WSRC-TR-2001-00555

Evaluating Centrifuges for Solid-Liquid Separation in the SRS Salt Processing Program

M. R. Poirier, M. A. Noratok, and S.D. Fink
Westinghouse Savannah River Site
Aiken, SC 29808

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U.S. Department of Energy.

Summary

As a pretreatment step for the caustic side solvent extraction (CSSX) flowsheet, the incoming salt solution that contains entrained sludge is contacted with monosodium titanate (MST) to adsorb strontium and actinides. The resulting slurry is filtered to remove the sludge and MST. Testing performed by the Savannah River Technology Center (SRTC) and the University of South Carolina showed cross-flow filtration rates lower than desired for simulated salt solution containing various concentrations of MST and sludge solids (i.e., 0.02 - 0.08 gpm/ft^2). Because of the low filtration rates measured during simulant and real waste testing, the authors investigated centrifugation as potential replacement for the cross-flow filters.

These tests used a pilot-scale decanter centrifuge. The centrifuge generated approximately 4100 Gs during the tests. The feed solutions for the test consisted of 5.6M sodium, average salt solution with insoluble solids. The insoluble solids in the tests included the following: (1) simulated Tank 8F sludge, (2) simulated Tank 8F sludge and MST, (3) simulated Tank 8F sludge, strontium nitrate, and sodium permanganate, and (4) simulated Tank 8F

sludge, MST, and Cytec HX-400 flocculant. The insoluble solids concentration for the tests measured 0.06 wt %, 0.29 wt %, 1.29 wt %, and 6.0 wt % (measured values < 0.5 wt % to 6.5 wt %).
The conclusions from this work follow.

- The decanter centrifuge did not remove sufficient insoluble solids to meet the target clarified liquid turbidity of 5 - 10 NTU.
- The product from the tests with Tank 8F simulated sludge had a turbidity of 91 ± 41 NTU.
- The product from the tests with Tank 8F simulated sludge plus MST had a turbidity of 271 ± 105 NTU.
- The product from the tests with Tank 8F simulated sludge plus strontium nitrate and sodium permanganate had a turbidity of 267 ± 130 NTU.
- The product from the tests with Tank 8F simulated sludge plus MST and a polymeric flocculant had a turbidity of 50 ± 18 NTU.

The testing does suggest that a centrifuge could be employed for solid-liquid separation under the following options.

- Using a combination of a centrifuge and polishing filter. Previous testing suggests centrifugation as a pretreatment could increase filter flux to 0.25 gpm/ft^2, but more thorough testing is needed to quantify the improvement.
- Insoluble solids removal could improve with a two-stage centrifugation system. The first stage would use a decanter type centrifuge, such as the one used in this testing. The second stage would use a disk centrifuge, which proves more effective at removing small, slow settling particles.
- A third option would allow the treated liquid with low solids content to pass directly to the solvent extraction process. The authors recommend a set of scouting tests be performed to examine whether the solids collect in the contactors.

Keywords: filtration, centrifuge, solid-liquid separation, sludge

Introduction

The Department of Energy selected Caustic Side Solvent Extraction (CSSX) as the preferred cesium removal technology for Savannah River Site waste.

As a pretreatment step for the CSSX flowsheet, the process contacts the incoming salt solution that contains entrained sludge with monosodium titanate (MST) to adsorb strontium and actinides. The resulting slurry is filtered to remove the sludge and MST with the filtrate processed through the solvent extraction system. Testing performed by SRTC and the University of South Carolina with simulated and real waste showed filtration rates of 0.02 - 0.08 gpm/ft^2.[1,2,3,4,5] Because of the low filtration rates measured during simulant and real waste testing, SRTC identified alternative solids-liquid separation technologies as potential replacement for the crossflow filters.[6] One technology identified as a possible replacement is the centrifuge.[7]

The centrifuge relies on centrifugal force to exaggerate the density difference between the particles in a liquid, so the solids will "settle" more quickly. Thus, the centrifuge can, theoretically, completely remove even small, colloidal solids, given a long enough period of operation. Separation occurs without a physical barrier, and therefore, no place exists for trapping of the solids. Centrifuges work best with fast settling solids.

The particle settling velocity can be estimated from the following equation

$$V_s = \left(\frac{\Delta\rho}{18\mu}\right) g d^2 \left(\frac{\Omega_b^{\,2} R_b}{g}\right)$$

where V_s is the settling velocity, $\Delta\rho$ is the density difference between the particle and the fluid, μ is viscosity, g is the gravitational constant, d is particle diameter, Ω_b is the rotational speed of the centrifuge bowl, and R_b is the bowl radius.[8] The required settling rate is described by

$$V_{s,req} = \frac{1}{2}\frac{h}{L}\frac{Q}{A}$$

where $V_{s,req}$ is the required settling rate, h is the distance between internal surfaces of the centrifuge, L is the centrifuge length, Q is flow rate, and A is cross-sectional area of the centrifuge. Combining these equations gives the following expression for centrifuge flow rate

$$Q = 2V_{s(1g)} \left(\frac{\Omega_b^{\,2} R_{av}}{g}\right)\left(\frac{LA}{h}\right)$$

where $V_{s(1g)}$ is settling rate under gravity settling, and R_{av} is the average radius of the bowl and the pool.[8]

As the equation shows, centrifuges work best with fast settling solid particles. We expect slow settling sludge particles in the feed to the Salt Processing Facility since the waste comes primarily from evaporator operations that allowed settling and removal of the larger sludge particles. Hobbs measured settling rates of solid particles in a such a sample from Tank 41H as 1 - 25 in/day.[9]

Centrifuges successfully treat streams in the SRS Separations canyons. They have operated since 1953. The bowls rotate at 1740 rpm and produce 1730 Gs.[10,11] The canyon centrifuges have a residence time of 3 - 6 minutes[10] versus 7 minutes in this test. The centrifuges separate MnO_2, which precipitates to remove fission products, and silicates, which are flocculated with a gelatin strike. The feed for the centrifuges is acid rather than basic, which could affect the particle morphology. The centrifuges used there are standard milk centrifuges with the motors remoted from the bowls for ease of periodic maintenance. The bowls have not required replacement.

Jacobs estimated the required target removal efficiency for this test as 99.5% (see Attachment 1 for details).[12] Since the baseline feed solution contains 1.15 g/L insoluble solids, the clarified product stream should contain less than 0.006 g/L insoluble solids. An insoluble solids concentration of 0.006 g/L corresponds to a turbidity of 5 - 10 NTU.[13]

Experimental

Apparatus

The Pilot Centrifuge Test Facility centered on an Alfa-Laval Sharples P600 series decanter centrifuge. The facility included a 100-gallon polypropylene slurry feed tank with a Lightnin�® Model EV5P50M � HP mixer. Clarified liquid product collected in a 150-gallon polypropylene tank, and the solids product collected in a modified 25-L polypropylene carboy. Figure 1 contains a photograph of the pilot test facility. Test slurry was fed to the centrifuge by way of a 3 HP Teel centrifugal pump with variable recycle back to the feed tank. Flow of the feed slurry was controlled manually by a 3/8" metering valve and monitored by a Fischer-Porter 3/8" magnetic flow meter. Data were logged by a computerized data acquisition system (DAS) that consisted of a Dell Dimension XPS T700r desktop computer running LabView version 5.1.

The operating principle behind the decanter centrifuge (see Figure 2) is that denser solids sediment against the rotating bowl wall. The less dense liquid phase forms a concentric inner layer. Personnel can vary the liquid or "pond" depth, with a maximum pond depth preferred for maximum liquid clarification.

The sedimented solid particles continuously exit from the centrifuge bowl by virtue of the action of a helical screw conveyor or "scroll". The scroll rotates at a slower speed than the bowl. The gearbox establishes the differential speed between the scroll and bowl. The solids are pushed out of the pond by the scroll and up the conical "beach". The centrifugal force generated by the rotating centrifuge compacts the solids and expels excess liquid. The concentrated solids discharge from the feed end of the centrifuge and the clarified liquid discharges from the opposite end.

Figure 1. Pilot Centrifuge Test Facility

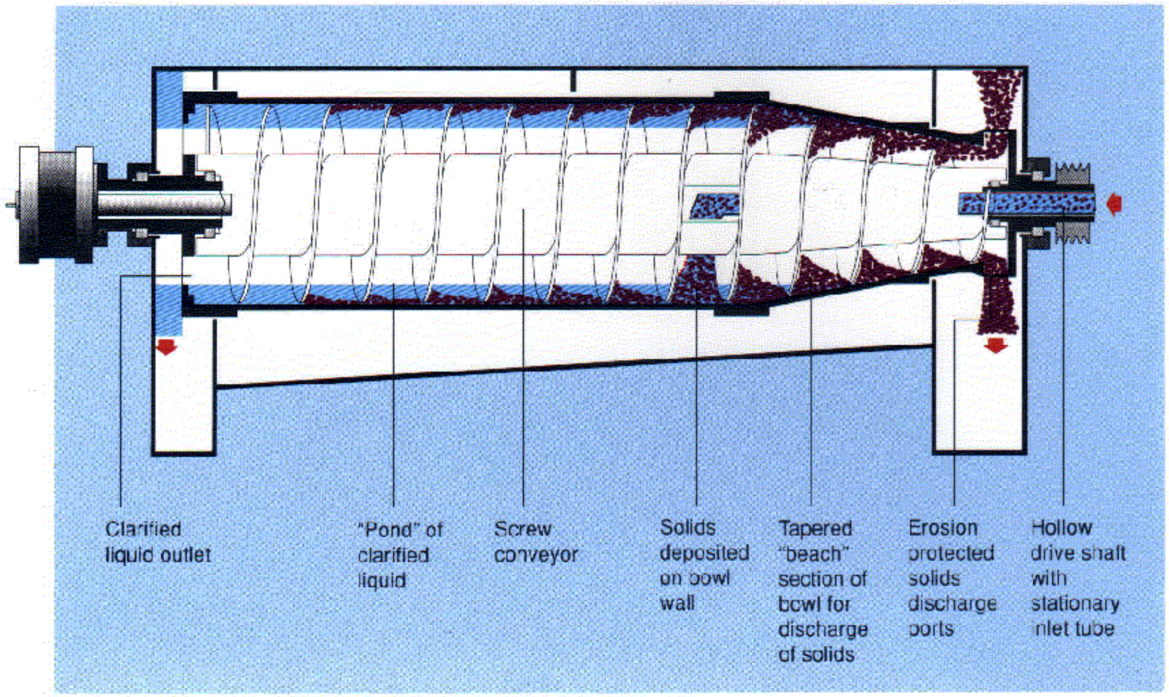

Figure 2. Schematic of Decanter Centrifuge

Feed Slurries

All slurries fed to the centrifuge were made from a stock 5.6 M sodium simulated average SRS High-Level Waste (see Table 1). We omitted sodium chloride and sodium fluoride from the feed at the vendor's request, to prevent corrosion. Personnel added insoluble solids to the solution in varying amounts. The insoluble solids for the various tests consisted of the following: (1) sim-ulated Tank 8F sludge, (2) simulated Tank 8F sludge and MST, (3) simulated Tank 8F sludge, strontium nitrate and sodium permanganate, and (4) simulated Tank 8F sludge, MST, and Cytec HX-400 flocculant. Table 2 shows the insoluble solids concentration for each test. In the tests with sodium permanganate, researchers added sodium formate as the reducing agent (4.5 moles of formate per mole of manganese). In the flocculant tests, personnel added the flocculant at 15 mg of flocculant per gram of insoluble solids (i.e., 1.5 wt % solids basis).

Previously, SRTC found that the addition of strontium nitrate and sodium permanganate improved strontium and actinide removal from Hanford High Level Waste solutions.[14] In addition, they found strontium nitrate and sodium permanganate addition improved cross-flow filtration rates. The researchers performed tests with those additives to evaluate the solid-liquid separation by centrifuge for this alternate process chemistry.

In other testing, SRTC found the addition of flocculants, such as Cytec HX-400, improved particle settling and filtration.[13,15] Tests included this additive to evaluate its impact on centrifugation.

Table 1. Centrifuge Test Supernate Composition

Species	Concentration
Na	5.6 (M)
K	0.015 (M)
Cs	0.00014 (M)
OH	1.93 (M)
NO_3	2.16 (M)
NO_2	0.53 (M)
AlO_2	0.31 (M)
CO_3	0.16 (M)
SO_4	0.15 (M)
PO_4	0.01 (M)
C_2O_4	0.004 (M)
SiO_3	0.004 (M)
MoO_4	0.0002 (M)
Tri-n-butyl phosphate	0.5 mg/L
Di-n-butyl phosphate	25 mg/L
Mono-n-butyl phosphate	25 mg/L
n-butanol	2 mg/L
Formate	1500 mg/L (0.033 M)

Table 2. Insoluble Solids Concentration for Centrifuge Tests

Sludge + MST	Sludge Only	Sludge + MnO4	Sludge + MST + Flocculant
0.031 wt % sludge 0.029 wt % MST	0.06 wt % sludge	0.031 wt % sludge 0.0065 M MnO_4 0.0065 M Sr	0.031 wt % sludge 0.029 wt % MST HX-400
0.15 wt % sludge 0.14 wt % MST	0.29 wt % sludge	0.15 wt % sludge 0.031 M MnO_4 0.031 M Sr	0.15 wt % sludge 0.14 wt % MST HX-400
0.67 wt % sludge 0.62 wt % MST	1.29 wt % sludge	0.67 wt % sludge 0.14 M MnO_4 0.14 M Sr	0.67 wt % sludge 0.62 wt % MST HX-400
3.1 wt % sludge 2.9 wt % MST	6.0 wt % sludge		3.13 wt % sludge 2.87 wt % MST HX-400

Experimental Operations

Each experiment began by combining simulated supernate solution and the appropriate amount of solids in the feed tank and agitating the mixture for a minimum of 15 minutes. Then, personnel collected a sample (~ 50 mL) of the feed for later turbidity measurement. Operators started the centrifuge in accordance with EDS Field Procedure FP-904. To achieve maximum liquid clarification, we operated the centrifuge at a maximum differential speed between the bowl and scroll by running the scroll at its minimum speed (approximately 1670 rpm) and running the bowl at its maximum safe operating speed of approximately 5000 rpm (approximately 4100 Gs). According to the following equation, with a gear ratio of 98:1, this condition yields a differential of approximately 34.

Δ(differential) = [Bowl speed - Scroll speed]/Gear ratio

Once the centrifuge reached the appropriate speed, personnel activated the DAS and then introduced feed. The initial tests used a slurry feed rate of approximately 0.5 gpm, but we later reduced the rate to 0.1 gpm to increase residence time in the centrifuge. Slurry feed to the centrifuge continued for two hours, during which time personnel collected samples of the clarified liquid product (~50 mL) every 15 minutes and analyzed them for turbidity. When the feed was consumed operators closed the feed valve, and stopped the Teel pump.

At the end of each test, personnel collected a concentrated solids product sample. Operators then rinsed the centrifuge with process water until the liquid product stream discharge appeared clear. Personnel shut down the centrifuge according to Field Procedure FP- 904.

Results

Table 3 shows the turbidity of the clarified liquid stream and the estimated insoluble solids concentration calculated from the equation developed by Martino et. al.[13] The results show the product turbidity significantly exceeds the target of 5 � 10 NTU. The product from the tests with Tank 8F simulated sludge had a turbidity of 91 ± 41 NTU.

Table 3. Centrifuge Product Turbidity

Feed Solids						Clarified Liquid		
Sludge (wt%)	MST (wt%)	Floc (wt%)	$Sr(NO_3)_2$ (M)	MnO_4 (M)	Insol. Solids meas. (wt%)	Turbidity (NTU)	Samples (#)	Insol. Solids (mg/L)
0.06	-	-	-	-	< 0.5	101.5 ± 21.8	9	28
0.29	-	-	-	-	< 0.5	68.7 ± 26.3	8	41
1.29	-	-	-	-	< 0.5	103.6 ± 68.0	6	42
6.0	-	-	-	-		Not measured		
0.031	-	-	0.0065	0.0065	< 0.5	227.3 ± 74.5	15	92
0.15	-	-	0.031	0.031	0.54	154.8 ± 24.1	9	63
0.67	-	-	0.14	0.14	5.5	445.1 ± 68.6	9	180
0.031	0.029	-	-	-	< 0.5	164.6 ± 19.6	9	67
0.15	0.14	-	-	-	< 0.5	392.4 ± 71.1	9	159
0.67	0.62	-	-	-	< 0.5	255.0 ± 29.5	9	103
0.031	0.029	0.0009	-	-	< 0.5	32.2 ± 6.9	9	13
0.15	0.14	0.0044	-	-	< 0.5	67.3 ± 10.4	9	27
0.67	0.62	0.019	-	-	0.80	48.1 ± 21.0	9	19

3.1	2.9	0.09	-	-	3.3	51.9 ± 12.5	9	21

The product from the tests with Tank 8F simulated sludge plus MST had a turbidity of 271 ± 105 NTU. The product turbidity with only sludge feed proved lower than the product turbidity with sludge and MST feed.

The product from the tests with Tank 8F simulated sludge plus strontium nitrate and sodium permanganate had a turbidity of 267 ± 130 NTU. The addition of strontium and permanganate led to higher product turbidity.

The product from the tests with Tank 8F simulated sludge plus MST and a polymeric flocculant had a turbidity of 50 ± 18 NTU. The addition of the flocculant improved product quality, but not to the level desired. In previous testing, flocculants showed significant improvement in particle settling rate.[13,15] However, in this test, shear from the recirculation pump and agitator probably tended to break down the flocculated solids as also observed in previous cross-flow filter tests.

According to the vendor (Alfa Laval), a 20 gpm decanter centrifuge (model CHNX-418) would be 3.5 m x 1.0 m x 2 m high. A 20 gpm disk centrifuge (model CHPX-513) would be 1.3 m x 1.5 m x 2 m high. The vendor provided a list of 62 units in nuclear service in Europe (see Attachment 2). The units are in research laboratories, power plants, and waste disposal facilities.

Even though it did not achieve the target solids removal, the testing does suggest that a centrifuge could be employed for solid-liquid separation under the following options: a combination of a centrifuge and polishing filter, a two-stage centrifugation system, or no additional treatment following the centrifuge.

The centrifuge reduced the insoluble solids level in the feed stream to 13 - 180 mg/L. This reduction in insoluble solids would slow cake buildup in a cross-flow filter and could increase filter flux. Previous SRTC testing investigated settling and decanting followed by polishing filtration. The tests showed that reducing the insoluble solids in the filter feed could increase cross-flow filter flux significantly.[13] Based on the settling study and the results from these tests, we estimate centrifugation as a pretreatment could increase filter flux to 0.25 gpm/ft^2. However, a firm estimate requires more thorough testing to quantify the improvement.

Insoluble solids removal could improve with a two-stage centrifugation system. The first stage would use a decanter type centrifuge, such as the one used in this testing. The second stage would use a disk centrifuge, which is more effective at removing small, slow settling particles. To evaluate this option, we could supply product samples from these tests to the vendor to evaluate the feasibility of the two-stage centrifugation process. The vendor recommended this approach.

The level at which insoluble solids adversely impact the centrifugal contactors has not been determined. Hence, another option would feed product samples from these tests to the 2 cm centrifugal contactors to determine whether the solids levels observed in these tests adversely impact them. The authors recommend a set of scouting tests to examine whether the solids collect in the contactors.

Conclusions

The conclusions from this work follow.

- The decanter centrifuge did not remove sufficient insoluble solids to meet the target clarified liquid turbidity of 5 - 10 NTU.
- The product from the tests with Tank 8F simulated sludge had a turbidity of 91 ± 41 NTU.
- The product from the tests with Tank 8F simulated sludge plus MST had a turbidity of 271 ± 105 NTU.
- The product from the tests with Tank 8F simulated sludge plus strontium nitrate and sodium permanganate had a turbidity of 267 ± 130 NTU.
- The product from the tests with Tank 8F simulated sludge plus MST and a polymeric flocculant had a turbidity of 50 ± 18 NTU.

Options

The testing does suggest that a centrifuge could be employed for solid-liquid separation under the following options:

- Use a combination of a centrifuge and polishing filter. Previous testing suggests centrifugation as a pretreatment could increase filter flux to 0.25 gpm/ft^2, but more thorough testing is needed to quantify the improvement.
- Insoluble solids removal could improve with a two-stage centrifugation system. The first stage would use a decanter type centrifuge, such as the one used in this testing. The second stage would use a disk centrifuge, which is more effective at removing small, slow settling particles.
- A third option would allow the treated liquid with low solids content to pass directly to the solvent extraction process. The authors recommend a set of scouting tests be performed to examine whether the solids collect in the contactors.

References

1. H. H. Saito, M. R. Poirier, S. W. Rosencrance, and J. L. Siler, "Improving Filtration Rates of Mono-Sodium Titanate (MST)-Treated Sludge Slurry with Chemical Additives", WSRC-TR-99-00343, September 15, 1999.
2. H. H. Saito, M. R. Poirier, and J. L. Siler, "Effect of Sludge Solids to Mono-Sodium Titanate (MST) Ratio on MST-Treated Sludge Slurry Cross-Flow Filtration Rates", WSRC-TR-99-00342, September 15, 1999.
3. Ralph Haggard, Travis Deal, Carol Stork, and Vince Van Brunt, "Final Report on the Crossflow Filter Testing for the Salt Disposition Alternative", USC-FRED-PSP-RPT-09-0-010, Rev. 0, December 4, 1998.
4. M. R. Poirier, "FY2000 FRED Test Report,"WSRC-TR-2001-00035, Rev. 0, January 11, 2001 and included report "Final Report on the Crossflow Filter Optimization with 5.6 M Sodium Salt Solution" (V. Van Brunt, C. Stork, T. Deal, and R. Haggard, USC-FRED-PSP-RPT-09-0-015, December 20, 2000).
5. M. R. Poirier, F. F. Fondeur, T. L. Fellinger, and S. D. Fink, "Cross-Flow Filtration Demonstration for Slurries Containing High Level Waste Sludge and Monosodium Titanate", WSRC-TR-2001-00212, April 11, 2001.
6. S. Subosits, Task Technical Request, HLW-SDT-TTR-2000-00013, October 11, 2000.
7. M. R. Poirier, "Evaluation of Solid-Liquid Separation Technologies to Remove Sludge and Monosodium Titanate from SRS High Level Waste", WSRC-TR-2000-00288, August 16, 2000.
8. B. C. Bershad, R. M. Chaffiotte, and W. F. Leung, "Making Centrifugation Work for You", Chemical Engineering, vol. 97, no. 8, pp. 84-89, 1990.
9. D. T. Hobbs, "Particle Size and Settling Velocity of Tank 41H Insoluble Solids", WSRC-TR-95-0249, May 30, 1995.
10. M. L. Hyder, W. C. Perkins, M. C. Thompson, G. A. Burny, E. R. Russell, H. P. Holcomb, and L. F. Landon, "Processing of Irradiated Enriched Uranium Fuels at the Savannah River Plant", DP-1500, April 1979.
11. H. J. Groh, "Removal of Silica from Solutions of Nuclear Fuels", DP-293, June 1958.

12. M. R. Poirier and M. A. Norato, "Task Technical and Quality Assurance Plan for Salt Processing Plant Centrifuge Test", WSRC-RP-2001-00737, June 29, 2001.
13. C. J. Martino, M. R. Poirier, F. F. Fondeur, and S. D. Fink, "Flocculating, Settling, and Decanting for the Removal of Monosodium Titanate and Simulated High-Level Waste Sludge from Simulated Salt Supernate", WSRC-TR-2001-00413, October 16, 2001.
14. C. A. Nash, S. W. Rosencrance, and W. R. Wilmarth, "Entrained Solids, Strontium-Transuranic Precipitation and Crossflow Filtration of AN102 Small C", WSRC-TR-2000-00341, August 2000.
15. M. R. Poirier, "Improving the Filtration of Sludge/Monosodium Titanate Slurries by the Addition of Flocculants", WSRC-TR-2001-00175, Rev. 0, March 27, 2001.

Attachment 1
Determination of Required Insoluble Solids Removal

Roy Jacobs

To: Steve Subosits, Herbert Elder, Joe Carter, Samuel Fink/WSRC/Srs, Michael Poirier/WSRC/Srs
cc:
Subject: Estimate of required sludge removal efficiency

01/17/01 08:13 AM

Gentlemen (and I mean that sincerely),

While considering alternatives to crossflow filtration (like floculation followed by settle/decant or centrifuging), I again asked the question "what removal efficiency is required to prevent busting the Saltstone alpha limit?" Since I've never heard an answer to that question, I decided to have a go at it myself. (See attached Excel file).

Assuming 600 mg sludge/L salt solution and alloting 25% of the alpha limit for sludge particles (5 nCi out of 20), I get a required efficiency of 99.5%. John Fowler suggested that a dead-end polishing filter might be needed downstream of a centrifuge or a settler.

Caution: This is all based on nominal conditions and the calc has not been reviewed. On the other hand, I did not include dilution from 6.4 to 5.6 M.

Roy

- SLUDGE~1.XLS

Estimate of Nominal Sludge Removal Efficiency

Bases:

Ci alpha/gal @13 wt% sluge solids in slurry

U232	1.20E-05
U234	3.00E-05
Np237	1.00E-05
Pu238	1.3

1.95 lbs sludge/gal slurry @ 19 wt% solids

From BDR 138*

*average 5 year old sludge feed to DWPF

600 mg sludge/L salt soln

density of 6.4 M salt soln = 1300 g/L

Calculations:

13/19 x 1.95 lbs sludge/gal slurry x 453.6 g/lb = 605 g sludge/gal slurry

1.3 Ci/gal x 1E9 nCi/Ci / (1000 mg/g x 605 g/gal) = 2148 nCi alpha/mg sludge

600 mg sludge/L salt soln x 2148 nCi alpha/mg sludge / 1300 g soln/L = 991 nCi alpha/g salt solution

Saltstone limit is 20 nCi/g. Assume that 25% of that can be alloted to alpha from sludge. Then the required removal efficiency is

(991 - 5) / 991 * 100 = 99.5 % efficiency

Attachment 2
ALFA Laval Centrifuges in European Nuclear Facilities

Customer	Country	Contractor	Machine	Qty.	Year	Location	Type
Euroatom	Italy		CRPX 207 SGV	1	1966	RL	Disk
RCN, Petten	Netherlands		BRPX 213 SFD		1971	WD	Disk
Toshiba	Japan		BRPX 213 SGV	2	1975	PP	Disk
Coarso	Italy		CRPX 207 SGP	2	1978	PP	Disk
EIR	Switzerland		BRPX 213 SGV	1	1978	RL	Disk
Mühlenberg	Switzerland		BRPX 207 SGV	2	1978	PP	Disk
Benznau	Switzerland		BRPX 207 SGV	1	1978	PP	Disk
Toshiba	Japan		BRPX 213 SGV	2	1980	PP	Disk
Toshiba	Japan		BRPX 417 SGV	2	1980	PP	Disk
Toshiba	Japan		BRPX 213 SGV	2	1981	PP	Disk

Toshiba	Japan		BRPX 417 SGV	2	1981	PP	Disk
Toshiba	Japan		BRPX 417 SGV	1	1981	PP	Disk
KKW Isar 1	Germany	Siemens	BRPX 213 SGV-34	1	1981	PP	Disk
KKW Brunsbüttel	Germany	Siemens	BRPX 213 SGV-34	1	1982	PP	Disk
Nersa	France		BRPX 213 SGV	1	1983	PP	Disk
KKW Phillipsburg 1	Germany	Siemens	BRPX 207 SGV-34	1	1983	PP	Disk
KKW Phillipsburg 1	Germany	Siemens	BRPX 213 SGV-34	1	1983	PP	Disk
KKW Phillipsburg 1	Germany	Siemens	KWNX 416 S-31G	1	1983	PP	Decanter
KKW Phillipsburg 2	Germany	Siemens	BRPX 213 SGV-34	1	1983	PP	Decanter
KKW Phillipsburg 2	Germany	Siemens	KWNX 416 S-31G	1	1983	PP	Decanter
Toshiba	Japan		BRPX 413 SGD	2	1983	PP	Disk
KKW Isar 2	Germany	Siemens	BRPX 213 SGV-34	1	1985	PP	Disk
KKW Isar 2	Germany	Siemens	KWNX 416 S-31G	1	1985	PP	Decanter
Idreco	Italy		BRPX 213 SGV	3	1985	PP	Disk
KKW Neckarwestheim	Germany	Siemens	BRPX 213 SGV-34	1	1985	PP	Disk
KKW Neckarwestheim	Germany	Siemens	KWNX 416 S-31G	1	1985	PP	Decanter
KKW Brockdorf	Germany	Siemens	BRPX 213 SGV-34	1	1985	PP	Disk
KKW Brockdorf	Germany	Siemens	KWNX 416 S-31G	1	1985	PP	Decanter
KKW Emsland	Germany	Siemens	BRPX 213 SGV-34	1	1985	PP	Disk
KKW Emsland	Germany	Siemens	KWNX 416 S-31G	1	1985	PP	Decanter
KKW Obrigheim	Germany		BRPX 213 SGV-34	1	1986	PP	Disk
KKW Obrigheim	Germany		KWNX 416 S-31G	1	1986	PP	Decanter
KKW Würgassen	Germany		BRPX 213 SGV-34	2	1987	PP	Disk
KKW Karlstein	Germany		NX 309	1	1987	RL	Decanter
KKW Grohnde	Germany		CHPX 510 SGD-34 CG	1	1990	PP	Disk
KKW Grohnde	Germany		KWNX 416 S-31G	1	1990	PP	Decanter
KKW Phillipsburg 1	Germany	Siemens	CHPX 510 SGD-34 CG	1	1990	PP	Disk
KKW Phillipsburg 1	Germany	Siemens	KWNX 416 S-31G	1	1990	PP	Decanter
KKW Karlstein	Germany		KWNX 409 S-31G	1	1992	RL	Decanter
KKW Isar 1	Germany		BRPX 213 SGV-34 CG	1	1992	PP	Disk
ABB Atom	Sweden		KWNX 416	1	1994	PP	Decanter
KKW Rheinsberg	Germany	Siemens	KWNX 416	1	1995	PP	Decanter
Teollisuuden Voima Oy	Finnland		KWNX 416	1	1995	PP	Decanter
Teollisuuden Voima Oy	Finnland		CHPX 510	1	1995	PP	Disk
Sage Brno (Temelin)	Czech Rep.		KWNX 418	1	1996	PP	Decanter
Sage Brno (Temelin)	Czech Rep.		CHPX 513	1	1996	PP	Disk
Teollisuuden Voima Oy	Finnland		KWNX 416	1	1996	PP	Decanter

Teollisuuden Voima Oy	Finnland		CHPX 510	1	1996	PP	Disk
Zwilag Würenlingen	Switzerland	BWB	BTPX 205 SGD-34 CDP	1	1997	WD	Disk
Yonggwang 5	Korea	HPA	CHPX 517 SGV-34 CGR	1	1997	PP	Disk
Yonggwang 5	Korea	HPA	KWNX 418 S-31	1	1997	PP	Decanter
Yonggwang 6	Korea	HPA	CHPX 517 SGV-34 CGR	1	1997	PP	Disk
Yonggwang 6	Korea	HPA	KWNX 418 S-31	1	1997	PP	Decanter
				62			
Key to location:	RL		Research lab				
	PP		Power Plant				
	WD		Waste disposal				