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Characterization of Tank 19 Residual Waste

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1. Introduction

Plans are to close Tank 19, a Type IV waste tank in the F-Area Tank Farm, by filling it with pumpable backfill materials. Most of the waste was removed from the tank in the 1980s, and more waste has been removed recently.

To obtain approval for closure, fate and transport groundwater modeling must be performed to ensure that closing the tank with the residual inventory complies with environmental performance standards. This report documents the basis for the residual waste inventories that will be used in the Tank 19 fate and transport modeling and Class C waste determination.

2. Summary

The total residual solids volume in Tank 19 was determined to be 15,100 gallons. The mass of solids on a dry basis is approximately 121,480 lb.

Most of the radionuclides in Tank 19 came from Purex Low Heat Waste from F Canyon. Based on the iron content of the residual solids in Tank 19, only about 8 wt % of the contaminants in Tank 19 came from Purex Low Heat Waste. The remaining solids were derived from zeolite (containing retained Cs-137) from the cesium removal column and coating waste (which had very low radioactivity) from F Canyon.

The composition of the waste in Tank 19 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 all constituents that are significant from a tank closure standpoint. The inventories reported for these key constituents are based on sample data. For all other radionuclides, the inventories are based on estimated values.

Samples and observations indicate that, with the exception of one sample of crusty material, the vigorous agitation during waste removal homogenized the solids in the tank, so sampling can be relied upon to give an accurate estimate of the entire tank contents. Visual examinations of the solid surface during pumping operations indicate that at least 92 vol % of the solids in the tank were moved during waste removal operations. A full-depth core sample taken from the spot in the tank that had the most potentially unmoved solids had concentrations similar to the other samples, which is further evidence that the tank was homogenized.

For some components, the concentrations measured in samples differed greatly from the concentrations predicted by process knowledge, probably because of the presence of zeolite and degraded forms of zeolite, which are known to be good absorbers of certain cations. The most notable constituent is Cs-137, which is enriched more than two orders of magnitude above its process knowledge estimate. This is expected, because the zeolite that was added to the tank was added specifically because of its high affinity for cesium.

Cs-137 has a short enough half-life (30 years) and moves slowly enough through the environment so that it does not migrate very far from the tank before decaying away. Thus, this elevated inventory of Cs-137 is not a performance assessment concern. There was also enrichment of Tc-99, although the Tc-99 concentration is still low because the tank contains predominantly solids derived from zeolite and coating waste.

3. Background

Tank 19 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 19 was placed in service in 1961 and initially received a small amount of low heat waste from Tank 17. It then served as an evaporator concentrate (saltcake) receiver from February 1962 to September 1976. Tank 19 also received the spent zeolite ion exchange media from a cesium removal column that once operated in the northeast riser of the tank to remove cesium from the evaporator overheads. From July 1980 to August 1981, the Tank 19 bulk waste removal program used two agitation pumps and a telescoping transfer jet assembly to reduce the waste volume in Tank 19 from over one million gallons to an estimated 33,000 gallons.

4. Waste Removal in Preparation for Tank Closure

From September 2000 to August 2001, heel removal was performed on the estimated 33,000 gallons of material remaining in Tank 19. In this campaign, three submersible ducted turbine mixers installed in the east, west, and southwest risers operated in varying orientations to suspend solids from the heel into the liquid. A centrifugal transfer pump in the northeast riser was used to transfer the slurry from Tank 19 to Tank 18. Decanted liquid from Tank 18 was recycled back to Tank 19 as the slurry media for each transfer. The southwest mixer, however, failed after 266 hours of operation, and the remaining transfers were performed using only the east and west mixers. These mixers, together with the transfer pump, completed approximately 3,000 hours of mixing and 46 transfers out of Tank 19. In August 2001, a spraywashing waterjet tool in the center riser was used to spray the interior tank walls with inhibited wash water to the highest historical waste level, which was 377 inches from the tank bottom, to dislodge contamination remaining after bulk waste removal.

5. Estimating the Tank 19 Residual Inventories

There are two kinds of residual material in Tank 19—solids and liquid (aqueous salt solution). 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 %), and most of the liquid in Tank 19 is in the solids.

Unlike Tanks 17 and 20, the two tanks that have been previously closed, the inventory of radionuclides in the liquid in Tank 19 must be accounted for to accurately estimate the inventory in the tank. In estimating the inventory in Tanks 17 and 20 in preparation for closure, the inventory of radionuclides in the liquid was assumed to be negligible and was not included in the total.[1,2] The bulk waste removal and spray washing in these tanks was done primarily by adding fresh water with each mixing batch, which washed soluble radionuclides out of the liquid. However, the recent heel removal in Tank 19 was conducted by using primarily recycled liquid from Tank 18. Since soluble radionuclides were not effectively washed out of the system, the concentrations of radionuclides in the Tank 19 liquid are much higher than in Tanks 17 and 20.

Most of the solids in Tank 19 are on the floor of the tank. However, Tank 19 also has a small inventory of visible solids on the stiffener bands on the inside of the tank.

5.1 Estimating the Mass of Solids

The mass of solids in the Tank 19 heel was estimated by first estimating the volume of the wet solids and then applying an estimate of the mass of dry solids per volume of wet solids.

During each waste removal step, the contents of the tank were agitated using submersible turbine mixers and then the slurry was pumped out, removing some of the solids that had been suspended during that step. The volume of wet solids was estimated by observing the liquid/solid interface in the tank while the slurry was being pumped out.[3] 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 solid 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. A separate mapping was developed for each pumping operation that was observed. However, not every pumping operation was mapped.

In Tank 19, there were also solids on the stiffener bands around the inside circumference of the tank. Tank 19 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. Historical photographs of Tank 19 show piles of solids built up on these angle bands. Attempts to remove all of these solids during spray washing were unsuccessful, and some solids (approximately 100 gallons) remain on the angles. To estimate this volume, the cross-sectional shape of the material on the angles was conservatively 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.

5.1.1 Solids Moved and/or Mixed by Waste Removal

Examination of the contour plots from all of the pumping operations indicate that at least 92 vol % of the solids in the tank were moved during waste removal, which indicates that the turbine mixers were effective at moving and mixing the contents of the tank. This is one piece of evidence that the solids are relatively homogeneous. The second piece of evidence that the solids are homogeneous is the samples (see section 5.4).

The estimate of 92% was derived by examining all the contour plots from the various pumping operations and comparing contours at similar levels. For example, if there was a spot in the tank that showed solids at the 3.4-inch level after every pumping operation, then that spot was identified as having more than 3.4 inches of unmoved solids. It was conservatively assumed that the height of solids was at least the next level at which data was available, in this case 5.4 inches. If in any of the pumping operations, only liquid was observed at that spot at the 3.4-inch level, then obviously the solids had been moved by the mixers at that spot.

Note that if a spot showed solids at, for example, 3.4 inches with each pumping operation, that does not necessarily mean that the solids were unmoved. It's possible that the solids were moved but that the mixer operation tended to always deposit solids at this point in the tank. Thus, this analysis technique produced an estimate of the maximum amount of solids that could have been unmoved.

By examining all the spots at each liquid level, a contour plot of possible areas of unmoved solids was developed.[3] Integrating the area under the contour plot, it was estimated that a maximum of 1,175 gallons of heel might not have moved. This was rounded to 1,200 gallons for this report. Thus, the amount of solids that were not moved by the Flygt mixers is less than 8% (1,200 gallons divided by 15,000 gallons); at least 92% of the solids were moved.

5.1.2 Final Mass of Solids

The final volume of solids in the tank was estimated from the contour plot developed during the final pumping operation, which occurred on August 23, 2001. For spots in the tank where the solids surface is underneath the liquid surface, it was assumed that the solids depth was 75% of the liquid level, which is conservative. Integrating under the contour plot developed during this pumping operation indicates that the tank contains 14,990 gallons of solids,[3] which was rounded to 15,000 gallons for this report. Adding this 15,000 gallons of solids in the heel to the 100 gallons of solids on the angle stiffeners provides the estimate of total solids in Tank 19 of 15,100 gallons.

The initial issue of this report, published on March 15, 2002, used a solids bulk density of 1.95 pounds of dry solid per gallon of wet solids. This was based on previous studies, which demonstrated that, on the average, there are approximately 1.95 pounds of dry solids per gallon of wet settled sludge.[4] However, in August 2002 a ceramics expert reviewed this report and noted that since the Tank 19 solids were primarily zeolite, the

bulk density was likely to be higher than that of settled sludge. As a result of this observation, High-Level Waste Engineering requested the Savannah River Technology Center (SRTC) to measure the bulk density of archived samples of Tank 19 solids, which had not been previously done. SRTC personnel designed experiments to measure this density and carried out the experiments in the SRTC Shielded Cells Facility.

The results of these experiments showed the average bulk density of the Tank 19 samples to be 0.964 gram of dry solids per milliliter of wet solids (8.045 pounds per gallon).[5] This is indeed higher than the average sludge bulk density of 1.95 pounds per gallon previously used. Assuming the solids on the stiffener bands have the same density as the heel solids, the estimated mass of dry solids in Tank 19 is as follows:

$$8.045\frac{lb}{gal} \bullet 15{,}100\ gal = 121{,}480\ lb \bullet \frac{1kg}{2.20462lb} = 55{,}102kg$$

5.2 Estimating the Volume of Liquid

The volume of liquid was estimated using the same contour information that was used to estimate the volume of solids. Typically, sludge contains 70-85% liquid by volume, i.e., it has the consistency of pudding. As noted previously, Tank 19 is primarily zeolite with more solids per gallon than ordinary sludge, so it is likely to have less entrained liquid than sludge. However, for the purposes of this calculation it was assumed that the solids contained 85 vol.% liquid[3]. Thus the volume of liquid in the solids is estimated as:

$$15{,}100\ gal \bullet 0.85 = 12{,}835\ gal$$

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 are protruding above the liquid surface. As mentioned previously, in these areas it was conservatively assumed that the solids occupied 75% of the volume. Assuming the remaining 25% is free liquid, the estimated free liquid in the tank is 1,800 gallons. Thus, the total estimated volume of liquid in the tank is 12,835 gallons of interstitial liquid plus 1,800 gallons of free liquid, or 14,635 gallons.

5.3 Estimating the 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 (1.19)[6], and converting to the appropriate units. The interstitial liquid in the 100 gallons of solids on the stiffener bands was not included because this liquid has likely evaporated.

$$15{,}000gal \bullet 0.85 \bullet \frac{1.19kg}{L} \bullet \frac{3.785L}{gal} = 57{,}428kg$$

5.4 Summary of Radioactive Waste Volumes

There are 15,100 gallons of solids in Tank 19. Based on the assumption in Section 5.2 that 85% of this volume is interstitial liquid, the 15,100 gallons of waste is comprised of 12,835 gallons of interstitial liquid and 2,265 gallons of dry solids. Based on the measured density of the heel material discussed in Section 5.1.2, this assumption underestimates the volume of solids and overestimates the volume of interstitial liquid in the heel. This is conservative in estimating the tank radionuclide and chemical inventories because it increases the estimated inventories in the liquid. Because the solids inventories are calculated on a weight basis, the underestimation of the dry solids volume has no effect on the estimation of the solids inventories. Additionally, there are an estimated 1,800 gallons of free liquid remaining in the tank. The following table summarizes the calculated waste volumes in the bottom of Tank 19.

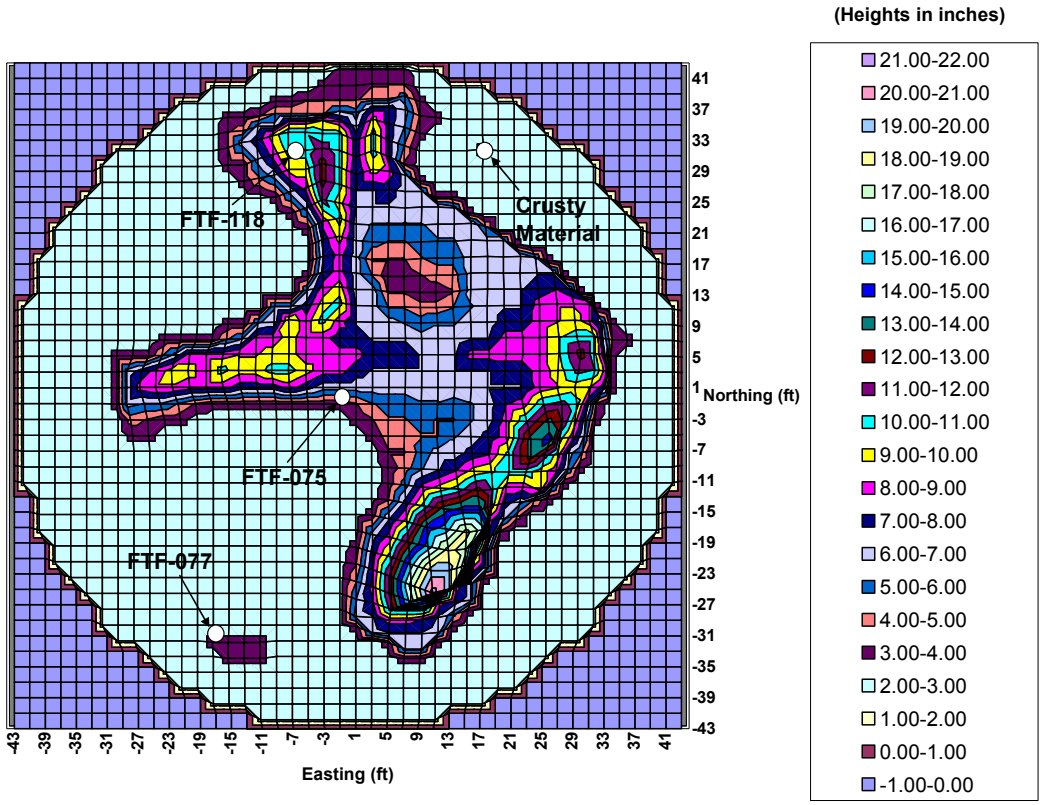
Dry solids	2,265 gallons
Interstitial liquid	12,835 gallons
Free liquid	1,800 gallons
Total	16,900 gallons

Therefore, there are 14,635 total gallons of liquid in Tank 19; this number was used to calculate the liquid radionuclide inventory from the liquid sample concentrations. The solids chemical and radionuclide inventories were determined using 121,480 lb of dry solids.

5.5 Sampling

A total of four solids samples from the residual materials in Tank 19 and one liquid sample from Tank 18 were obtained immediately preceding and following the waste removal campaign in 2000 and 2001. The results of these samples are documented in Tables 2, 3, and 5. Figure 1 shows the riser locations used to take each of the four samples from the Tank 19 heel.

Figure 1
Tank 19 Sample Locations



In revision 0 of this report an earlier sample taken in 1996 was also included as one of the samples. However, this sample was taken before the latest waste removal campaign, and the composition may have changed since the sample was taken because waste removal preferentially removed smaller particles, which might have had different composition than the large particles. Also, as part of the review of plutonium and americium analyses for revision 1, it was noted that the plutonium concentrations reported for this sample were markedly higher than the other four. A review of these results indicated that it was likely that the 1996 sample results were off by quite a bit due to the inability of SRTC (in 1996) to perform chemical separations before counting the sample, which improves accuracy considerably. Consequently, the 1996 sample was excluded from the averages used in estimating the tank radionuclide and chemical inventories.

The liquid sample was actually taken from Tank 18. However, as mentioned previously, waste removal from Tank 19 was conducted by slurrying material from Tank 19 to Tank 18, then transferring the liquid from Tank 18 back to Tank 19. Over 40 transfers between the two tanks were made during this waste removal campaign. Thus, the liquid in both tanks is well mixed and is the same composition. At the time of the final sampling, there was very little liquid in Tank 19. Minimizing the amount of liquid in Tank 19 before closure was desirable, because it reduced the residual inventory, but it made it difficult to obtain a liquid sample because there was no liquid under available sample risers. Thus, the sample was taken from Tank 18, which (at the time) held the bulk of the liquid that

had been transferred back and forth. The results of the liquid sample are reported in Table 2 and Table 5.

With the exception of one sample, the four solids samples appeared to be the same material and had similar compositions. The one exception was a sample of crusty material that was taken on 12/7/2000, before the mixing campaign. This hard, crusty material was on the top of a mound in the position for the transfer pump. The crusty material interfered with the installation of the transfer pump and was sampled to determine its composition. The analysis indicates that this is a different phase that is not typical of the bulk composition of the tank.

The crusty material had lower levels of key radionuclides than the other three samples. The composition of the material is noted in Table 2 and Table 5, but was excluded from the averages used in estimating the tank radionuclide and chemical inventories. Observation of the tank indicates that the crusty material represented a small volume, and excluding it is conservative because it had lower concentrations of key radionuclides. Also, this material was dissolved with a high pressure hydrolance and subsequently distributed throughout the tank during mixer operation.

One concern in characterizing the solids in Tank 19 was that there may be areas of the tank that were not mixed and that would have a different composition than the bulk solids. As mentioned previously, as much as 1,200 gallons of solids might not have moved during waste removal.

To determine the composition of these potentially unmoved solids, a new riser was core drilled through the roof of the tank a few feet east of the northwest riser. The location of the new riser was directly above the area that contained the largest volume of potentially unmoved solids.

A core sample was obtained from this location. The sample was transported to the SRTC High Level Caves, opened, and inspected. A group consisting of employees of SRTC Waste Process Technology (WPT) section and High Level Waste Engineering viewed the core and agreed that it appeared homogeneous. The sample contained coarse solids similar to what had been observed in the previous grab samples. Small portions of the core were archived in case analyses at different depths were desired at a future date. The rest of the core was mixed and analyzed.

The core sample results are quite similar to the other grab samples, confirming that the composition of the potentially unmoved core is about the same as the bulk solids that have been mixed. Perhaps this potentially unmoved mound had actually been moved, but the mixing patterns used during waste removal left a mound in this location each time the solids were mapped. Descriptions of the four samples taken of the residual solids in Tank 19 are shown in Table 1.

Table 1. Samples from Tank 19

No.	Sample Date	Description of Sample	Reason for Sample	Sample No.	Composition reported in
1	12/2000	Grab sample of surface solids under northeast riser	Characterize the crusty material that was blocking installation of the transfer pump	NA	Reference 7
2	9/2001	Grab sample under center riser	Characterize bulk solids in preparation for tank closure	FTF-075	References 8 and 13
3	9/2001	Grab sample under southwest riser	Characterize bulk solids in preparation for tank closure	FTF-077	References 8 and 11
4	12/2001	Core sample under new riser cored in tank roof over potentially unmoved mound	Compare the composition of potentially unmoved solids to the bulk solids that have been moved by the mixers	FTF-118	References 8 and 13
5	9/2001	Dip sample of liquid from Tank 18	Determine the composition of liquid in the Tank 18-19 system	FTF-076	Reference 8

5.6 Process Knowledge Estimates

5.6.1 Chemical Contaminants

Process knowledge estimates were developed only for chemicals which were not analyzed for in the FTF-076 liquid sample (Ag, Hg, As, and Se). The inventory estimates for solids and all other chemical contaminants in the Tank 19 liquid were based on samples alone. In the tanks previously closed, Tanks 17 and 20, the chemistry of the waste was well known, and the contents of the tank had been homogenized using slurry pumps. Therefore, process knowledge was used to predict the chemical inventories in these tanks. However, in Tank 19, reactions between the various compounds added to the tank have created new compounds, and video of the interior of the tank indicated it might not be homogeneous.

5.6.2 Radionuclides

Radionuclide estimates of the composition of residual waste in Tank 19 were derived from the Waste Characterization System (WCS)[9] and a special analysis which characterized additional radionuclides for Tank 19[10]. It is estimated that only about 8 wt % of the residual material in Tank 19 was derived from Purex Low Heat Waste, which is

the waste that is tracked by the WCS (see section 5.7.4, "Inventory of Purex Low Heat Waste").

The inventories and compositions of major sludge constituents in WCS are based on tank fill histories and sludge transfers from the canyons to the tank farms and between tanks. WCS computes the inventory of fission, decay, and activation products (H-3 through Ra-228 in Table 3) using concentrations based on yield distributions in SRS reactor assemblies, solubility data, and other information. WCS computes the inventory of sludge actinides (Ac-227 through Cf-249 in Table 3) using a combination of techniques used for chemicals and fission and activation products. The mass of major actinides in each transfer are known from canyon accountability records or process records. The concentration of minor actinides was estimated from yield distributions in SRS reactor assemblies. WCS also includes decay calculations.

5.6.3 Tc-99

The predicted tank inventory reported for the WCS estimate in Table 3 for Tc-99 is based on an adjusted concentration that is 13.5 times the concentration originally reported by WCS. This is the only nuclide for which the process knowledge concentration has been adjusted. The value for this radionuclide was adjusted for two reasons:

The performance evaluation predicts that the dose at the seepline will be predominantly due to Tc-99. Therefore, it is important to estimate this radionuclide conservatively. Sample results indicated that the concentration of Tc-99 in the residual solids in Tanks 17 and 20 was elevated relative to the concentration predicted by WCS for the bulk solids in these tanks. In particular, the ratio of Tc-99 to iron (iron is an indicator for sludge) was extremely high in Tank 20. The Tc-99 in Tank 17 was also enriched relative to WCS predictions, although not to the same extent as Tank 20.

The adjustment factor of 13.5 was chosen in September 1996 based on sample results from Tank 20. At that time the Tc-99 concentration predicted for Tank 20 by process knowledge was 6.95 E-05 Ci/kg, whereas the measured concentration in the Tank 20 solids was 0.94 microCi/gm, which is equivalent to 9.4 E-04 Ci/kg.[11] Since that time, the process knowledge estimate has changed slightly due to refinements in the method of calculation. However, the error introduced by using the old adjustment factor is small relative to other conservative assumptions, so there are no plans to revise the Tank 20 performance evaluation.

The need for the adjustment factor is thought to be due to the fact that Tc-99 behaves differently from other fission products. WCS predicts that most of the fission products go to High-Heat Waste, which is the waste produced by the first cycle of solvent extraction in the Purex process used in the SRS Canyons. However, less Tc-99 is removed in the first cycle than other fission products, so Low Heat Waste (the kind of waste in Tank 19) is enriched in Tc-99. Perhaps after a number of tank closures it may be possible to identify standard factors that can be incorporated into WCS.

In Tank 19, the inventory of Tc-99 is about 40% of the value predicted from process knowledge. The calculated inventory from the solids samples is 6.37 Ci versus a predicted inventory of 16.0 Ci. This suggests that the 13.5 multiplier factored into the predicted inventory is too conservative for Tank 19. However, backing out the 13.5 multiplier from the predicted inventory shows that the Tc-99 inventory is enriched by a factor of 5 when compared to the inventory predicted by WCS.

Table 2. Radionuclide Concentrations from Solids and Liquid Samples

	Solids:							Liquid:
Radio-nuclides	Crusty Solids Dec-00	FTF-075 Bulk Solids Sept-01	FTF-077 Bulk Solids Sept-01	FTF-118 Cored Solids Dec-01	Average Excluding Crusty Solids	Relative Std. Dev. Excluding Crusty Solids	Upper 95% Confidence Limit of Solids Concentration Based on Samples	FTF-076 Dip Sample from Tank 18
	(microCi/g)	(microCi/g)	(microCi/g)	(microCi/g)	(microCi/g)	(%)	(microCi/g)	(microCi/L)
H-3								6.83
Se-79		<6.46E-04	<8.67E-04	<4.48E-04	6.54E-04	32.1%	1.01E-03	<0.0226
Sr-90	0.530	<16.8	<16.9	0.658	6.58E-01**	12.5%**	7.25E-01**	
Tc-99	0.0205	0.0868	0.0888	0.109	9.49E-02	12.9%	1.16E-01	7.13
Cs-137	62.8	791	821	862	8.25E+02	4.3%	8.85E+02	4360
U-233	6.28E-04	<0.0106	<0.0107	≤1.28E-03	7.53E-03	71.9%	1.66E-02	<0.0466
U-234	7.49E-04	<6.85E-03	<6.90E-03	8.07E-04	8.07E-04**	3.2%**	8.51E-04**	<0.0301
U-235	8.56E-06	1.79E-05	1.33E-05	1.98E-05	1.70E-05	19.7%	2.26E-05	7.82E-05
U-236	1.99E-05	<7.09E-05	<7.14E-05	3.75E-05	3.75E-05**	21.9%**	5.13E-05**	<3.11E-04
U-238	2.80E-04	5.81E-04	4.49E-04	6.81E-04	5.70E-04	20.4%	7.67E-04	2.19E-03
Np-237	1.98E-04	<7.73E-04	<7.78E-04	1.61E-04	1.61E-04**	10.6%**	1.90E-04**	<3.39E-03
Pu-238	0.505	0.377*	0.253*	0.285*	3.05E-01	21.1%	4.14E-01	0.963
Pu-239	0.155	0.489*	0.400*	0.315*	4.01E-01	21.7%	5.48E-01	0.430
Pu-240	0.0575	0.169*	0.142*	0.107*	1.39E-01	22.3%	1.92E-01	<1.10
Pu-241		0.941*	0.810*	0.794*	8.48E-01	9.5%	9.84E-01	1.32
Pu-242	2.88E-04	<4.19E-03	<4.21E-03	<4.82E-04	2.96E-03	72.5%	6.58E-03	<0.0184
Am-241		0.179*	0.126*	0.083*	1.29E-01	37.0%	2.10E-01	<0.154

*Pu-238, Pu-239, Pu-240, Pu-241, and Am-241 concentrations are from WSRC-TR-2002-00540 (Reference 13). All other concentrations are from References 7 and 8.

**For Sr-90, U-234, U-236, and Np-237, there were three reported solids concentrations, two less-than-detection-limit values and one actual value. Both of the less-than-detection-limit values are greater than the actual value. Therefore, in the statistical treatment of these radionuclides, the average tank concentration was assumed to be equal to the actual concentration value. The 95% confidence concentrations for these radionuclides are based on standard deviations and number of measurements reported in WSRC-TR-2002-00107 (Reference 8).

Table 3. Tank 19 Radionuclide Inventories

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	Total Inventory Estimate (Solids + Liquids + Corrosion Product)
	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)
H-3	NVR			5.54E+00	3.78E-01	3.78E-01	0.0E+00	3.78E-01
C-14	1.40E-02		1.40E-02	9.75E-02		9.75E-02		1.12E-01
Co-60	7.22E+00		7.22E+00	5.71E-02		5.71E-02		7.28E+00
Ni-59	8.26E-01		8.26E-01	NVR				8.26E-01
Ni-63	7.61E+01		7.61E+01	1.38E-01		1.38E-01		7.62E+01
Se-79	6.83E-02	5.55E-02	5.55E-02	NVR	1.25E-03	1.25E-03	2.2E-03	5.89E-02
Sr-90	3.59E+03	4.00E+01	4.00E+01	6.88E-02		6.88E-02	4.6E-04	4.00E+01
Y-90	3.59E+03		4.00E+01	6.88E-02		6.88E-02		4.00E+01
Nb-94	3.62E-05		3.62E-05	3.62E-08		3.62E-08		3.63E-05
Tc-99	1.60E+01	6.37E+00	6.37E+00	2.96E-01	3.95E-01	3.95E-01	0.0E+00	6.76E+00
Ru-106	2.70E-04		2.70E-04	NVR				2.70E-04
Rh-106	2.70E-04		2.70E-04	NVR				2.70E-04
Sn-126	1.27E-01		1.27E-01	NVR				1.27E-01
Sb-125	2.59E+00		2.59E+00	NVR				2.59E+00
Sb-126	1.78E-02		1.78E-02	n/a				1.78E-02
Sb-126m	1.27E-01		1.27E-01	n/a				1.27E-01
Te-125m	6.32E-01		6.32E-01	NVR				6.32E-01
I-129	5.62E-06		5.62E-06	4.39E-05		4.39E-05		4.95E-05
Cs-134	7.49E-03		7.49E-03	NVR			1.1E-04	7.60E-03
Cs-135	7.91E-04		7.91E-04	NVR				7.91E-04
Cs-137	2.49E+02	4.88E+04	4.88E+04	2.80E+02*	2.42E+02	2.80E+02*	2.0E+02	4.92E+04
Ba-137m	2.35E+02		4.61E+04	2.65E+02*		2.65E+02*		4.64E+04
Ce-144	3.71E-06		3.71E-06	NVR				3.71E-06
Pr-144	3.71E-06		3.71E-06	NVR				3.71E-06
Pm-147	4.15E+01		4.15E+01	NVR				4.15E+01
Sm-151	1.30E+00		1.30E+00	n/a				1.30E+00
Eu-152	5.62E-03		5.62E-03	n/a				5.62E-03
Eu-154	1.47E+01		1.47E+01	NVR				1.47E+01
Eu-155	7.57E-02		7.57E-02	n/a				7.57E-02
Ra-226	1.06E-07		1.06E-07	n/a				1.06E-07
Ra-228	NVR			n/a				0.00E+00
Ac-227	2.85E-07		2.85E-07	n/a				2.85E-07
Th-229	2.61E-03		2.61E-03	n/a				2.61E-03
Th-230	1.29E-05		1.29E-05	n/a				1.29E-05
Th-232	NVR			NVR				0.00E+00
Pa-231	7.90E-07		7.90E-07	n/a				7.90E-07
U-232	2.09E-04		2.09E-04	7.96E-07		7.96E-07		2.10E-04
U-233	NVR	9.17E-01	9.17E-01	4.18E-02	2.58E-03	2.58E-03	6.3E-02	9.83E-01
U-234	NVR	4.69E-02	4.69E-02	NVR	1.67E-03	1.67E-03	4.1E-02	8.96E-02
U-235	1.37E-03	1.25E-03	1.25E-03	5.22E-06	4.33E-06	4.33E-06	1.1E-04	1.36E-03
U-236	NVR	2.83E-03	2.83E-03	NVR	1.72E-05	1.72E-05	4.2E-04	3.27E-03
U-238	1.25E-01	4.22E-02	4.22E-02	4.77E-04	1.21E-04	1.21E-04	3.0E-03	4.54E-02
Np-237	NVR	1.05E-02	1.05E-02	4.20E-03	1.88E-04	1.88E-04	5.7E-04	1.12E-02
Pu-238	5.14E+02	2.28E+01	2.28E+01	1.96E+00	5.34E-02	5.34E-02	1.7E+00	2.45E+01
Pu-239	7.34E+01	3.02E+01	3.02E+01	2.79E-01	2.38E-02	2.38E-02	9.4E-01	3.12E+01
Pu-240	1.64E+01	1.06E+01	1.06E+01	6.25E-02	6.09E-02	6.09E-02	<5.0E-01	1.11E+01
Pu-241	2.20E+03	5.42E+01	5.42E+01	8.37E+00	7.31E-02	7.31E-02	6.0E-01	5.49E+01
Pu-242	3.38E-02	3.63E-01	3.63E-01	1.28E-04	1.02E-03	1.02E-03	<8.3E-03	3.72E-01
Pu-244	1.66E-03		1.66E-03	n/a				1.66E-03
Am-241	2.04E+02	1.16E+01	1.16E+01	7.75E-01	8.53E-03	8.53E-03	<1.3E-01	1.17E+01
Am-242m	NVR			1.93E+00		1.93E+00		1.93E+00
Am-243	1.75E-07		1.75E-07	n/a				1.75E-07
Cm-242	9.07E-22		9.07E-22	n/a				9.07E-22
Cm-243	2.70E-06		2.70E-06	n/a				2.70E-06
Cm-244	3.04E-03		3.04E-03	1.15E-05		1.15E-05		3.05E-03
Cm-245	1.96E-09		1.96E-09	7.46E-12		7.46E-12		1.97E-09
Cm-247	6.16E-20		6.16E-20	n/a				6.16E-20
Cm-248	1.42E-20		1.42E-20	n/a				1.42E-20
Bk-249	5.36E-30		5.36E-30	n/a				5.36E-30
Cf-249	3.96E-22		3.96E-22	n/a				3.96E-22

*As described in Reference 10, predicted liquid inventories for Cs-137 and Ba-137m based on a 1/10/2002 dip sample. These sample results were selected to represent the tank inventory because they were from a more recent sample and are greater than sample FTF-076.

Note: Dose contributing beta emitters for Tank 19 were modeled separately for solids and liquid.

Table 4. Class C Radionuclide Inventories Decayed to 2020

Radio-nuclides	Inventory
	(Ci)
C-14	1.12E-01
Ni-59	8.26E-01
Ni-63	6.73E+01
Sr-90	2.57E+01
Nb-94	3.63E-05
Tc-99	6.76E+00
I-129	4.95E-05
Cs-137	3.25E+04
Np-237	1.13E-02
Pu-238	2.14E+01
Pu-239	3.12E+01
Pu-240	1.11E+01
Pu-241	2.30E+01
Pu-242	3.72E-01
Pu-244	1.66E-03
Am-241	1.24E+01
Am-242m	1.77E+00
Am-243	1.75E-07
Cm-242	1.45E+00
Cm-243	1.74E-06
Cm-244	1.53E-03
Cm-245	1.97E-09
Cm-247	6.16E-20
Cm-248	1.42E-20
Cf-249	3.82E-22

Table 5. Chemical Concentrations from Solids and Liquid Samples

	Solids:					Liquid:
Species	Crusty Solids Dec-00	FTF-075 Bulk Solids Sept-01	FTF-077 Bulk Solids Sept-01	FTF-118 Cored Solids Dec-01	Average Excluding Crusty Solids	FTF-076 Dip Sample from Tank 18
	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(mg/L)
Silver		6.18E-03	5.88E-03	2.06E-02	1.09E-02	0.182**
Aluminum	1.53E+01	1.44E+01	1.39E+01	1.24E+01	1.36E+01	3,340
Boron	2.90E-03	1.00E-02	≤4.40E-03	≤5.71E-03	6.70E-03	0.599
Barium	2.85E-02	7.13E-02	9.55E-02	1.04E-01	9.03E-02	<0.301
Calcium	1.48E+00	7.90E-01	8.36E-01	1.10E+00	9.08E-01	<0.100
Cadmium	5.69E-03	1.07E-02	9.67E-03	8.83E-03	9.73E-03	≤0.251
Cerium		<3.56E-01	<3.59E-01	<3.32E-01	3.49E-01	
Cobalt	1.00E-02	6.05E-03	7.40E-03	1.12E-02	8.22E-03	<0.301
Chromium	2.57E-02	3.86E-02	3.22E-02	3.54E-02	3.54E-02	25.9
Copper	3.39E-03	<4.46E-03	<4.50E-03	4.82E-03	4.59E-03	<0.301
Iron	1.46E+00	1.64E+00	1.90E+00	2.20E+00	1.91E+00	<0.401
Lanthanum	2.70E-02	<9.92E-03	<9.96E-03	2.39E-02	1.46E-02	<1.00
Lithium	4.70E-03	4.07E-03	4.18E-03	≤2.85E-03	3.70E-03	<0.301
Magnesium	4.08E-01	2.40E-01	2.55E-01	2.59E-01	2.51E-01	<0.100
Manganese	6.06E-02	1.42E-01	1.45E-01	1.23E-01	1.36E-01	<0.100
Molybdenum	7.24E-03	≤1.01E-02	≤8.71E-03	≤8.76E-03	9.20E-03	2.59
Sodium		1.74E+01	1.70E+01	1.61E+01	1.68E+01	97,300
Nickel	1.70E-02	1.61E-02	1.45E-02	1.18E-02	1.41E-02	<0.902
Phosphorus	3.50E-02	<4.22E-02	≤4.37E-02	3.78E-02	4.12E-02	48.2
Lead	2.70E-01	≤5.06E-02	≤4.78E-02	4.68E-02	4.84E-02	<4.61
Silicon	1.23E+01	9.91E+00	1.00E+01	1.04E+01	1.01E+01	18.9
Tin	2.70E-01	<2.49E-02	≤2.00E-02	≤2.43E-02	2.31E-02	13.4
Strontium	3.15E-02	1.94E-02	2.04E-02	2.19E-02	2.06E-02	<0.100
Titanium	9.45E-02	4.74E-02	5.88E-02	6.42E-02	5.68E-02	<0.100
Vanadium	6.40E-03	6.61E-03	6.77E-03	1.30E-02	8.79E-03	≤0.368
Zinc	6.00E-03	≤5.74E-03	≤5.00E-03	8.44E-03	6.39E-03	0.842
Zirconium		1.30E-02	1.87E-02	1.70E-02	1.62E-02	<0.301
Uranium	8.37E-02*	1.74E-01*	1.35E-01*	2.04E-01*	1.71E-01	6.56**
Mercury		4.84E-03	4.46E-03	<9.90E-03	6.40E-03	116
Potassium		1.04E-02	1.07E-02	<1.22E-02	1.11E-02	159
Arsenic	2.25E-04	<4.96E-04	<4.98E-04	<2.25E-03	1.08E-03	77.1**
Selenium	3.07E-04	≤5.12E-04	<4.98E-04	<2.25E-03	1.09E-03	791**
Fluoride						1,653
Chloride						258
Nitrate						50,228
Nitrite						34,784
Sulfate						11,144
Oxalate						1,135
Carbonate						26,404

*Uranium concentrations calculated based on measured concentrations of Uranium isotopes.

**Silver, Mercury, Arsenic, and Selenium liquid concentrations based on values predicted by WCS (Reference 9).

Table 6. Tank 19 Chemical Inventories

Species	Solids Inventory Based on 55,102 kg Solids	Liquid Inventory Based on 14,635 gallons	Total Inventory (Solids + Liquid)	Total Chemicals Concentration in 55,102 kg Solids	20% Additional Chemical Inventory	20% Chemical Inventory Concentration in 55,102 kg Solids
	(kg)	(kg)	(kg)	(g/g)	(g)	(g/g)
Silver	6.00E+00	1.01E-02	6.01E+00	1.09E-04	1.20E+03	2.18E-05
Aluminum	7.47E+03	1.85E+02	7.65E+03	1.39E-01	1.53E+06	2.78E-02
Boron	3.69E+00	3.32E-02	3.73E+00	6.76E-05	7.45E+02	1.35E-05
Barium	4.98E+01	1.67E-02	4.98E+01	9.03E-04	9.95E+03	1.81E-04
Calcium	5.00E+02	5.54E-03	5.00E+02	9.08E-03	1.00E+05	1.82E-03
Cadmium	5.36E+00	1.39E-02	5.38E+00	9.76E-05	1.08E+03	1.95E-05
Cerium	1.92E+02		1.92E+02	3.49E-03	3.85E+04	6.98E-04
Cobalt	4.53E+00	1.67E-02	4.54E+00	8.25E-05	9.09E+02	1.65E-05
Chromium	1.95E+01	1.43E+00	2.09E+01	3.80E-04	4.19E+03	7.60E-05
Copper	2.53E+00	1.67E-02	2.55E+00	4.62E-05	5.10E+02	9.25E-06
Iron	1.05E+03	2.22E-02	1.05E+03	1.91E-02	2.11E+05	3.82E-03
Lanthanum	8.04E+00	5.54E-02	8.10E+00	1.47E-04	1.62E+03	2.94E-05
Lithium	2.04E+00	1.67E-02	2.06E+00	3.73E-05	4.11E+02	7.46E-06
Magnesium	1.39E+02	5.54E-03	1.39E+02	2.51E-03	2.77E+04	5.03E-04
Manganese	7.51E+01	5.54E-03	7.51E+01	1.36E-03	1.50E+04	2.73E-04
Molybdenum	5.07E+00	1.43E-01	5.21E+00	9.46E-05	1.04E+03	1.89E-05
Sodium	9.27E+03	5.39E+03	1.47E+04	2.66E-01	2.93E+06	5.32E-02
Nickel	7.79E+00	5.00E-02	7.84E+00	1.42E-04	1.57E+03	2.84E-05
Phosphorus	2.27E+01	2.67E+00	2.54E+01	4.60E-04	5.07E+03	9.21E-05
Lead	2.67E+01	2.55E-01	2.69E+01	4.89E-04	5.38E+03	9.77E-05
Silicon	5.57E+03	1.05E+00	5.57E+03	1.01E-01	1.11E+06	2.02E-02
Tin	1.27E+01	7.42E-01	1.35E+01	2.44E-04	2.69E+03	4.88E-05
Strontium	1.13E+01	5.54E-03	1.13E+01	2.06E-04	2.27E+03	4.12E-05
Titanium	3.13E+01	5.54E-03	3.13E+01	5.68E-04	6.26E+03	1.14E-04
Vanadium	4.85E+00	2.04E-02	4.87E+00	8.83E-05	9.73E+02	1.77E-05
Zinc	3.52E+00	4.66E-02	3.57E+00	6.48E-05	7.14E+02	1.30E-05
Zirconium	8.94E+00	1.67E-02	8.96E+00	1.63E-04	1.79E+03	3.25E-05
Uranium	9.40E+01	3.64E-01	9.44E+01	1.71E-03	1.89E+04	3.43E-04
Mercury	3.53E+00	6.44E+00	9.96E+00	1.81E-04	1.99E+03	3.62E-05
Potassium	6.12E+00	8.81E+00	1.49E+01	2.71E-04	2.98E+03	5.42E-05
Arsenic	5.96E-01	4.27E+00	4.87E+00	8.83E-05	9.74E+02	1.77E-05
Selenium	5.99E-01	4.38E+01	4.44E+01	8.06E-04	8.88E+03	1.61E-04
Fluoride		9.16E+01	9.16E+01	1.66E-03	1.83E+04	3.32E-04
Chloride		1.43E+01	1.43E+01	2.59E-04	2.86E+03	5.18E-05
Nitrate		2.78E+03	2.78E+03	5.05E-02	5.56E+05	1.01E-02
Nitrite		1.93E+03	1.93E+03	3.50E-02	3.85E+05	6.99E-03
Sulfate		6.17E+02	6.17E+02	1.12E-02	1.23E+05	2.24E-03
Oxalate		6.29E+01	6.29E+01	1.14E-03	1.26E+04	2.28E-04
Carbonate		1.46E+03	1.46E+03	2.65E-02	2.93E+05	5.31E-03

Table 7. Tank 19 Waste Comparison to 10 CFR 61.55 Table 1

Radionuclides (Long-lived)	10 CFR 61.55 Class C Limit	Class C Units	Tank 19 Concentration in Class C Units	Factor Relative to Class C Limit	Waste Concentration in Class C Units with Tank Filled with Grout	Factor with Tank Filled with Grout
C-14	8	Ci/m^3	2.39E-04	2.98E-05	1.65E-05	2.1E-06
C-14 in activated metal	80	Ci/m^3	(1)	(1)	(1)	(1)
Ni-59 inactivated metal	220	Ci/m^3	(1)	(1)	(1)	(1)
Nb-94 in activated metal	0.2	Ci/m^3	(1)	(1)	(1)	(1)
Tc-99	3	Ci/m^3	1.44E-02	4.80E-03	9.95E-04	3.3E-04
I-129	0.08	Ci/m^3	1.06E-07	1.32E-06	7.29E-09	9.1E-08
Np-237	100	nCi/g	9.47E-03	9.47E-05	8.40E-04	8.4E-06
Pu-238	100	nCi/g	1.79E+01	1.79E-01	1.59E+00	1.6E-02
Pu-239	100	nCi/g	2.62E+01	2.62E-01	2.32E+00	2.3E-02
Pu-240	100	nCi/g	9.31E+00	9.31E-02	8.25E-01	8.2E-03
Pu-241	3500	nCi/g	1.93E+01	5.51E-03	1.71E+00	4.9E-04
Pu-242	100	nCi/g	3.12E-01	3.12E-03	2.76E-02	2.8E-04
Pu-244	100	nCi/g	1.39E-03	1.39E-05	1.23E-04	1.2E-06
Am-241	100	nCi/g	1.04E+01	1.04E-01	9.21E-01	9.2E-03
Am-242m	100	nCi/g	1.48E+00	1.48E-02	1.32E-01	1.3E-03
Am-243	100	nCi/g	1.47E-07	1.47E-09	1.30E-08	1.3E-10
Cm-242	20000	nCi/g	1.22E+00	6.08E-05	1.08E-01	5.4E-06
Cm-243	100	nCi/g	1.46E-06	1.46E-08	1.29E-07	1.3E-09
Cm-244	100	nCi/g	1.28E-03	1.28E-05	1.14E-04	1.1E-06
Cm-245	100	nCi/g	1.65E-09	1.65E-11	1.46E-10	1.5E-12
Cm-247	100	nCi/g	5.16E-20	5.16E-22	4.58E-21	4.6E-23
Cm-248	100	nCi/g	1.19E-20	1.19E-22	1.06E-21	1.1E-23
Cf-249	100	nCi/g	3.20E-22	3.20E-24	2.84E-23	2.8E-25
Sum of Class C Factors				0.7		0.0590
Alpha Emitting Transuranic nuclides with half-life > 5 years				0.7		0.0582

(1) Not present in Tank 19 waste

Table 8. Tank 19 Waste Comparison to 10 CFR 61.55 Table 2

Radionuclides (Short-lived)	10 CFR 61.55 Class C Limit	Class C Units	Tank 19 Concentration in Class C Units	Factor Relative to Class C Limit	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)
H-3	(1)	Ci/m^3	(1)	(1)	(1)	(1)
Co-60	(1)	Ci/m^3	(1)	(1)	(1)	(1)
Ni-63	700	Ci/m^3	1.43E-01	2.05E-04	9.91E-03	1.4E-05
Ni-63 in activated metal	7000	Ci/m^3	(2)	(2)	(2)	(2)
Sr-90	7000	Ci/m^3	5.48E-02	7.83E-06	3.78E-03	5.4E-07
Cs-137	4600	Ci/m^3	6.93E+01	1.51E-02	4.79E+00	1.0E-03
Sum of Class C Factors				0.015		0.0011

(1) There are no limits established for these radionuclides in Class C waste
(2) Not present in Tank 19

5.7 Estimated Inventories

5.7.1 Radionuclide Inventories in Tank 19 Waste

The estimated inventories of contaminants in Tank 19 are reported in Table 3. For each nuclide that is significant to tank closure, the inventory of that nuclide in the tank was estimated both by samples and process knowledge. 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 sample data is available, an upper 95% confidence limit on the average concentration is reported. As mentioned previously, in computing the sample average and upper 95% confidence limit, the sample of crusty material (Sample No. 1) was ignored, although the composition of this material is reported in Table 2 for comparison.

The formula used for computing the upper 95% confidence limit for each nuclide was

$$UpperBound = Mean + s\frac{(Upper\ Cutoff, 95\%)}{\sqrt{Number\ of\ \ samples}}$$

Where:

UpperBound = upper 95% confidence limit on the average concentration
Mean = mean of the available samples
s = sample standard deviation
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
6	5	2.015

An exception to this is the inventory reported for Sr-90, U-234, U-236, and Np-237. For these radionuclides, there were three reported solids concentrations, two less-than-detection-limit values and one actual value. Both of the less-than-detection-limit values are greater than the actual value. Therefore, in the statistical treatment of these radionuclides, the average tank concentration was assumed to be equal to the actual concentration value. The 95% confidence concentrations for these radionuclides are based on standard deviations and number of measurements reported in WSRC-TR-2002-00107 (Reference 8).

For most nuclides, the value estimated from samples was higher than process knowledge, indicating perhaps that absorption on the zeolite (or some other mechanism) has enriched the concentration of these nuclides. Chemical analysis of the crusty material showed that the original zeolite in the tank is significantly degraded to other mineral compounds. In fact, none of the original zeolite added to the tank was detected in this sample. Instead, degraded forms of mineral compounds were found that evidently formed from reactions between the original zeolite and the waste that was added to the tank.[7]

Like the original zeolite, these new compounds still have the ability to absorb certain cations, as evidenced by the higher-than-expected concentration for Cs-137. The Cs-137 concentration is more than two orders of magnitude higher than its process knowledge estimate. However, Cs-137 has a relatively short half-life (30 years) compared to the times for contaminants to move significantly from a closed waste tank (hundreds of years). Thus, the elevated level of Cs-137 is not a performance assessment concern. Tc-99, the major contributor to the tank seepline dose performance, is about 40% of its expected concentration.

To calculate the Tank 19 radionuclide inventory in the solids heel, the estimated radionuclide concentrations (on a curie per unit weight basis) were multiplied by the 55,102-kg of dry solids calculated (in Section 5.1) to remain in the tank. To calculate the radionuclide inventory in the liquid, the estimated radionuclide concentrations (on a curie per unit volume basis) were multiplied by the 14,635 gallons of liquid estimated (in Section 5.2) to remain in the tank.

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 25-35 wt%. This is less than the 85 vol% interstitial liquid assumed 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 25-35 wt% liquid in the solids samples, it is estimated that the radioactivity of around 1,200 gallons of liquid were double counted in the solids radionuclide inventory. Reducing the volume of liquid used to calculate the liquid radionuclide inventory by 1,200 gallons would only decrease the Tc-99 inventory in the tank by less than 0.5%. 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 14,635 gallons of liquid estimated to remain in the tank.

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[15].

5.7.2 Tank 19 Wall Corrosion Product

In support of Tank 19 closure, DOE requested that High Level Waste perform a quantitative analysis and evaluation to address any fixed contamination that may be present on the internal tank surfaces. A visual examination of video footage of the Tank 19 interior concluded that corrosion of the carbon steel walls had been light and general. Using general corrosion rates from laboratory and field test data and historical ultrasonic tank thickness measurements, the Savannah River Technology Center (SRTC) estimated that there were 497 pounds of corrosion product (rust) that had been exposed to radioactive waste on the tank interior surfaces[15]. High Level Waste provided SRTC data concerning the concentration of radionuclides present in the supernate historically in contact with the tank interior surfaces. SRTC 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 497 pounds of corrosion products. The "Wall Corrosion Product" column in Table 3 summarizes the calculated radioactive contamination on the tank interior corrosion products. This Wall Corrosion Product inventory is added to the tank inventory (solids +

liquids) in Table 3 to provide the Class C inventory, which is used in Class C calculations described below.

5.7.3 NRC Class C Calculation

For the purposes of performing Class C calculations, the total radionuclide inventories (solids + liquids + corrosion products) in Table 3 were decayed to 2020, which is the planning date for the closure of all F-Tank Farm tanks. Table 4 contains the decayed inventories for the Class C radionuclides[16].

The Class C calculations for the waste in Tank 19 are contained in Table 7 for long-lived radionuclides and Table 8 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, effective 1991. The units for the limits are shown in the column entitled "Class C Units." The next column, "Tank 19 Concentration in Class Units," shows the computed concentration of the Tank 19 residual waste converted to the appropriate units. For Class C limits on a volumetric basis, the decayed radionuclide inventories from Table 4 are divided by the sum of the volume of solids in the tank (15,100 gallons), the volume of equipment in the tank (120 ft^3, or 3.4 m^3, or 898 gal)[17], 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)[17] and converted to the appropriate units. For Class C limits on a mass basis, the decayed radionuclide inventories from Table 4 are divided by the mass of the tank system summarized in the following table and converted to the appropriate units:

Waste Solids	55,102 kg
Interstitial Liquid	57,428 kg
Wall Corrosion Products	225 kg
In-Tank Equipment + Waste Tank (shotcrete walls, dome, risers, steel liner, lifting plates, stiffener bands)	1.08E+06 kg[17]
Total Tank System Mass	**1,192,755 kg**

In the column "Factor relative to Class C Limit," the computed concentration in Tank 19 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 7, the long-lived radionuclide inventory in Tank 19 is below the upper concentration limit for Class C waste. As Table 8 indicates, the short-lived radionuclide inventory in Tank 19 is also below the concentration limit for Class C waste. Because the Tank 19 inventories are below Class C concentrations, grout is not needed for concentration averaging.

The next column, "Waste Concentration in Class C Units with Tank Filled with Grout” shows the concentration of the Tank 19 waste if one takes credit for the volume and mass of grout required to fill the tank cylinder and dome. The last column in Tables 7 and 8,

"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 reducing grout planned for use in Tank 19 has a unit weight of 120.9 lb/ft^3.[18] This is equivalent to a specific gravity of:

$$\frac{120.9 lb}{ft^3} \bullet \frac{kg}{2.205 lb} \bullet \frac{ft^3}{28.32 L} = 1.94$$

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:

$$h_{cylinder} - \frac{V_{solids}}{FF_{TypeIV}} - \frac{V_{equipment}}{FF_{TypeIV}} = 411 in - \frac{15{,}000 gal}{3{,}540 gal/in} - \frac{898 gal}{3{,}540 gal/in} = 406.5 in.$$

The dome volume is 875 cubic meters[17]; 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 can be derived to calculate the numbers in the column "Factor with Tank Filled with Grout" for the nuclides with mass-based Class C limits:

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

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)
M_{dome} = Mass of tank dome filled with grout (g)

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:

$$Factor = \frac{31.2 Ci \times 1{,}000{,}000{,}000 \frac{nCi}{Ci}}{\frac{100 nCi}{g} \times \left(406.5 in \times 3{,}540 \frac{gal}{in} \times \frac{3{,}785.4 mL}{gal} \times \frac{1.94 g}{mL} + 1{,}192{,}755{,}000 g + 1{,}697{,}500{,}000 g \right)} = 2.3E-2$$

5.7.4 Chemical Inventories

Table 5 shows the concentrations of chemical constituents in the solids and liquid samples taken from Tank 19. As mentioned previously, the sample of crusty material (Sample No. 1) was ignored in calculating the average concentration of each constituent in the tank, although the composition of this sample is reported in Table 5 for comparison. Table 6 shows the chemical inventories of the residual tank heel based on the sample concentration data in Table 5. The chemical inventory of the tank solids was calculated by multiplying the reported average of the chemical concentrations in the solids samples by the 55,102 kg of solids estimated to remain in the tank. The chemical inventory of the liquid was calculated by multiplying the chemical concentrations in the liquid sample by the 14,635 gallons of liquid estimated to remain in the tank. The total tank inventory was calculated by adding the solids and liquid inventories.

Fate and transport modeling of residual contaminants uses the concentration of the contaminants in the waste as an input. The concentrations listed in Table 6 are calculated by dividing the inventories by the mass of the solids (55,102,000g)

5.7.5 Inventory of Purex Low Heat Waste

Tank 19 has a much larger quantity of solids than the other two tanks that have been closed, Tanks 17 and 20. However, the amount of Purex waste that contributed to the solids in Tank 19 is approximately double the amount that remained in Tank 17.

The Tank 19 solids came from three different sources:
Zeolite—This was used in a cesium removal column that was used to decontaminate evaporator overheads. The spent zeolite resin from the column was dumped into the tank. 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 19. 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 19 can be estimated from the Tank 19 chemical compositions. Purex Low Heat Waste contains about 24 wt% iron[19] 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 19 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 19, Purex Low Heat Waste, and hydrated sodalite are as follows:

	Tank 19 Samples (wt%)	Purex LHW (wt%)	Hydrated sodalite (wt%)
Al	13.5	4.7	14.8
Fe	1.9	24.3	0.0
Na	16.8	3.8	16.8
Si	10.1	0.9	15.4
	42.4	33.6	47.0

Based on this information, the amounts that each source contributed to the solids in Tank 19 can be calculated as follows:

Constituent	Estimated wt%	Mass in Tank (lb)	Based on:
Zeolite (hydrated sodalite)	65.6	79,691	Si
Purex Low Heat Waste	7.9	9,597	Fe
Other (primarily coating waste)	26.5	32,192	Balance
Totals	100.0	121,480	

The estimated quantity of Purex Low Heat Waste that contributed to the samples, 9,597 lb, is about twice the quantity left in Tank 17 when it was closed, about 4,700 lb. The Tank 17 solids contained about 24% iron, exactly the concentration of iron in Purex Low Heat Waste. Thus, all the insoluble solids in the tank at closure[1] appeared to be derived almost exclusively from Purex Low Heat Waste. Even though Tank 19 has about 7 times the volume of solids in Tank l7 (15,100 gallons vs 2,200 gallons), the mass due to Purex Low Heat Waste is only about twice that of Tank 17.

Tank 20 had about 1,950 lbs of solids at the time of closure. The sample of the bulk of the heel material taken in preparation for closure in which the iron concentration was directly measured had an iron concentration of 7.9 wt %.[2] Thus, a best guess estimate of the percentage of Purex Low Heat Waste that contributed to the solids is 7.9/24.3 = 33 wt %. Thus, a reasonable estimate is that 630 lbs of Purex Low Heat Waste contributed to the solids in Tank 20.

5.7.6 Other Contaminants

Six risers in Tank 19 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 six risers contain an estimated total of 7750 pounds of lead.

In addition to the contaminants in Tanks 17-20, there will be contamination in other equipment in the area, such as the 1F Evaporator, the 1F Concentration Transfer System, ventilation systems, and transfer piping. The inventory of contaminants in these locations is expected to be small relative to the amount of contamination in the tanks.

6. References

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