had an acceptable poison ratio. Counter to the original hypothesis, this result indicates that the freshly precipitated manganese from SRE does not increase the manganese solubility to an extent that negatively impacts the ability of the manganese to poison the solid phase equivalent uranium-235. This result also validates the original assumption that it was not necessary to further test and measure the relative soluble percentages of manganese and uranium at the lower pH conditions of 3, 2, and 1 with excess acid additions.

Gadolinium is also being investigated in a separate study as a replacement for poisoning uranium in DWPF due to the much lower mass ratio of gadolinium to equivalent uranium-235 required.[21] The gadolinium percent soluble closely mimicked the manganese percent soluble, at 1.1%, 44 to 57%, and 80 to 91% at 70, 100, and 140% acid addition, respectively. Gadolinium concentration in the slurry and filtrate was measured by both ICP-ES and ICP-MS. While the slurry concentration was similar between the two methods, the filtrate concentration differed. Thus, two values are reported for gadolinium percent soluble at some conditions. Similar to the observation for the uranium versus manganese percent soluble, the uranium percent soluble exceeded the gadolinium percent soluble for all cases. These observations provide additional evidence that gadolinium may be a suitable replacement for manganese for poisoning in DWPF criticality control.

**Table 3-10. Total, insoluble, and soluble concentrations and the corresponding percent soluble for the SB10/SRE solubility tests at three acid addition levels**

| Analyte | Method | 70% Acid Addition | | | | 100% Acid Addition | | | | 140% Acid Addition | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) |
| Ag | ICP-MS | 8.81E-04 | -- | <2.9E-06 | <0.3% | 8.45E-04 | 8.37E-04 | 7.71E-06 | 0.9% | 8.40E-04 | 7.90E-04 | 5.00E-05 | 6.0% |
| Al | ICP-ES | 1.50E+00 | 1.49E+00 | 2.65E-03 | 0.2% | 1.39E+00 | 1.34E+00 | 4.79E-02 | 3.4% | 1.39E+00 | 1.26E+00 | 1.37E-01 | 9.9% |
| Ba | ICP-ES | 6.89E-03 | -- | <2.5E-04 | <4% | 6.67E-03 | 6.40E-03 | 2.74E-04 | 4.1% | 6.58E-03 | -- | <2.6E-04 | <4% |
| Ca | ICP-ES | 7.73E-02 | 6.10E-02 | 1.63E-02 | 21% | 7.48E-02 | 2.32E-02 | 5.16E-02 | 69% | 7.38E-02 | 1.37E-02 | 6.02E-02 | 81% |
| Ce | ICP-ES | 1.55E-02 | -- | <3.3E-03 | <21% | 1.48E-02 | -- | <3.3E-03 | <23% | 1.48E-02 | -- | <3.4E-03 | <23% |
| Co | ICP-MS | 3.35E-04 | -- | <1.5E-06 | <0.4% | 3.30E-04 | 2.68E-04 | 6.25E-05 | 19% | 3.26E-04 | 1.14E-04 | 2.12E-04 | 65% |
| Cr | ICP-ES | 2.26E-02 | -- | <8.8E-04 | <4% | 2.21E-02 | 1.29E-02 | 9.28E-03 | 42% | 2.17E-02 | 8.69E-03 | 1.30E-02 | 60% |
| $^{133}$Cs | ICP-MS | 1.18E-04 | 4.02E-05 | 7.81E-05 | 66% | 1.14E-04 | 8.94E-06 | 1.05E-04 | 92% | 1.12E-04 | 1.04E-05 | 1.02E-04 | 91% |
| Cu | ICP-ES | 4.18E-03 | -- | <1.3E-04 | <3% | 4.08E-03 | 3.74E-03 | 3.45E-04 | 8.5% | 4.04E-03 | 2.41E-03 | 1.63E-03 | 40% |
| Fe | ICP-ES | 1.18E+00 | -- | <4.0E-04 | <0.03% | 1.14E+00 | 1.13E+00 | 1.18E-02 | 1.0% | 1.12E+00 | 1.06E+00 | 5.78E-02 | 5.2% |
| Gd | ICP-ES | 6.62E-03 | -- | <3.5E-04 | <5% | 6.33E-03 | 2.71E-03 | 3.62E-03 | 57% | 6.27E-03 | 5.71E-04 | 5.70E-03 | 91% |
| | ICP-MS | 6.69E-03 | 6.62E-03 | 7.50E-05 | 1.1% | 6.44E-03 | 3.64E-03 | 2.80E-03 | 44% | 6.32E-03 | 1.23E-03 | 5.08E-03 | 80% |
| La | ICP-ES | 3.79E-03 | -- | <1.3E-04 | <3% | 3.73E-03 | 3.18E-03 | 5.48E-04 | 15% | 3.64E-03 | 1.89E-03 | 1.75E-03 | 48% |
| | ICP-MS | 4.84E-03 | 4.84E-03 | 8.49E-06 | 0.2% | 4.68E-03 | 3.99E-03 | 6.90E-04 | 15% | 4.61E-03 | 2.53E-03 | 2.08E-03 | 45% |
| Li | ICP-ES | 1.65E-03 | -- | <6.7E-04 | <41% | 1.55E-03 | -- | <6.9E-04 | <45% | 1.59E-03 | 5.76E-04 | 1.02E-03 | 64% |
| Mg | ICP-ES | 2.90E-02 | 2.27E-02 | 6.34E-03 | 22% | 2.83E-02 | 9.79E-03 | 1.85E-02 | 65% | 2.77E-02 | 4.11E-03 | 2.36E-02 | 85% |
| Mn | ICP-ES | 2.84E-01 | 2.80E-01 | 4.27E-03 | 1.5% | 2.76E-01 | 9.61E-02 | 1.80E-01 | 65% | 2.70E-01 | 3.21E-02 | 2.38E-01 | 88% |
| Na | ICP-ES | 1.99E+00 | 1.30E-01 | 1.86E+00 | 93% | 1.94E+00 | 2.29E-02 | 1.92E+00 | 99% | 1.92E+00 | 7.07E-02 | 1.85E+00 | 96% |
| Nd | ICP-MS | 1.59E-02 | 1.58E-02 | 5.00E-05 | 0.3% | 1.53E-02 | 1.24E-02 | 2.93E-03 | 19% | 1.50E-02 | 7.95E-03 | 7.08E-03 | 47% |
| Ni | ICP-ES | 3.74E-02 | -- | <2.6E-03 | <7% | 3.66E-02 | 2.80E-02 | 8.63E-03 | 24% | 3.56E-02 | 1.57E-02 | 1.98E-02 | 56% |
| $^{237}$Np | ICP-MS | 1.68E-04 | 1.59E-04 | 9.33E-06 | 5.5% | 1.68E-04 | 7.15E-05 | 9.66E-05 | 57% | 1.58E-04 | 4.44E-05 | 1.14E-04 | 72% |
| Pd | ICP-MS | 2.16E-04 | 2.10E-04 | 5.69E-06 | 2.6% | 2.17E-04 | 2.11E-04 | 6.24E-06 | 2.9% | 2.12E-04 | 2.07E-04 | 4.51E-06 | 2.1% |
| $^{239}$Pu | ICP-MS | 2.18E-03 | 2.17E-03 | 1.29E-05 | 0.6% | 2.13E-03 | 1.94E-03 | 1.93E-04 | 9.1% | 2.07E-03 | 1.26E-03 | 8.17E-04 | 39% |
| $^{240}$Pu | ICP-MS | 1.70E-04 | -- | <1.5E-06 | <1% | 1.67E-04 | 1.55E-04 | 1.25E-05 | 7.5% | 1.66E-04 | 1.09E-04 | 5.77E-05 | 35% |
| Rh | ICP-MS | 1.10E-03 | 8.91E-04 | 2.11E-04 | 19% | 1.06E-03 | 5.51E-04 | 5.14E-04 | 48% | 1.04E-03 | 3.39E-04 | 7.04E-04 | 68% |
| Ru | ICP-MS | 5.45E-03 | 4.95E-03 | 4.96E-04 | 9.1% | 5.29E-03 | 3.68E-03 | 1.61E-03 | 31% | 5.18E-03 | 2.60E-03 | 2.58E-03 | 50% |
| Sb | ICP-MS | 3.76E-05 | 3.47E-05 | 2.92E-06 | 7.8% | 3.62E-05 | 2.97E-05 | 6.56E-06 | 18% | 3.43E-05 | 1.90E-05 | 1.53E-05 | 45% |
| Si | ICP-ES | 3.90E-02 | -- | <1.6E-03 | <4% | 3.73E-02 | 2.56E-02 | 1.16E-02 | 31% | 3.85E-02 | 1.64E-02 | 2.21E-02 | 57% |
| Sr | ICP-ES | 3.16E-03 | 2.90E-03 | 2.65E-04 | 8.4% | 3.07E-03 | 1.89E-03 | 1.18E-03 | 39% | 3.00E-03 | 1.59E-03 | 1.42E-03 | 47% |
| $^{88}$Sr | ICP-MS | 2.06E-03 | 1.85E-03 | 2.02E-04 | 9.8% | 2.09E-03 | 1.25E-03 | 8.44E-04 | 40% | 1.97E-03 | 9.57E-04 | 1.01E-03 | 51% |
| $^{99}$Tc | ICP-MS | 2.38E-04 | 1.74E-04 | 6.39E-05 | 27% | 2.30E-04 | 1.48E-04 | 8.16E-05 | 36% | 2.25E-04 | 1.35E-04 | 9.05E-05 | 40% |
| Th | ICP-ES | 2.41E-01 | -- | <1.8E-03 | <1% | 2.37E-01 | 2.21E-01 | 1.62E-02 | 6.8% | 2.32E-01 | 1.98E-01 | 3.35E-02 | 14% |
| | ICP-MS | 2.29E-01 | 2.28E-01 | 6.73E-04 | 0.3% | 2.23E-01 | 2.09E-01 | 1.40E-02 | 6.3% | 2.18E-01 | 1.87E-01 | 3.09E-02 | 14% |
| Ti | ICP-ES | 1.72E-03 | -- | <1.1E-04 | <6% | 1.67E-03 | -- | <1.1E-04 | <7% | 1.64E-03 | -- | <1.1E-04 | <7% |
| U | ICP-ES | 3.18E-01 | 2.23E-01 | 9.46E-02 | 30% | 3.11E-01 | 3.03E-02 | 2.80E-01 | 90% | 3.03E-01 | 7.36E-03 | 2.95E-01 | 98% |
| | ICP-MS | 3.15E-01 | 2.21E-01 | 9.35E-02 | 30% | 3.06E-01 | 3.02E-02 | 2.76E-01 | 90% | 2.95E-01 | 7.45E-03 | 2.87E-01 | 97% |
| $^{233}$U | ICP-MS | 9.04E-05 | 7.88E-05 | 1.16E-05 | 13% | 8.80E-05 | 4.87E-05 | 3.93E-05 | 45% | 8.61E-05 | 4.29E-05 | 4.32E-05 | 50% |
| $^{234}$U | ICP-MS | 8.06E-05 | 6.08E-05 | 1.98E-05 | 25% | 7.78E-05 | 1.56E-05 | 6.22E-05 | 80% | 7.58E-05 | 8.24E-06 | 6.75E-05 | 89% |
| $^{235}$U | ICP-MS | 4.29E-03 | 2.94E-03 | 1.36E-03 | 32% | 4.16E-03 | 4.76E-04 | 3.68E-03 | 89% | 3.99E-03 | 1.51E-04 | 3.84E-03 | 96% |
| $^{236}$U | ICP-MS | 3.27E-04 | 2.47E-04 | 7.93E-05 | 24% | 3.16E-04 | 5.17E-05 | 2.64E-04 | 84% | 3.09E-04 | 3.12E-05 | 2.78E-04 | 90% |
| $^{238}$U | ICP-MS | 3.10E-01 | 2.18E-01 | 9.20E-02 | 30% | 3.01E-01 | 2.96E-02 | 2.71E-01 | 90% | 2.90E-01 | 7.22E-03 | 2.83E-01 | 98% |
| Zn | ICP-ES | 2.60E-03 | -- | <3.0E-04 | <11% | 2.49E-03 | -- | <3.1E-04 | <12% | 2.45E-03 | 1.87E-03 | 5.77E-04 | 24% |
| Zr | ICP-ES | 1.43E-02 | -- | <1.5E-04 | <1% | 1.39E-02 | 1.34E-02 | 4.68E-04 | 3.4% | 1.36E-02 | 1.20E-02 | 1.64E-03 | 12% |
| mass 241 | ICP-MS | 4.08E-05 | -- | <1.5E-06 | <4% | 3.90E-05 | 3.43E-05 | 4.67E-06 | 12% | 3.92E-05 | 2.52E-05 | 1.40E-05 | 36% |
| mass 242 | ICP-MS | 1.22E-05 | -- | <1.5E-06 | <12% | 1.28E-05 | -- | <1.5E-06 | <12% | 1.19E-05 | 9.61E-06 | 2.31E-06 | 19% |

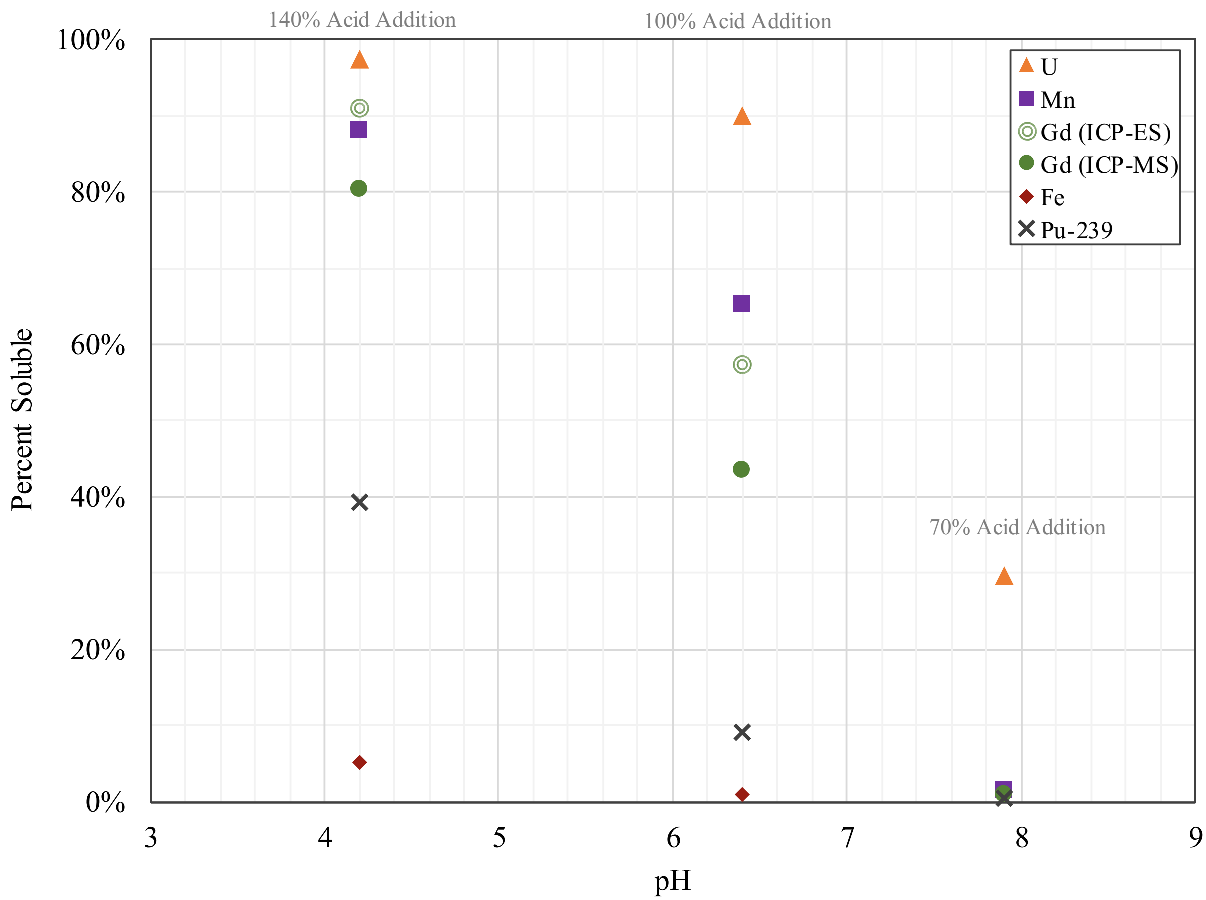


**Figure 3-2. Comparison of percent solubilities of key metals for the three SB10/SRE solubility tests**

The manganese and uranium isotopic results of Table 3-10 can be used to calculate the poison ratio in both the liquid (soluble) and solid (insoluble) phases. If the percent soluble of manganese was to precisely match the percent soluble of equivalent uranium-235, the product ratios of manganese to equivalent uranium-235 for both the solid and liquid phases would exactly match the ratio in the slurry. As seen in Table 3-5, the overall ratio of manganese to equivalent uranium-235 in the feed and products were measured at or near 64:1. For these test results, where the uranium percent soluble always exceed the manganese percent soluble, the poison ratio in the solid always exceeded that of the slurry and the poison ratio in the liquid always was lower than that of the slurry.

Calculation of the ratios of manganese to equivalent uranium-235 for the SB10/SRE solubility tests is presented in Table 3-11. Results for the ratio of manganese to equivalent uranium-235 are presented with 2 significant digits. Manganese to equivalent uranium-235 mass ratios in the solid phase ranged from 92:1 to 180:1. The uranium percent soluble exceeding the manganese percent soluble caused the poison ratio in the solid phase to always exceed the slurry poison ratio and not challenge the NCSE criticality poisoning mass ratio of 14:1. Manganese to equivalent uranium-235 mass ratios in the liquid phase ranged from 3.1:1 to 61:1. The sole condition where the manganese to equivalent uranium-235 ratio in the liquid phase was lower than the NCSE criticality poisoning mass ratio of 14:1 was the 70% acid addition. Concurrently, the $^{235}U(eq)$ concentration in the 70% acid addition product filtrate was 15.5 mg/L. It is likely that the soluble concentrations of manganese and uranium had reached their solubility limits for the 70% acid addition at the pH of 7.9. Thus, additional manganese added to the slurry would be unlikely to greatly impact the observed ratio of manganese to equivalent uranium-235 in the liquid phase.

**Table 3-11. Calculation of insoluble and soluble ratios of manganese to equivalent uranium-235**

| | 70% Acid Addition | | 100% Acid Addition | | 140% Acid Addition | |
|---|---|---|---|---|---|---|
| | Solid | Liquid | Solid | Liquid | Solid | Liquid |
| Mn (wt% slurry) | 2.80E-01 | 4.27E-03 | 9.61E-02 | 1.80E-01 | 3.21E-02 | 2.38E-01 |
| $^{235}$U(eq) (wt% slurry) | 3.05E-03 | 1.37E-03 | 5.45E-04 | 3.74E-03 | 2.11E-04 | 3.90E-03 |
| Mn:$^{235}$U(eq) | 92:1 | 3.1:1 | 180:1 | 48:1 | 150:1 | 61:1 |

The low manganese to $^{235}$U(eq) mass ratio of 3.1:1 in the liquid phase should not be a concern because the $^{235}$U(eq) concentration in the liquid of 15.5 mg/L is significantly lower than the applicable American Nuclear Society (ANS) 8.1 single parameter subcritical limit of 11600 mg/L.[22] Thus, the low $^{235}$U(eq) concentration in the liquid phase appears to offset the need to maintain the poison mass ratio in the liquid phase.

The 70% Hsu acid stoichiometry corresponds to 65% KMA stoichiometry for this feed. The lowest acid stoichiometry tested to date for CPC simulant testing of the NGA flowsheet is 77% KMA acid stoichiometry. While it is unlikely that an acid addition as low as 70% Hsu or 65% KMA stoichiometries would be recommended, a transient condition of lower acid addition is encountered during processing while proceeding to the target acid stoichiometry

Table 3-12 contains the measurement of ratios of manganese to equivalent uranium-235 for the SB10/SRE solubility test (from Table 3-5 and Table 3-11) compared with ratios for the unwashed SB10 Tank 51 sample (HTF-51-19-114 and HTF-51-20-15)[15] and various ratios from the SB9 NGA qualification and follow-on tests.[12, 23] Results are presented with 2 significant digits. Only the overall slurry ratios are given for test feeds. The soluble and insoluble ratios for the SB10/SRE test feed, the unwashed SB10 Tank 51 sample, and the SB9 NGA feed cannot be determined because the manganese concentration in the liquid portion of each of these feeds was below the detectable level.

**Table 3-12. Comparison of SB10/SRE test ratios of manganese to equivalent uranium-235 to previous sample results for SB10 sample without SRE and SB9 NGA flowsheet test feed, intermediate samples, and product samples**

| Mn:$^{235}$U(eq) | Total | Solid | Liquid |
|---|---|---|---|
| *SB10/SRE Solubility Test* | | | |
| SB10/SRE Feed (pH >13) | 64:1 | -- | -- |
| 70% Acid Addition Product (pH 7.9) | 64:1 | 92:1 | 3.1:1 |
| 100% Acid Addition Product (pH 6.4) | 64:1 | 180:1 | 48:1 |
| 140% Acid Addition Product (pH 4.2) | 66:1 | 150:1 | 61:1 |
| *As-Received Tank 51 SB10 Sample* | | | |
| Unwashed Tank 51 Sample (pH >14) | 120:1 | -- | -- |
| *SB9 NGA Qualification Test (SC-18, 87% Acid Addition)* | | | |
| SB9 Feed (pH >13) | 170:1 | -- | -- |
| After 1/2 Glycolic Acid Add (pH 6.9) | -- | -- | 2.3:1 |
| After Glycolic Acid Add (pH 4.8) | -- | -- | 60:1 |
| After 1.5 Hours Boiling (pH 6.3) | -- | -- | 100:1 |
| After 3.0 Hours Boiling (pH 6.6) | -- | -- | 140:1 |
| After 8.25 Hours Boiling (pH 6.7) | -- | -- | 160:1 |
| After 13.25 Hours Boiling | -- | -- | 200:1 |
| SRAT Product (pH 7.0) | 170:1 | 160:1 | 220:1 |
| SME Product (pH 7.0) | 170:1 | 170:1 | 180:1 |
| *Additional Acid Addition to SB9 NGA SRAT Product* | | | |
| SRAT Product at pH 3 | 150:1 | 750:1 | 100:1 |
| SRAT Procuct at pH 2 | 160:1 | 1000:1 | 120:1 |
| SRAT Product at pH 1 | 160:1 | 570:1 | 140:1 |

The SB9 SRAT and Slurry Mix Evaporator (SME) product analyses contained enough information to calculate the manganese to equivalent uranium-235 in the slurry and in both the insoluble and soluble phases.[23] The similarity of the percent soluble of both manganese and uranium lead to manganese poisoning ratios in the solid and liquid phases both nearly equaling that of the slurry.

Several intermediate samples were taken during the SB9 NGA qualification test performed with 87% Hsu and 78% KMA stoichiometries (see Figure 3-5 and Table 3-5 in the reference).[12] These samples included a sample half-way through glycolic acid addition, a sample immediately after completing glycolic acid addition, and samples during the dewater and reflux boiling. The poisoning of the slurry and insoluble fractions cannot be determined because only supernate concentrations were analyzed, but it is reasonable to assume that the slurry manganese to equivalent uranium-235 ratio would be 170:1, equal to that in the SB9 feed and SRAT and SME products for this mixture. Determining the poisoning ratios in the liquid phase required calculating the equivalent uranium-235 from the elemental uranium by assuming that the uranium isotopic distribution was the same as in the SB9 feed and product samples. The mid glycolic acid addition supernate sample had the lowest concentration of both manganese and uranium from any of the intermediate samples. The resulting mass ratio of manganese to equivalent uranium-235 in the liquid phase was 2.3:1 midway through the glycolic acid addition, but the equivalent uranium-235 concentration in the supernate was a relatively low 2.6 mg/kg. This transient SB9 observation is consistent with the SB10/SRE 70% acid addition observation. The post glycolic acid addition supernate sample had the highest manganese and uranium concentration of any of the intermediate or product supernate samples. At the end of glycolic addition, the manganese to equivalent uranium-235 mass ratio was 60:1 in the supernate with an equivalent uranium-235 concentration in the supernate of 54 mg/kg. Except for the mid and post glycolic acid samples, the samples taken during boiling contained a consistent concentration of manganese. In the same set of samples, the soluble uranium concentration decreased over the boiling period. Thus, the manganese poison ratio in the liquid increased during the SRAT cycle, ultimately being similar in both solid and liquid phases at the end of the SRAT and SME cycles.

The testing to add excess glycolic and nitric acid to the SB9 products yielded very high manganese to equivalent uranium-235 ratios in the solid phase while maintaining sufficiently high ratios in the liquid phase. The cause of the high ratios in the solid phase for these excess acid addition tests is the high percent soluble of the uranium isotopes relative to manganese.

A summary of the ratio of gadolinium to equivalent uranium-235 for the test feed and products is presented in Table 3-13. Separate ratios were calculated from the ICP-ES and ICP-MS measurements of gadolinium. The gadolinium poison ratio in the feed and product slurries was measured as 1.3 to 1.5. As expected from the relatively high uranium percent solubilities, the radio of gadolinium to uranium-235 in the solid phase was always greater than that in the feed slurry. As seen with manganese, the ratio of gadolinium to uranium-235 in the liquid phase was lowest in the 70% Hsu acid stoichiometry addition test.

**Table 3-13. Overall, insoluble, and soluble ratios of gadolinium to equivalent uranium-235**

| Gd:$^{235}$U(eq) | Feed | 70% Acid Addition | | | 100% Acid Addition | | | 140% Acid Addition | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Total | Solid | Liquid | Total | Solid | Liquid | Total | Solid | Liquid |
| Gd by ICP-ES | 1.29:1 | 1.50:1 | -- | -- | 1.48:1 | 5.0:1 | 0.97:1 | 1.52:1 | 2.7:1 | 1.46:1 |
| Gd by ICP-MS | 1.42:1 | 1.51:1 | 2.2:1 | 0.055:1 | 1.50:1 | 6.7:1 | 0.75:1 | 1.53:1 | 5.8:1 | 1.30:1 |

## 4.0 Conclusions

Acid was added to SB10 with SRE, consistent with the DWPF NGA flowsheet at 70%, 100%, and 140% Hsu acid stoichiometries. The mixtures were heated to 95 °C for 10 hours and filtrate was isolated for analyses. The following are the key results.

- Uranium percent soluble values exceeded the percent soluble values for manganese over the entire range tested, indicating that manganese poisoning in the solid phase will always be maintained. Thus, any increase in manganese solubility from the addition of SRE material to SB10 will not negatively impact the NCSE criticality control for manganese poisoning of equivalent uranium-235. Uranium solubility did not appear to be impacted by freshly precipitated sludge.

- Manganese percent soluble values were 2%, 65%, and 90% at the 70%, 100%, and 140% acid additions, respectively. For this specific SB10 and SRE mixture, the freshly precipitated manganese from SRE does not increase the manganese solubility to an extent that negatively impacts the ability of the manganese to poison the solid phase equivalent uranium-235.

- For the 100% and 140% acid additions, the mass ratios of manganese to equivalent uranium-235 were greater than the required 14:1 ratio in both liquid and solid phases.

- For the 70% acid addition, the mass ratio of manganese to equivalent uranium-235 in the liquid phase was 3.1:1 compared to the required 14:1. The low manganese to equivalent uranium-235 mass ratio in the liquid phase should not be a concern because the equivalent uranium-235 concentration in the liquid of 15.5 mg/L is significantly lower than the applicable ANS 8.1 single parameter subcritical limit of 11600 mg/L. A similar trend in the liquid phase poison ratio was noted for an intermediate sample from half-way through the glycolic acid addition during SB9 qualification testing with the NGA flowsheet.

- Gadolinium percent soluble values closely mimicked the percent soluble values for manganese. Likewise, uranium percent soluble values exceeded the gadolinium percent soluble for all cases. These observations provide additional evidence that gadolinium may be a suitable replacement for manganese in the DWPF criticality control for poisoning enriched uranium in future sludge batches.

## 5.0 Future Work

Savannah River Remediation requested anion analysis of the acid addition products to determine the level of nitrite and carbonate destruction. That information will be included in a separate document.

Because gadolinium measurements are important to future solubility testing, SRNL should investigate the cause for the difference in some of the ICP-ES and ICP-MS measurements of gadolinium in order to recommend the preferred analytical method.

## 6.0 Acknowledgements

The authors acknowledge the diligent support of the shielded cells technicians, primarily Kevin Haupfear and Raenan Stanley, who performed most of the hands-on work. Mark Jones, Nathan Wyeth, and technicians in SRNL Analytical Development provided the ICP-MS and ICP-ES analyses on which this study was based.

## 7.0 References

[1] Shirley, S. E.; Fitzpatrick, J. M.; Williams, H. M.; and Smith, N. A., "Path Forward: Sodium Reactor Experiment (SRE) Discard Proposal", X-EPF-H-00029, Revision 3, April 28, 2020.

[2] Shah, H. B. and Isom, S. T., "Projection of Sludge Batch 10 (SB10) Composition with Sodium Reactor Experiment (SRE) into Tank 51", SRR-LWP-2020-00016, Revision 0, April 15, 2020.

[3] Barnett, M. H. and Robinson, S. A., "Nuclear Criticality Safety Evaluation: Processing at DWPF", N-NCS-S-00012, Revision 0, April 2019.

[4] Pareizs, J. M. and Crawford, C. L., "Sludge Washing and Demonstration of the DWPF Flowsheet in the SRNL Shielded Cells for Sludge Batch 8 Qualification", SRNL-STI-2013-00116, Revision 0, April 2013.

[5] Pareizs, J. M.; Newell, J. D.; Martino, C. J.; Crawford, C. L.; and Johnson, F. C., "Sludge Washing and Demonstration of the DWPF Nitric/Formic Flowsheet in the SRNL Shielded Cells for Sludge Batch 9 Qualification", SRNL-STI-2016-00355, Revision 0, October 2016.

[6] Russell, K. J., "Delta Scope to Support SRE Addition to Sludge Batch 10", X-TTR-S-00079, Revision 0, March 19, 2020.

[7] Pareizs, J. M. and Martino, C. J., "Task Technical and Quality Assurance Plan for Sludge Batch 10 Sample Analysis and Qualification", SRNL-RP-2019-00658, Revision 1, May 4, 2020.

[8] Barnett, M. H. and Reilly, T. A., "Nuclear Criticality Safety Evaluation (NCSE): Double Contingency for Receipt, Transfer, Storage, and Neutralization of HB-Line Plutonium/Uranium Solutions Poisoned with Gadolinium", N-NCS-H-00179, Revision 3, February 2008.

[9] Coleman, C. J.; Bibler, N. E.; Ferrara, D. M.; and Siegwald, S. F., "Reaction of Formic and Nitric Acids with Savannah River Site Radioactive HLW Sludge in the DWPF Pre Treatment Steps", WSRC-MS-93-563, 1993.

[10] Herman, C. C. and Best, D. R., "Supplemental Solubility Data for SRAT Processing of Sludge Batch 3 with H-Canyon Slurry Containing Precipitated Pu and Gd in DWPF", WSRC-TR-2002-00508, Revision 0, November 15, 2002.

[11] Lambert, D. P.; Pareizs, J.; and Click, D. R., "Demonstration of the Glycolic-Formic Flowsheet in the SRNL Shielded Cells Using Actual Waste", SRNL-STI-2011-00622, Revision 0, November 2011.

[12] Martino, C. J.; Newell, J. D.; Crawford, C. L.; Pareizs, J. M.; and Williams, M. S., "Sludge Batch 9 Follow-on Actual-Waste Testing for the Nitric-Glycolic Flowsheet", SRNL-STI-2016-00726, Revision 0, March 2017.

[13] Bennett, W. M., "Waste Characterization Report for High Aluminum-Low Uranium and SRE Solutions In Tanks 16.3 and 16.4 for Disposal to Sludge Batch 10", SRNS-E1120-2020-00008, Revision 2, June 9, 2020.

[14] Hsu, C. W., "Defense Waste Processing Facility Nitric Acid Requirement for Treating Sludge", WSRC-RP-92-1056, Revision 0, September 4, 1992.

[15] Pareizs, J. M., "Analytical Results of the Tank 51H Sludge Batch 10 Qualification Sample", SRNL-L3100-2020-00008, Revision 1, March 30, 2020.

[16] Bibler, N. E., "Measuring and Predicting Fission Product Noble Metlas in Savannah River Site High Level Waste Sludges", WSRC-TR-2005-00098, Revision 0, April 2005.

[17] Baum, E. M.; Knox, H. D.; and Miller, T. R., *Nuclides and Isotopes, Chart of the Nuclides*. 15th ed.; KAPL, Inc.: Schenectady, NY, 1996.

[18] Conduct of Engineering Technical Reviews, Manual E7, Procedure 2.60, Revision 18. Savannah River Site: Aiken, SC, 2019.

[19] "Savannah River National Laboratory Technical Report Design Check Guidelines", WSRC-IM-2002-00011, Revision 2, August 2004.

[20] Koopman, D. C.; Best, D. R.; and Pickenheim, B. R., "SRAT Chemistry and Acid Consumption during Simulated DWPF Melter Feed Preparation", WSRC-STI-2008-00131, Revision 0, December 2008.

[21] Martino, C. J.; Lambert, D. P.; and Williams, M. S., "Task Technical and Quality Assurance Plan for Gadolinium Poison Testing for the Downstream Impacts from Accelerated Basin De-Inventory", SRNL-RP-2020-00173, Revision 0, June 25, 2020.

[22] "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors", American Nuclear Society, ANSI/ANS-8.1-2014 (R2018), 2018.

[23] Newell, J. D.; Pareizs, J. M.; Martino, C. J.; Reboul, S. H.; Coleman, C. J.; Edwards, T. B.; and Johnson, F. C., "Actual Waste Demonstration of the Nitric-Glycolic Flowsheet for Sludge Batch 9 Qualification", SRNL-STI-2016-00327, Revision 1, March 9, 2017.

# Appendix A. Reporting Replicate Analyses and Percent Soluble

## List of Appendix Tables

**Table A-1. Replicate analyses of the feed slurry by ICP-ES**

| Analyte | Feed Slurry (wt% of slurry) | | |
|---|---|---|---|
| | LW17436 | LW17437 | LW17438 |
| Ag | <1.1E-03 | <1.1E-03 | <1.1E-03 |
| Al | 1.58E+00 | 1.61E+00 | 1.61E+00 |
| B | <3.8E-04 | <3.8E-04 | <3.8E-04 |
| Ba | 7.16E-03 | 7.05E-03 | 6.96E-03 |
| Be | <5.4E-05 | <5.4E-05 | <5.5E-05 |
| Ca | 8.22E-02 | 7.80E-02 | 7.69E-02 |
| Cd | 4.64E-04 | 4.80E-04 | 4.78E-04 |
| Ce | 1.62E-02 | 1.61E-02 | 1.60E-02 |
| Co | <5.7E-04 | <5.7E-04 | <5.7E-04 |
| Cr | 2.38E-02 | 2.33E-02 | 2.32E-02 |
| Cu | 4.44E-03 | 4.36E-03 | 4.33E-03 |
| Fe | 1.22E+00 | 1.23E+00 | 1.22E+00 |
| Gd | 5.99E-03 | 5.91E-03 | 5.87E-03 |
| K | <6.4E-03 | <6.3E-03 | <6.4E-03 |
| La | 3.82E-03 | 3.72E-03 | 3.74E-03 |
| Li | 1.73E-03 | 1.60E-03 | 1.65E-03 |
| Mg | 3.01E-02 | 2.95E-02 | 2.92E-02 |
| Mn | 2.92E-01 | 2.97E-01 | 2.97E-01 |
| Mo | <1.1E-03 | <1.1E-03 | <1.1E-03 |
| Na | 1.96E+00 | 2.00E+00 | 1.98E+00 |
| Ni | 3.89E-02 | 3.82E-02 | 3.79E-02 |
| P | <7.4E-03 | <7.4E-03 | <7.4E-03 |
| Pb | <2.5E-03 | <2.5E-03 | <2.5E-03 |
| S | 5.34E-02 | 5.66E-02 | 5.36E-02 |
| Sb | <5.8E-03 | <5.8E-03 | <5.8E-03 |
| Si | 4.99E-02 | 4.84E-02 | 4.91E-02 |
| Sn | <1.6E-03 | <1.6E-03 | <1.6E-03 |
| Sr | 3.12E-03 | 3.06E-03 | 3.02E-03 |
| Th | 2.57E-01 | 2.63E-01 | 2.63E-01 |
| Ti | 1.87E-03 | 1.85E-03 | 1.88E-03 |
| U | 3.32E-01 | 3.36E-01 | 3.34E-01 |
| V | <1.5E-04 | <1.5E-04 | <1.5E-04 |
| Zn | 2.72E-03 | 2.67E-03 | 2.69E-03 |
| Zr | 1.59E-02 | 1.56E-02 | 1.54E-02 |

**Table A-2. Replicate analyses of the feed slurry by ICP-MS, fission products part 1 of 2**

| m/z | Feed Slurry (wt% of slurry) | | |
|---|---|---|---|
| | LW17440 | LW17441 | LW17442 |
| 59 | 3.39E-04 | 3.48E-04 | 3.54E-04 |
| 85 | <1.9E-05 | <1.9E-05 | <1.9E-05 |
| 86 | 7.95E-05 | 7.79E-05 | 7.94E-05 |
| 87 | 7.41E-05 | 7.58E-05 | 7.73E-05 |
| 88 | 2.07E-03 | 2.11E-03 | 2.07E-03 |
| 89 | 2.04E-03 | 2.04E-03 | 2.07E-03 |
| 90 | 2.10E-03 | 2.10E-03 | 2.17E-03 |
| 91 | 2.62E-03 | 2.63E-03 | 2.65E-03 |
| 92 | 2.34E-03 | 2.34E-03 | 2.38E-03 |
| 93 | 3.06E-03 | 3.05E-03 | 3.12E-03 |
| 94 | 2.63E-03 | 2.64E-03 | 2.65E-03 |
| 95 | 1.76E-04 | 1.70E-04 | 1.77E-04 |
| 96 | 2.32E-03 | 2.32E-03 | 2.36E-03 |
| 97 | 1.46E-04 | 1.43E-04 | 1.50E-04 |
| 98 | 1.60E-04 | 1.58E-04 | 1.61E-04 |
| 99 | 2.43E-04 | 2.48E-04 | 2.48E-04 |
| 100 | 2.42E-04 | 2.40E-04 | 2.51E-04 |
| 101 | 2.36E-03 | 2.38E-03 | 2.36E-03 |
| 102 | 2.03E-03 | 2.05E-03 | 2.08E-03 |
| 103 | 1.11E-03 | 1.11E-03 | 1.12E-03 |
| 104 | 1.00E-03 | 1.01E-03 | 1.02E-03 |
| 105 | 1.40E-04 | 1.38E-04 | 1.40E-04 |
| 106 | 1.59E-04 | 1.59E-04 | 1.64E-04 |
| 107 | 4.71E-04 | 4.74E-04 | 4.75E-04 |
| 108 | 2.75E-05 | 2.73E-05 | 3.20E-05 |
| 109 | 4.14E-04 | 4.24E-04 | 4.21E-04 |
| 110 | 5.28E-05 | 5.49E-05 | 5.70E-05 |
| 111 | 6.61E-05 | 6.57E-05 | 6.94E-05 |
| 112 | 1.05E-04 | 1.09E-04 | 1.11E-04 |
| 113 | <6.2E-05 | <6.2E-05 | <6.2E-05 |
| 114 | 1.15E-04 | 1.18E-04 | 1.14E-04 |
| 116 | 7.57E-03 | 7.74E-03 | 7.72E-03 |
| 117 | 7.18E-06 | 7.29E-06 | 7.30E-06 |
| 118 | 2.13E-05 | 2.10E-05 | 2.03E-05 |

**Table A-3. Replicate analyses of the feed slurry by ICP-MS, fission products part 2 of 2**

| m/z | Feed Slurry (wt% of slurry) | | |
|---|---|---|---|
| | LW17440 | LW17441 | LW17442 |
| 119 | 6.00E-03 | 6.06E-03 | 6.03E-03 |
| 120 | 2.07E-05 | 1.79E-05 | 1.99E-05 |
| 121 | 1.80E-05 | 1.99E-05 | 1.86E-05 |
| 122 | 4.72E-06 | 5.77E-06 | 4.91E-06 |
| 123 | 1.80E-05 | 1.78E-05 | 1.73E-05 |
| 124 | 3.86E-04 | 3.92E-04 | 3.96E-04 |
| 125 | 2.58E-05 | 2.69E-05 | 2.50E-05 |
| 126 | 5.89E-05 | 5.78E-05 | 6.43E-05 |
| 128 | 2.22E-04 | 2.23E-04 | 2.23E-04 |
| 130 | 1.16E-03 | 1.17E-03 | 1.18E-03 |
| 133 | 1.23E-04 | 1.22E-04 | 1.23E-04 |
| 134 | 1.38E-04 | 1.39E-04 | 1.39E-04 |
| 135 | 4.47E-05 | 4.68E-05 | 4.44E-05 |
| 136 | 6.47E-05 | 6.46E-05 | 6.53E-05 |
| 137 | 1.45E-03 | 1.45E-03 | 1.45E-03 |
| 138 | 4.97E-03 | 5.10E-03 | 5.11E-03 |
| 139 | 4.82E-03 | 4.84E-03 | 4.85E-03 |
| 140 | 9.95E-03 | 1.00E-02 | 1.00E-02 |
| 141 | 4.06E-03 | 4.05E-03 | 4.07E-03 |
| 142 | 5.40E-03 | 5.41E-03 | 5.46E-03 |
| 143 | 3.75E-03 | 3.76E-03 | 3.77E-03 |
| 144 | 4.36E-03 | 4.36E-03 | 4.40E-03 |
| 145 | 2.69E-03 | 2.71E-03 | 2.71E-03 |
| 146 | 2.25E-03 | 2.25E-03 | 2.27E-03 |
| 147 | 1.29E-03 | 1.30E-03 | 1.31E-03 |
| 148 | 1.41E-03 | 1.42E-03 | 1.43E-03 |
| 149 | 5.05E-05 | 5.22E-05 | 5.09E-05 |
| 150 | 1.21E-03 | 1.21E-03 | 1.22E-03 |
| 151 | 5.35E-05 | 5.24E-05 | 5.27E-05 |
| 152 | 3.79E-04 | 3.79E-04 | 3.83E-04 |
| 153 | 1.77E-04 | 1.77E-04 | 1.78E-04 |
| 154 | 2.50E-04 | 2.49E-04 | 2.51E-04 |
| 155 | 9.42E-04 | 9.43E-04 | 9.53E-04 |
| 156 | 1.36E-03 | 1.37E-03 | 1.38E-03 |
| 157 | 1.02E-03 | 1.02E-03 | 1.03E-03 |

**Table A-4. Replicate analyses of the feed slurry by ICP-MS, actinides**

| m/z | Feed Slurry (wt% of slurry) | | |
|---|---|---|---|
| | LW17440 | LW17441 | LW17442 |
| 232 | 2.44E-01 | 2.46E-01 | 2.49E-01 |
| 233 | 9.37E-05 | 9.44E-05 | 9.52E-05 |
| 234 | 9.15E-05 | 9.33E-05 | 9.18E-05 |
| 235 | 4.42E-03 | 4.51E-03 | 4.49E-03 |
| 236 | 3.13E-04 | 3.21E-04 | 3.18E-04 |
| 237 | 1.67E-04 | 1.70E-04 | 1.70E-04 |
| 238 | 3.23E-01 | 3.22E-01 | 3.24E-01 |
| 239 | 2.37E-03 | 2.38E-03 | 2.40E-03 |
| 240 | 1.81E-04 | 1.81E-04 | 1.83E-04 |
| 241 | 4.39E-05 | 4.40E-05 | 4.44E-05 |
| 242 | 1.40E-05 | 1.42E-05 | 1.40E-05 |
| 243 | <3.9E-06 | <3.9E-06 | <3.9E-06 |
| 244 | <3.9E-06 | <3.9E-06 | <3.9E-06 |

**Table A-5. Replicate analyses of the product slurries by ICP-ES**

| Analyte | Slurry, 70% Acid Addition (wt%) | | | Slurry, 100% Acid Addition (wt%) | | | Slurry, 140% Acid Addition (wt%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | LW17697 | LW17699 | LW17701 | LW17703 | LW17705 | LW17707 | LW17709 | LW17711 | LW17713 |
| Ag | <7.9E-04 | <8.0E-04 | <8.1E-04 | <8.0E-04 | <7.9E-04 | <7.9E-04 | <8.0E-04 | <7.9E-04 | <8.0E-04 |
| Al | 1.50E+00 | 1.48E+00 | 1.51E+00 | 1.45E+00 | 1.41E+00 | 1.31E+00 | 1.39E+00 | 1.42E+00 | 1.37E+00 |
| B | <8.2E-04 | <8.3E-04 | <8.4E-04 | <8.2E-04 | <8.2E-04 | <8.2E-04 | <8.3E-04 | <8.1E-04 | <8.2E-04 |
| Ba | 6.92E-03 | 6.86E-03 | 6.88E-03 | 6.86E-03 | 6.73E-03 | 6.43E-03 | 6.61E-03 | 6.60E-03 | 6.54E-03 |
| Be | <2.8E-05 | <2.8E-05 | <2.9E-05 | <2.8E-05 | <2.8E-05 | <2.8E-05 | <2.9E-05 | <2.8E-05 | <2.8E-05 |
| Ca | 7.75E-02 | 7.73E-02 | 7.71E-02 | 7.63E-02 | 7.54E-02 | 7.27E-02 | 7.40E-02 | 7.40E-02 | 7.35E-02 |
| Cd | <4.7E-04 | <4.8E-04 | <4.8E-04 | <4.8E-04 | <4.8E-04 | <4.7E-04 | <4.8E-04 | <4.7E-04 | <4.8E-04 |
| Ce | 1.56E-02 | 1.53E-02 | 1.55E-02 | 1.52E-02 | 1.48E-02 | 1.44E-02 | 1.47E-02 | 1.50E-02 | 1.46E-02 |
| Co | <5.9E-04 | <6.0E-04 | <6.0E-04 | <5.9E-04 | <5.9E-04 | <5.9E-04 | <6.0E-04 | <5.8E-04 | <5.9E-04 |
| Cr | 2.27E-02 | 2.24E-02 | 2.26E-02 | 2.27E-02 | 2.22E-02 | 2.15E-02 | 2.17E-02 | 2.17E-02 | 2.16E-02 |
| Cu | 4.22E-03 | 4.17E-03 | 4.14E-03 | 4.27E-03 | 4.07E-03 | 3.91E-03 | 4.08E-03 | 4.03E-03 | 4.00E-03 |
| Fe | 1.18E+00 | 1.18E+00 | 1.18E+00 | 1.18E+00 | 1.16E+00 | 1.08E+00 | 1.12E+00 | 1.12E+00 | 1.11E+00 |
| Gd | 6.63E-03 | 6.62E-03 | 6.60E-03 | 6.46E-03 | 6.28E-03 | 6.25E-03 | 6.30E-03 | 6.30E-03 | 6.21E-03 |
| K | <9.2E-03 | <9.3E-03 | <9.4E-03 | <9.2E-03 | <9.2E-03 | <9.2E-03 | <9.3E-03 | <9.1E-03 | <9.3E-03 |
| La | 3.84E-03 | 3.72E-03 | 3.81E-03 | 3.71E-03 | 3.79E-03 | 3.68E-03 | 3.70E-03 | 3.65E-03 | 3.58E-03 |
| Li | 1.66E-03 | 1.63E-03 | 1.67E-03 | 1.62E-03 | 1.58E-03 | 1.46E-03 | 1.56E-03 | 1.63E-03 | 1.59E-03 |
| Mg | 2.91E-02 | 2.90E-02 | 2.90E-02 | 2.88E-02 | 2.86E-02 | 2.75E-02 | 2.77E-02 | 2.78E-02 | 2.77E-02 |
| Mn | 2.86E-01 | 2.83E-01 | 2.83E-01 | 2.80E-01 | 2.78E-01 | 2.69E-01 | 2.70E-01 | 2.72E-01 | 2.69E-01 |
| Mo | <1.8E-03 | <1.8E-03 | <1.8E-03 | <1.8E-03 | <1.8E-03 | <1.8E-03 | <1.8E-03 | <1.8E-03 | <1.8E-03 |
| Na | 1.99E+00 | 1.98E+00 | 2.01E+00 | 1.99E+00 | 1.98E+00 | 1.86E+00 | 1.92E+00 | 1.93E+00 | 1.92E+00 |
| Ni | 3.75E-02 | 3.74E-02 | 3.72E-02 | 3.75E-02 | 3.67E-02 | 3.56E-02 | 3.59E-02 | 3.57E-02 | 3.51E-02 |
| P | <7.1E-03 | <7.2E-03 | <7.3E-03 | <7.2E-03 | <7.1E-03 | <7.1E-03 | <7.2E-03 | <7.1E-03 | <7.2E-03 |
| Pb | <4.0E-03 | <4.1E-03 | <4.1E-03 | <4.0E-03 | <4.0E-03 | <4.0E-03 | <4.1E-03 | <4.0E-03 | <4.0E-03 |
| S | <2.8E-01 | <2.8E-01 | <2.9E-01 | <2.8E-01 | <2.8E-01 | <2.8E-01 | <2.8E-01 | <2.8E-01 | <2.8E-01 |
| Sb | <1.2E-02 | <1.3E-02 | <1.3E-02 | <1.3E-02 | <1.2E-02 | <1.2E-02 | <1.3E-02 | <1.2E-02 | <1.3E-02 |
| Si | 3.94E-02 | 3.74E-02 | 4.01E-02 | 3.79E-02 | 3.53E-02 | 3.86E-02 | 3.84E-02 | 3.87E-02 | 3.83E-02 |
| Sn | <3.5E-03 | <3.6E-03 | <3.6E-03 | <3.5E-03 | <3.5E-03 | <3.5E-03 | <3.6E-03 | <3.5E-03 | <3.5E-03 |
| Sr | 3.17E-03 | 3.15E-03 | 3.17E-03 | 3.15E-03 | 3.10E-03 | 2.95E-03 | 3.01E-03 | 3.03E-03 | 2.97E-03 |
| Th | 2.43E-01 | 2.38E-01 | 2.42E-01 | 2.56E-01 | 2.34E-01 | 2.20E-01 | 2.35E-01 | 2.34E-01 | 2.26E-01 |
| Ti | 1.73E-03 | 1.71E-03 | 1.72E-03 | 1.73E-03 | 1.67E-03 | 1.62E-03 | 1.64E-03 | 1.67E-03 | 1.60E-03 |
| U | 3.19E-01 | 3.15E-01 | 3.20E-01 | 3.16E-01 | 3.14E-01 | 3.02E-01 | 3.03E-01 | 3.03E-01 | 3.02E-01 |
| V | <3.2E-04 | <3.2E-04 | <3.2E-04 | <3.2E-04 | <3.2E-04 | <3.2E-04 | <3.2E-04 | <3.1E-04 | <3.2E-04 |
| Zn | 2.55E-03 | 2.69E-03 | 2.57E-03 | 2.52E-03 | 2.54E-03 | 2.42E-03 | 2.45E-03 | 2.46E-03 | 2.43E-03 |
| Zr | 1.43E-02 | 1.43E-02 | 1.43E-02 | 1.44E-02 | 1.39E-02 | 1.34E-02 | 1.37E-02 | 1.37E-02 | 1.34E-02 |

**Table A-6. Replicate analyses of the product slurries by ICP-MS, fission products part 1 of 2**

| m/z | Slurry, 70% Acid Addition (wt%) | | | Slurry, 100% Acid Addition (wt%) | | | Slurry, 140% Acid Addition (wt%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | LW17698 | LW17700 | LW17702 | LW17704 | LW17706 | LW17708 | LW17710 | LW17712 | LW17714 |
| 59 | 3.36E-04 | 3.35E-04 | 3.35E-04 | 3.34E-04 | 3.34E-04 | 3.24E-04 | 3.25E-04 | 3.30E-04 | 3.24E-04 |
| 85 | 7.61E-06 | 7.20E-06 | 8.07E-06 | 7.47E-06 | 7.93E-06 | 6.91E-06 | 7.89E-06 | 6.73E-06 | 6.78E-06 |
| 86 | 7.92E-05 | 7.86E-05 | 7.62E-05 | 7.82E-05 | 7.45E-05 | 7.38E-05 | 7.41E-05 | 7.44E-05 | 7.28E-05 |
| 87 | 7.45E-05 | 7.16E-05 | 7.11E-05 | 7.41E-05 | 7.35E-05 | 6.96E-05 | 6.99E-05 | 7.09E-05 | 7.18E-05 |
| 88 | 2.08E-03 | 2.04E-03 | 2.05E-03 | 2.15E-03 | 2.05E-03 | 2.06E-03 | 1.97E-03 | 2.01E-03 | 1.94E-03 |
| 89 | 2.02E-03 | 2.03E-03 | 2.03E-03 | 2.02E-03 | 2.01E-03 | 1.91E-03 | 1.96E-03 | 1.97E-03 | 1.93E-03 |
| 90 | 2.10E-03 | 2.12E-03 | 2.12E-03 | 2.12E-03 | 2.07E-03 | 1.98E-03 | 2.07E-03 | 2.06E-03 | 1.98E-03 |
| 91 | 2.51E-03 | 2.54E-03 | 2.53E-03 | 2.52E-03 | 2.48E-03 | 2.37E-03 | 2.45E-03 | 2.44E-03 | 2.37E-03 |
| 92 | 2.29E-03 | 2.32E-03 | 2.30E-03 | 2.29E-03 | 2.26E-03 | 2.16E-03 | 2.22E-03 | 2.22E-03 | 2.16E-03 |
| 93 | 2.93E-03 | 2.97E-03 | 2.96E-03 | 3.01E-03 | 2.90E-03 | 2.78E-03 | 2.86E-03 | 2.87E-03 | 2.77E-03 |
| 94 | 2.56E-03 | 2.59E-03 | 2.56E-03 | 2.55E-03 | 2.53E-03 | 2.40E-03 | 2.47E-03 | 2.47E-03 | 2.40E-03 |
| 95 | 1.67E-04 | 1.71E-04 | 1.71E-04 | 1.68E-04 | 1.67E-04 | 1.60E-04 | 1.68E-04 | 1.65E-04 | 1.60E-04 |
| 96 | 2.34E-03 | 2.33E-03 | 2.31E-03 | 2.33E-03 | 2.27E-03 | 2.16E-03 | 2.23E-03 | 2.27E-03 | 2.15E-03 |
| 97 | 1.43E-04 | 1.48E-04 | 1.46E-04 | 1.44E-04 | 1.42E-04 | 1.36E-04 | 1.39E-04 | 1.40E-04 | 1.37E-04 |
| 98 | 1.56E-04 | 1.59E-04 | 1.59E-04 | 1.58E-04 | 1.56E-04 | 1.51E-04 | 1.53E-04 | 1.51E-04 | 1.47E-04 |
| 99 | 2.41E-04 | 2.38E-04 | 2.34E-04 | 2.32E-04 | 2.32E-04 | 2.25E-04 | 2.28E-04 | 2.27E-04 | 2.21E-04 |
| 100 | 2.44E-04 | 2.46E-04 | 2.44E-04 | 2.43E-04 | 2.37E-04 | 2.31E-04 | 2.34E-04 | 2.36E-04 | 2.30E-04 |
| 101 | 2.32E-03 | 2.38E-03 | 2.44E-03 | 2.36E-03 | 2.31E-03 | 2.22E-03 | 2.25E-03 | 2.26E-03 | 2.17E-03 |
| 102 | 2.06E-03 | 2.09E-03 | 2.05E-03 | 2.06E-03 | 2.01E-03 | 2.00E-03 | 2.02E-03 | 2.01E-03 | 1.96E-03 |
| 103 | 1.10E-03 | 1.11E-03 | 1.10E-03 | 1.08E-03 | 1.08E-03 | 1.04E-03 | 1.05E-03 | 1.05E-03 | 1.03E-03 |
| 104 | 1.00E-03 | 1.01E-03 | 9.91E-04 | 9.89E-04 | 9.81E-04 | 9.43E-04 | 9.65E-04 | 9.58E-04 | 9.41E-04 |
| 105 | 1.27E-04 | 1.33E-04 | 1.29E-04 | 1.34E-04 | 1.32E-04 | 1.27E-04 | 1.28E-04 | 1.31E-04 | 1.24E-04 |
| 106 | 1.49E-04 | 1.56E-04 | 1.49E-04 | 1.57E-04 | 1.52E-04 | 1.47E-04 | 1.47E-04 | 1.48E-04 | 1.43E-04 |
| 107 | 4.59E-04 | 4.65E-04 | 4.58E-04 | 4.49E-04 | 4.44E-04 | 4.32E-04 | 4.47E-04 | 4.43E-04 | 4.29E-04 |
| 108 | 2.80E-05 | 2.93E-05 | 2.82E-05 | 2.88E-05 | 2.90E-05 | 2.64E-05 | 2.73E-05 | 2.77E-05 | 2.71E-05 |
| 109 | 4.23E-04 | 4.23E-04 | 4.16E-04 | 4.08E-04 | 4.08E-04 | 3.93E-04 | 4.06E-04 | 4.00E-04 | 3.94E-04 |
| 110 | 5.45E-05 | 5.61E-05 | 5.44E-05 | 5.46E-05 | 5.46E-05 | 5.07E-05 | 5.16E-05 | 5.29E-05 | 5.24E-05 |
| 111 | 6.57E-05 | 6.34E-05 | 6.53E-05 | 6.47E-05 | 6.26E-05 | 6.12E-05 | 6.34E-05 | 6.38E-05 | 6.10E-05 |
| 112 | 1.08E-04 | 1.07E-04 | 1.06E-04 | 1.06E-04 | 1.06E-04 | 1.02E-04 | 1.01E-04 | 9.99E-05 | 9.95E-05 |
| 113 | <6.6E-05 | <6.7E-05 | <6.7E-05 | <6.6E-05 | <6.6E-05 | <6.6E-05 | <6.7E-05 | <6.5E-05 | <6.6E-05 |
| 114 | 1.19E-04 | 1.17E-04 | 1.18E-04 | 1.15E-04 | 1.14E-04 | 1.09E-04 | 1.12E-04 | 1.11E-04 | 1.09E-04 |
| 116 | 6.35E-03 | 6.27E-03 | 6.29E-03 | 6.50E-03 | 6.12E-03 | 5.97E-03 | 6.21E-03 | 5.97E-03 | 5.89E-03 |
| 117 | 8.10E-06 | 7.22E-06 | 9.14E-06 | 9.09E-06 | 7.40E-06 | 7.46E-06 | 8.08E-06 | 7.36E-06 | 7.51E-06 |
| 118 | 3.75E-05 | 3.97E-05 | 4.00E-05 | 3.80E-05 | 3.64E-05 | 3.42E-05 | 3.62E-05 | 3.59E-05 | 3.43E-05 |

**Table A-7. Replicate analyses of the product slurries by ICP-MS, fission products part 2 of 2**

| m/z | Slurry, 70% Acid Addition (wt%) | | | Slurry, 100% Acid Addition (wt%) | | | Slurry, 140% Acid Addition (wt%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | LW17698 | LW17700 | LW17702 | LW17704 | LW17706 | LW17708 | LW17710 | LW17712 | LW17714 |
| 119 | 5.08E-03 | 5.04E-03 | 5.01E-03 | 4.99E-03 | 4.85E-03 | 4.80E-03 | 4.80E-03 | 4.70E-03 | 4.64E-03 |
| 120 | 2.23E-05 | 2.25E-05 | 2.29E-05 | 2.14E-05 | 2.55E-05 | 2.61E-05 | 2.24E-05 | 2.08E-05 | 2.04E-05 |
| 121 | 1.91E-05 | 1.86E-05 | 1.90E-05 | 1.81E-05 | 1.92E-05 | 1.78E-05 | 1.65E-05 | 1.80E-05 | 1.64E-05 |
| 122 | 4.55E-06 | 4.31E-06 | 6.39E-06 | 4.82E-06 | 4.98E-06 | 4.54E-06 | 3.86E-06 | 3.91E-06 | 4.24E-06 |
| 123 | 1.94E-05 | 1.86E-05 | 1.83E-05 | 1.95E-05 | 1.73E-05 | 1.68E-05 | 1.62E-05 | 1.84E-05 | 1.75E-05 |
| 124 | 3.21E-04 | 3.25E-04 | 3.28E-04 | 3.45E-04 | 3.17E-04 | 3.03E-04 | 3.19E-04 | 3.17E-04 | 3.03E-04 |
| 125 | 3.32E-04 | 3.41E-04 | 3.47E-04 | 3.69E-04 | 3.24E-04 | 3.19E-04 | 3.32E-04 | 3.43E-04 | 3.17E-04 |
| 126 | 5.74E-05 | 5.29E-05 | 5.22E-05 | 5.41E-05 | 5.30E-05 | 5.23E-05 | 6.09E-05 | 5.25E-05 | 5.18E-05 |
| 128 | 5.30E-04 | 5.21E-04 | 5.36E-04 | 5.09E-04 | 4.98E-04 | 5.02E-04 | 4.96E-04 | 5.00E-04 | 4.90E-04 |
| 130 | 1.18E-03 | 1.16E-03 | 1.16E-03 | 1.14E-03 | 1.14E-03 | 1.11E-03 | 1.11E-03 | 1.10E-03 | 1.10E-03 |
| 133 | 1.21E-04 | 1.18E-04 | 1.15E-04 | 1.16E-04 | 1.13E-04 | 1.12E-04 | 1.12E-04 | 1.14E-04 | 1.10E-04 |
| 134 | 1.38E-04 | 1.36E-04 | 1.38E-04 | 1.36E-04 | 1.30E-04 | 1.31E-04 | 1.30E-04 | 1.31E-04 | 1.26E-04 |
| 135 | 4.75E-05 | 4.56E-05 | 4.63E-05 | 4.74E-05 | 4.33E-05 | 4.30E-05 | 4.42E-05 | 4.28E-05 | 4.16E-05 |
| 136 | 6.72E-05 | 6.57E-05 | 6.53E-05 | 6.84E-05 | 6.35E-05 | 6.27E-05 | 6.30E-05 | 6.33E-05 | 6.10E-05 |
| 137 | 1.45E-03 | 1.44E-03 | 1.44E-03 | 1.43E-03 | 1.40E-03 | 1.37E-03 | 1.38E-03 | 1.40E-03 | 1.35E-03 |
| 138 | 5.07E-03 | 5.01E-03 | 5.04E-03 | 4.94E-03 | 4.84E-03 | 4.74E-03 | 4.76E-03 | 4.74E-03 | 4.67E-03 |
| 139 | 4.85E-03 | 4.85E-03 | 4.83E-03 | 4.78E-03 | 4.67E-03 | 4.59E-03 | 4.61E-03 | 4.64E-03 | 4.58E-03 |
| 140 | 9.91E-03 | 9.96E-03 | 9.97E-03 | 9.83E-03 | 9.65E-03 | 9.46E-03 | 9.46E-03 | 9.51E-03 | 9.35E-03 |
| 141 | 4.09E-03 | 4.10E-03 | 4.21E-03 | 4.28E-03 | 3.99E-03 | 3.87E-03 | 3.88E-03 | 3.99E-03 | 3.86E-03 |
| 142 | 5.33E-03 | 5.39E-03 | 5.39E-03 | 5.31E-03 | 5.24E-03 | 5.09E-03 | 5.11E-03 | 5.15E-03 | 5.02E-03 |
| 143 | 3.63E-03 | 3.63E-03 | 3.65E-03 | 3.58E-03 | 3.53E-03 | 3.44E-03 | 3.45E-03 | 3.48E-03 | 3.42E-03 |
| 144 | 4.59E-03 | 4.65E-03 | 4.62E-03 | 4.53E-03 | 4.49E-03 | 4.40E-03 | 4.34E-03 | 4.42E-03 | 4.36E-03 |
| 145 | 2.72E-03 | 2.71E-03 | 2.73E-03 | 2.66E-03 | 2.61E-03 | 2.56E-03 | 2.55E-03 | 2.61E-03 | 2.57E-03 |
| 146 | 2.23E-03 | 2.24E-03 | 2.25E-03 | 2.19E-03 | 2.17E-03 | 2.12E-03 | 2.11E-03 | 2.15E-03 | 2.12E-03 |
| 147 | 1.31E-03 | 1.30E-03 | 1.28E-03 | 1.28E-03 | 1.26E-03 | 1.22E-03 | 1.24E-03 | 1.23E-03 | 1.21E-03 |
| 148 | 1.44E-03 | 1.43E-03 | 1.42E-03 | 1.41E-03 | 1.37E-03 | 1.35E-03 | 1.36E-03 | 1.36E-03 | 1.33E-03 |
| 149 | 5.31E-05 | 5.23E-05 | 5.04E-05 | 5.15E-05 | 5.03E-05 | 4.83E-05 | 4.88E-05 | 4.92E-05 | 4.78E-05 |
| 150 | 1.24E-03 | 1.23E-03 | 1.21E-03 | 1.19E-03 | 1.19E-03 | 1.15E-03 | 1.16E-03 | 1.16E-03 | 1.13E-03 |
| 151 | 5.44E-05 | 5.39E-05 | 5.27E-05 | 5.34E-05 | 5.19E-05 | 5.05E-05 | 5.09E-05 | 5.10E-05 | 4.96E-05 |
| 152 | 3.93E-04 | 3.87E-04 | 3.80E-04 | 3.77E-04 | 3.76E-04 | 3.64E-04 | 3.67E-04 | 3.69E-04 | 3.62E-04 |
| 153 | 1.82E-04 | 1.82E-04 | 1.79E-04 | 1.77E-04 | 1.76E-04 | 1.70E-04 | 1.72E-04 | 1.72E-04 | 1.69E-04 |
| 154 | 2.58E-04 | 2.57E-04 | 2.53E-04 | 2.53E-04 | 2.48E-04 | 2.41E-04 | 2.43E-04 | 2.42E-04 | 2.34E-04 |
| 155 | 9.77E-04 | 9.74E-04 | 9.55E-04 | 9.44E-04 | 9.39E-04 | 9.07E-04 | 9.17E-04 | 9.23E-04 | 8.93E-04 |
| 156 | 1.41E-03 | 1.41E-03 | 1.41E-03 | 1.39E-03 | 1.38E-03 | 1.32E-03 | 1.33E-03 | 1.36E-03 | 1.33E-03 |
| 157 | 1.04E-03 | 1.04E-03 | 1.02E-03 | 1.00E-03 | 1.00E-03 | 9.71E-04 | 9.85E-04 | 9.81E-04 | 9.56E-04 |

**Table A-8. Replicate analyses of the product slurries by ICP-MS, actinides**

| m/z | Slurry, 70% Acid Addition (wt%) | | | Slurry, 100% Acid Addition (wt%) | | | Slurry, 140% Acid Addition (wt%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | LW17698 | LW17700 | LW17702 | LW17704 | LW17706 | LW17708 | LW17710 | LW17712 | LW17714 |
| 232 | 2.30E-01 | 2.29E-01 | 2.28E-01 | 2.42E-01 | 2.21E-01 | 2.07E-01 | 2.24E-01 | 2.17E-01 | 2.13E-01 |
| 233 | 8.71E-05 | 9.11E-05 | 9.30E-05 | 9.31E-05 | 8.69E-05 | 8.41E-05 | 8.52E-05 | 8.71E-05 | 8.60E-05 |
| 234 | 8.16E-05 | 8.08E-05 | 7.96E-05 | 7.79E-05 | 7.94E-05 | 7.62E-05 | 7.73E-05 | 7.65E-05 | 7.35E-05 |
| 235 | 4.28E-03 | 4.34E-03 | 4.27E-03 | 4.21E-03 | 4.19E-03 | 4.07E-03 | 4.02E-03 | 4.01E-03 | 3.95E-03 |
| 236 | 3.29E-04 | 3.22E-04 | 3.29E-04 | 3.13E-04 | 3.15E-04 | 3.18E-04 | 3.13E-04 | 3.04E-04 | 3.10E-04 |
| 237 | 1.68E-04 | 1.70E-04 | 1.67E-04 | 1.75E-04 | 1.65E-04 | 1.64E-04 | 1.56E-04 | 1.58E-04 | 1.61E-04 |
| 238 | 3.09E-01 | 3.11E-01 | 3.09E-01 | 3.03E-01 | 3.03E-01 | 2.97E-01 | 2.93E-01 | 2.91E-01 | 2.87E-01 |
| 239 | 2.19E-03 | 2.18E-03 | 2.18E-03 | 2.21E-03 | 2.13E-03 | 2.06E-03 | 2.10E-03 | 2.08E-03 | 2.04E-03 |
| 240 | 1.70E-04 | 1.71E-04 | 1.70E-04 | 1.76E-04 | 1.64E-04 | 1.61E-04 | 1.68E-04 | 1.70E-04 | 1.61E-04 |
| 241 | 4.24E-05 | 3.71E-05 | 4.28E-05 | 3.87E-05 | 4.05E-05 | 3.78E-05 | 4.27E-05 | 3.81E-05 | 3.67E-05 |
| 242 | 1.24E-05 | 1.19E-05 | 1.24E-05 | 1.35E-05 | 1.18E-05 | 1.30E-05 | 1.12E-05 | 1.30E-05 | 1.15E-05 |
| 243 | <3.3E-06 | <3.3E-06 | <3.4E-06 | <3.3E-06 | <3.3E-06 | <3.3E-06 | <3.3E-06 | <3.3E-06 | <3.3E-06 |
| 244 | <3.3E-06 | <3.3E-06 | <3.4E-06 | <3.3E-06 | <3.3E-06 | <3.3E-06 | <3.3E-06 | <3.3E-06 | <3.3E-06 |

**Table A-9. Replicate analyses of the product filtrates by ICP-ES**

| Analyte | Supernate, 70% Acid Addition (mg/L) | | | Supernate, 100% Acid Addition (mg/L) | | | Supernate, 140% Acid Addition (mg/L) | | |
|---|---|---|---|---|---|---|---|---|---|
| | LW17730 | LW17722 | LW17724 | LW17726 | LW17728 | LW17720 | LW17732 | LW17734 | LW17736 |
| Ag | <5.8E+00 | <5.4E+00 | <5.8E+00 | <5.8E+00 | <5.9E+00 | <5.8E+00 | <5.9E+00 | <5.9E+00 | <6.0E+00 |
| Al | 3.14E+01 | 2.84E+01 | 3.01E+01 | 5.44E+02 | 5.41E+02 | 5.49E+02 | 1.56E+03 | 1.55E+03 | 1.56E+03 |
| B | <8.3E+00 | <7.8E+00 | <8.3E+00 | <8.4E+00 | <8.5E+00 | <8.4E+00 | <8.4E+00 | <8.5E+00 | <8.6E+00 |
| Ba | <2.9E+00 | <2.7E+00 | <2.9E+00 | 3.08E+00 | 3.24E+00 | 3.03E+00 | <2.9E+00 | <3.0E+00 | <3.0E+00 |
| Be | <2.3E+00 | <2.2E+00 | <2.3E+00 | <2.3E+00 | <2.4E+00 | <2.4E+00 | <2.4E+00 | <2.4E+00 | <2.4E+00 |
| Ca | 1.84E+02 | 1.83E+02 | 1.83E+02 | 5.63E+02 | 5.99E+02 | 6.00E+02 | 6.84E+02 | 6.80E+02 | 6.81E+02 |
| Cd | <4.9E+00 | <4.5E+00 | <4.8E+00 | <4.9E+00 | <5.0E+00 | <4.9E+00 | <4.9E+00 | <4.9E+00 | <5.0E+00 |
| Ce | <3.8E+01 | <3.5E+01 | <3.8E+01 | <3.8E+01 | <3.8E+01 | <3.8E+01 | <3.8E+01 | <3.8E+01 | <3.9E+01 |
| Co | <6.0E+00 | <5.6E+00 | <6.0E+00 | <6.0E+00 | <6.1E+00 | <6.1E+00 | <6.1E+00 | <6.1E+00 | <6.2E+00 |
| Cr | <1.0E+01 | <9.5E+00 | <1.0E+01 | 1.04E+02 | 1.05E+02 | 1.07E+02 | 1.47E+02 | 1.47E+02 | 1.47E+02 |
| Cu | <1.5E+00 | <1.4E+00 | <1.5E+00 | 3.58E+00 | 4.17E+00 | 4.03E+00 | 1.85E+01 | 1.85E+01 | 1.84E+01 |
| Fe | <4.7E+00 | <4.4E+00 | <4.7E+00 | 1.33E+02 | 1.35E+02 | 1.35E+02 | 6.55E+02 | 6.52E+02 | 6.55E+02 |
| Gd | <4.0E+00 | <3.8E+00 | <4.0E+00 | 4.09E+01 | 4.13E+01 | 4.14E+01 | 6.43E+01 | 6.47E+01 | 6.46E+01 |
| K | <9.4E+01 | <8.8E+01 | <9.4E+01 | <9.4E+01 | <9.6E+01 | <9.4E+01 | <9.5E+01 | <9.5E+01 | <9.6E+01 |
| La | <1.5E+00 | <1.4E+00 | <1.5E+00 | 5.85E+00 | 6.44E+00 | 6.41E+00 | 1.99E+01 | 1.97E+01 | 1.99E+01 |
| Li | <7.8E+00 | <7.3E+00 | <7.8E+00 | <7.8E+00 | <8.0E+00 | <7.8E+00 | 1.19E+01 | 1.10E+01 | 1.16E+01 |
| Mg | 7.15E+01 | 7.17E+01 | 7.17E+01 | 2.10E+02 | 2.10E+02 | 2.12E+02 | 2.69E+02 | 2.67E+02 | 2.67E+02 |
| Mn | 4.81E+01 | 4.81E+01 | 4.83E+01 | 2.03E+03 | 2.03E+03 | 2.07E+03 | 2.70E+03 | 2.69E+03 | 2.70E+03 |
| Mo | <1.8E+01 | <1.7E+01 | <1.8E+01 | <1.8E+01 | <1.9E+01 | <1.8E+01 | <1.9E+01 | <1.9E+01 | <1.9E+01 |
| Na | 2.11E+04 | 2.10E+04 | 2.10E+04 | 2.18E+04 | 2.17E+04 | 2.20E+04 | 2.11E+04 | 2.09E+04 | 2.10E+04 |
| Ni | <3.0E+01 | <2.8E+01 | <3.0E+01 | <9.8E+01 | <9.7E+01 | <9.9E+01 | <2.3E+02 | <2.2E+02 | <2.3E+02 |
| P | <3.6E+01 | <3.3E+01 | <3.6E+01 | <3.6E+01 | <3.7E+01 | <3.6E+01 | <3.6E+01 | <3.6E+01 | <3.7E+01 |
| Pb | <4.1E+01 | <3.8E+01 | <4.1E+01 | <4.1E+01 | <4.2E+01 | <4.1E+01 | <4.1E+01 | <4.1E+01 | <4.2E+01 |
| S | <2.0E+03 | <1.9E+03 | <2.0E+03 | <2.0E+03 | <2.1E+03 | <2.0E+03 | <2.0E+03 | <2.1E+03 | <2.1E+03 |
| Sb | <1.3E+02 | <1.2E+02 | <1.3E+02 | <1.3E+02 | <1.3E+02 | <1.3E+02 | <1.3E+02 | <1.3E+02 | <1.3E+02 |
| Si | <1.8E+01 | <1.7E+01 | <1.8E+01 | 1.31E+02 | 1.32E+02 | 1.33E+02 | 2.52E+02 | 2.48E+02 | 2.49E+02 |
| Sn | <3.6E+01 | <3.3E+01 | <3.6E+01 | <3.6E+01 | <3.7E+01 | <3.6E+01 | <3.6E+01 | <3.6E+01 | <3.7E+01 |
| Sr | 3.02E+00 | 2.98E+00 | 2.98E+00 | 1.33E+01 | 1.34E+01 | 1.36E+01 | 1.61E+01 | 1.60E+01 | 1.61E+01 |
| Th | <2.0E+01 | <1.9E+01 | <2.0E+01 | 1.83E+02 | 1.83E+02 | 1.86E+02 | 3.81E+02 | 3.77E+02 | 3.79E+02 |
| Ti | <1.2E+00 | <1.2E+00 | <1.2E+00 | <1.2E+00 | <1.3E+00 | <1.2E+00 | <1.2E+00 | <1.3E+00 | <1.3E+00 |
| U | 1.06E+03 | 1.08E+03 | 1.06E+03 | 3.18E+03 | 3.17E+03 | 3.22E+03 | 3.35E+03 | 3.36E+03 | 3.33E+03 |
| V | <3.2E+00 | <3.0E+00 | <3.2E+00 | <3.2E+00 | <3.3E+00 | <3.3E+00 | <3.3E+00 | <3.3E+00 | <3.3E+00 |
| Zn | <3.4E+00 | <3.2E+00 | <3.4E+00 | <3.4E+00 | <3.5E+00 | <3.5E+00 | 6.46E+00 | 6.51E+00 | 6.62E+00 |
| Zr | <1.7E+00 | <1.6E+00 | <1.7E+00 | 5.48E+00 | 5.10E+00 | 5.39E+00 | 1.84E+01 | 1.87E+01 | 1.87E+01 |

**Table A-10. Replicate analyses of the product filtrates by ICP-MS, fission products part 1 of 2**

| m/z | Supernate, 70% Acid Addition (mg/L) | | | Supernate, 100% Acid Addition (mg/L) | | | Supernate, 140% Acid Addition (mg/L) | | |
|---|---|---|---|---|---|---|---|---|---|
| | LW17731 | LW17723 | LW17725 | LW17727 | LW17729 | LW17721 | LW17733 | LW17735 | LW17737 |
| 59 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 7.16E-01 | 7.14E-01 | 7.04E-01 | 2.40E+00 | 2.41E+00 | 2.39E+00 |
| 85 | 7.66E-02 | 7.44E-02 | 6.96E-02 | 8.07E-02 | 8.45E-02 | 8.57E-02 | 7.22E-02 | 8.26E-02 | 7.99E-02 |
| 86 | 7.93E-02 | 7.18E-02 | 7.81E-02 | 3.49E-01 | 3.43E-01 | 3.56E-01 | 3.86E-01 | 3.89E-01 | 4.00E-01 |
| 87 | 2.31E-01 | 2.26E-01 | 2.16E-01 | 4.15E-01 | 4.24E-01 | 4.36E-01 | 4.66E-01 | 4.64E-01 | 4.60E-01 |
| 88 | 2.33E+00 | 2.25E+00 | 2.25E+00 | 9.56E+00 | 9.66E+00 | 9.59E+00 | 1.15E+01 | 1.15E+01 | 1.14E+01 |
| 89 | 1.82E-01 | 1.73E-01 | 1.79E-01 | 7.53E+00 | 7.68E+00 | 7.58E+00 | 1.28E+01 | 1.29E+01 | 1.28E+01 |
| 90 | 3.78E-01 | 3.68E-01 | 3.54E-01 | 3.47E+00 | 3.53E+00 | 3.51E+00 | 6.49E+00 | 6.60E+00 | 6.50E+00 |
| 91 | 2.84E-02 | 2.70E-02 | 2.66E-02 | 1.20E+00 | 1.22E+00 | 1.21E+00 | 3.33E+00 | 3.40E+00 | 3.31E+00 |
| 92 | 6.88E-02 | 6.73E-02 | 6.49E-02 | 1.11E+00 | 1.12E+00 | 1.13E+00 | 3.05E+00 | 3.08E+00 | 3.04E+00 |
| 93 | 3.68E-02 | 3.50E-02 | 3.16E-02 | 1.31E+00 | 1.29E+00 | 1.30E+00 | 3.89E+00 | 3.94E+00 | 3.89E+00 |
| 94 | 5.45E-02 | 5.75E-02 | 5.25E-02 | 1.27E+00 | 1.24E+00 | 1.23E+00 | 3.37E+00 | 3.37E+00 | 3.36E+00 |
| 95 | 1.93E-01 | 1.88E-01 | 1.85E-01 | 1.18E-01 | 1.21E-01 | 1.22E-01 | 3.58E-01 | 3.64E-01 | 3.53E-01 |
| 96 | 6.47E-02 | 6.45E-02 | 6.24E-02 | 1.08E+00 | 1.09E+00 | 1.07E+00 | 3.00E+00 | 3.02E+00 | 3.00E+00 |
| 97 | 1.71E-01 | 1.66E-01 | 1.63E-01 | 1.08E-01 | 1.05E-01 | 1.06E-01 | 3.19E-01 | 3.15E-01 | 3.11E-01 |
| 98 | 1.99E-01 | 1.99E-01 | 1.95E-01 | 1.22E-01 | 1.25E-01 | 1.25E-01 | 3.70E-01 | 3.72E-01 | 3.66E-01 |
| 99 | 7.33E-01 | 7.29E-01 | 7.03E-01 | 9.22E-01 | 9.34E-01 | 9.29E-01 | 1.02E+00 | 1.03E+00 | 1.02E+00 |
| 100 | 2.83E-01 | 2.80E-01 | 2.77E-01 | 4.97E-01 | 5.02E-01 | 4.95E-01 | 8.99E-01 | 9.05E-01 | 8.99E-01 |
| 101 | 2.48E+00 | 2.43E+00 | 2.41E+00 | 8.00E+00 | 8.02E+00 | 8.03E+00 | 1.28E+01 | 1.30E+01 | 1.28E+01 |
| 102 | 2.13E+00 | 2.15E+00 | 2.09E+00 | 6.98E+00 | 6.97E+00 | 7.05E+00 | 1.11E+01 | 1.12E+01 | 1.11E+01 |
| 103 | 2.41E+00 | 2.39E+00 | 2.36E+00 | 5.81E+00 | 5.79E+00 | 5.93E+00 | 7.96E+00 | 8.03E+00 | 7.94E+00 |
| 104 | 1.04E+00 | 1.04E+00 | 1.04E+00 | 3.34E+00 | 3.34E+00 | 3.37E+00 | 5.15E+00 | 5.18E+00 | 5.14E+00 |
| 105 | 3.45E-02 | 3.56E-02 | 4.58E-02 | 3.70E-02 | 4.77E-02 | 4.33E-02 | 3.09E-02 | 2.93E-02 | 3.18E-02 |
| 106 | 3.93E-02 | 3.90E-02 | 4.93E-02 | 6.14E-02 | 7.33E-02 | 5.93E-02 | 5.91E-02 | 6.12E-02 | 6.22E-02 |
| 107 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 4.24E-02 | 5.32E-02 | 5.19E-02 | 2.82E-01 | 2.89E-01 | 2.93E-01 |
| 108 | <1.7E-02 | <1.6E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | 2.43E-02 | 2.63E-02 | 2.64E-02 |
| 109 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 3.42E-02 | 4.14E-02 | 4.00E-02 | 2.71E-01 | 2.89E-01 | 2.75E-01 |
| 110 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 1.07E-01 | 1.11E-01 | 1.14E-01 | 1.69E-01 | 1.72E-01 | 1.71E-01 |
| 111 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 1.72E-01 | 1.74E-01 | 1.71E-01 | 2.61E-01 | 2.62E-01 | 2.62E-01 |
| 112 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 2.94E-01 | 2.91E-01 | 2.94E-01 | 4.57E-01 | 4.56E-01 | 4.55E-01 |
| 113 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 1.42E-01 | 1.46E-01 | 1.47E-01 | 2.15E-01 | 2.33E-01 | 2.25E-01 |
| 114 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 3.51E-01 | 3.48E-01 | 3.47E-01 | 5.20E-01 | 5.38E-01 | 5.22E-01 |
| 116 | 1.91E-01 | 1.88E-01 | 1.96E-01 | 4.31E+00 | 4.27E+00 | 4.29E+00 | 9.55E+00 | 9.61E+00 | 9.56E+00 |
| 117 | <1.7E-02 | <1.6E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | 2.69E-02 | 2.78E-02 | 2.66E-02 |
| 118 | 5.61E-02 | 6.18E-02 | 5.81E-02 | 2.45E-01 | 2.42E-01 | 2.41E-01 | 2.73E-01 | 2.78E-01 | 2.63E-01 |

**Table A-11. Replicate analyses of the product filtrates by ICP-MS, fission products part 2 of 2**

| m/z | Supernate, 70% Acid Addition (mg/L) | | | Supernate, 100% Acid Addition (mg/L) | | | Supernate, 140% Acid Addition (mg/L) | | |
|---|---|---|---|---|---|---|---|---|---|
| | LW17731 | LW17723 | LW17725 | LW17727 | LW17729 | LW17721 | LW17733 | LW17735 | LW17737 |
| 119 | 1.62E+01 | 1.63E+01 | 1.64E+01 | 4.82E+01 | 4.85E+01 | 4.95E+01 | 5.09E+01 | 5.14E+01 | 5.14E+01 |
| 120 | <1.7E-02 | <1.6E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | 4.29E-02 | 4.69E-02 | 4.38E-02 |
| 121 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 4.05E-02 | 4.38E-02 | 3.57E-02 | 1.00E-01 | 8.77E-02 | 8.66E-02 |
| 122 | <1.7E-02 | <1.6E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 |
| 123 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 3.32E-02 | 3.67E-02 | 3.38E-02 | 7.69E-02 | 8.65E-02 | 8.11E-02 |
| 124 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 2.00E-01 | 2.05E-01 | 2.08E-01 | 4.83E-01 | 4.85E-01 | 4.69E-01 |
| 125 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 2.07E-01 | 2.31E-01 | 2.35E-01 | 5.19E-01 | 5.28E-01 | 5.11E-01 |
| 126 | 8.11E-02 | 8.26E-02 | 7.60E-02 | 2.38E-01 | 2.35E-01 | 2.31E-01 | 3.11E-01 | 3.09E-01 | 3.09E-01 |
| 128 | 1.08E+00 | 1.07E+00 | 1.06E+00 | 3.21E+00 | 3.17E+00 | 3.31E+00 | 3.27E+00 | 3.26E+00 | 3.31E+00 |
| 130 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 3.10E-02 | 3.04E-02 | 3.09E-02 | 1.13E-01 | 1.11E-01 | 1.08E-01 |
| 133 | 9.01E-01 | 8.74E-01 | 8.70E-01 | 1.19E+00 | 1.20E+00 | 1.20E+00 | 1.17E+00 | 1.15E+00 | 1.13E+00 |
| 134 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 7.84E-02 | 7.91E-02 | 8.10E-02 | 4.37E-02 | 4.25E-02 | 4.27E-02 |
| 135 | 1.04E-01 | 1.04E-01 | 9.45E-02 | 1.47E-01 | 1.48E-01 | 1.60E-01 | 1.42E-01 | 1.46E-01 | 1.38E-01 |
| 136 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 2.94E-02 | 3.33E-02 | 2.87E-02 | 3.99E-02 | 3.65E-02 | 3.90E-02 |
| 137 | 2.40E-01 | 2.27E-01 | 2.25E-01 | 1.32E+00 | 1.34E+00 | 1.33E+00 | 7.69E-01 | 7.62E-01 | 7.54E-01 |
| 138 | 3.66E-02 | 3.67E-02 | 2.98E-02 | 2.15E+00 | 2.21E+00 | 2.19E+00 | 1.27E+00 | 1.28E+00 | 1.27E+00 |
| 139 | 9.82E-02 | 9.63E-02 | 9.30E-02 | 7.54E+00 | 7.97E+00 | 8.03E+00 | 2.34E+01 | 2.37E+01 | 2.35E+01 |
| 140 | 3.83E-02 | 3.29E-02 | 3.19E-02 | 2.61E+00 | 2.78E+00 | 2.78E+00 | 1.42E+01 | 1.43E+01 | 1.41E+01 |
| 141 | 1.11E-01 | 1.07E-01 | 1.03E-01 | 6.79E+00 | 7.06E+00 | 7.09E+00 | 1.96E+01 | 1.97E+01 | 1.94E+01 |
| 142 | 2.92E-02 | 2.72E-02 | 2.67E-02 | 1.90E+00 | 2.02E+00 | 2.02E+00 | 8.43E+00 | 8.39E+00 | 8.41E+00 |
| 143 | 1.30E-01 | 1.32E-01 | 1.31E-01 | 7.59E+00 | 7.96E+00 | 7.96E+00 | 1.87E+01 | 1.87E+01 | 1.84E+01 |
| 144 | 1.57E-01 | 1.53E-01 | 1.47E-01 | 8.65E+00 | 9.03E+00 | 9.14E+00 | 2.23E+01 | 2.22E+01 | 2.21E+01 |
| 145 | 9.64E-02 | 9.90E-02 | 9.55E-02 | 5.65E+00 | 5.90E+00 | 5.95E+00 | 1.39E+01 | 1.40E+01 | 1.36E+01 |
| 146 | 8.44E-02 | 8.26E-02 | 8.00E-02 | 4.64E+00 | 4.86E+00 | 4.90E+00 | 1.20E+01 | 1.20E+01 | 1.19E+01 |
| 147 | 6.14E-02 | 6.12E-02 | 6.00E-02 | 3.10E+00 | 3.19E+00 | 3.25E+00 | 6.86E+00 | 6.90E+00 | 6.84E+00 |
| 148 | 5.22E-02 | 5.08E-02 | 5.16E-02 | 2.95E+00 | 3.09E+00 | 3.13E+00 | 7.20E+00 | 7.27E+00 | 7.15E+00 |
| 149 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 1.20E-01 | 1.29E-01 | 1.22E-01 | 2.69E-01 | 2.70E-01 | 2.64E-01 |
| 150 | 5.27E-02 | 4.88E-02 | 4.89E-02 | 2.75E+00 | 2.87E+00 | 2.90E+00 | 6.37E+00 | 6.43E+00 | 6.32E+00 |
| 151 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 1.26E-01 | 1.33E-01 | 1.33E-01 | 2.79E-01 | 2.81E-01 | 2.79E-01 |
| 152 | 1.99E-02 | 1.89E-02 | 1.90E-02 | 9.49E-01 | 9.78E-01 | 9.90E-01 | 2.08E+00 | 2.10E+00 | 2.09E+00 |
| 153 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 4.59E-01 | 4.67E-01 | 4.74E-01 | 9.63E-01 | 9.75E-01 | 9.64E-01 |
| 154 | 2.70E-02 | 2.68E-02 | 2.61E-02 | 1.02E+00 | 1.05E+00 | 1.06E+00 | 1.86E+00 | 1.88E+00 | 1.86E+00 |
| 155 | 1.27E-01 | 1.27E-01 | 1.22E-01 | 4.62E+00 | 4.72E+00 | 4.80E+00 | 8.44E+00 | 8.53E+00 | 8.43E+00 |
| 156 | 1.77E-01 | 1.78E-01 | 1.71E-01 | 6.49E+00 | 6.65E+00 | 6.80E+00 | 1.20E+01 | 1.21E+01 | 1.19E+01 |
| 157 | 1.33E-01 | 1.31E-01 | 1.31E-01 | 4.78E+00 | 4.90E+00 | 5.02E+00 | 8.91E+00 | 8.90E+00 | 8.86E+00 |

**Table A-12. Replicate analyses of the product filtrates by ICP-MS, actinides**

| m/z | Supernate, 70% Acid Addition (mg/L) | | | Supernate, 100% Acid Addition (mg/L) | | | Supernate, 140% Acid Addition (mg/L) | | |
|---|---|---|---|---|---|---|---|---|---|
| | LW17731 | LW17723 | LW17725 | LW17727 | LW17729 | LW17721 | LW17733 | LW17735 | LW17737 |
| 232 | 7.51E+00 | 7.70E+00 | 7.59E+00 | 1.59E+02 | 1.59E+02 | 1.61E+02 | 3.50E+02 | 3.49E+02 | 3.52E+02 |
| 233 | 1.29E-01 | 1.33E-01 | 1.31E-01 | 4.47E-01 | 4.43E-01 | 4.52E-01 | 4.91E-01 | 4.92E-01 | 4.86E-01 |
| 234 | 2.39E-01 | 2.13E-01 | 2.20E-01 | 6.59E-01 | 7.41E-01 | 7.23E-01 | 7.75E-01 | 7.68E-01 | 7.51E-01 |
| 235 | 1.52E+01 | 1.54E+01 | 1.54E+01 | 4.19E+01 | 4.16E+01 | 4.21E+01 | 4.34E+01 | 4.36E+01 | 4.36E+01 |
| 236 | 8.84E-01 | 9.08E-01 | 8.94E-01 | 3.00E+00 | 2.99E+00 | 3.02E+00 | 3.13E+00 | 3.18E+00 | 3.12E+00 |
| 237 | 1.05E-01 | 1.07E-01 | 1.04E-01 | 1.10E+00 | 1.09E+00 | 1.10E+00 | 1.29E+00 | 1.30E+00 | 1.28E+00 |
| 238 | 1.04E+03 | 1.05E+03 | 1.03E+03 | 3.07E+03 | 3.06E+03 | 3.13E+03 | 3.21E+03 | 3.20E+03 | 3.21E+03 |
| 239 | 1.43E-01 | 1.48E-01 | 1.47E-01 | 2.20E+00 | 2.18E+00 | 2.21E+00 | 9.31E+00 | 9.34E+00 | 9.10E+00 |
| 240 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 1.42E-01 | 1.42E-01 | 1.42E-01 | 6.52E-01 | 6.57E-01 | 6.52E-01 |
| 241 | <1.7E-02 | <1.6E-02 | <1.7E-02 | 5.14E-02 | 5.35E-02 | 5.43E-02 | 1.59E-01 | 1.58E-01 | 1.58E-01 |
| 242 | <1.7E-02 | <1.6E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | 2.65E-02 | 2.66E-02 | 2.53E-02 |
| 243 | <1.7E-02 | <1.6E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 |
| 244 | <1.7E-02 | <1.6E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 | <1.7E-02 |

**Table A-13. Percent soluble calculated from the concentrations in each phase on a slurry basis, ICP-ES**

| Analyte | 70% Acid Addition | | | | 100% Acid Addition | | | | 140% Acid Addition | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) |
| Ag | <8.0E-04 | -- | <5.0E-04 | -- | <7.9E-04 | -- | <5.2E-04 | -- | <8.0E-04 | -- | <5.2E-04 | -- |
| Al | 1.50E+00 | 1.49E+00 | 2.65E-03 | 0.2% | 1.39E+00 | 1.34E+00 | 4.79E-02 | 3.4% | 1.39E+00 | 1.26E+00 | 1.37E-01 | 9.9% |
| B | <8.3E-04 | -- | <7.2E-04 | -- | <8.2E-04 | -- | <7.4E-04 | -- | <8.2E-04 | -- | <7.5E-04 | -- |
| Ba | 6.89E-03 | -- | <2.5E-04 | <4% | 6.67E-03 | 6.40E-03 | 2.74E-04 | 4.1% | 6.58E-03 | -- | <2.6E-04 | <4% |
| Be | <2.8E-05 | -- | <2.0E-04 | -- | <2.8E-05 | -- | <2.1E-04 | -- | <2.8E-05 | -- | <2.1E-04 | -- |
| Ca | 7.73E-02 | 6.10E-02 | 1.63E-02 | 21% | 7.48E-02 | 2.32E-02 | 5.16E-02 | 69% | 7.38E-02 | 1.37E-02 | 6.02E-02 | 81% |
| Cd | <4.8E-04 | -- | <4.2E-04 | -- | <4.8E-04 | -- | <4.3E-04 | -- | <4.8E-04 | -- | <4.4E-04 | -- |
| Ce | 1.55E-02 | -- | <3.3E-03 | <21% | 1.48E-02 | -- | <3.3E-03 | <23% | 1.48E-02 | -- | <3.4E-03 | <23% |
| Co | <6.0E-04 | -- | <5.2E-04 | -- | <5.9E-04 | -- | <5.3E-04 | -- | <5.9E-04 | -- | <5.4E-04 | -- |
| Cr | 2.26E-02 | -- | <8.8E-04 | <4% | 2.21E-02 | 1.29E-02 | 9.28E-03 | 42% | 2.17E-02 | 8.69E-03 | 1.30E-02 | 60% |
| Cu | 4.18E-03 | -- | <1.3E-04 | <3% | 4.08E-03 | 3.74E-03 | 3.45E-04 | 8.5% | 4.04E-03 | 2.41E-03 | 1.63E-03 | 40% |
| Fe | 1.18E+00 | -- | <4.0E-04 | <0.03% | 1.14E+00 | 1.13E+00 | 1.18E-02 | 1.0% | 1.12E+00 | 1.06E+00 | 5.78E-02 | 5.2% |
| Gd | 6.62E-03 | -- | <3.5E-04 | <5% | 6.33E-03 | 2.71E-03 | 3.62E-03 | 57% | 6.27E-03 | 5.71E-04 | 5.70E-03 | 91% |
| K | <9.3E-03 | -- | <8.1E-03 | -- | <9.2E-03 | -- | <8.3E-03 | -- | <9.2E-03 | -- | <8.4E-03 | -- |
| La | 3.79E-03 | -- | <1.3E-04 | <3% | 3.73E-03 | 3.18E-03 | 5.48E-04 | 15% | 3.64E-03 | 1.89E-03 | 1.75E-03 | 48% |
| Li | 1.65E-03 | -- | <6.7E-04 | <41% | 1.55E-03 | -- | <6.9E-04 | <45% | 1.59E-03 | 5.76E-04 | 1.02E-03 | 64% |
| Mg | 2.90E-02 | 2.27E-02 | 6.34E-03 | 22% | 2.83E-02 | 9.79E-03 | 1.85E-02 | 65% | 2.77E-02 | 4.11E-03 | 2.36E-02 | 85% |
| Mn | 2.84E-01 | 2.80E-01 | 4.27E-03 | 1.5% | 2.76E-01 | 9.61E-02 | 1.80E-01 | 65% | 2.70E-01 | 3.21E-02 | 2.38E-01 | 88% |
| Mo | <1.8E-03 | -- | <1.6E-03 | -- | <1.8E-03 | -- | <1.6E-03 | -- | <1.8E-03 | -- | <1.7E-03 | -- |
| Na | 1.99E+00 | 1.30E-01 | 1.86E+00 | 93% | 1.94E+00 | 2.29E-02 | 1.92E+00 | 99% | 1.92E+00 | 7.07E-02 | 1.85E+00 | 96% |
| Ni | 3.74E-02 | -- | <2.6E-03 | <7% | 3.66E-02 | 2.80E-02 | 8.63E-03 | 24% | 3.56E-02 | 1.57E-02 | 1.98E-02 | 56% |
| P | <7.2E-03 | -- | <3.1E-03 | -- | <7.1E-03 | -- | <3.2E-03 | -- | <7.2E-03 | -- | <3.2E-03 | -- |
| Pb | <4.0E-03 | -- | <3.5E-03 | -- | <4.0E-03 | -- | <3.6E-03 | -- | <4.0E-03 | -- | <3.7E-03 | -- |
| S | <2.8E-01 | -- | <1.8E-01 | -- | <2.8E-01 | -- | <1.8E-01 | -- | <2.8E-01 | -- | <1.8E-01 | -- |
| Sb | <1.2E-02 | -- | <1.1E-02 | -- | <1.2E-02 | -- | <1.1E-02 | -- | <1.2E-02 | -- | <1.1E-02 | -- |
| Si | 3.90E-02 | -- | <1.6E-03 | <4% | 3.73E-02 | 2.56E-02 | 1.16E-02 | 31% | 3.85E-02 | 1.64E-02 | 2.21E-02 | 57% |
| Sn | <3.5E-03 | -- | <3.1E-03 | -- | <3.5E-03 | -- | <3.2E-03 | -- | <3.5E-03 | -- | <3.2E-03 | -- |
| Sr | 3.16E-03 | 2.90E-03 | 2.65E-04 | 8.4% | 3.07E-03 | 1.89E-03 | 1.18E-03 | 39% | 3.00E-03 | 1.59E-03 | 1.42E-03 | 47% |
| Th | 2.41E-01 | -- | <1.8E-03 | <1% | 2.37E-01 | 2.21E-01 | 1.62E-02 | 6.8% | 2.32E-01 | 1.98E-01 | 3.35E-02 | 14% |
| Ti | 1.72E-03 | -- | <1.1E-04 | <6% | 1.67E-03 | -- | <1.1E-04 | <7% | 1.64E-03 | -- | <1.1E-04 | <7% |
| U | 3.18E-01 | 2.23E-01 | 9.46E-02 | 30% | 3.11E-01 | 3.03E-02 | 2.80E-01 | 90% | 3.03E-01 | 7.36E-03 | 2.95E-01 | 98% |
| V | <3.2E-04 | -- | <2.8E-04 | -- | <3.2E-04 | -- | <2.9E-04 | -- | <3.2E-04 | -- | <2.9E-04 | -- |
| Zn | 2.60E-03 | -- | <3.0E-04 | <11% | 2.49E-03 | -- | <3.1E-04 | <12% | 2.45E-03 | 1.87E-03 | 5.77E-04 | 24% |
| Zr | 1.43E-02 | -- | <1.5E-04 | <1% | 1.39E-02 | 1.34E-02 | 4.68E-04 | 3.4% | 1.36E-02 | 1.20E-02 | 1.64E-03 | 12% |

**Table A-14. Percent soluble calculated from the concentrations in each phase on a slurry basis, ICP-MS fission products part 1 of 2**

| | 70% Acid Addition | | | | 100% Acid Addition | | | | 140% Acid Addition | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m/z | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) |
| 59 | 3.35E-04 | -- | <1.5E-06 | <0.4% | 3.30E-04 | 2.68E-04 | 6.25E-05 | 19% | 3.26E-04 | 1.14E-04 | 2.12E-04 | 65% |
| 85 | 7.62E-06 | 1.11E-06 | 6.51E-06 | 85% | 7.44E-06 | 8.26E-08 | 7.35E-06 | 99% | 7.13E-06 | 2.21E-07 | 6.91E-06 | 97% |
| 86 | 7.80E-05 | 7.12E-05 | 6.77E-06 | 8.7% | 7.55E-05 | 4.48E-05 | 3.07E-05 | 41% | 7.38E-05 | 3.92E-05 | 3.46E-05 | 47% |
| 87 | 7.24E-05 | 5.25E-05 | 1.99E-05 | 27% | 7.24E-05 | 3.50E-05 | 3.74E-05 | 52% | 7.09E-05 | 2.99E-05 | 4.09E-05 | 58% |
| 88 | 2.06E-03 | 1.85E-03 | 2.02E-04 | 9.8% | 2.09E-03 | 1.25E-03 | 8.44E-04 | 40% | 1.97E-03 | 9.57E-04 | 1.01E-03 | 51% |
| 89 | 2.03E-03 | 2.01E-03 | 1.58E-05 | 0.8% | 1.98E-03 | 1.31E-03 | 6.68E-04 | 34% | 1.95E-03 | 8.16E-04 | 1.14E-03 | 58% |
| 90 | 2.11E-03 | 2.08E-03 | 3.25E-05 | 1.5% | 2.06E-03 | 1.75E-03 | 3.08E-04 | 15% | 2.04E-03 | 1.46E-03 | 5.77E-04 | 28% |
| 91 | 2.53E-03 | 2.53E-03 | 2.42E-06 | 0.1% | 2.46E-03 | 2.35E-03 | 1.06E-04 | 4.3% | 2.42E-03 | 2.12E-03 | 2.95E-04 | 12% |
| 92 | 2.30E-03 | 2.29E-03 | 5.94E-06 | 0.3% | 2.24E-03 | 2.14E-03 | 9.85E-05 | 4.4% | 2.20E-03 | 1.93E-03 | 2.70E-04 | 12% |
| 93 | 2.95E-03 | 2.95E-03 | 3.05E-06 | 0.1% | 2.90E-03 | 2.78E-03 | 1.14E-04 | 3.9% | 2.83E-03 | 2.49E-03 | 3.45E-04 | 12% |
| 94 | 2.57E-03 | 2.56E-03 | 4.86E-06 | 0.2% | 2.49E-03 | 2.38E-03 | 1.10E-04 | 4.4% | 2.45E-03 | 2.15E-03 | 2.97E-04 | 12% |
| 95 | 1.70E-04 | 1.53E-04 | 1.67E-05 | 9.8% | 1.65E-04 | 1.55E-04 | 1.06E-05 | 6.4% | 1.64E-04 | 1.32E-04 | 3.17E-05 | 19% |
| 96 | 2.33E-03 | 2.32E-03 | 5.66E-06 | 0.2% | 2.26E-03 | 2.16E-03 | 9.50E-05 | 4.2% | 2.21E-03 | 1.95E-03 | 2.66E-04 | 12% |
| 97 | 1.45E-04 | 1.31E-04 | 1.48E-05 | 10% | 1.41E-04 | 1.32E-04 | 9.36E-06 | 6.6% | 1.38E-04 | 1.11E-04 | 2.78E-05 | 20% |
| 98 | 1.58E-04 | 1.41E-04 | 1.75E-05 | 11% | 1.55E-04 | 1.44E-04 | 1.09E-05 | 7.1% | 1.50E-04 | 1.18E-04 | 3.26E-05 | 22% |
| 99 | 2.38E-04 | 1.74E-04 | 6.39E-05 | 27% | 2.30E-04 | 1.48E-04 | 8.16E-05 | 36% | 2.25E-04 | 1.35E-04 | 9.05E-05 | 40% |
| 100 | 2.45E-04 | 2.20E-04 | 2.48E-05 | 10% | 2.37E-04 | 1.93E-04 | 4.38E-05 | 18% | 2.33E-04 | 1.54E-04 | 7.96E-05 | 34% |
| 101 | 2.38E-03 | 2.17E-03 | 2.16E-04 | 9.1% | 2.30E-03 | 1.59E-03 | 7.05E-04 | 31% | 2.23E-03 | 1.09E-03 | 1.14E-03 | 51% |
| 102 | 2.07E-03 | 1.88E-03 | 1.88E-04 | 9.1% | 2.02E-03 | 1.41E-03 | 6.15E-04 | 30% | 2.00E-03 | 1.01E-03 | 9.84E-04 | 49% |
| 103 | 1.10E-03 | 8.91E-04 | 2.11E-04 | 19% | 1.06E-03 | 5.51E-04 | 5.14E-04 | 48% | 1.04E-03 | 3.39E-04 | 7.04E-04 | 68% |
| 104 | 1.00E-03 | 9.08E-04 | 9.21E-05 | 9.2% | 9.71E-04 | 6.77E-04 | 2.95E-04 | 30% | 9.55E-04 | 4.99E-04 | 4.56E-04 | 48% |
| 105 | 1.30E-04 | 1.26E-04 | 3.42E-06 | 2.6% | 1.31E-04 | 1.27E-04 | 3.75E-06 | 2.9% | 1.27E-04 | 1.25E-04 | 2.71E-06 | 2.1% |
| 106 | 1.51E-04 | 1.48E-04 | 3.76E-06 | 2.5% | 1.52E-04 | 1.46E-04 | 5.68E-06 | 3.7% | 1.46E-04 | 1.41E-04 | 5.37E-06 | 3.7% |
| 107 | 4.61E-04 | -- | <1.5E-06 | <0.3% | 4.41E-04 | 4.37E-04 | 4.32E-06 | 1.0% | 4.40E-04 | 4.14E-04 | 2.54E-05 | 5.8% |
| 108 | 2.85E-05 | -- | <1.5E-06 | <5% | 2.81E-05 | -- | <1.5E-06 | <5% | 2.74E-05 | 2.51E-05 | 2.27E-06 | 8.3% |
| 109 | 4.21E-04 | -- | <1.5E-06 | <0.3% | 4.03E-04 | 4.00E-04 | 3.39E-06 | 0.8% | 4.00E-04 | 3.75E-04 | 2.46E-05 | 6.1% |
| 110 | 5.50E-05 | -- | <1.5E-06 | <3% | 5.33E-05 | 4.36E-05 | 9.72E-06 | 18% | 5.23E-05 | 3.72E-05 | 1.51E-05 | 29% |
| 111 | 6.48E-05 | -- | <1.5E-06 | <2% | 6.28E-05 | 4.77E-05 | 1.51E-05 | 24% | 6.27E-05 | 3.96E-05 | 2.31E-05 | 37% |
| 112 | 1.07E-04 | -- | <1.5E-06 | <1% | 1.05E-04 | 7.90E-05 | 2.57E-05 | 25% | 1.00E-04 | 5.99E-05 | 4.02E-05 | 40% |
| 113 | <6.7E-05 | -- | <1.5E-06 | -- | <6.6E-05 | -- | 1.27E-05 | >19% | <6.6E-05 | -- | 1.98E-05 | >30% |
| 114 | 1.18E-04 | -- | <1.5E-06 | <1% | 1.13E-04 | 8.21E-05 | 3.06E-05 | 27% | 1.11E-04 | 6.40E-05 | 4.65E-05 | 42% |
| 116 | 6.30E-03 | 6.28E-03 | 1.70E-05 | 0.3% | 6.20E-03 | 5.82E-03 | 3.77E-04 | 6.1% | 6.02E-03 | 5.18E-03 | 8.46E-04 | 14% |
| 117 | 8.15E-06 | -- | <1.5E-06 | <18% | 7.98E-06 | -- | <1.5E-06 | <19% | 7.65E-06 | 5.25E-06 | 2.39E-06 | 31% |
| 118 | 3.91E-05 | 3.39E-05 | 5.20E-06 | 13% | 3.62E-05 | 1.49E-05 | 2.13E-05 | 59% | 3.55E-05 | 1.15E-05 | 2.40E-05 | 68% |

**Table A-15. Percent soluble calculated from the concentrations in each phase on a slurry basis, ICP-MS fission products part 2 of 2**

| | 70% Acid Addition | | | | 100% Acid Addition | | | | 140% Acid Addition | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m/z | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) |
| 119 | 5.04E-03 | 3.60E-03 | 1.44E-03 | 29% | 4.88E-03 | 5.99E-04 | 4.28E-03 | 88% | 4.71E-03 | 1.89E-04 | 4.52E-03 | 96% |
| 120 | 2.26E-05 | -- | <1.5E-06 | <6% | 2.43E-05 | -- | <1.5E-06 | <6% | 2.12E-05 | 1.73E-05 | 3.93E-06 | 19% |
| 121 | 1.89E-05 | 1.74E-05 | 1.46E-06 | 7.7% | 1.84E-05 | 1.49E-05 | 3.52E-06 | 19% | 1.70E-05 | 8.88E-06 | 8.08E-06 | 48% |
| 122 | 5.08E-06 | -- | <1.5E-06 | <29% | 4.78E-06 | -- | <1.5E-06 | <31% | 4.00E-06 | -- | <1.5E-06 | <38% |
| 123 | 1.87E-05 | 1.73E-05 | 1.46E-06 | 7.8% | 1.78E-05 | 1.48E-05 | 3.04E-06 | 17% | 1.74E-05 | 1.02E-05 | 7.20E-06 | 41% |
| 124 | 3.25E-04 | 3.23E-04 | 1.46E-06 | 0.4% | 3.22E-04 | 3.04E-04 | 1.79E-05 | 5.6% | 3.13E-04 | 2.71E-04 | 4.23E-05 | 14% |
| 125 | 3.40E-04 | 3.38E-04 | 1.46E-06 | 0.4% | 3.37E-04 | 3.17E-04 | 1.97E-05 | 5.9% | 3.31E-04 | 2.85E-04 | 4.59E-05 | 14% |
| 126 | 5.42E-05 | 4.71E-05 | 7.08E-06 | 13% | 5.31E-05 | 3.25E-05 | 2.06E-05 | 39% | 5.50E-05 | 2.77E-05 | 2.74E-05 | 50% |
| 128 | 5.29E-04 | 4.34E-04 | 9.48E-05 | 18% | 5.03E-04 | 2.19E-04 | 2.84E-04 | 56% | 4.95E-04 | 2.05E-04 | 2.90E-04 | 59% |
| 130 | 1.17E-03 | -- | <1.5E-06 | <0.1% | 1.13E-03 | 1.13E-03 | 2.70E-06 | 0.2% | 1.10E-03 | 1.09E-03 | 9.76E-06 | 0.9% |
| 133 | 1.18E-04 | 4.02E-05 | 7.81E-05 | 66% | 1.14E-04 | 8.94E-06 | 1.05E-04 | 92% | 1.12E-04 | 1.04E-05 | 1.02E-04 | 91% |
| 134 | 1.37E-04 | -- | <1.5E-06 | <1% | 1.32E-04 | 1.25E-04 | 6.99E-06 | 5.3% | 1.29E-04 | 1.25E-04 | 3.79E-06 | 2.9% |
| 135 | 4.65E-05 | 3.76E-05 | 8.93E-06 | 19% | 4.46E-05 | 3.13E-05 | 1.33E-05 | 30% | 4.29E-05 | 3.03E-05 | 1.25E-05 | 29% |
| 136 | 6.61E-05 | -- | <1.5E-06 | <2% | 6.48E-05 | 6.22E-05 | 2.68E-06 | 4.1% | 6.24E-05 | 5.90E-05 | 3.40E-06 | 5.4% |
| 137 | 1.44E-03 | 1.42E-03 | 2.04E-05 | 1.4% | 1.40E-03 | 1.28E-03 | 1.17E-04 | 8.4% | 1.38E-03 | 1.31E-03 | 6.73E-05 | 4.9% |
| 138 | 5.04E-03 | 5.04E-03 | 3.04E-06 | 0.1% | 4.84E-03 | 4.65E-03 | 1.92E-04 | 4.0% | 4.72E-03 | 4.61E-03 | 1.12E-04 | 2.4% |
| 139 | 4.84E-03 | 4.84E-03 | 8.49E-06 | 0.2% | 4.68E-03 | 3.99E-03 | 6.90E-04 | 15% | 4.61E-03 | 2.53E-03 | 2.08E-03 | 45% |
| 140 | 9.95E-03 | 9.94E-03 | 3.05E-06 | 0.0% | 9.65E-03 | 9.41E-03 | 2.39E-04 | 2.5% | 9.44E-03 | 8.19E-03 | 1.25E-03 | 13% |
| 141 | 4.13E-03 | 4.12E-03 | 9.52E-06 | 0.2% | 4.05E-03 | 3.44E-03 | 6.14E-04 | 15% | 3.91E-03 | 2.18E-03 | 1.73E-03 | 44% |
| 142 | 5.37E-03 | 5.37E-03 | 2.45E-06 | 0.0% | 5.21E-03 | 5.04E-03 | 1.74E-04 | 3.3% | 5.09E-03 | 4.35E-03 | 7.43E-04 | 15% |
| 143 | 3.64E-03 | 3.63E-03 | 1.16E-05 | 0.3% | 3.52E-03 | 2.83E-03 | 6.89E-04 | 20% | 3.45E-03 | 1.81E-03 | 1.64E-03 | 48% |
| 144 | 4.62E-03 | 4.61E-03 | 1.35E-05 | 0.3% | 4.47E-03 | 3.69E-03 | 7.86E-04 | 18% | 4.37E-03 | 2.41E-03 | 1.96E-03 | 45% |
| 145 | 2.72E-03 | 2.71E-03 | 8.59E-06 | 0.3% | 2.61E-03 | 2.10E-03 | 5.13E-04 | 20% | 2.58E-03 | 1.36E-03 | 1.22E-03 | 47% |
| 146 | 2.24E-03 | 2.23E-03 | 7.29E-06 | 0.3% | 2.16E-03 | 1.74E-03 | 4.22E-04 | 20% | 2.13E-03 | 1.07E-03 | 1.06E-03 | 50% |
| 147 | 1.30E-03 | 1.29E-03 | 5.39E-06 | 0.4% | 1.25E-03 | 9.73E-04 | 2.79E-04 | 22% | 1.23E-03 | 6.19E-04 | 6.06E-04 | 49% |
| 148 | 1.43E-03 | 1.43E-03 | 4.57E-06 | 0.3% | 1.37E-03 | 1.11E-03 | 2.69E-04 | 20% | 1.35E-03 | 7.15E-04 | 6.37E-04 | 47% |
| 149 | 5.20E-05 | -- | <1.5E-06 | <3% | 5.00E-05 | 3.92E-05 | 1.09E-05 | 22% | 4.86E-05 | 2.50E-05 | 2.36E-05 | 49% |
| 150 | 1.23E-03 | 1.22E-03 | 4.44E-06 | 0.4% | 1.18E-03 | 9.27E-04 | 2.50E-04 | 21% | 1.15E-03 | 5.89E-04 | 5.63E-04 | 49% |
| 151 | 5.37E-05 | -- | <1.5E-06 | <3% | 5.20E-05 | 4.05E-05 | 1.15E-05 | 22% | 5.05E-05 | 2.58E-05 | 2.47E-05 | 49% |
| 152 | 3.87E-04 | 3.85E-04 | 1.70E-06 | 0.4% | 3.72E-04 | 2.87E-04 | 8.55E-05 | 23% | 3.66E-04 | 1.81E-04 | 1.85E-04 | 50% |
| 153 | 1.81E-04 | -- | <1.5E-06 | <1% | 1.75E-04 | 1.34E-04 | 4.10E-05 | 24% | 1.71E-04 | 8.57E-05 | 8.54E-05 | 50% |
| 154 | 2.56E-04 | 2.54E-04 | 2.36E-06 | 0.9% | 2.47E-04 | 1.56E-04 | 9.16E-05 | 37% | 2.40E-04 | 7.47E-05 | 1.65E-04 | 69% |
| 155 | 9.68E-04 | 9.57E-04 | 1.11E-05 | 1.1% | 9.30E-04 | 5.16E-04 | 4.14E-04 | 45% | 9.11E-04 | 1.63E-04 | 7.48E-04 | 82% |
| 156 | 1.41E-03 | 1.40E-03 | 1.55E-05 | 1.1% | 1.36E-03 | 7.78E-04 | 5.84E-04 | 43% | 1.34E-03 | 2.76E-04 | 1.06E-03 | 79% |
| 157 | 1.03E-03 | 1.02E-03 | 1.17E-05 | 1.1% | 9.92E-04 | 5.61E-04 | 4.31E-04 | 43% | 9.74E-04 | 1.89E-04 | 7.85E-04 | 81% |

**Table A-16. Percent soluble calculated from the concentrations in each phase on a slurry basis, ICP-MS actinides**

| Analyte (m/z) | 70% Acid Addition | | | | 100% Acid Addition | | | | 140% Acid Addition | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) | Total (wt% slurry) | Solid (wt% slurry) | Liquid (wt% slurry) | Soluble (%) |
| $^{232}$Th | 2.29E-01 | 2.28E-01 | 6.73E-04 | 0.3% | 2.23E-01 | 2.09E-01 | 1.40E-02 | 6.3% | 2.18E-01 | 1.87E-01 | 3.09E-02 | 14% |
| $^{233}$U | 9.04E-05 | 7.88E-05 | 1.16E-05 | 13% | 8.80E-05 | 4.87E-05 | 3.93E-05 | 45% | 8.61E-05 | 4.29E-05 | 4.32E-05 | 50% |
| $^{234}$U | 8.06E-05 | 6.08E-05 | 1.98E-05 | 25% | 7.78E-05 | 1.56E-05 | 6.22E-05 | 80% | 7.58E-05 | 8.24E-06 | 6.75E-05 | 89% |
| $^{235}$U | 4.29E-03 | 2.94E-03 | 1.36E-03 | 32% | 4.16E-03 | 4.76E-04 | 3.68E-03 | 89% | 3.99E-03 | 1.51E-04 | 3.84E-03 | 96% |
| $^{236}$U | 3.27E-04 | 2.47E-04 | 7.93E-05 | 24% | 3.16E-04 | 5.17E-05 | 2.64E-04 | 84% | 3.09E-04 | 3.12E-05 | 2.78E-04 | 90% |
| $^{237}$Np | 1.68E-04 | 1.59E-04 | 9.33E-06 | 5.5% | 1.68E-04 | 7.15E-05 | 9.66E-05 | 57% | 1.58E-04 | 4.44E-05 | 1.14E-04 | 72% |
| $^{238}$U | 3.10E-01 | 2.18E-01 | 9.20E-02 | 30% | 3.01E-01 | 2.96E-02 | 2.71E-01 | 90% | 2.90E-01 | 7.22E-03 | 2.83E-01 | 98% |
| $^{239}$Pu | 2.18E-03 | 2.17E-03 | 1.29E-05 | 0.6% | 2.13E-03 | 1.94E-03 | 1.93E-04 | 9.1% | 2.07E-03 | 1.26E-03 | 8.17E-04 | 39% |
| $^{240}$Pu | 1.70E-04 | -- | <1.5E-06 | <1% | 1.67E-04 | 1.55E-04 | 1.25E-05 | 7.5% | 1.66E-04 | 1.09E-04 | 5.77E-05 | 35% |
| mass 241 | 4.08E-05 | -- | <1.5E-06 | <4% | 3.90E-05 | 3.43E-05 | 4.67E-06 | 12% | 3.92E-05 | 2.52E-05 | 1.40E-05 | 36% |
| mass 242 | 1.22E-05 | -- | <1.5E-06 | <12% | 1.28E-05 | -- | <1.5E-06 | <12% | 1.19E-05 | 9.61E-06 | 2.31E-06 | 19% |
| mass 243 | <3.3E-06 | -- | <1.5E-06 | -- | <3.3E-06 | -- | <1.5E-06 | -- | <3.3E-06 | -- | <1.5E-06 | -- |
| mass 244 | <3.3E-06 | -- | <1.5E-06 | -- | <3.3E-06 | -- | <1.5E-06 | -- | <3.3E-06 | -- | <1.5E-06 | -- |

**Distribution List:**

cj.bannochie@srnl.doe.gov
alex.cozzi@srnl.doe.gov
brady.lee@srnl.doe.gov
a.fellinger@srnl.doe.gov
samuel.fink@srnl.doe.gov
brenda.garcia-diaz@srnl.doe.gov
connie.herman@srnl.doe.gov
dennis.jackson@srnl.doe.gov
joseph.manna@srnl.doe.gov
daniel.mccabe@srnl.doe.gov
gregg.morgan@srnl.doe.gov
frank.pennebaker@srnl.doe.gov
amy.ramsey@srnl.doe.gov
william.ramsey@srnl.doe.gov
eric.skidmore@srnl.doe.gov
michael.stone@srnl.doe.gov
boyd.wiedenman@srnl.doe.gov
Records Administration (EDWS)
bill.clark@srs.gov
jeffrey.crenshaw@srs.gov
james.folk@srs.gov
curtis.gardner@srs.gov
pauline.hang@srs.gov
anna.murphy@srs.gov
tony.polk@srs.gov
anthony.robinson@srs.gov
mark-a.smith@srs.gov
patricia.suggs@srs.gov
thomas.temple@srs.gov
chris.martino@srnl.doe.gov
matthew02.williams@srnl.doe.gov
daniel.lambert@srnl.doe.gov
john.pareizs@srnl.doe.gov
charles02.coleman@srnl.doe.gov
Kevin.Brotherton@srs.gov
Richard.Edwards@srs.gov
terri.fellinger@srs.gov
Joseph.fields@srs.gov
jeffrey.gillam@srs.gov
barbara.hamm@srs.gov
robert.hoeppel@srs.gov
Thomas.Huff@srs.gov
bill.holtzscheiter@srs.gov
Vijay.Jain@srs.gov
Jeremiah.Ledbetter@srs.gov
jeff.ray@srs.gov
Azadeh.Samadi-Dezfouli@srs.gov
hasmukh.shah@srs.gov
aaron.staub@srs.gov
celia.aponte@srs.gov
timothy.baughman@srs.gov
earl.brass@srs.gov
Azikiwe.hooker@srs.gov
Ryan.McNew@srs.gov
phillip.norris@srs.gov
Christine.Ridgeway@srs.gov
arthur.wiggins@srs.gov
Grace.Chen@srs.gov
thomas.colleran@srs.gov
Spencer.Isom@srs.gov
MARIA.RIOS-ARMSTRONG@SRS.GOV
daniel.tenpenny@srs.gov
marvin.barnett@srs.gov
tara.smith@srnl.doe.gov
eloy.saldivar@srs.gov
william.bennett@srs.gov
bill.giddings@srs.gov
david.henley@srs.gov
timothy.tice@srs.gov
steven.brown@srs.gov
brett.clinton@srs.gov
james.therrell@srs.gov
kenneth.burrows@srs.gov
john.lint@srs.gov
kevin.usher@srs.gov
stephen.yano@srs.gov
jeffrey.schaade@srs.gov
anthony.carraway@srs.gov
gdavid.sanders@srs.gov
richard.burns@srs.gov