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Characterization of Residual Waste Remaining in 242-F Evaporator System

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1. Introduction

Plans are to close the 242-F Evaporator System and associated process equipment by filling the vessels and buildings with pumpable backfill materials. A campaign of waste removal and flushing was completed in 1988 and repeated in 1991/92. More waste materials were removed in CY2004 as part of the Tank Closure Projects strategy for closing waste handling facilities. To obtain approval for closure, fate and transport groundwater modeling must be performed to ensure that closing the evaporator system 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 fate and transport modeling of the 242-F system.

2. Summary

There are two types of residual material remaining in the 242-F system—solids (waste sludge and non-waste sludge/sediment e.g., zeolite, and materials, e.g., materials used in waste removal) and liquid (aqueous salt solution). Based on dose rates and video inspections, there is no indication of waste sludge in the 242-F system's pit and cells. Based on radiochemistry analysis performed at the Savannah River National Laboratory (SRNL), most of the radionuclides remaining in the evaporator vessel and Concentrate Transfer System (CTS) pump tank are the result of processing F-Canyon Plutonium Recovery and Extraction (PUREX) low heat waste supernate streams from Low Heat Waste. The overheads tanks contain zeolite, a resin used to remove ^{137}Cs from the overheads stream. The total solids residual heel in the 242-F Evaporator System is estimated to be 202.3 gallons (see Table 1). The mass of solids is estimated to be ~878 lbs of zeolite and ~780 lbs of process waste (see Table 4). The total liquids residual in the 242-F Evaporator System is estimated to be 242 gallons (see Table 2).

Chemical inventories are estimated in Table 10. It should be noted that the inventories are based on either actual sample results or analysis thresholds. For those inventories based on threshold analysis—denoted by '<', actual chemical inventories are less than the thresholds of the analysis and therefore the quantities are conservatively estimated.

3. Background

The 242-F system was constructed around 1960 in the 200-F Area Tank Farm. While in service, the system processed supernate waste. The function of the 242-F Evaporator was to reduce the volume of the liquid waste that resulted from the processing of nuclear material. The resultant concentrate was fed to the 242-3F CTS pump tank for subsequent transfer to F tank farm waste storage tanks. Figures 1 and 2 provide a schematic and elevation view, respectively of the 242-F System's components. The equipment relative to the evaporator system includes the following:

1) Evaporator Pot – The evaporator pot, located inside the 242-F evaporator cell (242-F facility), is a stainless steel cylindrical vessel with a cone bottom. The cylindrical portion is 8' in diameter and 8'-9¾" high. The cone has a maximum diameter of 8' and is 5'-11"

in height. The evaporator was used to concentrate liquid in order to reduce waste volumes.

2) Evaporator Cell – The evaporator cell is a cuboid with a 16' x 15' base x 25' high. The cell includes a floor sump measuring 2' x 2' x 2'-6" deep. The cell provided containment for the evaporator and served as shielding for personnel protection. The cell includes a stainless steel liner.
3) Receiver Cell – The receiver cell is a cuboid with a 15' x 9'-8" base and a height of 6'-4". The receiver cell includes a floor sump with a 1'-6" x 1'-6" base x 1'6" depth. The receiver cell provided containment for the two overheads tanks.
4) CTS Pump Tank – The stainless steel tank, located inside the 242-3F CTS Pit, is a cylindrical vessel with a diameter of 8' and a height of 8'-4". The CTS pump tank functioned as a pump reservoir for transferring concentrated waste received from the evaporator to underground storage tanks within the F Tank Farm.
5) CTS Pit – The CTS Pit is a cuboid having a 12' x 12' base x 21' height. The pit includes a floor sump having a 1'-6" x 1'-6" base x 1'-6" depth. The CTS provided containment for the CTS pump tank and featured a stainless steel liner. Cell covers provided personnel protection.
6) North and South Overheads Tanks – The overheads tank, located inside the 242-F Receiver Cell, are each cylindrical stainless steel vessels having a diameter of 6' and a height of 6'. The overheads tanks functioned as receipt tanks for liquids condensed from evaporator vapors.
7) Condenser – The condenser is a stainless steel cylindrical vessel with an outer diameter of 18" and a height of 9'-10.25". The condenser functioned to condense evaporator vapors into liquid fed to the north and south overheads tanks.

Following facility lay up in 1988; the evaporator was emptied and flushed. Water and inhibitors were added to the evaporator pot with the resultant solution being used to flush the CTS tank interior. The procedure employed to desalt and de-scale the evaporator; Procedure 241FH323Q, required flushing of the evaporator pot until the specific gravity of the last flush batch was below 1.10. The flush water was transferred to the CTS tank and then pumped to receipt tanks within the F Tank Farm. In the late 1991- early 1992 timeframe, this process was repeated prior to reclassification of the 242-F system as an 'inactive process area' under the then current safety basis documents. More recently, the CTS pump tank has been used as a catch tank for rainwater collection, a non-waste processing function.

Before initiating closure field activities, baseline inspections were performed on the 242 F evaporator system components which include the 242-F receiver cell, north and south overhead tanks, the 242-F evaporator cell and evaporator vessel, the 242-3F CTS Pit and the 242-3F CTS tank. Historical video documentation was used where possible in order to minimize personnel exposure.

Transfer lines to and from the 242-F evaporator and 242-3F CTS have been isolated as well as utilities and services (e.g., electricity, steam, ventilation, etc.). Isolations were ensured by physically disconnecting and blanking service and process lines. This isolation methodology incapacitated all motive forces and ensures that no waste will enter any of these facilities.

4. Waste Removal in Preparation for Closure

Personnel exposure during the waste removal campaigns totaled approximately 2.4 rem[1] collected mainly during equipment installations, heel transfers and system isolations. The campaign succeeded in reducing both the wet solids heel volume and the liquid heel.

4.1 Overheads Tanks, Condenser and Receiver Cell

During the November 2003 heel removal campaign, various mixing and transfer cycles were completed. Both the north and south overheads tanks were re-circulated before transferring contents to Tank 26.

Video inspection[2, 3,] of the 242-F receiver cell confirmed the absence of solid process wastes, i.e., "sludge". Considerable litter remains in the cell including hard hats, tapes, conduit, etc. These miscellaneous items are consistent with past practices for facilities of this nature and do not represent a radiological issue for seepline dose calculations.

Boroscope camera inspection of the 242-F Condenser was analyzed to be inconclusive. Process design precludes a normal path for process solids waste entering the condenser. Process history does not include an identified incident of solid process waste entering the condenser. This report therefore assumes that the entire condenser vessel is free of solid process waste.

Video inspection of the south overhead tank revealed a granular material residue or non-process waste sediment[4], sloping from 2" to 12" inches across the floor of the tank. Inspections[2,5] indicated <2 inches of this material is in the north overheads tank. The north overhead tank is estimated to contain ~14 gallons of this material; the south overhead tank, ~98 gallons. The material was subsequently sampled and identified as zeolite[4,6]. Zeolite is a resin used in cesium removal columns through which the evaporator overheads passed.

4.2 CTS Pit and Tank

During the May-July 2004 heel removal campaign, various mixing and transfer cycles were completed from the CTS tank. Contents of the CTS tank were slurried and pumped to the CTS sump which was subsequently transferred to Tank 26 via the north overheads tank and pump. Part of this transferred material included flush water added to the tank and pit for dose rate mitigation during isolation activities.

Video inspection[2,7] of the 242-3F CTS pit confirms the absence of solid process waste within the cell[8]. No solid waste was observed on the interior pit walls, pump tank exterior, floor sump or piping. Considerable litter was apparent including spent process jumpers, hard hats, tapes, Hanford connector components, conduit, etc.

Figure 1 Schematic representation of the 242-F System Prior to Isolation.

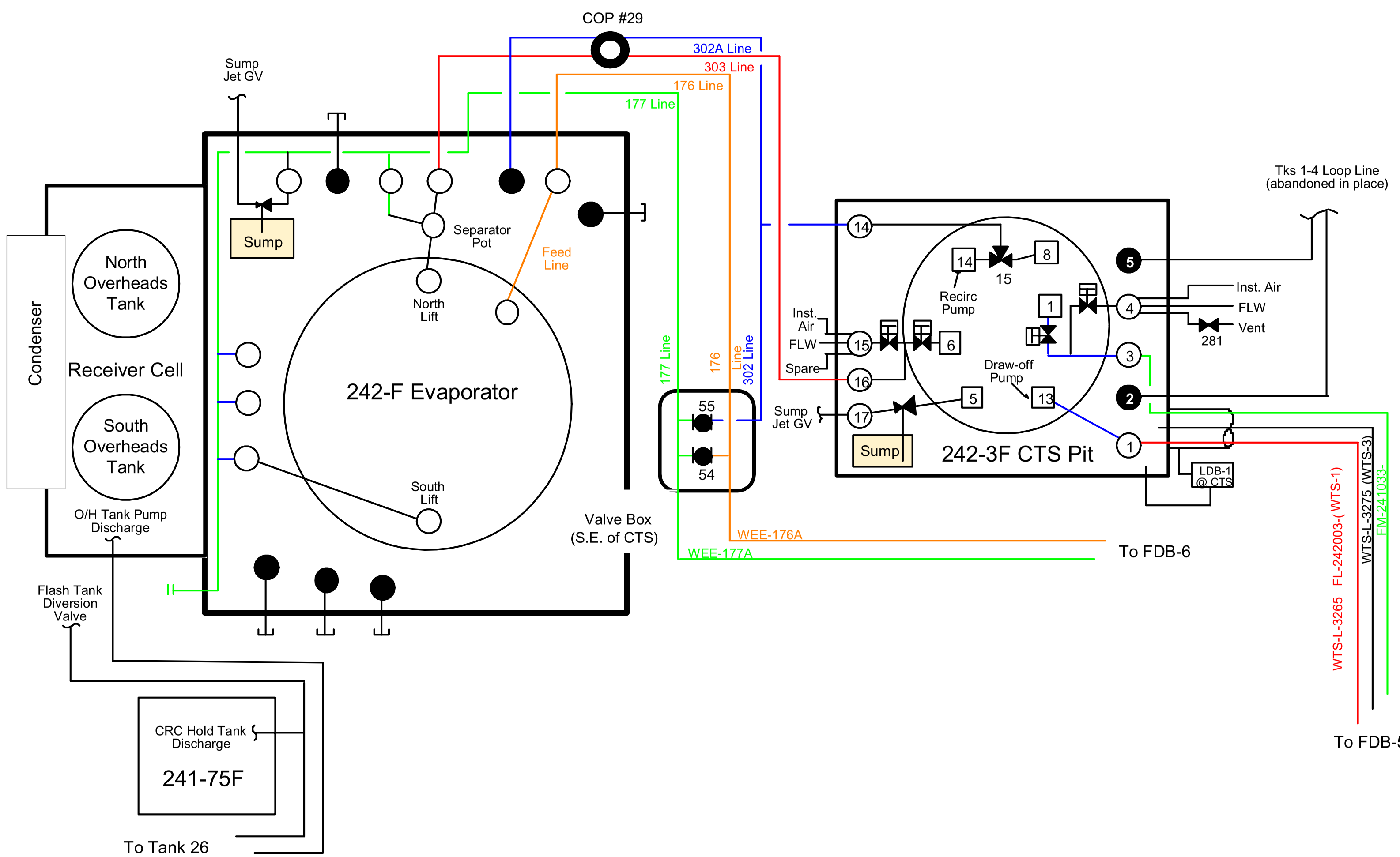
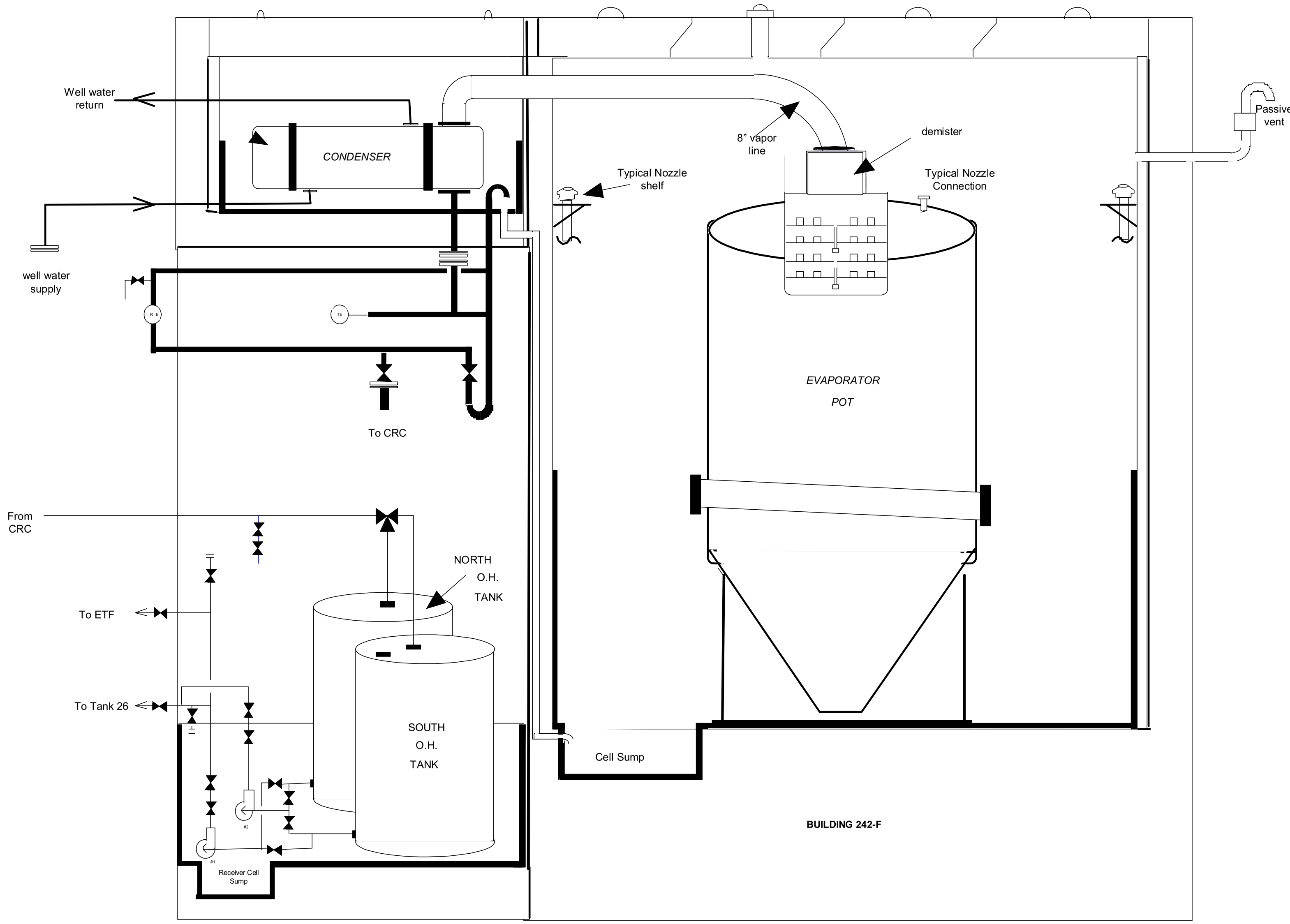


Figure 2. 242-F Evaporator Elevation



Video inspection of the interior of the CTS tank was performed and evaluated. No solid waste was observed on the interior tank walls, steam coils, or pump externals. A very thin scale was observed on the warming coil and a <1" layer of coarse sediment was evident at the bottom of the tank. Video based estimates placed the volume of this sediment at ~90 gallons[9]. The cell was found to be free of sludge-like materials.

4.3 Evaporator Cell and Vessel

During the April-May 2004 heel removal campaign, various mixing and transfer cycles were completed from the 242-F evaporator. Contents of the evaporator pot were slurried and pumped to the 242-F cell sump and subsequently transferred to Tank 26 via the north overheads tank and pump. Approximately 900 gallons[10] of existing contaminated rain and flush water collected in the 242-F and 242-3F sumps was also transferred to Tank 26 during batch processing through the north overheads tank.

Video inspection[11,12] of the 242-F evaporator cell confirmed the absence of sludge waste; however, salt was known to have migrated to the 242-F cell sump. The salt was associated with leaking tank connectors where salt had accumulated on the exterior of the tank and/or connectors. The interior of the 242-F evaporator cell has been subject to rainwater in-leakage through the cell covers for a number of years and must be periodically pumped. Results from samples obtained from the evaporator cell in 1998 permitted transfer of the cell contents to Tank 18 under contaminated rainwater requirements in the then approved safety basis. Considerable litter remains in the cell including hard hats, tapes, Hanford connector components, conduit, spent process jumpers, etc.

Video inspection of the 242-F evaporator vessel indicated that conditions of the vessel appeared consistent with normal operations including vessel flushing. Discoloration in the vessel and liquid level marks on the vessel wall are normal with no unusual conditions noted. The inspection indicated the presence of ~300 gallons of residual flush water and less than 3 gallons of unsuspended silt-like material, i.e., highly mobile sediment.

4.4 Waste Removal Summary

The waste removal campaign from September 2003 to June 2004 recycled approximately 1,500 gallons of residual flush water and collected rain water contained in the 242-F and 242-3F respective vessels. Over 15 hours of slurry mixing were conducted within the system's vessels and subsequent transfer to Tank 26. In addition, approximately 7400 gallons of shielding water was added for worker protection and served as additional flush for the CTS tank and pit. This water was also transferred to Tank 26 during heel removal.

5. Estimating the 242-F Evaporator System Residual Inventories

Following liquid heel removal, each vessel was inspected directly by video camera; fiber optics were used to inspect the condenser. The residual solids volume was estimated for each vessel within the 242-F system by observing solid levels relative to the internal tank fixtures and components. The vessels associated with the 242-F system are all 8' in diameter or less. Given these small sizes, contour mapping was not considered beneficial.

5.1 Estimating the Volume of Solids

Typically the volume of the residual solids in a vessel was estimated by averaging minimum and maximum depths of any residuals. Table 1 provides a list of estimates of residual non-waste solids following heel removal.

5.1.1 Final Volume of Residual Solids in the Evaporator Vessel

During the post heel removal video inspection scale was found on the evaporator pot and internal components. These components included warming coils, the evaporator tube bundle and various supporting structures for these components. Previous flushing and descaling efforts were successful in dislodging waste present on these components, leaving a negligible amount of material (~1 gallon) in the form of scale and loose debris. During the heel removal campaign, the total volume of free liquid was reduced from ~300 gals to 30 gallons. The solids volume removed is estimated to be a similar reduction of 90%; however, for conservancy, the estimated residual solids volume was conservatively increased by a factor of 3 (i.e., 0.1 gallons × = 0.3 gallons) as no direct visual measurement was available.

5.1.2 Final Volume of Residual Solids Heel in the Evaporator Cell

No solids heel remained in the evaporator cell following the heel removal campaign[13]. Some operational/maintenance debris was evident such as hard hats, rags, absorbent materials and insulation. There was no evidence of radioactive process waste solids.

5.1.3 Final Volume of Residual Solids Heel in the Receiver Cell

No solids heel remained in the receiver cell following the heel removal campaign. Some operational/maintenance debris was evident such as hard hats, rags, absorbent materials, shielding, sample bottles and sampling tools. There was no evidence of radioactive process waste solids.

5.1.4 Final Volume of Residual Solids Heel in North and South Overheads Tanks

Similar to the evaporator vessel there was also scale on the overhead tanks internal components, i.e., steam coils, etc. Additionally, 14 gallons of material remain in the north overheads tank, 98 gallons in the south overheads tank[2,5]. The material was sampled and analyzed and found to be zeolite.

5.1.5 Final Volume of Residual Solids Heel in the CTS Tank

Similar to the evaporator vessel there was also scale on the CTS tank internal components, i.e., steam coils, etc. Previous flushing and descaling efforts associated with the evaporator were successful in dislodging and removing residual process waste from the CTS tank and leaving a small amount of material (~90 gallons) in the form of sediment[8,9].

5.1.6 Final Volume of Residual Solids in the CTS Pit

No solids heel remained in the CTS Pit following the heel removal campaign. Some operational/maintenance debris was evident such as retired jumpers, connector heads, hard hats, rags, absorbent materials, insulation and mud (well water sediment). There was no evidence of radioactive process waste materials.

5.1.7 Summary of Final Volume of Residual Solids

The estimate of final volume of 242-F system solids is a compilation of the estimates from the 242-F system constituents—tanks, vessels and sumps. Table 1 provides a break down of the compilation. Debris volumes, i.e., dropped hard hats, etc., have not been included.

Table 1: Table of Residual Solids (gallons)

	Solids Related to Waste processing	Solids from Waste Processing Support (zeolite, etc.)	Total, all solids
242-F Evaporator	0.3	None detected	0.3
242-F Evaporator Cell Floor and Sump	None detected	None detected	0
242-F Receiver Cell Floor and Sump	None detected	None Detected	0
242-3F CTS Tank	90	None Detected	90
242-3F CTS Pit Floor and Sump	None detected	None Detected	0
242-F North Overheads Tank	None detected	14	14
242-F South Overheads Tank	None detected	98	98
242-F Condenser	None detected	None detected	0
242-F System Total	90.3	112	202.3

5.2 Estimating the Volume of Interstitial Liquid

The volume of liquid in 242-F system was estimated using video inspection following heel removal. The volume of interstitial supernate in freshly slurried sludge has been estimated to be 70 volume percent for settled sludge[14] and 85 volume percent for freshly slurried sludge[15]. For purposes of this calculation, the volume of interstitial supernate is conservative estimated to be 85 $^{vol.}/_{o}$, the higher of the two numbers. Using criteria applied to Tank 19[16], the 85 volume percent is also applied to the zeolite residuals, therefore the volume of liquid in the sludge is estimated as:

$$Xgal_{solids} \times 0.85 = Ygal_{interstitial}$$

In addition to the interstitial liquid in the non-waste sludge, free liquid also exists in some vessels. Thus, the total estimated volume of liquid in the 242-F system is 173 gallons of interstitial liquid plus 69 gallons of free liquid, or 242 gallons. Table 2 lists the liquid assignments for each of the 242-F system's vessels.

Table 2: Table of Estimated Residual Liquids (gallons)

	Free liquid	Interstitial liquid	Total Liquid
242-F Receiver Cell Sump	10	0	10
242-F North Overheads Tank	2	12	14
242-F South Overheads Tank	2	83	85
242-F Condenser	0	0	0
242-3F CTS Tank	5	77	82
242-3F CTS pit sump	10	0	10
242-F Evaporator	30	>1	31
242-F Evaporator Cell Sump	10	0	10
242-F System Total	69	173	242

5.3 Summary of Waste Sampling Analysis

A sample of the contents of the south overheads tank was analyzed by the SRNL and found to have constituents typical of zeolite[16,20]. A sample of the contents of the CTS tank was analyzed by the SRNL and found to have constituents typical of waste tank sludge and zeolite; similar to the Tank 18 southwest mound. A sample of the contents of the evaporator was analyzed by the SRNL and found to have waste tank sludge-like composition.

An estimated 90.3 gallons of wet sludge resides in the 242-F Evaporator System and 112 estimated gallons of non-waste material identified as zeolite. Based on the assessment in Section 5.2 that 85% of the heel is interstitial liquid, the 202.3 gallon wet solids heel is comprised of 171.9 gallons of interstitial liquid and 30.3 gallons of dry solids. The solids chemical and radionuclide inventories were determined on a mass basis and were unaffected by volume. Additionally, there is an estimated 69 gallons of free liquid remain in the system's vessels and sumps.

5.3.1 Sampling

Following the heel removal campaign in each vessel/sump, camera inspections were performed to assess the efficacy of liquid/solid heel removal. Where adequate volumes existed to support sampling, samples were taken to estimate the characterization of residual solids. No process knowledge estimates were developed for chemical inventories in 242-F system. The inventory estimates for chemical contaminants in 242-F system were based on samples alone.

5.3.2 Sample Locations

Three samples were obtained of the residual materials in 242-F system during the waste removal campaign in 2004. Figure 3 shows the locations of each of the residual solids samples in relation to the vessels within the 242-F system. The samples were transported to the SRNL, opened, inspected, and analyzed.

5.4 Density Analysis

The sludge sample solids fractions and density measurements are reported in Table 3 for the south overheads tanks. Samples pulled from the evaporator and CTS tank lacked sufficient volumes to complete density determinations. Earlier sample densities reported for the residual Tank 18 heel were assumed for the material remaining in the evaporator vessel and CTS tank, i.e., the PUREX and PUREX/zeolite densities reported for Tank 18 were assumed for the evaporator vessels and CTS, respectively. This assumption is based on process history of Tank 18 serving as the CTS feed tank and analytical results of the samples[4,25] compared to Tank 18 material analyses. The densities on a dry basis were calculated by multiplying the densities on a wet basis by the solids fractions for each sample.

Figure 3 242-F system Sample Locations

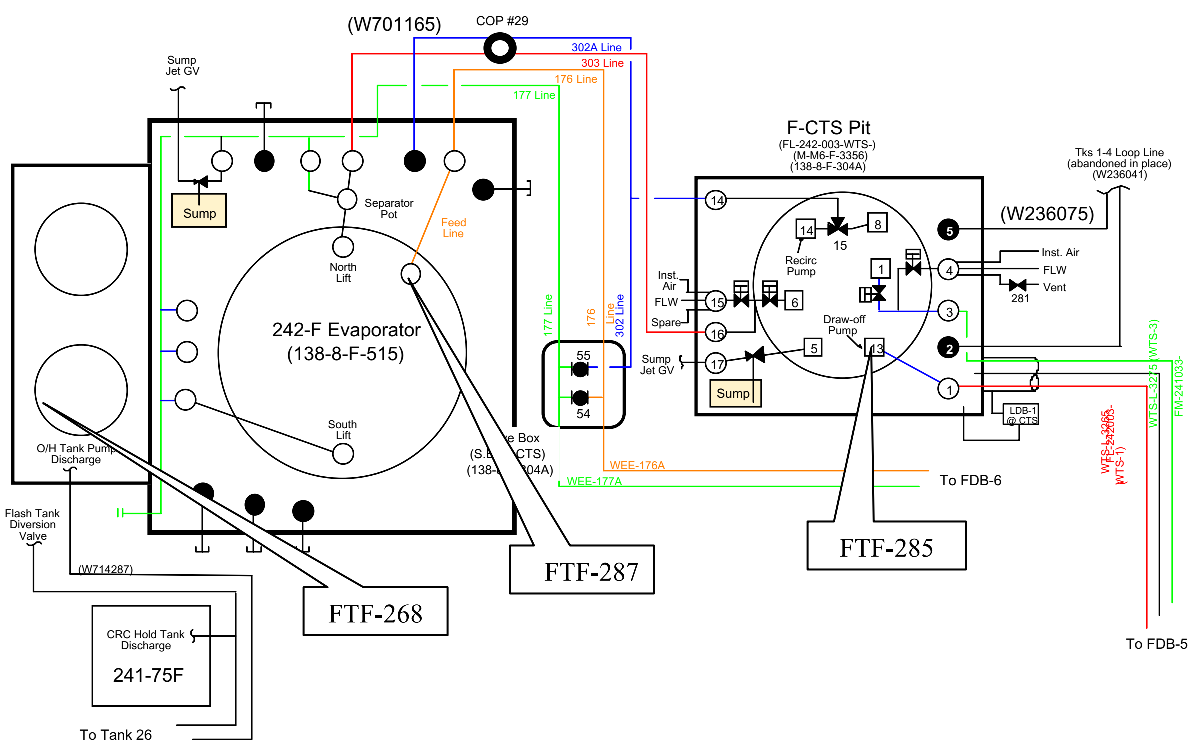


Table 3 Solids Fractions and Density Results

	Units	Sample		
		FTF-268 Overheads Tanks*	FTF-285 CTS est'd**	FTF 287[17] Evaporator est'd**
"Wet" Density	(g wet solids)/(mL wet solids)	1.62	1.47	1.44
Solids Fraction	weight percent	0.58	0.72	0.55
"Dry" Density	(g dry solids)/(mL wet sludge)	0.94	1.04	0.82

*Direct measure.
**Based on Tank 18 direct measure.

5.4.1 Mass of Solids

The mass of solids within the 242-F system was estimated by multiplying the residual solids volumes by the respective densities. Studies preformed for Tanks 18 and 19[18] have demonstrated that, on average, there are typically from 8.05 to 8.64 pounds of dry sludge solids per gallon of wet settled sludge[19]. Comparatively, SRNL has measured the density of fresh zeolite as ranging from 6.58[20] to 7.10[21] pounds of dry solids per gallon of wet material. The estimated average bulk density for the CTS Tank and the Evaporator vessel was assumed to be the same as found in Tank 18, i.e., 1.04 g/mL (equivalent to 8.64 pounds of dry solids per gallon of wet sludge) for the PUREX/zeolite mix found in the CTS tank and 0.82 g/mL (equivalent to 6.83 pounds of dry solids per gallon of wet sludge) for the PUREX waste found in the evaporator. The "dry" density of the 112 gallon overhead tanks contents is 0.94 g/mL (equivalent to 7.84 pounds of dry solids per gallon of wet sludge) as measured by SRNL.

For example, the estimated mass of dry solids in the overhead tanks was calculated as follows:

$$Mass_{Overhead} = 112 gal \times 7.84 \frac{lb}{gal} = 878.1 lb$$

Table 4 summarizes the volumes, masses, and densities of the material in 242-F system.

Table 4. Inventories and Densities

	Volume. (gal)	Dry Sludge Density (lb/gal)	Estimated Dry Mass (lbs)
Zeolite in Overheads Tanks			
N. Overheads	14	7.84	109.8
S. Overheads	98	7.84	768.3
Total Zeolite	112		878.1
Residual Sludge in Evaporator Vessel			
Evaporator	0.3	6.83	2
Residual Sludge + Zeolite in CTS Tank			
CTS Tank	90	8.64	777.6
Total Sludge	90.3		779.6

5.5 Radionuclide Analysis

The measured radionuclide concentrations in the 242-F system's samples are reported in Table 5. Those numbers preceded by a '<' sign are the detection limits, or thresholds, of the radio-chemical analysis methodology; the actual radionuclide concentrations are known to be less. The detection limit is used for those radionuclides preceded by the '<' notation in subsequent calculations and represent conservative estimates of actual concentrations.

Only radionuclides significant to tank closure performance objectives were measured. A number of the nuclides (^{14}C, ^{59}Ni, ^{129}I, ^{232}U, ^{244}Cm, ^{245}Cm, ^{238}Pu, ^{239}Pu, ^{241} Am) with NRC Class C limits are expected to be present in SRS wastes at very low concentrations and have a negligible impact on the sourced term when the wastes are classified[22]. The reasons these nuclides may be present at very low concentrations are: 1) they are fission products that are produced at very low yields in a normal fission-product spectrum (C-14, Ni-59, I-129); 2) they are impurities present at very low concentrations (U-232); or 3) they are produced by neutron capture of uranium at very low yields (all Cm and Bk isotopes). Analyzing for these nuclides is virtually certain to yield a result that is below the detection limit. Thus, analyzing for these nuclides is generally not considered cost effective and was not included in the 242-F system analysis.

Table 5 Measured Radionuclide Concentrations in Samples ($^{\mu Ci}/_{g}$)

	FTF 268, S. Overheads	FTF 285, CTS Tank	FTF 287, Evaporator
^{3}H	Not analyzed	<4.60E-01	<1.6E-02
^{60}Co	Not analyzed	Not analyzed	1.33E+00
^{79}Se	<3.33E-04	5.00E-06	8.27E-06
^{90}Sr	3.25E-01	1.52E+02	5.95E+01
^{99}Tc	<2.25E-03	3.10E-01	1.37E+00
^{137}Cs	6.03E+00	1.93E+03	1.02E+03
^{233}U	<2.55E-02	<9.10E-03	<1.20E-02
^{234}U	<1.65E-02	<5.90E-03	<7.60E-03
^{235}U	<5.69E-06	1.48E-05	8.72E-05
^{236}U	<1.70E-04	<6.10E-05	1.47E-04
^{238}U	4.86E-06	1.11E-03	8.05E-03
^{237}Np	<1.86E-03	1.34E-03	3.89E-03
^{238}Pu	<4.53E-02	2.95E+00	5.74E+00
^{239}Pu	<1.64E-01	4.16E+00	1.50E+01
^{240}Pu	<6.00E-01	1.09E+00	3.32E+00
^{241}Pu	<7.93E-02	1.51E+01	4.73E+01
^{242}Pu	<1.01E-02	<3.70E-03	<4.80E-03
^{241}Am	<7.39E-03	2.95E+00	4.41E+00

5.5.1 NRC Class C Calculation

Tables 7, 8, and 9 are the results of the Class C calculations for the residuals in each of the 242-F system vessels. The analysis threshold limits are used when the concentrations are below detection levels. Contents of the column, Solids Inventory in Overheads Tanks (Ci), were generated by converting the radioisotope concentrations listed in Table 5 into Curies. For example, the ^{99}Tc concentration in the combined North and South Overheads Tanks equates to 8.98E-04 Curies using the formula when rounded:

$$2.25E-03\left({}^{\mu Ci}\!/_{g}\right)\times 112\,(gals)\times 7.84\left({}^{\text{lbs}}\!/_{gal}\right)\times\left({}^{Kg}\!/_{2.2lb}\right)\times 1E-06\left({}^{Ci}\!/_{\mu Ci}\right)\times 1000\left({}^{g}\!/_{Kg}\right)=8.98\text{E - }04Ci$$

The column entitled "Class C Upper Limit" shows the Class C limit for each radionuclide[23]. The units for the value in the column are shown in the next column, entitled "Class C Units." The next column, "242-F system Concentration in Class Units," shows the computed concentration of the 242-F system residuals converted to the appropriate units. Following the example above, the ^{99}Tc Curies for the overheads tank are converted to Class C Limit Units as follows:

$$8.98E-04(Ci)\Big/112(gals)\times 264.172(gals)\Big/\left(m^{3}\right)=2.12\text{E}-03\,{}^{Ci}\!/_{m^{3}}$$

For those Class C Limits given in nCi/gm, the conversion is modified, i.e., the concentrations (*Table 5*) in mCi/gm are converted to nCi/gm. For example, in the overheads tanks, for the radionuclide ^{240}Pu, the Inventory in Class C Units is calculated as:

$$6.00\text{E}-01\left(\mu Ci/g\right)\times 1000\left(\eta Ci/\mu Ci\right) = 6.00\text{E}+02\,\eta Ci/g$$

In the column "Factor relative to Class C Limit," the computed concentration in 242-F system is divided by the 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, the solids in each 242-F system vessel are above the upper concentration limit for Class C waste. For the concentration limits with volume in the denominator, these concentrations are calculated from the total curies in the pit or cell from the volume of the residual heels. This is conservative because it does not credit the volume of free liquid (approximately 69 gal, for all 242-F System vessels; (evaporator vessel, CTS tank and Overheads tanks) remaining. For the concentration limits with mass in the denominator, these concentrations are calculated from the total curies in each pit or cell and the mass of dry solids in the heel. This is conservative because it does not credit the mass of the 243 gallons of liquid in the heel.

The last column, "Factor with X.X Inches Grout," shows the factors if one takes credit for the mass of grout covering the entire cell/pit floor in computing the radionuclide concentration. The reducing grout planned for use in the first layer has a specific gravity of 1.94. As can be seen from the summation at the bottom of the column, the grout layer thickness is sufficient to bring the sum of the Class C factors to less than 1.000. A number below 1.000 means that the average concentration of the waste plus grout in each of the 242-F system vessels will be less than the upper limit for Class C waste. The contribution of each nuclide to the sum of the Class C factors is calculated with the following formula:

$$Factor = \frac{I}{C \times h_{grout} \times FF \times \rho_{grout}}$$

where:

Factor = individual radionuclide contribution to the sum of the Class C factors
I = inventory of radionuclide in tank (Ci)
C = Class C concentration limit (nCi/g)
h_{grout} = height of encapsulating grout used for concentration averaging (in.)
FF_{Vessel} = fill factor for a cell/pit (gal/in)
ρ_{grout} = grout density (g/mL)

For example, the following calculates the contribution of ^{239}Pu to the sum of the Class C factors when crediting 63 inches of grout for concentration averaging in the CTS Pit:

$$Factor = \frac{1.47Ci \times 1{,}000{,}000{,}000\frac{nCi}{Ci}}{\frac{100nCi}{g} \times 63ins. \times 89.77\frac{gal}{in} \times \frac{3.784L}{gal} \times \frac{1{,}000mL}{L} \times \frac{1.94g}{mL}} = 0.35$$

The grout designed for use in 242-F system has not yet been approved for closure, and there is a possibility that the grout used for Tanks 17 and 20, which had a specific gravity of 2.4, will be used instead. The contribution of ^{239}Pu to the sum of the Class C factors for this type grout would be 0.28.

Table 6. Class C Radionuclide Inventories in North and South Overhead Heel (FTF 268)

Species	Inventory in Overheads Tanks (Ci)	Class C Upper Limit	Class C Units	Inventory in Class C Units	Factor Relative to Class C limit	Factor with 5.79 Inches Grout
^{79}Se	1.33E-04	None				
^{90}Sr	1.30E-01	7.00E+03	Ci/m^3	3.06E-01	4.37E-05	1.09E-05
^{90}Y	1.30E-01	None				
^{99}Tc	8.98E-04	3.00E+00	Ci/m^3	2.12E-03	7.06E-04	1.75E-04
^{137}Cs	2.41E+00	4.60E+03	Ci/m^3	5.68E+00	1.23E-03	3.07E-04
^{137}Ba	2.25E+00	None				
^{233}U	1.02E-02	None				
^{234}U	6.59E-03	None				
^{235}U	2.27E-06	None				
^{236}U	6.79E-05	None				
^{238}U	1.94E-06	None				
^{237}Np	7.42E-04	100	nCi/gm	1.86E+00	1.86E-02	2.24E-03
^{238}Pu	1.81E-02	100	nCi/gm	4.53E+01	4.53E-01	5.46E-02
^{239}Pu	6.55E-02	100	nCi/gm	1.64E+02	1.64E+00	1.98E-01
^{240}Pu	2.39E-01	100	nCi/gm	6.00E+02	6.00E+00	7.23E-01
^{241}Pu	3.17E-03	3500	nCi/gm	7.93E+00	2.27E-03	2.73E-04
^{242}Pu	4.03E-03	100	nCi/gm	1.01E+01	1.01E-01	1.22E-02
^{241}Am	2.95E-03	100	nCi/gm	7.39E+00	7.39E-02	8.91E-03
Sum of Class C Factors for Key Radionuclides					8.3	0.9998

Table 7. Class C Radionuclide Inventories in CTS Tank Heel

Species	Inventory in 242-3F Tank (Ci)	Class C Upper Limit	Class C Units	Inventory in Class C Units	Factor Relative to Class C limit	Factor with 62.7 Inches Grout
^{3}H	1.63E-01	None				
^{79}Se	1.77E-06	None				
^{90}Sr	5.37E+01	7.00E+03	Ci/m^3	1.5E+02	2.25E-02	3.60E-04
^{90}Y	5.37E+01	None				
^{99}Tc	1.10E-01	3.00E+00	Ci/m^3	3.22E-01	1.07E-01	1.71E-03
^{137}Cs	6.82E+02	4.60E+03	Ci/m^3	2.00E+03	4.35E-01	6.96E-03
^{137}Ba	6.38E+02	None				
^{233}U	3.22E-03	None				
^{234}U	2.09E-03	None				
^{235}U	5.23E-06	None				
^{236}U	2.16E-05	None				
^{238}U	3.92E-04	None				
^{237}Np	4.74E-04	100	nCi/gm	1.34E+00	1.34E-02	1.15E-04
^{238}Pu	1.04E+00	100	nCi/gm	2.95E+03	2.95E+01	2.52E-01
^{239}Pu	1.47E+00	100	nCi/gm	4.16E+01	4.16E+01	3.56E-01
^{240}Pu	3.85E-01	100	nCi/gm	1.09E+01	1.09E+01	9.32E-02
^{241}Pu	5.34E+00	3500	nCi/gm	1.51E+04	4.31E+00	3.69E-02
^{242}Pu	1.31E-03	100	nCi/gm	3.70E+00	3.70E-02	3.16E-04
^{241}Am	1.04E+00	100	nCi/gm	2.95E+03	2.95E+01	2.52E-01
Sum of Class C Factors for Key Radionuclides					116.4	0.9996

Table 8. Class C Radionuclide Inventories in Evaporator Heel

Species	Inventory in Evaporator Vessel (Ci)	Class C Upper Limit	Class C Units	Inventory in Class C Units	Factor Relative to Class C limit	Factor with 0.27 Inches Grout
^{3}H	1.49E-05	None				
^{60}Co	1.24E-03	None				
^{79}Se	7.70E-09	None				
^{90}Sr	5.54E-02	7.00E+03	Ci/m^3	4.88E+01	6.97E-03	5.50E-05
^{99}Tc	1.28E-03	3.00E+00	Ci/m^3	1.12E+00	3.75E-01	2.96E-03
^{137}Cs	9.50E-01	4.60E+03	Ci/m^3	8.37E+02	1.82E-01	1.44E-03
^{137}Ba	8.88E-01	None				
^{233}U	1.12E-05	None				
^{234}U	7.08E-06	None				
^{235}U	8.12E-08	None				
^{236}U	1.37E-07	None				
^{238}U	7.50E+00	None				
^{237}Np	3.62E-06	100	nCi/gm	3.89E+00	3.89E-02	1.30E-04
^{238}Pu	5.35E-03	100	nCi/gm	5.74E+03	5.74E+01	1.92E-01
^{239}Pu	1.40E-02	100	nCi/gm	1.50E+04	1.50E+02	5.01E-01
^{240}Pu	3.09E-03	100	nCi/gm	3.32E+03	3.32E+01	1.11E-01
^{241}Pu	4.41E-02	3500	nCi/gm	4.73E+04	1.35E+01	4.51E-02
^{242}Pu	4.47E-06	100	nCi/gm	4.80E+00	4.80E-02	1.60E-04
^{241}Am	4.11E-03	100	nCi/gm	4.41E+03	4.41E+01	1.47E-01
Sum of Class C Factors for Key Radionuclides					298.9	0.9998

5.6 Nonradionuclide Analyses

The SRNL radiochemical analyses indicate that the evaporator vessel contains high concentrations of Fe (23.2 weight percent), a signature element for PUREX. Moderate concentrations of Al (1.43 weight percent), Ca (1.64 weight percent), Na (5.82 weight percent), and U (5.82 weight percent) were also detected. Chemical analyses indicate that the overheads tanks contain high concentrations of Si (24.8 weight percent), a signature element for zeolite, and moderate concentrations of Al (8.01 weight percent), Fe (2.75 weight percent) and Ca (2.57 weight percent). Due to piping arrangements permitting communications between the north and south overheads tanks and an operational history of mixing between the two tanks, the same radiochemistry is assumed to exist in the north overheads tank as was found in the south. Chemical analyses indicate that the CTS tank contains high concentrations of Fe (15.1 weight percent), Al (14.8 weight percent) and Si (12.2 weight percent). Moderate concentrations of Ca (1.65 weight percent) and Na 4.14 weight percent). The high concentrations found in the CTS nonradionuclide analyses indicate the presence of a mixture of PUREX and zeolite.

The measured chemical (nonradionuclide) concentrations in the 242-F System samples are reported in Table 9. For previous closures, i.e., Tanks 17-20, a supernate sample was supplied for anion analysis. A supernate sample was not deemed necessary for the 242-F Evaporator System’s components as estimates could be obtained from the ICP-ES analysis; therefore, only solids sampling was conducted. To calculate the chemical inventories of the solids, the concentrations measured from the solids samples (Table 9) were multiplied by the total mass in each vessel. Table 10 lists the chemical inventories. Those numbers preceded by a ‘<’ sign are the detection limits, or thresholds, of the chemical analysis methodology; the actual chemical concentrations are known to be less. The detection limit is used for those radionuclides preceded by the ‘<’ notation in subsequent calculations and represent conservative estimates of actual concentrations.

5.6.1 Inventory of PUREX Low Heat Waste

The 242-F system solids came from three different sources:

Zeolite—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 believed to have been dumped into overheads tanks. 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 overheads tanks and the CTS tank was 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 242-F system. 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 242-F system can be estimated from the 242-F Evaporator System chemical compositions. PUREX Low Heat Waste contains about 24 wt iron[24] 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 242-F Evaporator System came from PUREX Low Heat Waste supernate. This is conservative because it does not take into account iron from airborne dust/dirt from continuous ventilation for 40 years, storage tank corrosion, process component corrosion (e.g., CTS tank pump housings) 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 242-F system 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.

Table 9 Measured Nonradionuclide Concentrations in Samples (weight percent)

Species	FTF 268 S. Overheads	FTF 285 CTS Tank	FTF 287 Evaporator
Silver	<7.84E-03	1.74E-03	2.33E-02
Aluminum	8.01E+00	1.48E+01	1.43E+00
Boron	<1.01E-01	<6.70E-03	9.10E-03
Barium	1.82E-01	2.57E-02	7.95E-02
Calcium	2.57E+00	1.65E+00	1.64E+00
Cadmium	<1.27E-02	9.86E-03	3.19E-02
Cerium	<1.31E-01	1.73E-02	5.33E-01
Cobalt	1.31E-03	Not Analyzed	Not analyzed
Chromium	<3.72E-02	6.44E-02	2.72E-01
Copper	<9.78E-03	7.03E-02	8.96E-02
Iron	2.75E+00	1.51E+01	2.32E+01
Gadolinium	<1.17E-02	2.04E-02	8.46E-02
Lanthanum	<1.57E-02	5.19E-03	1.88E-02
Lithium	<3.81E-02	2.51E-02	2.66E-02
Magnesium	5.97E-01	7.80E-01	1.11E+00
Manganese	7.88E-02	1.76E+00	9.31E-01
Molybdenum	<6.55E-02	6.01E-02	1.09E-01
Sodium	6.14E-01	4.14E+00	5.82E+00
Nickel	5.09E-02	1.10E-01	3.23E-01
Phosphorus	<5.15E-01	5.20E-01	7.69E-01
Lead	<3.28E-01	1.06E-01	1.74E-01
Sulfur	1.37E-01	5.66E-02	5.84E-02
Antimony	<6.36E-02	6.68E-02	8.85E-02
Silicon	2.48E+01	1.22E+01	6.69E-01
Tin	<1.55E-01	9.58E-02	2.46E-01
Strontium	6.76E-01	3.78E-01	4.25E-01
Titanium	1.58E-01	4.57E-02	1.48E-02
Uranium	<2.49E-01	3.30E-01	2.40E+00
Vanadium	<3.03E-02	7.48E-03	5.32E-03
Zinc	1.26E-01	3.38E-01	2.98E-01
Zirconium	<1.37E-02	3.49E-03	1.69E-03
Mercury	7.95E-02	2.58E-02	1.08E-01
Potassium	9.48E-01	1.55E-01	1.17E-01
Arsenic	<5.93E-03	<3.20E-03	<2.20E-03
Selenium	<5.93E-03	<3.20E-03	<2.20E-03

Table 10 Nonradionuclide Inventories (Kg) in Residual Heels

	FTF 268 Overheads	FTF 285 CTS Tank	FTF 287 Evaporator
Silver	3.20E-02	6.15E-03	2.17E-04
Aluminum	3.27E+01	5.23E+01	1.33E-02
Boron	4.12E-01	2.37E-02	8.48E-05
Barium	7.43E-01	9.08E-02	7.40E-04
Calcium	1.05E+01	5.83E+00	1.53E-02
Cadmium	5.19E-02	3.49E-02	2.97E-04
Cerium	5.35E-01	6.11E-02	4.96E-03
Cobalt	5.35E-03	Not analyzed	Not analyzed
Chromium	1.52E-01	2.28E-01	2.53E-03
Copper	3.99E-02	2.48E-01	8.35E-04
Iron	1.12E+01	5.34E+01	2.16E-01
Gadolinium	4.78E-02	7.21E-02	7.88E-04
Lanthanum	6.41E-02	1.83E-02	1.75E-04
Lithium	1.56E-01	8.87E-02	2.48E-04
Magnesium	2.44E+00	2.76E+00	1.03E-02
Manganese	3.22E-01	6.22E+00	8.67E-03
Molybdenum	2.67E-01	2.12E-01	1.02E-03
Sodium	2.51E+00	1.46E+01	5.42E-02
Nickel	2.08E-01	3.89E-01	3.01E-03
Phosphorus	2.10E+00	1.84E+00	7.16E-03
Lead	1.34E+00	3.75E-01	1.62E-03
Sulfur	5.59E-01	2.00E-01	5.44E-04
Antimony	2.60E-01	2.36E-01	8.24E-04
Silicon	1.01E+02	4.31E+01	6.23E-03
Tin	6.33E-01	3.39E-01	2.29E-03
Strontium	2.76E+00	1.34E+00	3.96E-03
Titanium	6.45E-01	1.62E-01	1.38E-04
Uranium	1.02E+00	1.17E+00	2.24E-02
Vanadium	1.24E-01	2.64E-02	4.95E-05
Zinc	5.14E-01	1.19E+00	2.78E-03
Zirconium	5.59E-02	1.23E-02	1.57E-05
Mercury	3.25E-01	9.12E-02	1.01E-03
Potassium	3.87E+00	5.48E-01	1.09E-03
Arsenic	2.42E-02	1.13E-02	2.05E-05
Selenium	2.42E-02	1.13E-02	2.05E-05

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 242-F system, PUREX Low Heat Waste, and hydrated sodalite are listed in Table 11. The elemental compositions indicate that the CTS tank has both zeolite and PUREX Low Heat Waste present. The elemental composition table provides good evidence that the 112 gallons within the overheads tanks is primarily composed of zeolite and the 0.3 gallons within the evaporator vessel is primarily composed of PUREX low heat waste.

Table 11. Measured Major Elemental Compositions Compared to PUREX Low Heat Waste and Hydrated Sodalite.

	Concentration in 112-gals Overhead Tanks	Concentration in 90-gals CTS Tank[25]	Concentration in 0.3 gal Evaporator	PUREX Low Heat Waste	Hydrated Sodalite
	(wt. percent)	(wt. percent)	(wt. percent)	(wt. percent)	(wt. percent)
Al	8.01	14.8	1.43	4.7	14.8
Ca	2.57	1.65	1.64	2.54	
Fe	2.75	15.1	23.2	24.3	0.0
Mg	0.597	1.76	1.11		
Na	0.614	4.14	5.82	3.8	16.8
Si	24.8	12.2	0.669	0.9	15.4
U	<0.249	0.330	2.40		

5.6.2 Other Contaminants

Some piping associated with the 242-F system was shielded with metallic lead which acted as radiation shielding during waste processing. Plans are to leave the shielding within the 242-F system when closed. The weight of the shielding is estimated to be less than 500 pounds of lead.

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