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**NUCLEAR CRITICALITY SAFETY EVALUATION DWPF
MELTER - BATCH 1 (U)**

by

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DWPF MELTER - BATCH 1(U)

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1.0 INTRODUCTION

The Savannah River Site (SRS) High Level Nuclear Waste will be vitrified in the Defense Waste Processing Facility (DWPF) for long term storage and disposal. This is a preliminary safety evaluation for the Melt Cell of the DWPF vitrification process for Batch 1 waste.

This evaluation demonstrates that the material in the Melt Cell remains subcritical for the contents of Batch 1 which contains uranium with less than 1% by weight U-235 (1).

2.0 DESCRIPTION

Waste salt solution is processed in the Tank Farm In-Tank Precipitation process to remove cesium-137 and to adsorb strontium on monosodium titanate (MST). The filtered tetraphenylborate slurry is then washed in the DWPF Late Wash Facility (LWF) before it is fed to the DWPF Salt Processing Cell (SPC). In the Salt Processing Cell the precipitate slurry is processed in the Precipitate Reactor (PR). The Precipitate Hydrolysis Aqueous (PHA) product from the PR is then combined with the sludge feed and the frit in the DWPF Chemical Process Cell (CPC) to produce a melter feed. In the Melt Cell the waste is immobilized in a glass matrix and transferred to sealed canisters.

3.0 REQUIREMENTS DOCUMENTATION

There are no specific documents which apply uniquely to this evaluation.

4.0 METHODOLOGY

The JOSHUA (J70) Nuclear Criticality Safety Module (2) HRXN was used for this analysis. HRXN computes the atom densities for mixtures and combines them with the Hansen-Roach 16-group nuclear cross sections to calculate infinite system multiplication factors and to prepare cross sections for transport codes. ANISN solves the one-dimensional radiation transport equation in the discrete ordinates approximation.

Calculation biases for these modules have been established by Clark for uranium and plutonium (3,4). The DWPF waste contains uranium, plutonium and traces of other actinides, however, the primary fissile material is uranium. For uranium systems with a hydrogen-to-fissile (H/F) of 100, HRXN-ANISN calculates a K_{eff} of 0.97 for a critical system. At this point on the bias curve, $H/F = 100$, the calculated multiplication factor of 0.97 is at a minimum so its use for other H/F ratios is conservative. With a safety factor of 0.05 a K_{eff} of 0.92 would be safe. For plutonium systems at the same H/F ratio, HRXN-ANISN calculates a K_{eff} of 1.00

for a critical system so a calculated multiplication factor of 0.92 would be safe for plutonium. Because of the lack of experimental data, there are no bias corrections for other materials, such as iron, manganese, aluminum and sodium. The safety margin of 0.05 is sufficient to cover the bias for these materials.

5.0 DISCUSSION OF CONTINGENCIES

This evaluation is for feed to the melter in which the only fissile materials are in Batch 1 sludge. Batch 1 sludge contains uranium enriched to less than 1% U-235 (1). The evaluation demonstrates that the melter is safe from a criticality standpoint as long as the U-235 enrichment remains below 40% and there are no mechanisms to separate the fissile material from other metal oxides. This calculation assumes that the melt mixture is near the optimum hydrogen-to-fissile ratio and that the neutron poisons, boron and lithium, are not present. Because of the conservatism of assuming optimum H/F ratios and the assumption that all of the boron and lithium poisons are removed, and, because of the large margin between U-235 enrichments of 40% and less than 1%, a double contingency analysis was not performed. Assurance must be given that the sludge feed is properly represented by reference 6 and that there is no credible mechanism for isolating the fissile materials.

This analysis is for Batch 1 feed in a melter which contains no fissile materials from previous runs. For different feed material compositions and for multiple batches, additional evaluations must be performed.

6.0 EVALUATION AND RESULTS

Clark (5) has analyzed the melter for the case in which the appropriate amount of frit has not been added and the melter inventory becomes saturated with waste oxides. He analyzed for uranium enriched to 2.66% U-235 and plutonium with 60.83% Pu-239. For this case HRXN calculates a safe infinite multiplication factor, K_{inf} , of 0.075. Clark also has shown that the system remains safe if the fissile isotope content is doubled.

Feed material for the melter comes from the Slurry Mix Evaporator (SME) as an aqueous slurry containing 58 weight percent water. This water is driven off in the melter. Contents of the feed and the glass are listed in Table 1 (6). For this analysis the manganese, magnesium and sodium formates have been converted to an equivalent quantity of metal oxides.

Table 1
Melter Composition

	Melter Feed		Glass	
	Lb/hr	Wt Frac.	Lb/hr	Wt Frac.
Water	340.03	5.79E-01		
Al ₂ O ₃	10.28	1.75E-02	10.17	4.56E-02
B ₂ O ₃	12.96	2.21E-02	17.25	7.74E-02
Ca(NO ₃) ₂	2.61	4.44E-03		
Cu(COOH) ₂	1.55	2.64E-03		
Fe ₂ O ₃	23.73	4.04E-02	21.14	9.49E-02
FeO			2.11	9.49E-03
H ₃ BO ₃	8.08	1.38E-02		
KCOOH	9.48	1.61E-02		
K ₂ O	0.11	1.92E-04	5.38	2.41E-02
Li ₂ O	11.34	1.93E-02	11.23	5.04E-02
(Li6) ₂ O	0.85	1.45E-03	0.84	3.78E-03
(Li7) ₂ O	10.49	1.79E-02	10.39	4.66E-02
MgO	4.67	7.96E-03	4.63	2.08E-02
MnO ₂	3.18	5.41E-03		
MnO			2.77	1.24E-02
Na ₂ O	14.01	2.39E-02	19.57	8.78E-02
NaNO ₃	15.84	2.70E-02		
SiO ₂	126.00	2.15E-01	124.70	5.60E-01
U ₃ O ₈	2.33	3.97E-03	2.31	1.03E-02
PuO ₂	0.01	1.47E-05	0.01	3.84E-05
Sum	586.98	1.00	222.84	1.00
Flow	599.1 Lb/hr		228.0 Lb/hr	
Density	82.65 Lb/ft ³		156.6 Lb/ft ³	
	1.306 g/cc		2.475 g/cc	
% Flow	98.0%		97.7%	

The materials listed in Table 1, which constitute 98.0% and 97.7% of the mass of the feed and the glass respectively, were analyzed with the results shown in Table 2. For these cases the uranium was treated as U₃O₈ at 100% U-235 and plutonium as PuO₂ at 100% Pu-239.

Table 2
HRXN Analysis
Materials from Table 1
(JOB 1321)

Melter Feed	K _{inf} 0.0285
Melter Glass	0.1074

(The notation JOB 1321 indicates that the values in the table are on microfiche DWPf6508 Job 1321)

These materials contain boron with 19.9% boron-10 and lithium with 7.5% Lithium-6, both of which are good neutron poisons. An analysis was done for the extreme cases in which all of the boron and lithium were removed and for different water contents in the feed material. These results are in Table 3.

Table 3
HRXN Analysis
Reduced Boron and Water
(JOB 1321)

Melter Feed	K _{inf}
1/10 water, All B & Li, 100 % U-235	0.0429
1/100 water, All B & Li, 100 % U-235	0.0721
All water, No B & Li, 100 % U-235	0.571
1/100 water, No B & Li, 100 % U-235	1.298
1/100 water, No B & Li, 40% U-235	0.853
1/100 water, 2% B, No Li, 100% U-235	0.711
1/100 water, 1% B, No Li, 100% U-235	0.992
Glass	
No B & Li, 100 % U-235	1.329
No B & Li, 50 % U-235	0.956
No B & Li, 40 % U-235	0.854
2% B, No Li, 100 % U-235	0.848
1% B, No Li, 100 % U-235	1.01

The notation 1/10 water means that the water content was reduced to 1/10 of the value in Table 1 and the mixture density adjusted on the basis that all materials are in solution. The material contents for these cases are listed in Appendix 1. The notation no B & Li, 1% B or 2% B means that the B₂O₃, H₃BO₃ and the Li₂O contents were reduced and the solution density adjusted accordingly. For the case of 1/100 water the hydrogen-to-fissile ratio, H/F, is 151, which is near the most reactive H/F combination. These data indicate that, even without corrections for finite geometry, and, in the extreme case for which no boron or lithium is included, the melter will always remain subcritical as long as the uranium enrichment remains below 40% U-235 and the metal oxides remain with the fissile oxides. If the boron content of the glass is greater than 2 % of the value in Table 1, the melter remains safe even for 100 % U-235.

The active volume of the melter is cylindrical, 6 feet (1.83 m) in diameter with a nominal height 34 inches (0.86 m) (7). The melter nominally contains 5.61 X 10³ kg glass. For the weight fractions listed in Table 1, the glass contains 57.8 kg U₃O₈ and 216 g PuO₂. At 40 % uranium enrichment and 100% Pu-239 this mass corresponds to 19.6 kg U-235 and 190 g Pu-239. A cylinder with radius 0.91 m and thickness 0.86 m is a

flat, "high leakage" geometry. An ANISN calculation with the glass material and no boron or lithium ($K_{inf} = 1.329$) in an infinite planar geometry 0.86 m thick with 30-cm water reflection on both sides has $K_{eff} = 0.85$ (JOB 867). A correction for radial leakage in this planar geometry reduces K_{eff} to 0.50. Thus, if all of the boron and lithium were lost and if 100% enriched uranium were in the melter and if the material in the melter were constrained to a thickness no greater than 0.86 m, the system would remain safe.

CONCLUSION

Compositions of the feed material and of the glass from reference 6 have been used to determine the criticality safety of the Melter under normal conditions. These materials remain safe from a criticality standpoint. For a case in which all of the boron and lithium is lost, the melter remains safe for feed material described in Table 1 with the uranium enriched to no more than 40% U-235. For the composition listed in Table 1 this value corresponds to 19.6 kg U-235 and 190 g Pu-239. If the boron (19.9% B-10) content of the glass is greater than 2% of the value in Table 1, the melter remains safe even for 100% U-235. The material in the DWPf sludge feed Batch 1 can be processed in the melter cell safely since it contains uranium with less than 1% by weight U-235 (1).

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APPENDIX A

COMPOSITIONS OF MATERIALS IN MELTER

The following tables were generated on a spread sheet with the assumption that the materials are in solution and the solution density is determined from

$$\frac{1}{\rho_s} = \sum_i \frac{(wt. \text{ frac.})_i}{\rho_i}$$

where the subscript s refers to the solution and i to the individual components. Compound densities were taken from the Handbook of Physics and Chemistry, 34th edition.

Melter Feed to DWPF	Lb/hr	Wt. Frac.	Density	Wt. Frac/ Density
Water	340.03	5.80E-01	1.00	0.5802
Al ₂ O ₃	10.28	1.75E-02	3.50	0.0050
B ₂ O ₃	12.96	2.21E-02	1.84	0.0120
Ca(NO ₃) ₂	2.61	4.45E-03	2.36	0.0019
Cu(COOH) ₂	1.55	2.64E-03	1.83	0.0014
Fe ₂ O ₃	23.73	4.05E-02	5.24	0.0077
H ₃ BO ₃	8.08	1.38E-02	1.44	0.0096
KCOOH	9.48	1.62E-02	1.91	0.0085
Li ₂ O	11.34	1.93E-02	2.01	0.0096
(Li6) ₂ O	0.85	1.45E-03		
(Li7) ₂ O	10.49	1.79E-02		
MgO	4.67	7.97E-03	3.58	0.0022
MnO ₂	3.18	5.42E-03	5.03	0.0011
Na ₂ O	14.01	2.39E-02	2.27	0.0105
NaNO ₃	15.84	2.70E-02	2.26	0.0120
SiO ₂	126.00	2.15E-01	2.32	0.0927
U ₃ O ₈	2.33	3.97E-03	8.39	0.0005
PuO ₂	0.01	1.47E-05	11.46	1.287E-06
Sum	586.08	1.00		0.75
		Density	g/cc	1.325

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Melter Feed 1/10 Water		Wt. Frac/ Density		
	Lb/hr	Wt. Frac.	Density	Density
Water	34.03	1.22E-01	1.00	0.1215
Al ₂ O ₃	10.28	3.67E-02	3.50	0.0105
B ₂ O ₃	12.96	4.63E-02	1.84	0.0251
Ca(NO ₃) ₂	2.61	9.31E-03	2.36	0.0039
Cu(COOH) ₂	1.55	5.53E-03	1.83	0.0030
Fe ₂ O ₃	23.73	8.47E-02	5.24	0.0162
H ₃ BO ₃	8.08	2.88E-02	1.44	0.0200
KCOOH	9.48	3.38E-02	1.91	0.0177
Li ₂ O	11.34	4.05E-02	2.01	0.0201
(Li6) ₂ O	0.85	3.04E-03		
(Li7) ₂ O	10.49	3.75E-02		
MgO	4.67	1.67E-02	3.58	0.0047
MnO ₂	3.18	1.13E-02	5.03	0.0023
Na ₂ O	14.01	5.00E-02	2.27	0.0220
NaNO ₃	15.84	5.66E-02	2.26	0.0250
SiO ₂	126.00	4.50E-01	2.32	0.1939
U ₃ O ₈	2.33	8.31E-03	8.39	0.0010
PuO ₂	0.01	3.09E-05	11.46	2.692E-06
Sum	280.08	1.00		0.49
		Density	g/cc	2.054

Melter Feed 1/100 Water		Wt. Frac/ Density		
	Lb/hr	Wt. Frac.	Density	Density
Water	3.40	1.36E-02	1.00	0.0136
Al ₂ O ₃	10.28	4.12E-02	3.50	0.0118
B ₂ O ₃	12.96	5.20E-02	1.84	0.0282
Ca(NO ₃) ₂	2.61	1.05E-02	2.36	0.0044
Cu(COOH) ₂	1.55	6.21E-03	1.83	0.0034
Fe ₂ O ₃	23.73	9.51E-02	5.24	0.0182
H ₃ BO ₃	8.08	3.24E-02	1.44	0.0225
KCOOH	9.48	3.80E-02	1.91	0.0199
Li ₂ O	11.34	4.55E-02	2.01	0.0226
(Li6) ₂ O	0.85	3.41E-03		
(Li7) ₂ O	10.49	4.21E-02		
MgO	4.67	1.87E-02	3.58	0.0052
MnO ₂	3.18	1.27E-02	5.03	0.0025
Na ₂ O	14.01	5.62E-02	2.27	0.0247
NaNO ₃	15.84	6.35E-02	2.26	0.0281
SiO ₂	126.00	5.05E-01	2.32	0.2177
U ₃ O ₈	2.33	9.33E-03	8.39	0.0011
PuO ₂	0.01	3.46E-05	11.46	3.023E-06
Sum	249.45	1.00		0.42
		Density	g/cc	2.359

Melter Feed

No Boron or Lithium

	Lb/hr	Wt. Frac.	Density	Wt. Frac/ Density
Water	340.03	6.14E-01	1.00	0.6141
Al ₂ O ₃	10.28	1.86E-02	3.50	0.0053
B ₂ O ₃	0.00	0.00E+00	1.84	0.0000
Ca(NO ₃) ₂	2.61	4.71E-03	2.36	0.0020
Cu(COOH) ₂	1.55	2.80E-03	1.83	0.0015
Fe ₂ O ₃	23.73	4.29E-02	5.24	0.0082
H ₃ BO ₃	0.00	0.00E+00	1.44	0.0000
KCOOH	9.48	1.71E-02	1.91	0.0090
Li ₂ O	0.00	0.00E+00	2.01	0.0000
(Li6) ₂ O	0.00	0.00E+00		
(Li7) ₂ O	0.00	0.00E+00		
MgO	4.67	8.44E-03	3.58	0.0024
MnO ₂	3.18	5.73E-03	5.03	0.0011
Na ₂ O	14.01	2.53E-02	2.27	0.0111
NaNO ₃	15.84	2.86E-02	2.26	0.0127
SiO ₂	126.00	2.28E-01	2.32	0.0981
U ₃ O ₈	2.33	4.20E-03	8.39	0.0005
PuO ₂	0.01	1.56E-05	11.46	1.362E-06
Sum	553.70	1.00		0.77
		Density	g/cc	1.306

Melter Feed

No B or Li 1/100 water

	Lb/hr	Wt. Frac.	Density	Wt. Frac/ Density
Water	3.40	1.57E-02	1.00	0.0157
Al ₂ O ₃	10.28	4.74E-02	3.50	0.0135
B ₂ O ₃	0.00	0.00E+00	1.84	0.0000
Ca(NO ₃) ₂	2.61	1.20E-02	2.36	0.0051
Cu(COOH) ₂	1.55	7.13E-03	1.83	0.0039
Fe ₂ O ₃	23.73	1.09E-01	5.24	0.0209
H ₃ BO ₃	0.00	0.00E+00	1.44	0.0000
KCOOH	9.48	4.37E-02	1.91	0.0229
Li ₂ O	0.00	0.00E+00	2.01	0.0000
(Li6) ₂ O	0.00	0.00E+00		
(Li7) ₂ O	0.00	0.00E+00		
MgO	4.67	2.15E-02	3.58	0.0060
MnO ₂	3.18	1.46E-02	5.03	0.0029
Na ₂ O	14.01	6.45E-02	2.27	0.0284
NaNO ₃	15.84	7.30E-02	2.26	0.0323
SiO ₂	126.00	5.80E-01	2.32	0.2502
U ₃ O ₈	2.33	1.07E-02	8.39	0.0013
PuO ₂	0.01	3.98E-05	11.46	3.474E-06
Sum	217.08	1.00		0.40
		Density	g/cc	2.481

Glass	Lb/hr	Wt. Frac.	Density	Wt Frac/ Density
Water	0.00	0.00E+00	1.00	0.0000
Al ₂ O ₃	10.17	4.60E-02	3.50	0.0131
B ₂ O ₃	17.25	7.80E-02	1.84	0.0423
Fe ₂ O ₃	21.14	9.55E-02	5.24	0.0182
FeO	2.11	9.55E-03	5.70	0.0017
K ₂ O	5.38	2.43E-02	2.32	0.0105
Li ₂ O	11.23	5.08E-02	2.01	0.0252
(Li6) ₂ O	0.84	3.81E-03		
(Li7) ₂ O	10.39	4.69E-02		
MgO	4.63	2.09E-02	3.58	0.0058
MnO	2.77	1.25E-02	5.45	0.0023
Na ₂ O	19.57	8.84E-02	2.27	0.0390
SiO ₂	124.70	5.64E-01	2.32	0.2429
U ₃ O ₈	2.31	1.04E-02	8.39	0.0012
PuO ₂	0.01	3.87E-05	11.46	3.374E-06
Sum	221.27	1.00		0.40
		Density	g/cc	2.486

Glass	No B or Li	Lb/hr	Wt. Frac.	Density	Wt Frac/ Density
Water		0.00	0.00E+00	1.00	0.0000
Al ₂ O ₃		10.17	5.28E-02	3.50	0.0151
B ₂ O ₃		0.00	0.00E+00	1.84	0.0000
Fe ₂ O ₃		21.14	1.10E-01	5.24	0.0209
FeO		2.11	1.10E-02	5.70	0.0019
K ₂ O		5.38	2.79E-02	2.32	0.0120
Li ₂ O		0.00	0.00E+00	2.01	0.0000
(Li6) ₂ O		0.00	0.00E+00		
(Li7) ₂ O		0.00	0.00E+00		
MgO		4.63	2.40E-02	3.58	0.0067
MnO		2.77	1.44E-02	5.45	0.0026
Na ₂ O		19.57	1.02E-01	2.27	0.0447
SiO ₂		124.70	6.47E-01	2.32	0.2788
U ₃ O ₈		2.31	1.20E-02	8.39	0.0014
PuO ₂		0.01	4.44E-05	11.46	3.873E-06
Sum		192.79	1.00		0.38
			Density	g/cc	2.603

DATE

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6/16/94

END