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Evaluation of Sludge Batch 5 Qualification with ISDP Salt Batch 1 Compliance to DWPF Waste Acceptance Criteria

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1.0 PURPOSE

The purpose of this report is to document the acceptability of Sludge Batch 5 with the initial macrobatch operation of the Interim Salt Disposition Project (ISDP) waste to the Defense Waste Processing Facility (DWPF).

2.0 BACKGROUND AND SUMMARY

This report was prepared to comply with the requirements listed in the Waste Acceptance Criteria for Sludge, Actinide Removal Process (ARP), and Modular Caustic Side Solvent Extraction Unit (MCU) Process Transfers to 512-S and DWPF (Ref. 1). The requirements for transfers to 512-S were evaluated during ISDP Salt Batch 1 qualification (Ref. 2). The calculations of sludge concentrations are based entirely on the Tank 51 sample processed at SRNL. This is conservative because Tank 51 is blended with the dilute feed in the DWPF Feed Tank (Tank 40). This report documents the acceptability of sludge only as well as Sludge Batch 5 sludge slurry combined with ARP / MCU products for feed to DWPF. All criteria were met for unblended Tank 51 material.

Sludge Batch 4, which is the heel material in Tank 40H, has been fed to DWPF since May 2007. It is well characterized and has been processed without undue difficulty. Its acceptability is documented in Reference 21. Sludge Batch 4 has experienced two decants during processing. The decants were evaluated in Reference 2 and Reference 22.

Sludge Batch 5 is the first sludge batch that deploys a caustic treatment technology used to reduce the amount of aluminum in the sludge slurry. The purpose of aluminum dissolution is to reduce the amount of aluminum in the sludge batch, which consequently reduces the number of canisters that would have to be produced in the sludge batch. Sludge Batch 5 consist of transfers from Tank 7F sludge slurry on top of a small heel left from Sludge Batch 4 processing.

The Sludge Batch 5 (SB5) qualification sample was obtained on March 21, 2008. Since Extended Sludge Processing (ESP) washing was not yet completed, the sample was washed to simulate the rest of the SB5 processing. Its preparation and processing are described fully in Reference 3. The radionuclides and chemicals in the qualification sample were reported in References 4 and 5.

SRNL also conducted shielded cells runs to formulate the operability of Sludge Batch 5. SRAT and SME chemical and radionuclide concentrations and masses were reported in References 6 and 7. SRNL recommends that DWPF target 20 weight percent solids in the Sludge Receipt and Adjustment Tank (SRAT) and 45 weight percent solids in the Slurry Mixed Evaporator (SME) (Ref. 7). Sludge Batch 5 will use a 130% stoichiometric acid strategy (Ref. 6).

3.0 DISCUSSION OF RESULTS

3.1 Compliance with 512-S WAC (Ref. 1)

WAC compliance of the material to be transferred from 241-96H to 512-S (Salt Batch 1) was documented in X-ESR-H-00120 (Ref. 2). All DWPF WAC criteria were met for Salt Batch 1 (Ref. 1).

3.2 Compliance with DWPF WAC (Ref. 1)

MST/sludge solids will be sent from ARP to the DWPF. The SE will be sent from MCU to the DWPF. These streams will be added to Sludge Batch 5 in the SRAT. Compliance with the DWPF WAC is being evaluated against the Sludge Batch 5 with the ARP/MCU material of ISDP Salt Batch 1.

3.2.1 NOx Emissions (DWPF WAC 5.4.1)

The estimated annual NO_x emissions from DWPF shall not exceed 103.52 tons/year. Potential NO_x emissions for the batch were determined using the algorithm provided in Reference 1. The estimated NO_x emission for the decanted Sludge Batch 5 is 25.31 tons per year. This is approximately 24.5% of the DWPF WAC target of 103.5 tons per year. The algorithm assumes that at least 50% of the acid required will be added as formic acid. This percentage is significantly higher for SB5. Details of predicted NO_x emission calculations for SB5 can be found in Attachment 1.

The NO_x emissions for ARP contribution was calculated to be bounding at 65.5 tons/year (Ref. 2). This value is higher than the actual predicted ARP contribution. The calculated value does not take into account that most of the soluble compounds will proceed to Tank 50H or the MST/sludge solids are washed before entering DWPF. The expected NO_x contribution is less than 10 tons/year.

The estimated NO_x emission for the decanted Sludge Batch 5 with the ARP contribution is 90.8 tons per year. This is approximately 88% of the DWPF WAC target of 103.5 tons per year.

3.2.2 Canister Heat Generation (DWPF WAC 5.4.2)

The heat generation per canister produced in the DWPF shall not exceed 437 watts/canister as calculated from the radionuclide content of the glass.

The projected canister heat generation was determined to be 225.2 watts per canister (195.7 watts/canister from sludge, 9.19 watts/canister from MST sludge solids and 20.3 watts/canister from strip effluent at 4.08 Ci/gallon) (Ref. 2). The calculated value is approximately 52 percent of the DWPF WAC limit of 437 watts/canister. Calculations for canister heat generation from sludge can be found in Attachment 2.

3.2.3 Gamma Shielding (DWPF WAC 5.4.3)

The sludge to be transferred to DWPF shall not exceed specific gamma source strength values of 4070 mR/hr/gallon and 3.7 mR/hr/gram insoluble solids. Transfers from MCU are limited to 16.5 Ci/gallon Cs-137.

A list of radionuclides, which were previously determined to be all inclusive of the radionuclides that contribute to 1% or more of the total gamma dose in the sludge slurry, is used to show that the design basis for shielding is not exceeded. The radionuclides are Co-60, Ru-106, Sb-125, Cs-134, Cs-137, Ce-144, Eu-154, Eu-155, and Pu-238. The reported μCi/g dried solids for each radionuclide from the washed Sludge Batch 5 sample analytical results have been multiplied by a conversion factor and the specific isotope gamma dose constant to obtain the contribution of each radionuclide (Ref. 4). The computed gamma source strength values for the 19 radionuclides are then summed together. In addition, the gamma source strengths were converted to a slurry gallon basis. This is shown in Attachment 3. The calculated value for the Sludge Batch 5 is 3.25E-01 mR/hr/g insoluble solids or 8.8 percent of the WAC limit of 3.7 mR/hr/g insoluble solids and 1.57E+02 mR/hr/gal or 3.9 percent of the WAC limit of 4070 mR/hr/gallon.

The MCU contribution to gamma shielding is limited to 16.5 Ci/gallon Cs-137. The contribution from Cs-137 in Salt Batch 1 was determined to be 4.08 Ci/gallon (Ref. 2). MCU continues to conduct periodic sampling of the SE in order to monitor cesium concentration (Ref. 8 and 24).

3.2.4 Neutron Shielding (DWPF WAC 5.4.4)

The total alpha curie per gram of solids value for the sludge feed to DWPF shall not exceed 1.5E-03 Ci/gram insoluble solids.

The neutron production rate is related to the total amount of alpha emitters. Alpha results from the Sludge Batch 5 qualification sample were compared to the limit (Ref. 4). Calculations are shown in Attachment 4. The total alpha concentration of 7.25E-04 Ci/g insoluble solids is approximately 48.3 percent of the DWPF WAC limit of 1.5E-03 Ci/gram insoluble solids.

3.2.5 Inhalation Dose Potential (DWPF WAC 5.4.5)

The inhalation dose potential for the streams to be transferred to DWPF shall have a total rem/gallon value less than or equal to 2.47E+08 rem/gallon for the sludge stream, a Cs-137 concentration less than or equal to 1.34 Ci/gallon for the sludge stream and a Cs-137 concentration less than or equal to 16.5 Ci/gallon for cesium strip effluent transfers.

Two methods have been specified in the WAC for the inhalation dose calculation. The first method evaluates the dose by determining the total alpha and Sr-90 content of the sludge feed from Tank 51H. The reported Ci/gallon values are multiplied by the dose conversion factors to obtain a final rem per gallon value. For total alpha, the dose conversion factor is the conversion factor for Pu-238. The rem per gallon values for total alpha and Sr-90 are then summed and compared to the WAC limit.

The second method compares the eleven major inhalation dose radionuclides in the Tank 51H feed. These radionuclides are Sr-90, Ru-106, Cs-137, Ce-144, Pm-147, Pu-238, Pu-239, Pu-240, Pu-241, Am-241, and Cm-244. Similar to the first method, rem per gallon values are calculated for each radionuclide and then summed together. The rem per gallon value is then compared to the WAC limit.

The first method resulted in the inhalation dose being approximately 6.11E+07 rem/gallon or 24.7 percent of the WAC limit. The second method resulted in the inhalation dose being approximately 5.42E+07 rem/gallon or 22.0 percent of the DWPF WAC limit of 2.47E+08 rem/gallon for the sludge stream. Results of the calculations can be found in Attachment 5. Both methods show Sludge Batch 5 well below the DWPF WAC limit for total IDP.

The Cs-137 concentration in the sludge stream is 3.00E-01 Ci/gallon which is 22.4 percent of the DWPF WAC limit of 1.34 Ci/gallon.

The MCU contribution is limited to 16.5 Ci/gallon of Cs-137. The concentration of 4.08 Ci/gallon (0.272 Ci/gal * 15) is approximately 25 percent of the WAC limit (Ref. 2).

3.2.6 **Nuclear Criticality Safety** (DWPF WAC 5.4.6)

The nuclear criticality criteria for the DWPF facility will be met as long as sludge transfers from the Tank Farm meet four requirements and the ARP/MCU process requires feed to an Eq. U-235 fissile mass less than or equal to a single subcritical U-235 (eq.) mass accumulated within the ARP/MCU boundary as defined in N-NCS-H-00192 (Ref. 9).

Four limits must be satisfied in order to comply with this requirement.

1. The Pu-240 concentration shall exceed the Pu-241 concentration. (SB5 ratio is 26:1)
2. The overall Fe to Equivalent Pu-239 weight ratio shall be greater than 160:1 and only Fe from the Tank Farm material shall be included in the calculation of the ratio. (SB5 ratio is 405:1)
3. The Eq. Pu-239 concentration shall be $\leq$ 0.59 g/gallon if non-Tank Farm Pu is included in the sludge batch. There is no Eq. Pu-239 concentration limit if only Tank Farm Pu is included in the sludge batch. (Eq. Pu-239 in SB5 is 0.297 g/gallon)

4. The Eq. U-235 enrichment shall be ≤ 0.93 wt. %. (Eq. U-235 enrichment for SB5 is 0.729, which is 78.4 percent of the WAC limit)

A Nuclear Criticality Safety Assessment (NCSA) (Ref. 10) was performed that demonstrates that the ISDP Batch 1 is compliant with the requirements from the Actinide Removal Process/Modular Caustic Side Extraction Unit Nuclear Criticality Safety Evaluation (ARP/MCU NCSE) (Ref. 9).

3.2.7 **Glass Solubility** (DWPF WAC 5.4.7)

The concentration of the elements shown below shall not be exceeded. The results are shown below and the calculations are shown in Attachment 7. Since the values from ISDP Batch 1 are based on 100% attainment in ARP/MCU, the value are quite conservative. The values for sludge contribution to the weight % are based on a high sludge oxide loading of 40%. The sludge contributions are also conservative since DWPF will target a waste load of ~34%. The values for contribution from ISDP Salt Batch 1 are identical to those calculated for the evaluation of it and Sludge Batch 4 combined. Since the analytical input source and the ARP/MCU flowsheet basis have not changed since the SB4 evaluation, these remain valid (Ref. 11 and 12).

Species	Limit Wt. % in glass	Value	Percent Of Limit
TiO_2	2	0.797	39.9%
Cr_2O_3	0.3	0.241	80.3%
PO_4	3	2.200	73.3%
NaF	1	0.723	72.3%
NaCl	1	0.148	14.8%
Cu	0.5	0.039	7.80%
SO_4 Na_2SO_4	0.6 (0.88)	--- 0.327	--- 37.2%

3.2.8 **Corrosive Species** (DWPF WAC 5.4.8)

The concentration of SO_4^{2-} in washed sludge shall not exceed 0.058 M slurry and the concentration of Hg shall not exceed 21 g/l slurry.

Sulfate concentration for Sludge Batch 5 was measured from the Tank 51 qualification sample. The concentration is 586 mg/kg (Ref. 6). The concentration for SO_4^{2-} in washed sludge was calculated to be 0.0070 M in slurry (see Attachment 8). The value is approximately 12 percent of the WAC limit of 0.058 M.

The quantity of sulfate in the Salt Batch 1 feed is 0.123 M (Table 4, Ref. 12). However, the MST/sludge solids will be washed before entering DWPF to reach a sodium concentration of 0.6 M and soluble compounds will proceed in the CSS to MCU and finally to Saltstone. There will be negligible sulfate in the washed MST/sludge slurry.

The quantity of mercury for Sludge Batch 5 was determined from the Tank 51 qualification sample mass of total solids times the mercury concentration in 2.22 wt. % of total solids (Ref. 5). The mass of mercury was calculated value is 4.33 g/L (see Attachment 8).

The quantity of mercury in the Salt Batch 1 feed is 9.75E-03 g/L (Table 2, Ref. 12). Combined with the mercury from the sludge slurry, the total quantity of mercury is 4.33 g/L. The value is 20.6 percent of the WAC limit of 21 g/L.

3.2.9 Sludge Solids Content (DWPF WAC 5.4.9)

The sludge feed sent to DWPF has a target range of 12-19 weight percent dry total solids. The washed Sludge Batch 5 qualification sample was measured to be 17.09 weight percent (Ref. 4). The ARP process will transfer up to five weight percent total solids to the Sludge Receipt and Adjustment Tank (SRAT) via the PRFT (Ref. 13). Therefore, the target weight percent of 12-19 is met.

3.2.10 Glass Quality and Processability (DWPF WAC 5.4.10)

SRNL verified the quality and processability of Sludge Batch 5 material from a sample of Tank 51. The sample was processed at SRNL to match the planned processing in Extended Sludge Processing at DWPF. Frit 418 was used to make glass with the prepared sludge. The targeted waste loading was 34 weight percent sludge oxides.

Leach rates were measured using the standard Product Consistency Test (PCT-ASTM 2002) and met the durability standards by a wide margin. The other quality and processability limits were met as seen in the table below (Ref. 7).

Attribute	Limit	Value	Evaluation
Boron Leach Rate	≤16.70 g/l	0.759	Passes
Lithium Leach Rate	≤ 9.57 g/l	0.789	Passes
Sodium Leach Rate	≤ 13.35 g/l	0.759	Passes
Liquidus Temperature -	≤1050° Celsius	878	Passes
High Viscosity	≤110 poise	77	Passes
Low Viscosity	≥ 20 poise	77	Passes
Homogeneity Constraint	$Al_2O_3 \geq 4$ wt% **OR**	7.25	Passes
Homogeneity Constraint	$Al_2O \geq 3$ wt% **AND** $\Sigma M_2O < 19.3$ wt% where $\Sigma M_2O = Na_2O + Li_2O + Cs_2O + K_2O$ wt%	Not Required, Primary Constraint Met	Not Required
Nepheline (Mass) Ratio	$SiO_2 / (SiO_2 + Na_2O + Al_2O_3) > 0.62$	0.730	Passes

Impact of blending ARP/MCU product with sludge is minor for Sludge Batch 5 material (Ref. 19 and 20). The amount of sludge solids with the MST is small because the feed to ARP has been clarified by settling in Tank 49. The main impact is the addition of TiO_2 from the MST used in ARP. This is considered separately as a glass solubility requirement.

3.2.11 H_2 Generation/N_2O Concentration (DWPF WAC 5.4.11)

The WAC criteria for hydrogen generation rate in the SRAT shall not exceed 0.65 lb/hr for 6000 gallons of SRAT product and the SME shall not exceed 0.223 lb/hr for 6000 gallons of SME product. The nitrous oxide concentration in the SRAT vapor space shall not exceed 15 volume percent. The criteria were met during Shielded Cell testing at SRNL for Sludge Batch 5 (Ref. 6 and 7). The SRAT cycle during the shielded cells run yielded a hydrogen generation rate of 0.495 lb/hr and a nitrous oxide concentration of 3.31 volume percent (Ref. 6). The SME cycle during the shielded cells run yielded a hydrogen generation rate of 0.15 lb/hr (Ref. 7). SRNL has performed simulated Sludge Batch 5 SRAT/SME with the latest estimates of the ARP/MCU compositions (without entrained organics from MCU). The results showed no processing changes for the Sludge Batch 5 Flowsheets and the ARP/MCU additions did not negatively impact DWPF processing (Ref. 23).

3.2.12 Radiolytic Hydrogen Generation (DWPF WAC 5.4.12)

The total radiolytic hydrogen generation rate (HGR) shall not exceed 8.95E-05 ft^3/hr/gal at 25°C.

The total hydrogen generation rate is based on the cumulative sum of a mixture of radionuclide hydrogen generation conversion factors multiplied by the radionuclide heat rate. This evaluation was done using Tank 51 values for Sludge Batch 5 and ISDP Salt Batch 1. Calculation results are shown in Attachment 9.

The value of hydrogen generated is 2.26E-05 ft^3/hr-gallon for Sludge Batch 5. This calculated value is 26 percent of the DWPF WAC limit of 8.95E-05 ft^3/hr-gallon. The contribution from both the sludge batch and salt batch were combined by determining the curies per batch. The batch size was assumed to be the amount of Tank 51H transfer to Tank 40H. The combined value is 2.43E-05 ft^3/hr-gallon and is only 27 percent of the DWPF WAC limit of 8.95E-05 ft^3/hr-gallon.

3.2.13 Organic Contribution (DWPF WAC 5.4.13)

Organic material present in sludge feed transferred to DWPF shall contribute less than 0.1% to the hydrogen LFL except for transfers from MCU. Transfers from MCU shall not exceed 87 ppm Isopar L of Strip Effluent.

Based on tank farm operational history and sludge processing, the potential volatile organic content in the waste for DWPF sludge processing will not be a significant contributor to vapor space flammability (Ref. 14). The organic material is negligible in Salt Batch 1, as shown in Reference 2 for ARP/MCU.

Prior testing has shown less than 87 ppm carryover (Ref. 15). The criterion for Strip Effluent will be evaluated by analyzing samples after the start of Sludge-Salt coupled operation (Ref. 8 and 24).

3.2.14 pH (DWPF WAC 5.4.14)

Transfers from MCU must meet the following pH constraints:

a) Strip effluent shall have a pH ≥ 2 and ≤ 4 (nominally 0.01 M HNO_3)
b) A full line volume water or SE flush shall be transferred through the Strip Effluent Transfer Lines within 2 weeks after Contactor Cleaning Solution (nominally 3M HNO_3) is transferred.

The pH criterion will be met by the nitric acid purchase specification and procedural control (Ref. 16). The full line volume water or SE flush will be controlled by procedural measurement (Ref. 16). The measured pH in the Strip Effluent stream during ESS testing is 3 (Table 34 of Ref. 12), which is above the lower WAC limit of pH of 2 and below the upper WAC pH limit of 4.

3.2.15 Temperature (DWPF WAC 5.4.15)

Wastes entering the DWPF facilities shall meet the following temperature Limits:

a) Sludge transfers from Tank 40 shall be ≤ 45°C
b) Strip Effluent transfers from MCU shall be ≤ 40°C

The temperature limit for sludge transfers from Tank 40 will be met by direct measurement and process knowledge (Ref. 16). The temperature limit for MCU strip effluent will be met by process control (Ref. 16).

3.2.16 Particle Size (DWPF WAC 5.4.16)

New product streams entering the DWPF facilities shall have a maximum particle size of 80 mesh sieve or equivalent. This criterion is for future non-sludge and non-salt streams (e.g., product stream from treatment of Tank 48H material) that may be transferred to DWPF for disposal. Sludge Batch 5 processing is not expected to contain a non-sludge or non-salt stream.

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Attachment 1: NO_x Emissions (DWPF WAC 5.4.1)

The computational technique for sludge processing for total NO_x emission is described in the WAC (Ref. 1).

NO_x total =19.1(0.70 $[OH^-]$+1.40$[CO_3^=]$+1.86$[NO_2^-]$+$[NO_3^-]$+0.84$[Mn^{4+}]$+0.70$[Hg^{2+}]$)

	Result (M)	Factor	NO_x contribution
Hydroxide	7.39E-01	0.7	5.17E-01
Carbonate	1.22E-01	1.4	1.70E-01
Nitrite	2.15E-01	1.86	3.99E-01
Nitrate	1.14E-01	1	1.14E-01
Manganese ion	1.30E-01	0.84	1.09E-01
Mercury ion	2.16E-02	0.7	1.51E-02
NO_x emission			**1.33E+00**
NO_x Total (tons/yr) (NO_x total = 19.1 * NO_x emission)			**2.53E+01**

Data from Ref. 6. TIC analysis was assumed for the carbonate value.

Converting wt% dry solids to Molarity in slurry
M slurry = wt% dry solids/100*wt% total solids/100*SpG slurry*1000/MW

Converting mg/kg dry to Molarity in slurry
M slurry = mg/kg * SpG slurry/1000 mg/g / MW g/mol

Wt% total solids = 17.09 (Ref. 6)
SpG slurry = 1.14 (Ref. 6)

The ARP contribution to NOx emissions was determined to be 6.55E+01 tons/year for Salt Batch 1 (Ref. 2).

<u>Total NO_x Emission</u>

DWPF	**25.31 tons/year**
ARP	**65.50 tons/year**
TOTAL	**90.81 tons/year**

WAC LIMIT 103.52 tons/year
Sludge only contribution: Percent of Limit 24.5%

WAC LIMIT 103.52 tons/year
Coupled contribution: Percent of Limit 87.7%

Attachment 2: Canister Heat Generation (DWPF WAC 5.4.2)

The computational technique for sludge processing for canister heat generation is described in the WAC (Ref. 1).

Canister Heat Generation (W/canister) = 2200 (0.00670[Sr-90] + 0.0195[Ru-106] + 0.00474[Cs-137] + 0.00800[Ce-144] + 0.0286[U-233] + 0.0326[Pu-238] + 0.0302[Pu-239] + 0.0306[Pu-240] + 0.0328[Am-241] + 0.0344[Cm-244])

Species	µCi/g dried sludge	Ci/g dried sludge slurry	Ci/lb calcined sludge solids	Decay Heat Generation, W/Ci	Species Contribution to Canister Heat Generation (W/ lb calcined solids)
Sr-90*	2.15E+04	2.15E-02	7.97E+00	6.70E-03	5.34E-02
Ru-106*	5.20E-01	5.20E-07	1.93E-04	1.95E-02	3.76E-06
Cs-137*	4.06E+02	4.06E-04	1.51E-01	4.74E-03	7.14E-04
Ce-144*	1.30E+00	1.30E-06	4.82E-04	8.00E-03	3.86E-06
U-233	9.60E-02	9.60E-08	3.56E-05	2.86E-02	1.02E-06
Pu-238	3.23E+02	3.23E-04	1.20E-01	3.26E-02	3.90E-03
Pu-239	2.43E+01	2.43E-05	9.01E-03	3.02E-02	2.72E-04
Pu-240	8.65E+00	8.65E-06	3.21E-03	3.06E-02	9.82E-05
Am-241	4.14E+01	4.40E-05	1.63E-02	3.28E-02	5.04E-04
Cm-244	3.10E+01	3.10E-05	1.15E-02	3.44E-02	3.95E-04
Total Species Contribution (W/ lbs calcined solids)					5.93E-02
Canister Heat Generation (W/canister)					130.57

Data from Ref. 4.
* These radionuclides' Decay Heat Generation (W/Ci) contains daughter products in secular equilibrium.

Ci/lb calcined sludge solids = Ci/g dried sludge slurry * (454g/lb) / Dried to Calcine Factor

Dried to Calcine Factor = 13.96 / 17.09 (Ref. 6)
= 0.817 g calcined/ g dried sludge

The corrected ARP/MCU contribution is determined below:

ARP contribution is 9.19 W/canister
MCU contribution is 20.3 W/canister

Attachment 2 (continued): Canister Heat Generation (DWPF WAC 5.4.2)

ARP contribution

Species	Salt Batch 1 Feed Ci/gal	Decay Heat Generation, W/Ci	Species Contribution to Canister Heat Generation (W/gal)
Sr-90*	3.86E-02	6.70E-03	2.59E-04
Ru-106*	1.08E-05	1.95E-02	2.11E-07
Cs-137*	6.16E+00	4.74E-03	2.92E-02
Ce-144*	1.79E-05	8.00E-03	1.43E-07
U-233	1.44E-05	2.86E-02	4.12E-07
Pu-238	3.27E-04	3.26E-02	1.07E-05
Pu-239	3.27E-04	3.02E-02	9.88E-06
Pu-240	4.31E-03	3.06E-02	1.32E-04
Am-241	2.55E-04	3.28E-02	8.36E-06
Cm-244	6.51E-05	3.44E-02	2.24E-06
Total Species Contribution (W/ gallon)			2.96E-02

Data from Ref. 2.
* These radionuclides' Decay Heat Generation (W/Ci) contains daughter products in secular equilibrium.

ARP feeds DWPF at a rate of 1,552 gallons per week. DWPF produces nominally 5 canisters per week.

Canister Heat Generation for ARP

Total Species Contribution * 1,552 gallon/week / 5 canister/week
= 2.96E-02 W/gallon * 1552 gallon/week / 5 canister/week
=9.19 W/canister

MCU contribution

The maximum Cs-137 concentration that MCU will transfer to DWPF is 4.08 Ci/gallon. MCU feeds DWPF at a rate of 5,242 gallons/week.

Canister Heat Generation for MCU

Cs-137 concentration * Decay Heat Generation (including daughter products in secular equilibrium) * 5,242 gallons/week / 5 canister/week.
= 4.08 Ci/gallon * 4.74E-03 W/Ci * 5242 gallon/week / 5 canister/week
= 20.3 W/canister

Attachment 2 (continued): Canister Heat Generation (DWPF WAC 5.4.2)

<u>Total Canister Heat Generation</u>	
DWPF	**195.68 W/canister**
ARP	**9.19 W/canister**
MCU	**20.3 W/canister**
TOTAL	**225.15 W/canister**

WAC LIMIT 437 W/canister
Sludge only contribution: Percent of Limit 44.8%

WAC LIMIT 437 W/canister
Coupled contribution: Percent of Limit 51.5%

Attachment 3: Gamma Shielding at DWPF (DWPF WAC 5.4.3)

Species	**µCi/g dried sludge**	**Ci/g dried sludge**	**Gamma Dose Constant (mR/hr/µ Ci)**	**Gamma Dose Constant (mR/hr/ Ci)**	**Gamma Source Strength (mR/hr/g)**	**Gamma Source Strength (mR/hr/ gal)**
Co-60	3.80E+00	3.80E-06	1.37E-03	1.37E+03	5.21E-03	3.84E+00
Ru-106	5.20E-01	5.20E-07	1.38E-04	1.38E+02	7.18E-05	5.29E-02
Sb-125	2.00E-01	2.00E-07	3.80E-04	3.80E+02	7.60E-05	5.60E-02
Cs-134	3.20E+00	3.20E-06	9.99E-04	9.99E+02	3.20E-03	2.36E+00
Cs-137	4.06E+02	4.06E-04	3.82E-04	3.82E+02	1.55E-01	1.14E+02
Ce-144	1.30E+00	1.30E-06	2.33E-05	2.33E+01	3.03E-05	2.23E-02
Eu-154	3.09E+01	3.09E-05	7.56E-04	7.56E+02	2.34E-02	1.72E+01
Eu-155	3.57E+00	3.57E-06	6.67E-05	6.67E+01	2.38E-04	1.76E-01
Pu-238	3.23E+02	3.23E-04	7.90E-05	7.90E+01	2.55E-02	1.88E+01
Gamma Source Strength (mR/hr/g)						2.13E-01
Gamma Source Strength (mR/hr/gal						1.57E+02

Data from Ref. 4

Gamma Source Strength (mR/hr/gal) = mR/hr/g*(Grams dried solids/gallon of slurry)
Grams dried solids/gallon of slurry = SpG slurry * 1000* 3.785 * (wt% total solids/100)
= 1.14 * 1000 * 3.785 * (17.09 / 100) = 737.4

The total Gamma Source Strength for insoluble solids is determined by the addition of Gamma Source Strength in Ci/g dried sludge multiply by the ratio of total solids to insoluble solids (17.09 / 11.19) (Ref. 4).
Gamma Source Strength = 2.13E-01* (1.527) = 3.25E-01 mR/hr/g insoluble solids

Gamma Source Strength	**1.57E+02 mR/hr/gallon**
WAC LIMIT	**4070 mR/hr/gallon**
Percent of Limit	**8.78%**

Gamma Source Strength	**3.25E-01 mR/hr/g insoluble solids**
WAC LIMIT	**3.7 mR/hr/g insoluble solids**
Percent of Limit	**3.86%**

Attachment 4: Neutron Shielding (DWPF WAC 5.4.4)

The contribution from the decanted sludge is the following:
Total Alpha 4.74E+02 µCi/g TS (Ref. 4)

Total Solids (TS) = 17.09 (Ref. 4)
Insoluble Solids = 11.09 (Ref. 4)

Ci/g insoluble solids
= 4.74E+02 µCi/g TS * (1 Ci/1E+06 µCi) * (17.09 TS/ 11.09 IS)
= 7.25E-04 Ci/g insoluble solids

Neutron Shielding	**7.25E-04 Ci/g insoluble solids**
WAC LIMIT	**1.50E-03 Ci/g insoluble solids**
Percent of Limit	**48.3%**

Attachment 5: Inhalation Dose Potential to Meet the DWPF Requirement (DWPF WAC 5.4.5)

Method 1

Radionuclide	Results (Ci/gal	Dose Potential CEDE DCF (rem/Ci)	IDP (rem/gal)
Alpha	3.51E-01	1.70E+08	5.97E+07
Sr-90	1.59E+01	8.90E+04	1.42E+06
Total Dose (rem/gal)			6.11E+07
DWPF WAC limit			2.47E+08
% of WAC limit			24.73%

Method 2

Radionuclide	Results (Ci/gal)	Dose Potential CEDE DCF (rem/Ci)	IDP (rem/gal)
Sr-90	1.59E+01	8.90E+04	1.42E+06
Ru-106	3.80E-04	2.40E+05	9.12E+01
Cs-137	3.00E-01	1.90E+04	5.70E+03
Ce-144	9.60E-04	2.00E+05	1.92E+02
Pm-147	6.20E-02	1.90E+04	1.18E+03
Pu-238	2.39E-01	1.70E+08	4.06E+07
Pu-239	1.79E-02	1.90E+08	3.40E+06
Pu-240	6.40E-03	1.90E+08	1.22E+06
Pu-241	1.10E-01	3.30E+06	3.63E+05
Am-241	3.06E-02	1.60E+08	4.90E+06
Cm-244	2.29E-02	1.00E+08	2.29E+06
Total Dose (rem/gal)			5.42E+07
DWPF WAC limit			2.47E+08
% of WAC limit			21.95%

Dose Potential CEDE DCF references and defined in the DWPF WAC (Ref. 1). Data from Reference 4.

Attachment 6: Nuclear Criticality Safety (DWPF WAC 5.4.6)

Radionuclide	µCi/g total dried	Ci/g total dried	Specific Activity (Ci/g)	g/g total solids	wt% dried sludge slurry
U-233	9.60E-02	9.60E-08	9.68E-03	9.92E-06	9.92E-04
U-235	8.10E-04	8.10E-10	2.16E-06	3.75E-04	3.75E-02
Pu-239	2.43E+01	2.43E-05	6.22E-02	3.91E-04	3.91E-02
Pu-240	8.65E+00	8.65E-06	2.28E-01	3.80E-05	3.80E-03
Pu-241	1.50E+02	1.50E-04	1.03E+02	1.46E-06	1.46E-04
Am-242m	6.60E-01	6.60E-07	9.72E+00	6.79E-08	6.79E-06
Cm-244	3.10E+01	3.10E-05	8.09E+01	3.83E-07	3.83E-05
Cm-245	8.90E-02	8.90E-08	1.72E-01	5.18E-07	5.18E-05

Data from Ref. 4

Species	wt% dried sludge slurry
Fe	1.63E+01
U	5.33E+00

Data from Ref. 6

Pu-240 to Pu-241: 3.80E-03 / 1.46E-04
= 26.06:1

Eq. Pu-239 = Pu-239 + Pu-241 + Cm-244 + 15(Cm-245) + 35(Am-242m)
= (3.91E-02 + 1.46E-04 +3.83E-05 + 15*5.18E-05 +
35*6.79E-06) wt% dried solids
= 4.03E-02 wt% dried solids

Eq. U-235 = U-235 + (1.4*[U-233]) = (3.75E-02 + 1.4*9.92E-04) wt% dried solids
= 3.89E-02 wt% dried solids

To calculate % Eq. U-235 Enrichment, Divide Eq. U-235 by the U concentration to calculate Eq. U-235 Enrichment:

% U-235 Enrichment = (Eq. U-235/U)*100 = (3.89E-02 / 5.33E+00) * 100 = 0.729

% U-235 Enrichment is 0.729%
WAC Enrichment LIMIT is 0.93%
Percent of Limit = 78.4%

Fe/Eq. Pu-239 = 1.63E+01 / 4.03E-02 = 4.05E+02

Attachment 6: Nuclear Criticality Safety (DWPF WAC 5.4.6)

Sludge Batch 5 contains a plutonium drop from H Canyon; therefore, the Eq. Pu-239 concentration shall be ≤ 0.59 g/gallon does apply.

The weight percent of Eq. Pu-239 is 4.03E-02 wt% dried solids.

To determine the grams Eq. Pu-239

= (wt.% Eq. Pu-239 / 100) * SpG slurry * 1000* 3.785 * (wt% total solids/100)

= (4.03E-02 / 100) * 1.14 * 1000 * 3.785 * (17.09 / 100)

= 2.97E-01

0.297 g/gallon is less than 0.59 g/gallon.

Attachment 7: Glass Solubility (DWPF WAC 5.4.7)

The DWPF WAC limit for species concentrations for species shown below.

This evaluation was performed using average values for both sludge and salt contributions to the weight % of the given species. Since the values from ISDP Batch 1 are based on 100% attainment in ARP/MCU, the value are quite conservative. The values for sludge contribution to the weight % are based on a high sludge oxide loading – 40% , so they too are conservative since DWPF will realized a target 34% loading (as forecast).

The values for contribution from ISDP Batch 1 are identical to those calculated for the evaluation of it and Sludge Batch 4 combined. Since the analytical input source and the ARP/MCU flowsheet basis have not changed since the SB4 evaluation, these values remain valid (Ref. 11 and 12).

Weight Percent of Species Partially Soluble in Glass

	Weight Percent in Glass			
Species	Limit, weight %	Weight. % From Sludge	Weight % from ISDP Batch 1	Total
TiO_2	2.0%	0.017%	0.780%	0.797%
Cr_2O_3	0.3%	0.034%	0.207%	0.241%
PO_4	3.0%	0.320%	1.880%	2.200%
NaF	1.0%	0.307%	0.416%	0.723%
NaCl	1.0%	0.142%	0.005%	0.148%
Cu	0.5%	0.031%	0.008%	0.039%
SO_4	0.6%	0.185%	0.142%	0.327%

This WAC requires that concentrations of species only partially soluble in glass be less than the solubility limit. The species can be present in both the sludge feed and the MCU product. The contribution from MCU product has already been estimated for ISDP Batch 1. The inputs into these calculations have not changed and same glass concentrations for MCU product will be used in this analysis (Ref. 2).

Attachment 7 (continued): Glass Solubility (DWPF WAC 5.4.7)

The calculations of sludge concentrations are based entirely on the Tank 51 sample processed at SRNL. This is conservative because it ignores the "blend down" from the dilute feed in the DWPF Feed Tank (Tank 40). Further, the projected concentrations from the latest washing model for the four soluble species are much lower than the SRNL sample values (Ref. 17).

The calculations outlines below are on a basis of 1 liter of Tank 51 material.

The total solids mass = slurry density * wt. % total solids (Ref. 6)
= 1.14 * 17.09/100 = 0.1949 kg

The mass insoluble solid = slurry density * wt. % insoluble solids (Ref. 6)
= 1.14 * 11.20/100 = 0.1277 kg

The supernate mass = total mass of slurry - mass insoluble solids
= 0.1949 kg – 0.1277 kg = 0.672 kg

The supernate volume = supernate mass / the supernate density (Ref. 6)
= 0.672kg / 1.06 kg/L = 0.955 L

Attachment 7 (continued): Glass Solubility (DWPF WAC 5.4.7)

SRNL reported the Elemental Weight % in the prepared sample (Ref. 5). La, Zn and Zr weight percentages were estimated from the SRAT or SME reports using their ratio to Fe (Ref. 6 and 7).

Glass Oxide Form	Elemental Weight %, Total Solids Basis	Gravimetric Factor	Oxide Mass, kg/L
Al2O3	8.91%	1.8895	0.032818
B2O3	0.00%	3.2199	0.000000
BaO	0.11%	1.1165	0.000231
CaO	1.31%	1.3992	0.003573
Ce2O3	0.00%	1.1713	0.000000
Cr2O3	0.05%	1.4616	0.000133
CuO	0.06%	1.2518	0.000152
Fe2O3	16.30%	1.4297	0.045430
La2O3	0.29%	1.1728	0.000664
Li2O	0.00%	2.1525	0.000000
MgO	0.60%	1.6583	0.001953
MnO	3.66%	1.2912	0.009213
Na2O	15.20%	1.3480	0.039941
NiO	2.34%	1.2726	0.005805
PbO	0.04%	1.0772	0.000076
SiO2	0.92%	2.1393	0.003849
ThO2	0.00%	1.1379	0.000000
TiO2	0.02%	1.6685	0.000065
U3O8	5.33%	1.1792	0.012253
ZnO	0.14%	1.2447	0.000340
ZrO2	0.13%	1.3508	0.000331
Total Oxide Mass			0.156828

This estimate matches the measured oxide mass of the sample (0.1596 kg/L) within 2%. This confirms the validity of using the sum of individual oxide masses to estimate the total mass.

Assuming a waste loading of 40%, the mass of glass produced per liter is the mass of sludge oxide divided by the loading: 0.3921 kg /L.

Attachment 7 (continued): Glass Solubility (DWPF WAC 5.4.7)

TiO_2 and Cr_2O_3 elemental oxide mass/ mass of glass produced

weight % TiO_2 = 0.000065 kg TiO_2 / 0.3921 kg glass = 0.017%

weight % Cr_2O_3 = 0.000133 kg Cr_2O_3 / 0.3921 kg glass = 0.034 %

Weight % Cu in glass from sludge
= weight % Cu / total mass of solids / mass of glass produced
= 0.0624 * 0.1949 / 0.3921 = 0.031%

Weight % PO_4^{3-} in glass from sludge
= weight % P (Ref. 5) * total mass solids * ratio PO_4^{3-}/P / mass of glass produced
= 0.21 % P * 0.1949 kg * 3.066 kg PO_4^{3-}/P 0.3921 kg glass
= 0.320%

Weight % NaF in glass from sludge =
= Molarity F (Ref. 3) * Volume Supernate * molecular weight of NaF /1000 g per kg / mass of glass produced
= 0.03 * 0.9550 L * 41.99 /1000 g per kg / 0.3921 * 100%
= 0.307%

Weight % NaCl in glass from sludge =
= Molarity Cl (Ref. 3) * Volume Supernate * molecular weight of NaCl /1000 g per kg / mass of glass produced
= 0.01 * 0.9550 L * 58.44 /1000 g per kg / 0.3921 * 100%
= 0.142%

Weight % SO_4^{2-} in glass from sludge =
= Molarity SO_4^{2-} (Ref. 3) * Volume Supernate * molecular weight of SO_4^{2-} /1000 g per kg / mass of glass produced
= 0.0079 * 0.9550 L * 96.06 /1000 / 0.3921 *100%
= 0.185 %
Note: The weight % SO_4^{2-} in glass calculated from the slurry analysis was slightly less than the value shown here.

Attachment 7 (continued): Glass Solubility (DWPF WAC 5.4.7)

Summary:

Species	Limit Wt. % in glass	Value	Percent Of Limit
TiO_2	2	0. 797	39.85%
Cr_2O_3	0.3	0.241	80.33%
PO_4	3	2.200	73.33%
NaF	1	0.723	72.30%
NaCl	1	0.148	14.80%
Cu	0.5	0.039	7.80%
SO_4^{-2} Na_2SO_4	0.6 (.88)	--- 0.327	--- 37.16%

Attachment 8: Corrosive Species (DWPF WAC 5.4.8)

The concentration of SO_4^{2-} in washed sludge shall not exceed 0.058 M slurry. The concentration of Hg shall not exceed 21 g/l slurry.

The sludge properties are the following (Ref. 6):
Weight Percent total solids: 17.09%
Density of slurry: 1.14

Sulfate Concentration
MW: 96.06 Amount in sludge (Ref. 5): 586 mg/kg

M slurry = mg/kg * SpG slurry/1000 mg/g / MW g/mol
= 586 * 1.14 / 1000 / 96.06
= 0.00695 M

ARP/MCU contribution is negligible. Sludge contribution is 11.99% of DWPF WAC limit.

Mercury Concentration
Amount in sludge: 2.22 wt.% TS

M slurry = wt% dry solids / 100 *wt% total solids / 100 * SpG slurry * 1000
= (2.22 / 100) * (17.09 /100) * 1.14 * 1000
= 4.33 g/L

ARP/MCU contribution is 0.00975 g/L. The total mercury concentration is 4.33 g/L or 20.64 % of DWPF WAC limit.

Attachment 9: Hydrogen Generation Rate for DWPF (DWPF WAC 5.4.12)

Radionuclide	Results (Ci/gal)	"Q" Value (W/Ci)	R (ft^3 $H_2/10^6$ BTU)	Heat Generation (W/gal)	Hydrogen Generation (ft^3 H_2/hr/gal)
Co-60	2.81E-03	1.54E-02	48.36	4.33E-05	7.15E-09
Y-90	1.59E+01	5.54E-03	48.36	8.81E-02	1.45E-05
Sr-90	1.59E+01	1.16E-03	48.36	1.84E-02	3.04E-06
Ru-106	3.80E-04	5.95E-04	48.36	2.26E-07	3.73E-11
Rh-106	3.80E-04	1.89E-02	48.36	7.20E-06	1.19E-09
Sb-125	1.50E-04	3.37E-03	49.36	5.06E-07	8.52E-11
Cs-134	2.40E-03	1.02E-02	48.36	2.45E-05	4.04E-09
Cs-137	3.00E-01	1.01E-03	48.36	3.03E-04	5.00E-08
Ba-137m	2.88E-01	3.94E-03	48.36	1.13E-03	1.87E-07
Ce-144	9.60E-04	6.58E-04	48.36	6.32E-07	1.04E-10
Pr-144	9.60E-04	7.34E-08	48.36	7.04E-11	1.16E-14
Pm-147	6.20E-02	3.67E-04	48.36	2.28E-05	3.76E-09
Eu-154	2.28E-02	9.08E-03	48.36	2.07E-04	3.42E-08
Pu-238	2.39E-01	3.26E-02	134.7	7.79E-03	3.58E-06
Pu-239	1.79E-02	3.02E-02	134.7	5.41E-04	2.49E-07
Pu-240	6.40E-03	3.06E-02	134.7	1.96E-04	8.99E-08
Pu-241	1.10E-01	3.20E-05	48.36	3.52E-06	5.81E-10
Am-241	3.06E-02	3.28E-02	134.7	1.00E-03	4.62E-07
Cm-244	2.29E-02	3.44E-02	134.7	7.87E-04	3.62E-07
Total (ft3 H2/hr/gal)					**2.26E-05**
DWPF WAC limit (ft3 H2/hr/gal)					**8.95E-05**
% of WAC limit					**25.27%**

R values are defined in the DWPF WAC (Ref. 1). Data from Ref. 4
Q values are defined in Ref. 18

Attachment 9 (continued): Hydrogen Generation Rate for DWPF (DWPF WAC 5.4.12)

DWPF operates in batches to produce nominally 186 canisters a year. Nominally 5 canisters are produced in each 6,000 gallon batch. Therefore, DWPF processes 223,200 gallons a year. ARP/MCU contribution is additive to the sludge contribution and is assumed to be a gallon per gallon of sludge. The ARP/MCU contribution in Ci/year was determined during ISDP Salt Batch 1 qualification (Ref. 2).

Radionuclide	Salt Results (Ci/year)	(Ci/gal)	Sludge Results (Ci/gal)	Total (Ci/gal)
Co-60	6.95E-02	3.04E-07	2.81E-03	2.81E-03
Y-90	3.01E+03	1.32E-02	1.59E+01	1.59E+01
Sr-90	3.01E+03	1.32E-02	1.59E+01	1.59E+01
Ru-106	8.42E-01	3.68E-06	3.80E-04	3.84E-04
Rh-106	8.42E-01	3.68E-06	3.80E-04	3.84E-04
Sb-125	5.12E-01	2.24E-06	1.50E-04	1.52E-04
Cs-134	1.08E+03	4.72E-03	2.40E-03	7.12E-03
Cs-137	4.80E+05	2.10E+00	3.00E-01	2.40E+00
Ba-137m	4.51E+05	1.97E+00	2.88E-01	2.26E+00
Ce-144	1.40E+00	6.12E-06	9.60E-04	9.66E-04
Pr-144	1.40E+00	6.12E-06	9.60E-04	9.66E-04
Pm-147	6.51E+00	2.85E-05	6.20E-02	6.20E-02
Eu-154	8.56E-01	3.74E-06	2.28E-02	2.28E-02
Pu-238	3.36E+02	1.47E-03	2.39E-01	2.40E-01
Pu-239	2.55E+01	1.11E-04	1.79E-02	1.80E-02
Pu-240	2.55E+01	1.11E-04	6.40E-03	6.51E-03
Pu-241	2.24E+01	9.83E-05	1.10E-01	1.10E-01
Am-241	1.42E+02	6.25E-04	3.06E-02	3.12E-02
Cm-244	1.99E+01	8.75E-05	2.29E-02	2.30E-02

Attachment 9 (continued): Hydrogen Generation Rate for DWPF (DWPF WAC 5.4.12)

The Hydrogen Generation rate can be determined for coupled operations using the same method as sludge only.

Radionuclide	Results (Ci/gal)	"Q" Value (W/Ci)	R (ft^3 $H_2/10^6$ BTU)	Heat Generation (W/gal)	Hydrogen Generation (ft^3 H_2/hr /gal)
Co-60	2.81E-03	1.54E-02	48.36	1.36E+01	2.24E-03
Y-90	1.59E+01	5.54E-03	48.36	2.76E+04	4.55E+00
Sr-90	1.59E+01	1.16E-03	48.36	5.78E+03	9.53E-01
Ru-106	3.84E-04	5.951E-04	48.36	7.13E-02	1.18E-05
Rh-106	3.84E-04	1.894E-02	48.36	2.27E+00	3.74E-04
Sb-125	1.52E-04	3.37E-03	49.36	1.60E-01	2.69E-05
Cs-134	7.12E-03	1.02E-02	48.36	1.80E+01	2.98E-03
Cs-137	2.40E+00	1.01E-03	48.36	5.56E+02	9.18E-02
Ba-137m	2.26E+00	3.94E-03	48.36	2.05E+03	3.38E-01
Ce-144	9.66E-04	6.580E-04	48.36	1.99E-01	3.28E-05
Pr-144	9.66E-04	7.338E-08	48.36	2.21E-05	3.66E-09
Pm-147	6.20E-02	3.67E-04	48.36	7.12E+00	1.18E-03
Eu-154	2.28E-02	9.08E-03	48.36	6.48E+01	1.07E-02
Pu-238	2.40E-01	3.26E-02	134.7	2.45E+03	1.13E+00
Pu-239	1.80E-02	3.02E-02	134.7	1.70E+02	7.82E-02
Pu-240	6.51E-03	3.06E-02	134.7	6.20E+01	2.85E-02
Pu-241	1.10E-01	3.20E-05	48.36	3.52E-06	5.81E-10
Am-241	3.12E-02	3.28E-02	134.7	1.03E-03	4.71E-07
Cm-244	2.30E-02	3.44E-02	134.7	7.90E-04	3.63E-07
Total (ft3 H2/hr/gal)					**2.43E-05**
DWPF WAC limit (ft3 H2/hr/gal)					**8.95E-05**
% of WAC limit					**27.16%**