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Characterization of Tank 18 Residual Waste

J. L. Thomas, 766-H

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Author

J. L. Thomas, Planning Integration and Technology — Date: 8/16/05

Technical Review

H. Q. Tran, Data Acquisition, Evaluation, and Management — Date: 8/16/05

Approvals

T. C. Robinson, Tank Closure Planning Manager — Date: 8/16/05

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1. Introduction

Plans are to close Tank 18, a Type IV waste tank in the F-Area Tank Farm. Most of the waste was removed from the tank in the 1980s, and more waste has been removed in 2003. This report documents the basis for the residual waste inventories that will be used in the Tank 18 fate and transport modeling and Class C waste determination. The purpose of this revision is to document inventories of radionuclides not previously characterized in the Waste Characterization System (WCS) and to characterize contamination potentially present on the interior walls of Tank 18.

2. Summary

The total residual solids volume in Tank 18 was determined to be approximately 4,334 gallons. The mass of solids on a dry basis is approximately 36,062 lb.

Most of the radionuclides in Tank 18 came from Purex Low Heat Waste from F Canyon. Based on the iron and silicon content of the residual solids in Tank 18, about 43% of the residual solids in Tank 18 is derived from Purex Low Heat Waste, about 46% is derived from zeolite, and about 11% is derived from coating waste (which had very low radioactivity). Zeolite was transferred into Tank 18 during Tank 19 waste removal in 2001. The source of the zeolite in Tank 19 was a cesium removal column that once operated above the Northeast riser of Tank 19. Zeolite was used as the ion exchange media in this column and contains retained Cs-137.

The composition of the solids in Tank 18 has been determined by two methods: 1) samples and 2) estimates based on the knowledge of fission yields and the composition of Purex Low Heat Waste. The samples were analyzed for principle constituents that are important to environmental modeling, used in 10 CFR 61.55 Class C determination, and anticipated to be present in significant amounts based on process history. The inventories reported for these principle constituents are based on sample data. For all other radionuclides, the inventories are based on predicted values.

Video observations of the residual heel conducted throughout the 2003 heel removal campaign showed that there was an approximately 11” high mound in the Southwest of the tank that was never moved or mixed by the ADMP. Visually, this mound appears to have a different consistency than the rest of the tank contents. Whereas most of the solids mounds in Tank 18 have a smooth surface texture and relatively gentle sloping sides, the Southwest mound appears to have fairly steep slopes and a jagged, uneven texture. Samples of the residual waste showed that this Southwest mound has a different composition than the other solids. The material in the Southwest mound is mostly composed of Purex, while the material in the remainder of the tank has a much higher composition of zeolite. Samples and observations indicate that, with the exception of the Southwest mound, the agitation during waste removal homogenized the majority of the solids in the tank. Thus, the Southwest mound was sampled and characterized differently than the solids in the remainder of the tank.

The inventory for the principle nuclides important to Tank Closure estimated from samples was within a factor of the inventory estimated from process knowledge. Chemical analysis of some of the zeolite-derived material in the heel of Tank 19 showed that the original zeolite in the tank is significantly degraded to other mineral compounds possibly formed from reactions between the original zeolite and the other waste added to the tank. Like the original zeolite, these new compounds still have the ability to absorb certain cations, as evidenced by the fact that the concentration of Cs-137 in samples was two orders of magnitude greater than the concentration predicted by process knowledge.

3. Background

Tank 18 is a Type IV underground waste storage tank located in the F-Tank Farm. It is a cylindrical-shaped, carbon steel tank with a diameter of 85 feet, a height of 34.25 feet, and a working capacity of 1.3 million gallons. Steel angle stiffener rings around the interior and an outer concrete shell provide support to the liner. The concrete tank dome rises 11 feet and contains six perimeter risers and one center riser.

Tank 18 has been used to store low-heat sludge waste and supernate since 1959. The bulk waste removal campaign in 1986 – 1987 reduced the waste volume in Tank 18 from over one million gallons to approximately 35,000 gallons. Tank 17 heel removal in 1997 and Tank 19 heel removal in 2001 added small amounts of solids and some liquid to Tank 18. Prior to Tank 18 heel removal in 2003, Tank 18 contained approximately 47,000 gallons of solids[1].

4. Waste Removal in Preparation for Tank Closure

From January 2003 to July 2003, heel removal was performed on the approximately 47,000 gallons of material remaining in Tank 18. In this campaign, an Advanced Design Mixer Pump (ADMP) was installed in the center riser to suspend solids from the heel into a slurry in order to transfer the solids from the tank. The ADMP is a 300-hp recirculating, long-shaft centrifugal pump capable of achieving a flowrate of 5,200 gpm through each opposing discharge nozzle. The ADMP was mounted to a Rotek bearing assembly to provide azimuth control of the discharge jets. A centrifugal transfer pump in the northeast riser was used to transfer the liquid slurry from Tank 18 to Tank 7. After an initial inhibitor addition at the beginning of waste removal, well water was used as the slurry media for each ensuing batch transfer. Despite unexpected mixer pump phenomena that hindered waste removal progress[2], the waste removal campaign completed over 1,000 hours of mixing and 6 transfers out of Tank 18. Approximately 800,000 gallons of water were added to Tank 18 throughout the campaign to wash and slurry the residual solids. In June of 2003, the interior of Tank 18 was water-washed using a rotating nozzle deployed from the center riser. Its purpose was to spray the interior tank walls with inhibited wash water to dislodge contamination potentially deposited on the walls and stiffening rings of the tank.

5. Estimating the Tank 18 Residual Inventories

There are two kinds of residual material in Tank 18—solids and liquids. The liquid includes free liquid and interstitial liquid that is trapped in the solids. Tank farm experience shows that the sludges typically contain high amounts of interstitial liquid (70-85 vol %). Most of the solids in Tank 18 are on the floor of the tank. However, Tank 18 also has a small inventory of visible solids on the stiffener bands on the inside of the tank. Additionally, a small inventory of contaminants are potentially present on the corrosion products on portions of the tank wall.

5.1 Estimating the Volume of Solids

5.1.1 Final Volume of Solids Heel

During each slurry removal batch, the ADMP would agitate the contents of the tank and then the liquid would be pumped out, removing the solids that had been suspended during that batch. The residual solids volume was estimated by observing the liquid/solid interface in the tank while the liquid was being pumped out. As the liquid level decreased, the solids began to be observed above the surface of the liquid. At various liquid levels, the "shoreline" where the liquid surface met the solids surface was mapped. By combining the shoreline mappings at various liquid depths, a contour plot, like a topographic map, was developed that showed the solids height at each location in the tank.

It is very difficult to discern the solids heights underneath the murky liquid layer in the tank. Based on both overhead and submersible video camera observations, it was assumed that the solids depth was approximately 50% of the liquid level in areas of the tank where the solids surface is underneath the liquid level. Integrating under the contour plot developed during the final pumping operation indicates that the tank heel contains approximately 4,320 gallons of solids[3].

5.1.2 Volume of Southwest Solids Mound

Video observations of the residual heel conducted throughout the 2003 waste removal campaign showed that there was an approximately 11" high mound in the Southwest portion of the tank that was never moved or mixed by the ADMP. Visually, this mound appeared to have a different consistency than the rest of the tank contents. Whereas most of the solids mounds in Tank 18 had a smooth surface texture and relatively gentle sloping sides, the Southwest mound appeared to have fairly steep slopes and a jagged, uneven texture. Samples of the residual waste showed that this Southwest mound had a different composition than the other solids.

The volume of the Southwest mound was estimated using the contour plot developed during the final pumping operations in the tank. By assuming that the Southwest mound consisted of all areas in the south of the tank with solids heights greater than 4", the volume of the Southwest mound was calculated to be approximately 760 gallons[3]. This material was characterized differently than the remainder of the solids in Tank 18.

5.1.3 Volume of Waste on Tank Interior Stiffener Bands

In Tank 18, there were also solids on the stiffener bands around the inside circumference of the tank. Tank 18 has three bands of steel angles that were designed to “stiffen” and provide support to the steel tank liner. The top angle protrudes 4 inches from the tank wall, while the bottom two angles extend 5 inches. Following water washing, no visible quantities of waste material were evident on the walls of Tank 18. Water washing succeeded in dislodging almost all of the waste present on the stiffening bands, leaving only a small amount of material (about 14 gallons) on the lowest stiffening band in the southwest of the tank. To estimate this volume, the cross-sectional shape of the material on the angles was assumed to be a rectangle formed on one side by the total length of the angle extending out from the tank wall and on the other side by the estimated height of residual material against the tank wall. Video footage of the angle stiffeners was used to estimate the length and height dimensions (along the tank wall axis) of the solids piles. Adding this 14 gallons of solids to the 4,320 gallons of solids in the heel provides the total Tank 18 solids inventory of approximately 4,334 gallons.

5.2 Estimating the Volume of Liquid

The volume of liquid in Tank 18 was estimated using the same contour information that was used to estimate the residual solids volume. Referenced documents estimate two different values for the amount of interstitial liquid in sludge—70 vol. % for settled sludge[4] and 85 vol. % for freshly slurried sludge[5]. For the purpose of this calculation, the volume of interstitial liquid is estimated to be 85 vol. %, the higher of the two numbers. Thus the volume of liquid in the solids is estimated as:

$$4{,}334\ gal \times 0.85 = 3{,}684 gal$$

In addition to the liquid in the solids, there is also free liquid above the solids in the areas of the tank where no solids is protruding above the liquid surface. As mentioned previously, in these areas it was estimated that the solids occupied approximately 50% of the volume. Assuming the remaining 50% is free liquid, the estimated free liquid in the tank is approximately 2,410 gallons[3]. Thus, the total estimated volume of liquid in the tank is 3,684 gallons of interstitial liquid plus 2,410 gallons of free liquid, or 6,094 gallons. This volume was used to calculate the liquid radionuclide inventory.

5.3 Summary of Radioactive Waste Volumes

There are approximately 4,334 gallons of wet solids in Tank 18. Based on the estimation in Section 5.2 that 85% of the heel is interstitial liquid, the 4,334 gallons of solids are comprised of approximately 3,684 gallons of interstitial liquid and 650 gallons of dry solids. This dry solids volume estimate does not effect the estimation of the contaminant inventories in the solids. The solids chemical and radionuclide inventories were determined on a mass basis and were unaffected by volume. Additionally, there are an estimated 2,410 gallons of free liquid remaining in the tank. The following table summarizes the calculated waste volumes in the bottom of Tank 18.

Table 1. Summary of Tank 18 Waste Volumes

Dry heel solids		650 gallons
Interstitial heel liquid	+	3,684 gallons
Total Solids Volume		4,334 gallons
Free liquid	+	2,410 gallons
Total Waste		6,744 gallons

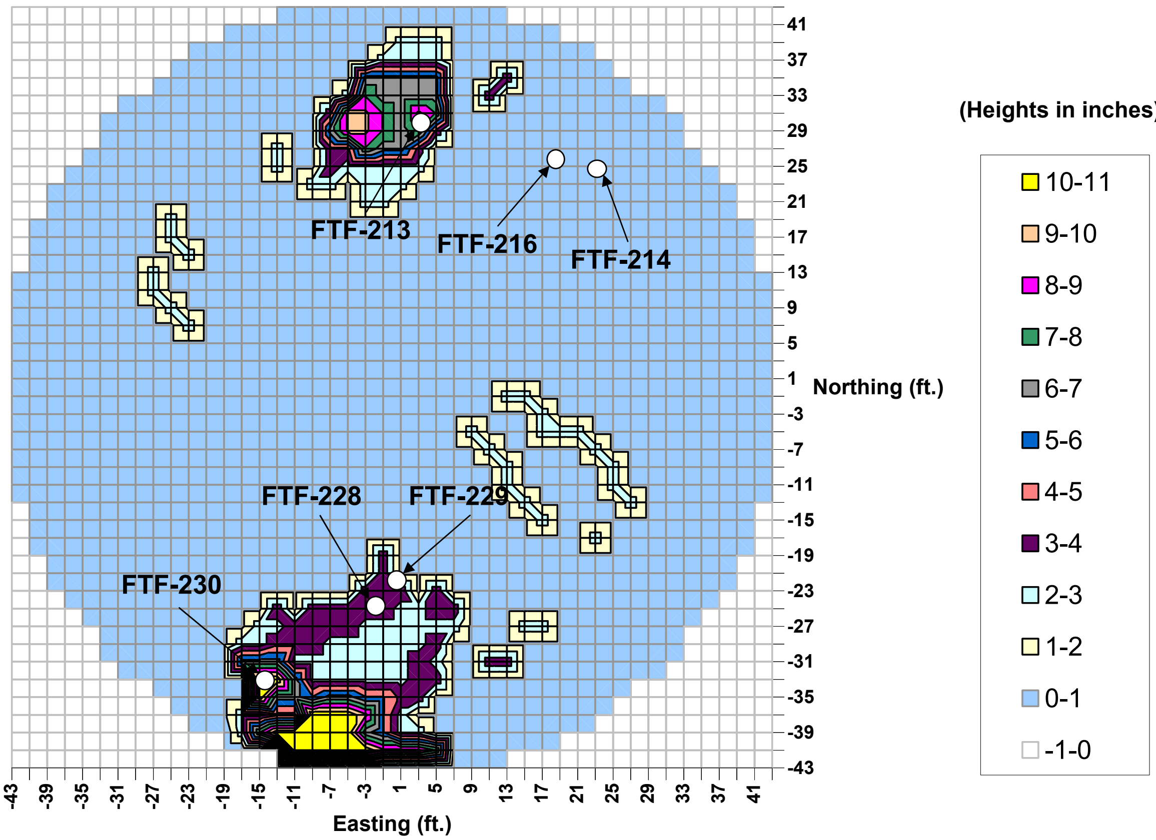
There are approximately 6,094 total gallons of liquid in Tank 18; this number was used to calculate the liquid radionuclide inventory from the liquid concentrations.

5.4 Sampling

5.4.1 Sample Locations

A total of six solids samples and one liquid sample were obtained of the residual materials in Tank 18 following the heel removal campaign in 2003. Figure 1 shows the locations of each of the six solids samples in relation to the contour plot of the residual heel.

Figure 1. Tank 18 Sample Locations



The samples were transported to the SRNL High Level Caves, opened, inspected, and analyzed. The results of these samples are documented in Tables 2, 4, and 6. Analysis of the samples showed that five of the six solids samples appeared to be the same material and had similar compositions. The sample that did not align with the other 5 was the sample taken from the approximately 11” high Southwest mound (FTF-230). Video observations of the residual heel conducted throughout the 2003 waste removal campaign showed that this Southwest mound was never moved or mixed by the ADMP. Visually, this mound appeared to have a different consistency than the rest of the tank contents. Whereas most of the solids mounds in Tank 18 had a smooth surface texture and relatively gentle sloping sides, the Southwest mound appeared to have fairly steep slopes and a jagged, uneven texture. Consequently, the Southwest mound was characterized differently than the material in the remainder of the tank.

5.4.2 Sample Density Results

The solids sample solids fractions and density measurements[6] are reported in the following table. The densities on a dry basis were calculated by multiplying the densities on a wet basis by the solids fractions for each sample.

Table 2. Solids Fractions and Density Results

	Units	No. 1 FTF-213	No. 2 FTF-214	No.3 FTF-216	No. 4 FTF-228	No. 5 FTF-229	No. 6 FTF-230
"Wet" Density	(g wet solids per mL wet solids)	1.4	1.3	1.4	1.4	1.5	1.3
Solids Fraction	(wt. %)	67.0%	71.0%	71.0%	65.8%	72.2%	54.8%
"Dry" Density	(g dry solids per mL wet solids)	0.94	0.92	0.99	0.92	1.08	0.71

For the density results, an upper 95% confidence limit on the average value is used to estimate the mass of solids in the tank. The formula used for computing the upper 95% confidence limit for the density was:

$$Density = \overline{D} + (UpperCutoff, 95\%) \times \sqrt{\frac{{s_D}^2}{NumberOfSamples}} \qquad \text{Eqn } \{1\}$$

Where:

Density = upper 95% confidence limit on the average density
$\overline{D}$ = mean density
s_D = standard deviation of the density results
Upper Cutoff, 95% = Upper Cutoff from the standard one-tailed Students t-table at 95% confidence, as follows:

Number of Samples	Degrees of Freedom	One-tailed Cutoff, 95% confidence
2	1	6.314
3	2	2.920
4	3	2.353
5	4	2.132

As mentioned previously, the approximately 760 gallon Southwest mound was characterized differently than the 3,574 gallons of waste in the remainder of the tank. The mass of dry solids in the 3,574 gallons of waste was estimated using the 95% confidence limit of the sample results from the 5 samples of this material. However, only one sample (FTF-230) was available with which to characterize the Southwest mound, making it impossible to apply a standard 95% confidence limit to the density of this material. To calculate a 95% confidence interval upper bound for the density of this

Southwest mound using Eqn {1}, it was assumed that the relative standard deviation and 95% Upper Cutoff of this mound were equal to the relative standard deviation and 95% Upper Cutoff of the 5 samples taken from the other areas of the tank. The measured density of sample FTF-230 was assumed to be the mean density of the Southwest mound. The number of samples credited in the denominator of Eqn {1} was one sample. Using these assumptions and inputs, an estimate of the 95% confidence limit of the Southwest mound density was calculated using Eqn {1}. The following table displays the 95% confidence interval upper bound on the density of the 760-gal unmoved Southwest mound and the density of the remaining 3,574-gal solids in the tank.

Table 3. Calculated 95% Confidence Interval Upper Bounds for Solids Densities

	Units	Average of Samples 1-5	Relative Std. Dev. (%)	95% Confidence Interval Upper Bound for Samples 1-5	No. 6 FTF-230	95% Confidence Interval Upper Bound for Sample No. 6
"Wet" Density	(g wet solids per mL wet solids)	1.4	5.1%	1.47	1.3	1.44
Solids Fraction	(wt. %)	69.4%	4.1%	72.1%	54.8%	59.5%
"Dry" Density	(g dry solids per mL wet solids)	0.97	7.1%	1.04	0.71	0.82

5.4.3 Sample Radionuclide Results

The measured radionuclide concentrations in the solids and liquid samples[6] are reported in the following table.

Table 4. Measured Radionuclide Concentrations in Samples

	No. 1 FTF-213	No. 2 FTF-214	No.3 FTF-216	No. 4 FTF-228	No. 5 FTF-229	Average of Samples 1-5	Relative Std. Dev. Of Samples 1-5	No. 6 FTF-230	Dip Sample
	(µCi/g)	(µCi/g)	(µCi/g)	(µCi/g)	(µCi/g)	(µCi/g)	(%)	(µCi/g)	(µCi/L)
H-3									<2.67
Se-79	<7.97E-04	<1.09E-04	<1.13E-03	<5.54E-03	<3.82E-04	1.59E-03	140.8%	<5.81E-04	
Sr-90	60.1	97.4	103.0	67.0	81.5	8.18E+01	22.7%	42.3	
Tc-99	0.094	0.104	0.096	0.091	0.089	9.48E-02	6.1%	0.053	4.09E-01
Cs-137	370.0	738.0	747.0	876.0	874.0	7.21E+02	28.7%	67.5	57
U-233	<5.13E-02	<5.27E-02	<5.69E-02	<9.20E-03	<9.20E-03	3.59E-02	68.1%	<9.20E-03	<0.6240
U-234	<3.31E-02	<3.40E-02	<3.67E-02	9.37E-03	1.00E-02	9.69E-03*	4.6%*	1.87E-02	<0.4030
U-235	3.66E-04	4.10E-04	4.22E-04	3.95E-04	3.50E-04	3.89E-04	7.7%	7.30E-04	3.6E-04
U-236	3.88E-04	4.61E-04	4.17E-04	3.88E-04	3.67E-04	4.04E-04	9.0%	7.12E-04	<4.17E-03
U-238	9.23E-03	9.91E-03	1.06E-02	1.05E-02	9.57E-03	9.96E-03	5.9%	1.93E-02	9.12E-03
Np-237	4.23E-03	4.89E-03	3.95E-03	3.76E-03	3.17E-03	4.00E-03	15.8%	9.99E-03	<4.55E-02
Pu-238	3.41	4.57	4.09	4.90	4.78	4.35E+00	14.0%	2.00	0.165
Pu-239	7.44	7.03	7.58	7.57	7.06	7.34E+00	3.7%	13.30	<4.01
Pu-240	1.60	1.59	1.67	1.79	1.56	1.64E+00	5.6%	2.92	<14.70
Pu-241	11.4	11.6	13.5	<15.4	<15.7	1.22E+01*	9.5%*	<26.7	<7.18E-01
Pu-242	<2.02E-02	<2.08E-02	<2.24E-02	3.82E-03	<3.63E-03	3.73E-03**	3.6%**	<3.63E-03	<0.2460
Am-241	4.04	3.36	3.48	3.86	3.25	3.60E+00	9.4%	8.89	0.502

*For U-234 and Pu-241, the values reported for the average and relative standard deviation for Samples 1-5 are based on actual detected values; the reported less-than-detection-limit values are excluded from the statistical analysis of these radionuclides.

**For Pu-242, the values reported for the average and relative standard deviation for Samples 1-5 are based on one detected value (FTF-228) and one less-than-detection-limit value (FTF-229). The use of less-than-detection-limit FTF-229 value is justified because it is less than detected FTF-228 value and one order of magnitude less than the other three less-than-detection-limit values.

5.4.4 Sample Nonradionuclide Results

The measured chemical (nonradionuclide) concentrations in the solids and liquid samples[6] are reported in the following table.

Table 5. Measured Nonradionuclide Concentrations in Samples

	Solids:								Liquid:
	No. 1 FTF-213	No. 2 FTF-214	No.3 FTF-216	No. 4 FTF-228	No. 5 FTF-229	Average of Samples 1-5	Relative Std. Dev. Of Samples 1-5	No. 6 FTF-230	Dip Sample
	(wt.%)	(wt.%)	(wt.%)	(wt.%)	(wt.%)	(wt.%)	(%)	(wt.%)	(mg/L)
Silver	<1.51E-02	<1.49E-02	<1.49E-02	<1.49E-02	2.49E-02	1.69E-02	26.3%	<1.48E-02	<1.56
Aluminum	1.47E+01	1.44E+01	1.39E+01	1.40E+01	1.63E+01	1.47E+01	6.6%	7.28E+00	<16.10
Boron	<1.62E+00	<1.61E+00	<1.63E+00	<1.61E+00	<1.62E+00	1.62E+00	0.5%	<1.61E+00	<169.00
Barium	2.53E-02	2.25E-02	2.21E-02	2.66E-02	1.88E-02	2.31E-02	13.2%	<1.49E-02	<1.56
Calcium	2.85E+00	2.40E+00	2.94E+00	2.55E+00	2.16E+00	2.58E+00	12.4%	3.63E+00	<47.10
Cadmium	5.99E-01	5.99E-01	6.52E-01	8.15E-01	6.22E-01	6.57E-01	13.8%	8.06E-01	<2.08
Cerium	<2.47E-01	<2.47E-01	<2.49E-01	<2.46E-01	<2.48E-01	2.47E-01	0.5%	<2.46E-01	<25.80
Cobalt	3.35E-03	5.11E-03	8.90E-03	1.57E-03	1.60E-03	4.11E-03	74.3%	3.05E-03	
Chromium	7.00E-02	7.29E-02	7.41E-02	3.47E-02	6.28E-02	6.29E-02	26.0%	3.37E-02	<1.77
Copper	<3.09E-02	<3.09E-02	<3.11E-02	<3.08E-02	<3.11E-02	3.10E-02	0.4%	<3.08E-02	<3.22
Iron	8.01E+00	9.84E+00	7.78E+00	9.71E+00	9.56E+00	8.98E+00	11.1%	1.75E+01	<990.00
Gadolinium	<2.69E-02	<2.69E-02	<2.71E-02	<2.68E-02	<2.70E-02	2.69E-02	0.4%	<2.68E-02	<2.29
Lanthanum	<2.00E-02	<1.99E-02	<2.01E-02	<1.99E-02	<2.00E-02	2.00E-02	0.4%	<1.99E-02	<2.08
Lithium	<8.48E-02	<8.46E-02	<8.53E-02	<8.45E-02	<8.51E-02	8.49E-02	0.4%	<8.43E-02	<8.84
Magnesium	1.93E+00	1.47E+00	1.81E+00	1.68E+00	1.16E+00	1.61E+00	18.9%	5.89E+00	<6.45
Manganese	1.08E+00	1.11E+00	1.10E+00	1.51E+00	1.12E+00	1.18E+00	15.4%	1.54E+00	<2.29
Molybdenum	<2.04E-01	<2.03E-01	<2.05E-01	<2.03E-01	<2.04E-01	2.04E-01	0.4%	<2.03E-01	<21.20
Sodium	3.49E+00	4.85E+00	5.76E+00	5.99E+00	5.13E+00	5.04E+00	19.5%	2.78E+00	613
Nickel	9.77E-02	1.12E-01	8.98E-02	8.77E-02	1.03E-01	9.80E-02	10.1%	2.03E-01	<7.80
Phosphorus	<4.84E-01	<4.83E-01	<4.87E-01	<4.82E-01	<4.86E-01	4.84E-01	0.4%	<4.81E-01	<50.50
Lead	<2.45E-01	<2.45E-01	<2.47E-01	<2.44E-01	<2.46E-01	2.45E-01	0.5%	<2.44E-01	<25.60
Sulfur	<3.81E-01	<3.80E-01	<3.83E-01	<3.79E-01	<3.83E-01	3.81E-01	0.5%	<3.79E-01	<39.70
Antimony	<1.51E-01	<1.50E-01	<1.51E-01	<1.50E-01	<1.51E-01	1.51E-01	0.4%	<1.50E-01	<15.70
Silicon	4.53E+00	8.14E+00	5.68E+00	8.51E+00	7.49E+00	6.87E+00	24.8%	1.36E+00	25.3
Tin	<2.44E-01	<2.44E-01	<2.46E-01	<2.43E-01	<2.45E-01	2.44E-01	0.5%	<2.43E-01	<25.50
Strontium	5.79E-01	4.87E-01	5.95E-01	5.69E-01	4.80E-01	5.42E-01	10.0%	8.17E-01	<10.40
Titanium	9.11E-03	1.16E-02	1.05E-02	2.21E-02	1.74E-02	1.41E-02	38.6%	2.52E-02	<0.62
Uranium	2.76E+00	2.97E+00	3.17E+00	3.02E+00	2.85E+00	2.95E+00	5.3%	5.70E+00	27.3
Vanadium	<1.10E-02	<1.10E-02	<1.11E-02	<1.09E-02	<1.10E-02	1.10E-02	0.6%	1.28E-02	<1.14
Zinc	<5.49E-02	<5.47E-02	<5.52E-02	<5.46E-02	<5.51E-02	5.49E-02	0.5%	<5.46E-02	<5.72
Zirconium	<1.20E-02	<1.19E-02	<1.19E-02	<1.19E-02	<1.20E-02	1.19E-02	0.5%	<1.19E-02	<1.25
Mercury	1.61E-02	4.56E-02	7.57E-04	5.55E-02	2.20E-01	6.76E-02	130.2%	<1.09E-02	<2.29
Potassium	6.49E-03	2.07E-02	2.61E-02	<1.49E-02	<1.49E-02	1.66E-02	44.1%	<1.48E-02	4.49
Arsenic	<4.98E-03	<4.96E-03	<5.02E-03	<4.97E-03	<5.01E-03	4.99E-03	0.5%	<4.96E-03	<0.52
Selenium	<4.98E-03	<4.96E-03	<5.02E-03	<4.96E-03	<5.01E-03	4.99E-03	0.6%	<4.96E-03	<0.52
Fluoride									31.20
Chloride									27.80
Nitrate									336.00
Nitrite									201.00
Sulfate									52.00
Phosphate									<104.00
Oxalate									86.70

5.5 Process Knowledge Estimates

5.5.1 Chemical Contaminants

No process knowledge estimates were developed for chemical inventories in Tank 18. The inventory estimates for chemical contaminants in Tank 18 were based on samples alone.

5.5.2 Radionuclides

Radionuclide estimates of the composition of residual solids and liquid in Tank 18 were derived from the Waste Characterization System (WCS)[7] and a special analysis which characterized additional radionuclides for Tank 18[8].

5.6 Estimated Inventories

5.6.1 Mass of Solids

The mass of solids in Tank 18 was estimated by multiplying the residual solids volumes by the measured density of the solids. Previous studies have demonstrated that, on average, there are typically about 1.95 pounds of dry sludge solids per gallon of wet settled sludge[9]. Some of the residual solids in Tank 18 originated from waste removed from Tank 19 in 2001. The solids remaining in Tank 19 were primarily zeolite, which has a higher bulk density than typical sludge. Analysis of the Tank 19 closure samples showed that the average bulk density of the material in Tank 19 was 8.05 pounds of dry solids per gallon of wet solids. For the Tank 18 samples, the Savannah River National Laboratory (SRNL) measured the average bulk density to be similar to the density of the Tank 19 samples. As reported in Section 5.4.2, the 95% confidence upper bound for the "dry" density of the 760 gallon unmoved Southwest mound is 0.82 g/mL (equivalent to 6.82 pounds of dry solids per gallon of wet solids). The 95% confidence interval upper bound for the "dry" density of the 3,560 gallons of solids in the remainder of the tank is 1.04 g/mL (equivalent to 8.64 pounds of dry solids per gallon of wet solids). For comparison, SRNL had previously measured the density of fresh IE-95 zeolite resin to be about 7.10 pounds of dry solids per gallon of wet material[10]. The bulk densities in Tanks 18 and 19 are higher than this potentially due to the fact that the waste removal process tends to leave behind the heavier, faster settling material.

The estimated mass of the dry solids in the unmoved Southwest mound, the dry solids in the remainder of the tank, and the total dry solids was calculated as follows:

$$Mass_{SW} = 760 gal \times 6.82 \frac{lb}{gal} = 5{,}183 lb$$

$$Mass_{remainder} = 3{,}574 gal \times 8.64 \frac{lb}{gal} = 30{,}879 lb$$

$$Mass_{total} = 5{,}183lb + 30{,}879lb = 36{,}062lb \times \frac{1kg}{2.20462lb} = 16{,}357kg$$

The following table summarizes the volumes, masses, and densities of the material in Tank 18.

Table 6. Solids Inventories and Densities

	Southwest Mound Solids	Remaining Solids (excluding SW mound)	Total Solids
Volume (gal)	760	3,574	4,334
Mass of solids (lb)	5,183	30,879	36,062
Wet Solids Density (g wet solids per mL wet solids)	1.44	1.47	
Dry Solids Density (g dry solids per mL wet solids)	0.82	1.04	

5.6.2 Mass of Interstitial Liquid

The mass of interstitial liquid is used in the Class C calculations. The mass of interstitial liquid is calculated by multiplying the volume of interstitial liquid by the specific gravity (1.02[11]), and converting to the appropriate units. The mass of the interstitial liquid in the 14 gallons of solids on the stiffener bands was not included because this liquid has likely evaporated.

$$4{,}320gal \bullet 0.85 \bullet \frac{1.02kg}{L} \bullet \frac{3.7854L}{gal} = 14{,}178kg$$

5.6.3 Radionuclide Inventories

For each radionuclide that is significant to tank closure, the inventory of that radionuclide in the tank was estimated both by samples and process knowledge. For radionuclides where sample data was available, the inventories reported for these key constituents are based on sample data. For all other radionuclides, the inventories are based on predicted estimates. Exceptions to this are the inventories reported for Y-90 and Ba-137m, which are the daughter products of Sr-90 and Cs-137. Y-90 is assumed to be in secular equilibrium with the Sr-90 inventory measured in samples, while Ba-137m is assumed to be in secular equilibrium with Cs-137 at 94.6% of the Cs-137 inventory measured in samples.

For nuclides for which solids sample data is available, an upper 95% confidence limit on the average concentration is reported. To calculate the 95% confidence interval upper bound for the Tank 18 radionuclide inventories based on sample data, an equation with the same form as Eqn {1} was used:

$$I_i(UpperLimit) = I_i + (UpperCutoff, 95\%) \times \sqrt{s_{I_i}^{\ 2}} \qquad \text{Eqn } \{2\}$$

Where:

$I_i(UpperLimit)$ = upper 95% confidence limit on the contaminant inventory (Ci)
I_i = Inventory of contaminant based on average density and concentration (Ci)
s_{I_i} = Standard deviation of contaminant inventory
Upper Cutoff, 95% = Upper Cutoff from the standard one-tailed Students t-table at 95% confidence

To calculate I_i, the inventory in the 760-gal unmoved Southwest mound was added to the inventory in the remaining 3,574-gal solids in the tank:

$$I_i = \left[\overline{D} \times \overline{C_i} \times V\right]_{SW} + \left[\overline{D} \times \overline{C_i} \times V\right]_{remainder} \qquad \text{Eqn } \{3\}$$

where
$\overline{D}$ = Average "dry basis" solids density based on samples (mass of dry solids per gallon of wet solids)
$\overline{C_i}$ = Average measured concentration of contaminant in solids based on samples (Ci per unit mass)
V = Volume of solids (gallons)

The concentrations and densities used in Eqn {3} have variances associated with them. Propagating these variances to calculate a variance for the resulting contaminant inventories involves Eqn {4}[12]. Eqn. {4} represents a Taylor series expansion of Eqn {3} with only the linear terms retained. (Note: uncertainties were not calculated for the volumes used; the uncertainties associated with the volumes (s_V) were assumed to be zero):

$$s_{I_i}^{\ 2} = \left[\left(\frac{\partial I_i}{\partial \overline{D}}\right)^2 s_{\overline{D}}^{\ 2} + \left(\frac{\partial I_i}{\partial \overline{C_i}}\right)^2 s_{\overline{C_i}}^{\ 2}\right]_{SW} + \left[\left(\frac{\partial I_i}{\partial \overline{D}}\right)^2 s_{\overline{D}}^{\ 2} + \left(\frac{\partial I_i}{\partial \overline{C_i}}\right)^2 s_{\overline{C_i}}^{\ 2}\right]_{remainder} \qquad \text{Eqn } \{4\}$$

where

$$s_{\overline{D}}^{\ 2} = \frac{s_D^{\ 2}}{NumberOfSamples}$$

and

$$s_{\overline{C_i}}^{\ 2} = \frac{s_{C_i}^{\ 2}}{NumberOfSamples}$$

As mentioned previously, the 760 gallon Southwest mound was characterized differently than the 3,574 gallons of waste in the remainder of the tank. The standard deviations for the density and concentration measurements in the 3,574 gallons of waste were calculated based on the results of samples 1-5. However, only one sample (FTF-230) was available with which to characterize the Southwest mound, making it impossible to calculate a standard deviation for the properties of this material. Instead, it was assumed that the relative standard deviations of the properties of the Southwest mound were equal to the relative standard deviations calculated from samples 1-5. To offset the fact that the standard deviation of the Southwest mound is not known, only one sample was taken credit for in the uncertainty analysis of the Southwest mound. Making the above substitutions into Eqn {4} and entering values for the number of samples calculates the variance of the inventories:

$$s_{I_i}^{\;2} = \left[\frac{\left(V \times \overline{C_i}\right)^2}{1} s_{D_i}^{\;2} + \frac{\left(V \times \overline{D}\right)^2}{1} s_C^{\;2} \right]_{SW} + \left[\frac{\left(V \times \overline{C_i}\right)^2}{NumberOfSamples} s_{D_i}^{\;2} + \frac{\left(V \times \overline{D}\right)^2}{NumberOfSamples} s_C^{\;2} \right]_{remainder}$$

Eqn {5}

To calculate the 95% confidence interval upper bound for the solids inventories according to Eqn {2}, it was assumed that the degrees of freedom of the Southwest mound was equal to the degrees of freedom of the solids in the remainder of the tank. For most radionuclides, the degrees of freedom credited was 4. Exceptions to this are U-234, Pu-241, and Pu-242. For these radionuclides, some of the sample results were excluded because of level of detection issues as explained in the Table 4 footnote. The table at the end of this section reports the 95% confidence interval upper bounds for radionuclide inventories calculated using Eqn {2}.

To calculate the radionuclide inventory in the liquid based on samples, the measured radionuclide concentrations from the liquid sample (on a curie per unit volume basis) were multiplied by the 6,094 gallons of liquid estimated to remain in the tank. The total tank radionuclide inventories were calculated by adding the radionuclide inventories from the solids and the liquid.

In the total tank radionuclide inventory, however, some of the radionuclide inventory of the interstitial liquid in the solids were doubly accounted for. When the solids samples were analyzed in the lab, they were weighed, dried to a constant temperature, and then weighed again. From the difference in weights, the interstitial liquid (liquid) in the solids samples was estimated to be around 25-45 wt%. This is less than the 85 vol% interstitial liquid estimated to exist in the tank solids heel due to leakage of liquid from the sampler—it was not designed to be water-tight—and also to evaporation. Due to the radioactivity contribution of the 25-45 wt% liquid in the solids samples, it is estimated that the radioactivity of around 1,500 gallons of liquid were double counted in the solids radionuclide inventory. However, because the liquid is so dilute, reducing the volume of liquid used to calculate the liquid radionuclide inventory by 1,500 gallons would only decrease the Tc-99 inventory in the tank by less than 0.2%. For conservatism, this was not taken into account in calculating the liquid radionuclide inventory; the liquid volume used to calculate the liquid radionuclide inventory was equal to the 6,094 gallons of liquid estimated to remain in the tank.

The inventory for the radionuclides estimated from samples was within a factor of the inventory estimated from process knowledge. The exception to this is the Cs-137 inventory, which was about 50 times higher than its process knowledge estimate. Cs-137 is higher than predicted due to the presence of zeolite, which retains Cs-137. The relatively good correlation between process knowledge and sample results is probably due to the fact that Tank 18 was a sludge tank and did not contain saltcake.

The calculated radionuclide inventories in the heel are reported in Table 7.

5.6.4 Tank 18 Wall Corrosion Product

In support of tank closure, a quantitative analysis and evaluation was performed to address any fixed contamination that may be present on the internal Tank 18 surfaces. A visual examination of video footage of the Tank 18 interior concluded that corrosion of the carbon steel walls had been light and general. The surface appeared typical for carbon steel exposed to either an alkaline aqueous environment or an ambient vapor space environment. There was no evidence of extensive pitting corrosion. Using general corrosion rates from laboratory and field test data and historical ultrasonic tank thickness measurements, the Savannah River National Laboratory (SRNL) estimated that there were 329 kg of corrosion product (rust) that had been exposed to radioactive waste on the interior surface of the tank walls. High Level Waste provided SRNL data concerning the concentration of radionuclides present in the supernate historically in contact with the tank interior surfaces. SRNL then used measured K_d values, which quantify how key constituents partition between a solid and a liquid phase in contact with each other, to calculate the potential amount of radioactive contamination absorbed onto the 329 kg of corrosion products[13]. The “Wall Corrosion Product Inventory” column in Table 7 summarizes the calculated radioactive contamination on the tank interior corrosion products. This wall corrosion product inventory is added to the solids and liquids inventories to provide the “Total Inventory Estimate” in Table 7.

Fate and transport modeling of residual contaminants uses the concentration of the contaminants in the waste as an input. The concentrations of radionuclides used as input to the fate and transport model are documented in a separate report[14].

Table 7. Radionuclide Inventories in Heel

Radio-nuclides	Predicted Solids Inventory	Solids Inventory Based on Samples	Solids Inventory (Based on samples where available, else predicted values)	Predicted Liquid Inventory	Liquid Inventory Based on Samples	Liquid Inventory (Based on samples where available, else predicted values)	Wall Corrosion Product Inventory (X-CLC-F-00440)	Total Inventory Estimate (Solids + Liquids + Corrosion Products)
	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)
H-3	NVR			2.31E+00	6.16E-02	6.16E-02	0.0E+00	6.16E-02
C-14	1.55E-02		1.55E-02	4.06E-02		4.06E-02	0.0E+00	5.61E-02
Co-60	4.32E+00		4.32E+00	2.38E-02		2.38E-02	6.6E-05	4.35E+00
Ni-59	9.12E-01		9.12E-01	NVR				9.12E-01
Ni-63	8.04E+01		8.04E+01	5.77E-02		5.77E-02	6.7E-03	8.04E+01
Se-79	7.54E-02	5.04E-02	5.04E-02	NVR			6.5E-05	5.05E-02
Sr-90	3.41E+03	1.41E+03	1.41E+03	2.86E-02		2.86E-02	1.7E-03	1.41E+03
Y-90	3.41E+03		1.41E+03	2.86E-02		2.86E-02		1.41E+03
Nb-94	4.00E-05		4.00E-05	4.00E-08		4.00E-08	2.9E-08	4.01E-05
Tc-99	1.77E+01	1.47E+00	1.47E+00	1.23E-01	9.43E-03	9.43E-03	0.0E+00	1.48E+00
Ru-106	9.72E-05		9.72E-05	NVR				9.72E-05
Rh-106	9.72E-05		9.72E-05	NVR				9.72E-05
Sn-126	1.40E-01		1.40E-01	NVR				1.40E-01
Sb-125	1.17E+00		1.17E+00	NVR				1.17E+00
Sb-126	1.96E-02		1.96E-02	n/a				1.96E-02
Sb-126m	1.40E-01		1.40E-01	n/a				1.40E-01
Te-125m	2.87E-01		2.87E-01	n/a				2.87E-01
I-129	6.21E-06		6.21E-06	2.08E-07		2.08E-07	0.0E+00	6.42E-06
Cs-134	3.05E-03		3.05E-03	NVR			2.4E-04	3.29E-03
Cs-135	8.74E-04		8.74E-04	NVR				8.74E-04
Cs-137	2.38E+02	1.23E+04	1.23E+04	1.17E+02	1.32E+00	1.32E+00	3.3E+02	1.26E+04
Ba-137m	2.25E+02		1.16E+04	1.10E+02		1.25E+00		1.16E+04
Ce-144	1.44E-06		1.44E-06	NVR				1.44E-06
Pr-144	1.44E-06		1.44E-06	NVR				1.44E-06
Pm-147	1.85E+01		1.85E+01	NVR				1.85E+01
Sm-151	4.58E+01		4.58E+01	n/a				4.58E+01
Eu-152	1.98E-01		1.98E-01	n/a				1.98E-01
Eu-154	1.06E+01		1.06E+01	NVR				1.06E+01
Eu-155	2.67E+00		2.67E+00	n/a				2.67E+00
Ra-226	4.90E-07		4.90E-07	n/a				4.90E-07
Ra-228	NVR			n/a				0.00E+00
Ac-227	1.64E-06		1.64E-06	n/a				1.64E-06
Th-229	2.27E-03		2.27E-03	n/a				2.27E-03
Th-230	6.00E-05		6.00E-05	n/a				6.00E-05
Th-232	NVR			NVR				0.00E+00
Pa-231	4.57E-06		4.57E-06	n/a				4.57E-06
U-232	2.17E-04		2.17E-04	4.00E-07		4.00E-07		2.18E-04
U-233	NVR	7.98E-01	7.98E-01	1.74E-02	1.44E-02	1.44E-02	3.6E+00	4.41E+00
U-234	NVR	2.18E-01	2.18E-01	NVR	9.30E-03	9.30E-03	2.3E+00	2.53E+00
U-235	1.66E-03	7.21E-03	7.21E-03	3.03E-06	8.30E-06	8.30E-06	2.1E-03	9.31E-03
U-236	NVR	7.44E-03	7.44E-03	NVR	9.62E-05	9.62E-05	2.4E-02	3.15E-02
U-238	8.95E-02	1.84E-01	1.84E-01	1.71E-04	2.10E-04	2.10E-04	5.3E-02	2.37E-01
Np-237	NVR	8.44E-02	8.44E-02	1.75E-03	1.05E-03	1.05E-03	3.3E-02	1.18E-01
Pu-238	3.81E+02	6.99E+01	6.99E+01	7.26E-01	3.81E-03	3.81E-03	2.5E-01	7.01E+01
Pu-239	5.44E+01	1.32E+02	1.32E+02	1.04E-01	9.25E-02	9.25E-02	7.7E+00	1.40E+02
Pu-240	1.39E+01	2.97E+01	2.97E+01	2.61E-02	3.39E-01	3.39E-01	2.8E+01	5.81E+01
Pu-241	2.44E+02	2.52E+02	2.52E+02	7.43E-01	1.66E-02	1.66E-02	3.2E-01	2.52E+02
Pu-242	1.78E-02	7.41E-02	7.41E-02	3.55E-05	5.67E-03	5.67E-03	4.8E-01	5.60E-01
Pu-244	3.39E-04		3.39E-04	n/a				3.39E-04
Am-241	2.85E+01	7.24E+01	7.24E+01	8.20E-02	1.16E-02	1.16E-02	1.7E+00	7.41E+01
Am-242m	NVR			8.03E-01		8.03E-01		8.03E-01
Am-243	6.15E-06		6.15E-06	n/a				6.15E-06
Cm-242	3.19E-20		3.19E-20	n/a				3.19E-20
Cm-243	9.52E-05		9.52E-05	n/a				9.52E-05
Cm-244	1.69E+02		1.69E+02	3.43E-01		3.43E-01		1.69E+02
Cm-245	2.17E-09		2.17E-09	3.97E-12		3.97E-12		2.17E-09
Cm-247	2.17E-18		2.17E-18	n/a				2.17E-18
Cm-248	5.02E-19		5.02E-19	n/a				5.02E-19
Bk-249	1.89E-28		1.89E-28	n/a				1.89E-28
Cf-249	1.39E-20		1.39E-20	n/a				1.39E-20

5.6.5 Class C Radionuclide Inventories Decayed to 2020

For the purposes of performing Class C calculations, the total radionuclide inventories (solids + liquids + corrosion products) in Table 7 were decayed to 2020, which is the planning date for the closure of all F-Tank Farm tanks. Table 8 below contains the decayed inventories for the Class C radionuclides[15]:

Table 8. Class C Radionuclide Inventories Decayed to 2020

Radionuclides	Inventory
	(Ci)
C-14	5.60E-02
Ni-59	9.12E-01
Ni-63	7.16E+01
Sr-90	9.28E+02
Nb-94	4.01E-05
Tc-99	1.48E+00
I-129	6.42E-06
Cs-137	8.52E+03
Np-237	1.19E-01
Pu-238	6.14E+01
Pu-239	1.40E+02
Pu-240	5.81E+01
Pu-241	1.11E+02
Pu-242	5.60E-01
Pu-244	3.39E-04
Am-241	7.68E+01
Am-242m	7.39E-01
Am-243	6.14E-06
Cm-242	6.08E-01
Cm-243	6.30E-05
Cm-244	8.83E+01
Cm-245	2.17E-09
Cm-247	2.17E-18
Cm-248	5.02E-19
Cf-249	1.34E-20

5.6.6 NRC Class C Calculation

The Class C calculations for the waste in Tank 18 are contained in Table 9 for long-lived radionuclides and Table 10 for short-lived radionuclides. The "sum of fractions" calculation methodology and the Class C limits in the tables are outlined in Nuclear Regulatory Commission regulation 10 CFR 61.55. The units for the limits are shown in the column entitled "Class C Units." The next column, "Tank 18 Concentration in Class Units," shows the computed concentration of the Tank 18 residual waste converted to the appropriate units. For Class C limits on a volumetric basis, the decayed radionuclide inventories from Table 8 are divided by the sum of the volume of solids in the tank (4,334 gallons), the volume of equipment in the tank (170 ft^3, or 4.8 m^3, or 1,272 gal)[16], and the volume of the waste tank system (shotcrete walls, dome, risers, steel liner, lifting plates, stiffener bands: 14,430 ft^3 or 408.6 m^3)[16] and converted to the appropriate units. For Class C limits on a mass basis, the decayed radionuclide inventories from Table 8 are divided by the mass of the tank system summarized in the following table and converted to the appropriate units:

Waste Solids	16,357 kg
Interstitial Liquid	14,178 kg
Wall Corrosion Products	329 kg
In-Tank Equipment + Waste Tank (shotcrete walls, dome, risers, steel liner, lifting plates, stiffener bands)	1.09E+06 kg[16]
Total Tank System Mass	**1,120,864 kg**

In the column "Factor relative to Class C Limit," the computed concentration in Tank 18 is divided by the Class C limit to obtain a Class C factor for each radionuclide. To be within the Class C designation the sum of all of these factors must be less than or equal to 1. As can be seen from the sum at the bottom of the column in Table 9, the long-lived radionuclide inventory in Tank 18 is currently 3.8 times the upper concentration limit for Class C waste. As Table 10 indicates, the short-lived radionuclide inventory in Tank 18 is currently below the concentration limit for Class C waste.

The next column, "Factor with 123" Grout," shows the factors if one takes credit for the mass of 123.0 inches of grout covering the solids heel in computing the radionuclide concentration. This equates to filling the tank with grout to a level of 124.2 inches (123.0" of grout + 1.2" of waste).

The reducing grout planned for use in the first layer has a unit weight of 120.9 lb/ft^3.[17] This is equivalent to a specific gravity of:

$$\frac{120.9lb}{ft^3} \bullet \frac{kg}{2.20462lb} \bullet \frac{ft^3}{28.32L} = 1.94$$

As can be seen from the summation at the bottom of the column, 123.0 inches (10.25 feet) of grout is sufficient to bring the sum of the Class C factors to less than 1.000 for the long-lived radionuclides in Table 9. A number below 1.000 means that the average concentration of the waste plus grout in Tank 18 will be less than the upper limit for Class C waste. For the Class C limits on a mass basis, the contribution of each nuclide to the sum of the Class C factors is calculated with the following formula:

$$Factor = \frac{I}{C \times \left(h_{grout} \times FF_{TypeIV} \times \rho_{grout} + M_{\tan k}\right)} \qquad \text{Eqn } \{6\}$$

where:
Factor = individual radionuclide contribution to the sum of the Class C factors
I = total inventory (solids + liquids + corrosion products) of radionuclide in tank (Ci)
C = Class C concentration limit (nCi/g)
h_{grout} = height of encapsulating grout used for concentration averaging (in.)
FF_{TypeIV} = fill factor for a Type IV tank (gal/in)
ρ_{grout} = grout density (g/mL)
M_{tank} = Total tank system mass (g)

For example, the following calculates the contribution of Pu-239 to the sum of the Class C factors when crediting 123.0 inches of grout for concentration averaging:

$$Factor = \frac{140Ci \times 1{,}000{,}000{,}000\,\frac{nCi}{Ci}}{\frac{100nCi}{g} \times \left(123.0in \times 3{,}540\,\frac{gal}{in} \times \frac{3{,}785.4mL}{gal} \times \frac{1.94g}{mL} + 1{,}120{,}864{,}000\text{g}\right)} = 0.32$$

The last column in Tables 9 and 10, "Factor with Tank Filled with Grout" shows the factors if one takes credit for the mass of grout required to fill the tank cylinder and dome. The cylindrical portion of the tank is 411 inches tall. Subtracting for the waste and equipment volumes, the height of grout required to fill the tank to 411" is:

$$h_{cylinder} - \frac{V_{solids}}{FF_{TypeIV}} - \frac{V_{equipment}}{FF_{TypeIV}} = 411in - \frac{4{,}334gal}{3{,}540gal/in} - \frac{1{,}272gal}{3{,}540gal/in} = 409.4in.$$

The dome volume is 875 cubic meters[16]; filling this volume with grout adds 1,697,500 kg (875 m^3 x 1,000 L/m^3 x 1.94 kg/L) to the closed tank system. Using these heights and masses, an equation similar to Eqn {6} can be used to calculate the numbers in the column "Factor with Tank Filled with Grout" for the nuclides with mass-based Class C limits. For example, the following calculates the contribution of Pu-239 to the sum of the Class C factors when crediting a tank full of grout for concentration averaging:

$$Factor = \frac{140Ci \times 1{,}000{,}000{,}000\,\frac{nCi}{Ci}}{\frac{100nCi}{g} \times \left(409.4in \times 3{,}540\,\frac{gal}{in} \times \frac{3{,}785.4mL}{gal} \times \frac{1.94g}{mL} + 1{,}120{,}864{,}000\text{g} + 1{,}697{,}500{,}000\text{g}\right)} = 0.10$$

Table 9. Tank 18 Waste Comparison to 10 CFR 61.55 Table 1

Radionuclides (Long-lived)	10 CFR 61.55 Class C Limit	Class C Units	Tank 18 Concentration in Class C Units	Factor Relative to Class C Limit	Factor with 123" Grout	Waste Concentration in Class C Units with Tank Filled with Grout	Factor with Tank Filled with Grout
C-14	8	Ci/m^3	1.30E-04	1.63E-05	3.4E-06	8.2E-06	1.0E-06
C-14 in activated metal	80	Ci/m^3	(1)	(1)	(1)	(1)	(1)
Ni-59 inactivated metal	220	Ci/m^3	(1)	(1)	(1)	(1)	(1)
Nb-94 in activated metal	0.2	Ci/m^3	(1)	(1)	(1)	(1)	(1)
Tc-99	3	Ci/m^3	3.44E-03	1.15E-03	2.4E-04	2.2E-04	7.3E-05
I-129	0.08	Ci/m^3	1.49E-08	1.87E-07	3.9E-08	9.5E-10	1.2E-08
Np-237	100	nCi/g	1.06E-01	1.06E-03	2.8E-04	8.8E-03	8.8E-05
Pu-238	100	nCi/g	5.48E+01	5.48E-01	1.4E-01	4.6E+00	4.6E-02
Pu-239	100	nCi/g	1.25E+02	1.25E+00	3.2E-01	1.0E+01	1.0E-01
Pu-240	100	nCi/g	5.18E+01	5.18E-01	1.3E-01	4.3E+00	4.3E-02
Pu-241	3500	nCi/g	9.90E+01	2.83E-02	7.3E-03	8.2E+00	2.4E-03
Pu-242	100	nCi/g	5.00E-01	5.00E-03	1.3E-03	4.2E-02	4.2E-04
Pu-244	100	nCi/g	3.02E-04	3.02E-06	7.9E-07	2.5E-05	2.5E-07
Am-241	100	nCi/g	6.85E+01	6.85E-01	1.8E-01	5.7E+00	5.7E-02
Am-242m	100	nCi/g	6.59E-01	6.59E-03	1.7E-03	5.5E-02	5.5E-04
Am-243	100	nCi/g	5.48E-06	5.48E-08	1.4E-08	4.6E-07	4.6E-09
Cm-242	20000	nCi/g	5.42E-01	2.71E-05	7.0E-06	4.5E-02	2.3E-06
Cm-243	100	nCi/g	5.62E-05	5.62E-07	1.5E-07	4.7E-06	4.7E-08
Cm-244	100	nCi/g	7.88E+01	7.88E-01	2.0E-01	6.6E+00	6.6E-02
Cm-245	100	nCi/g	1.94E-09	1.94E-11	5.0E-12	1.6E-10	1.6E-12
Cm-247	100	nCi/g	1.94E-18	1.94E-20	5.0E-21	1.6E-19	1.6E-21
Cm-248	100	nCi/g	4.48E-19	4.48E-21	1.2E-21	3.7E-20	3.7E-22
Cf-249	100	nCi/g	1.20E-20	1.20E-22	3.1E-23	1.0E-21	1.0E-23
Sum of Class C Factors				3.8	0.994		0.319
Alpha Emitting Transuranic nuclides with half-life > 5 years				3.8	0.987		0.316

(1) Not present in Tank 18 waste

Table 10. Tank 18 Waste Comparison to 10 CFR 61.55 Table 2

Radionuclides (Short-lived)	10 CFR 61.55 Class C Limit	Class C Units	Tank 18 Concentration in Class C Units	Factor Relative to Class C Limit	Factor with 123" Grout	Waste Concentration in Class C Units with Tank Filled with Grout	Factor with Tank Filled with Grout
Total of all nuclides with less than 5 year half-life	(1)	Ci/m^3	(1)	(1)	(1)	(1)	(1)
H-3	(1)	Ci/m^3	(1)	(1)	(1)	(1)	(1)
Co-60	(1)	Ci/m^3	(1)	(1)	(1)	(1)	(1)
Ni-63	700	Ci/m^3	1.67E-01	2.38E-04	4.9E-05	1.1E-02	1.5E-05
Ni-63 in activated metal	7000	Ci/m^3	(2)	(2)	(2)	(2)	(2)
Sr-90	7000	Ci/m^3	2.16E+00	3.08E-04	6.4E-05	1.4E-01	2.0E-05
Cs-137	4600	Ci/m^3	1.98E+01	4.31E-03	8.9E-04	1.3E+00	2.7E-04
Sum of Class C Factors				0.005	0.0010		0.000307

(1) There are no limits established for these radionuclides in Class C waste
(2) Not present in Tank 18

5.6.7 Chemical (Nonradionuclide) Inventories

No process knowledge estimates were developed for chemical inventories in Tank 18. The inventory estimates for chemical contaminants in Tank 18 were based on sample analysis alone. The 95% confidence interval upper bound for the nonradionuclide inventories was calculated using the same uncertainty propagation method used to calculate the 95% confidence interval upper bound for the radionuclide inventories.

To calculate the chemical inventories in the liquid, the measured chemical concentrations from the liquid sample (on a mass per unit volume basis) were multiplied by the 6,094 gallons of liquid estimated to remain in the tank. The total tank chemical inventories were calculated by adding the radionuclide inventories from the solids and the liquid.

The calculated chemical inventories in the heel are reported in the following table.

Fate and transport modeling of residual contaminants uses the concentration of the contaminants in the waste as an input. The concentrations listed in Table 11 are calculated by dividing the inventories by the mass of the rust and heel solids (16,686 kg).

Table 11. Nonradionuclide Inventories in Heel

	Solids Inventory	Liquid Inventory	Total Heel Inventory (Solids + Liquid)	Concentration of Total Chemical Inventory in 16,686 kg Solids
	(kg)	(kg)	(kg)	(g/g)
Silver	3.13E+00	3.60E-02	3.17E+00	1.90E-04
Aluminum	2.25E+03	3.71E-01	2.26E+03	1.35E-01
Boron	2.61E+02	3.90E+00	2.65E+02	1.59E-02
Barium	3.78E+00	3.60E-02	3.81E+00	2.28E-04
Calcium	4.65E+02	1.09E+00	4.66E+02	2.79E-02
Cadmium	1.17E+02	4.80E-02	1.17E+02	7.00E-03
Cerium	3.98E+01	5.95E-01	4.04E+01	2.42E-03
Cobalt	9.98E-01	0.00E+00	9.98E-01	5.98E-05
Chromium	1.11E+01	4.08E-02	1.11E+01	6.68E-04
Copper	4.99E+00	7.43E-02	5.06E+00	3.03E-04
Iron	1.72E+03	2.28E+01	1.74E+03	1.04E-01
Gadolinium	4.34E+00	5.28E-02	4.39E+00	2.63E-04
Lanthanum	3.22E+00	4.80E-02	3.27E+00	1.96E-04
Lithium	1.37E+01	2.04E-01	1.39E+01	8.31E-04
Magnesium	3.98E+02	1.49E-01	3.98E+02	2.38E-02
Manganese	2.15E+02	5.28E-02	2.15E+02	1.29E-02
Molybdenum	3.28E+01	4.89E-01	3.33E+01	2.00E-03
Sodium	8.53E+02	1.41E+01	8.67E+02	5.19E-02
Nickel	1.89E+01	1.80E-01	1.91E+01	1.14E-03
Phosphorus	7.80E+01	1.16E+00	7.92E+01	4.74E-03
Lead	3.95E+01	5.91E-01	4.01E+01	2.40E-03
Sulfur	6.14E+01	9.16E-01	6.23E+01	3.73E-03
Antimony	2.43E+01	3.62E-01	2.46E+01	1.48E-03
Silicon	1.15E+03	5.84E-01	1.15E+03	6.91E-02
Tin	3.94E+01	5.88E-01	4.00E+01	2.39E-03
Strontium	9.73E+01	2.40E-01	9.75E+01	5.84E-03
Titanium	3.19E+00	1.44E-02	3.20E+00	1.92E-04
Uranium	5.44E+02	6.30E-01	5.45E+02	3.26E-02
Vanadium	1.81E+00	2.63E-02	1.84E+00	1.10E-04
Zinc	8.84E+00	1.32E-01	8.97E+00	5.38E-04
Zirconium	1.92E+00	2.88E-02	1.95E+00	1.17E-04
Mercury	2.01E+01	5.28E-02	2.02E+01	1.21E-03
Potassium	3.46E+00	1.04E-01	3.56E+00	2.13E-04
Arsenic	8.03E-01	1.20E-02	8.15E-01	4.89E-05
Selenium	8.03E-01	1.20E-02	8.15E-01	4.89E-05
Fluoride		7.20E-01	7.20E-01	4.31E-05
Chloride		6.41E-01	6.41E-01	3.84E-05
Nitrate		7.75E+00	7.75E+00	4.65E-04
Nitrite		4.64E+00	4.64E+00	2.78E-04
Sulfate		1.20E+00	1.20E+00	7.19E-05
Phosphate		2.40E+00	2.40E+00	1.44E-04
Oxalate		2.00E+00	2.00E+00	1.20E-04

5.6.8 Inventory of Purex Low Heat Waste

The Tank 18 solids came from three different sources:

- Zeolite—Waste removal in Tank 19 transferred some of the zeolite from that tank into Tank 18. Zeolite was used as the ion exchange media in a cesium removal column that was used to decontaminate evaporator overheads. The spent zeolite resin from the column was dumped into Tank 19. The zeolite was in the form of relatively large, fast settling solids. The presence of zeolite and compounds derived from it is thought to be the reason that waste removal from the tank was so difficult, since these solids were difficult to suspend and transfer.
- Coating waste—Coating waste was the waste produced when the cladding (the coating) was stripped off SRS target tubes containing depleted uranium and plutonium. The tubes were clad with aluminum, which has a low neutron cross section and thus would not accumulate much radioactive materials. The cladding was stripped off using sodium hydroxide. The resulting waste was very low in radioactivity and was sent primarily to Type IV tanks (the single-walled tanks).
- Purex Low Heat Waste—This is the High Level Waste that is responsible for most of the radionuclides in Tank 18. Wastes from the first cycle of solvent extraction in the F-Area Canyon are called Purex High Heat Waste. Purex Low Heat Waste includes all other wastes, from second cycle, any subsequent cycles, and other sources.

The amount that each source contributed to the solids in Tank 18 can be estimated from the Tank 18 chemical compositions. Purex Low Heat Waste contains about 24 wt% iron[18] and is assumed to be the only source that contained a significant amount of iron. Thus, it can be assumed that most of the iron in the tank came from Purex Low Heat Waste. This is conservative because it does not take into account iron from airborne dust/dirt from continuous ventilation for 40 years, tank corrosion, and impurity iron in the zeolite (chabazite mined from natural deposits). Zeolite is primarily sodium aluminosilicates and is the only source that contained a significant amount of silicon. Thus, it can be assumed that most of the silicon in Tank 18 came from zeolite.

Unfortunately, coating waste contains no signature element. It is largely aluminum hydroxide. Aluminum is also in Purex Low Heat Waste and zeolite.

Assuming the zeolite can be represented by hydrated sodalite with a chemical formula of $Na_8(Al_6Si_6O_{24})(NO_3)_2{*}4H_20$, the compositions of the major chemical constituents in Tank 18, Purex Low Heat Waste, and hydrated sodalite are as follows:

Table 12. Elemental Compositions

	Tank 18 Concentration in 760-gal SW Mound based on Sample #6	Tank 18 Concentration in remaining 3,574-gal solids based on Avg. of Samples 1-5	Tank 18 Concentration in Total 4,334-gal Solids based on 95% Confidence Interval Upper Bound Inventory	Purex Low Heat Waste	Hydrated Sodalite
	(wt.%)	(wt.%)	(wt. %)	(wt.%)	(wt.%)
Al	7.3	14.7	13.8	4.7	14.8
Fe	17.5	9.0	10.5	24.3	0.0
Na	2.8	5.0	5.2	3.8	16.8
Si	1.4	6.9	7.0	0.9	15.4

The concentrations of these key elements in the total solids were calculated by dividing the 95% confidence interval upper bound inventory of each signature element by the total mass of solids in the tank (16,357-kg). Based on this information, the amounts that each source contributed to the solids in Tank 18 can be calculated as follows:

Table 13. Composition of Tank 18 Solids

Constituent	Estimated composition of Tank 18 solids	Estimated mass in Tank 18 heel	Estimated volume in Tank 18 heel	Based on:
	(wt.%)	(lb)	(gal)	
Zeolite (hydrated sodalite)	45.7	16,480	1,981	Si
Purex Low Heat Waste	43.1	15,579	1,872	Fe
Other (primarily coating waste)	11.2	4,003	481	Balance
Totals	100.0	36,062	4,334	

The estimated quantities of zeolite and Purex in Table 13 were calculated by dividing the concentration of the material signature elements (Si and Fe) in the solids by the concentrations of these elements in zeolite and Purex. The results show that about 46% of the material in Tank 18 was derived from zeolite, about 43% was derived from Purex, and about 11% was derived from coating waste.

The constituent analysis also shows that the 760-gal unmoved Southwest mound is composed of a different material than the solids in the remainder of the tank. The Southwest mound is mostly Purex, while the remainder of the solids have a much higher composition of zeolite. This is supported by the fact that the Southwest mound has more iron and less silicon than the waste in the remainder of the tank. This is also supported by the fact that the Cs-137 inventory was much less in the 760-gal Southwest mound than in the remainder of the tank. Zeolite was used in the tank farms specifically for its high Cs-137 affinity, so one would expect there to be more Cs-137 in the solids that contains more solids derived from zeolite.

The difference in constituent makeup for the two solids volumes in Tank 18 is likely due to the fact that the ADMP did not erode or mix the solids remaining in the Southwest mound. These solids would contain mostly Purex and less of the zeolite transferred from Tank 19 in 2001. The Tank 18 waste removal campaign in 2003 has likely mixed the zeolite from Tank 19 with all of waste in the tank other than the Southwest mound which was not eroded or mixed by the ADMP.

5.6.9 Other Contaminants

Three risers in Tank 18 contain lead, which acted as radiation shielding when the tank stored HLW. Plans are to leave these risers in place when the tank is closed. These three risers contain a total of approximately 800 pounds of lead.

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