Resorcinol-Formaldehyde Ion Exchange Resin Chemistry for High Level Waste Treatment - 10161

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ABSTRACT

A principal goal at the Savannah River Site is to safely dispose of the large volume of liquid nuclear waste held in many storage tanks. In-tank ion exchange technology is being considered for cesium removal using a polymer resin made of resorcinol formaldehyde that has been engineered into microspheres. The waste under study is generally lower in potassium and organic components than Hanford waste; therefore, the resin performance was evaluated with actual dissolved salt waste. The ion exchange performance and resin chemistry results are discussed.

INTRODUCTION

Removal of cesium from stored liquid waste at the Savannah River Site (SRS) will be performed on a large scale by solvent extraction when the Salt Waste Processing Facility comes on line. To support tank closure needs at SRS and Hanford, there is a more immediate need to treat salt waste. To address this potential, another separation technology called Small Column Ion Exchange (SCIX) is under consideration that would allow in-situ treatment of stored waste. The word “small” is relative because a column may be as tall as 20 feet and 2 feet in diameter. “Small Column” here means small relative to industrial sized columns, so that it can completely fit down an SRS waste storage tank riser.

Ion Exchange (IX) is a mature technology to remove cesium from liquid wastes. Resorcinol-formaldehyde (RF) resin was patented by the Savannah River National Laboratory [1] to remove cesium from highly alkaline wastes. The resin is a resorcinol ($C_6H_6O_2$) formaldehyde (CH_2O) condensation polymer. This resin has a strong preference for H^+ and can be eluted by using acid to remove Cs^+ and its competitors. Its relative affinities has been estimated [2] to be $H^+ > Cs^+ > Rb^+ > K^+ > Na^+$. RF resin can withstand multiple cycles of loading and acid elution before its usefulness is exhausted. The original ground-gel form of RF resin contained shards and irregular shaped particles, resulting in significant flow resistance and inconsistent results as shards cracked and broke down creating fines, as seen with CST [3] and SL-644 resins[2] [4, 5]. Because of the poor hydraulic performance of the ground-gel form, the RF resin was improved by the Waste Treatment and Immobilization Plant DOE River Protection Project. RF resin was processed into microspheres by Microbeads AS, in Skedsmokorset, Norway, leading to much better and consistent flow performance [4-6] as was previously shown [7]. In its spherical form RF resin is referred to as sRF.

There has been considerable research both computationally and experimentally with sRF on radioactive alkaline wastes. However, most of those studies have been limited to wastes stored at the Hanford Site [4, 8-10]. One significant difference between some of those wastes is the concentration of potassium. Potassium is a competitor of cesium for sites on the sRF resin so its

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[2] CST and SL-644 are two cesium specific ion exchangers. CST is a Crystalline Silicotitanate resin trademarked as IONSIV® IE-911 by UOP LLC, and SL-644 is trademarked as SuperLig® 644 by IBC Advanced Technologies Inc.

presence will affect loading performance. In general, SRS wastes have low concentrations of potassium (<0.05 M). Besides not having experimental data of sRF performance with SRS wastes, hitherto computational modeling [2] has a need for benchmark data for low potassium feed.

To evaluate flow through resin columns, the models [2] studied the effect of temperatures, i.e., 25°C, 35°C, 45°C and found that as temperature increased, cesium loading decreased; therefore, the lower temperature was selected. The models further evaluated waste treatment at flowrates [in terms of (resin) bed volume (BV)] of 0.7 BV/h, 1.4 BV/h, and 2.8 BV/h. The resin was found to be more effective at the slower rates, but it takes longer to treat equivalent volumes. For this study the middle flow rate of 1.4 BV/h was chosen. The other important feature selected for the column test was the intended lead-lag design where the lead IX column does most of the cesium removal. The lag column, connected in series, captures cesium that leaves the lead column once the lead column approaches saturation. To begin the next cycle the lead column is eluted, regenerated and moved to the lag position. The partially loaded lag column is moved up to the lead position and the cycle repeats.

EXPERIMENTAL WORK

Resin History and Handling

The spherical RF ion exchange resin was purchased from Microbeads AS and shipped in acid form. Resin is stored in hydrogen form under deionized water in sealed containers. The specific material had not previously seen pretreatment or use and was procured for large-scale column work [4]. It had been stored in large metal drums since 2005. This elutable resin needs pretreatment before use and was done to an existing specification [11], which includes converting the resin to sodium form and then back to hydrogen form. The process swells, shrinks, and cleans the resin.

Test Equipment

The experimental rig is shown in Fig. 1. The target resin bed height in each column was 6.5 cm in order to compare to other tests [8-10]. The columns had an inside diameter of 1.435 cm, leading to a flow area of 1.617 cm^2, and the target bed volume was 10.5 mL for sodium form resin. A liquid freeboard of 2 cm was left above each bed. The actual resin bed heights turned out to be an average of 11.2 mL. This height can fluctuate slightly with each cycle because the resin polymer loosens with use. Cycling causes sRF to shrink during acid elution and then swell during alkaline regeneration. Acid elution shrinks bed volumes approximately 25%.

The tubing and valve arrangement allows either column to be in the lead position while the other functions as the lag column. Changing valve alignments also changes column feed to waste, displacement, elution, or regeneration liquids. Radioactive testing commenced with the resin beds both eluted and regenerated. Cycle 1 operated with Column 1 (left column in Fig. 1) as the lead column. Its effluent fed the lag column, Column 2 (right column in Fig. 1). Once the cesium concentration in the Column 1 effluent attained a set breakthrough point, the process was stopped in order to elute and regenerate Column 1. Cycle 2 commenced with Column 2 in the lead position while Column 1 was in the lag position.

During the test the average ambient temperature was above 25°C; therefore, the heating tapes seen on each column in Fig. 1 were not necessary, but cooling air was used to keep the temperatures of the columns below 27°C. The temperature of liquid flowing through the columns was measured just under each of the resin bed screens by installed calibrated thermocouples.

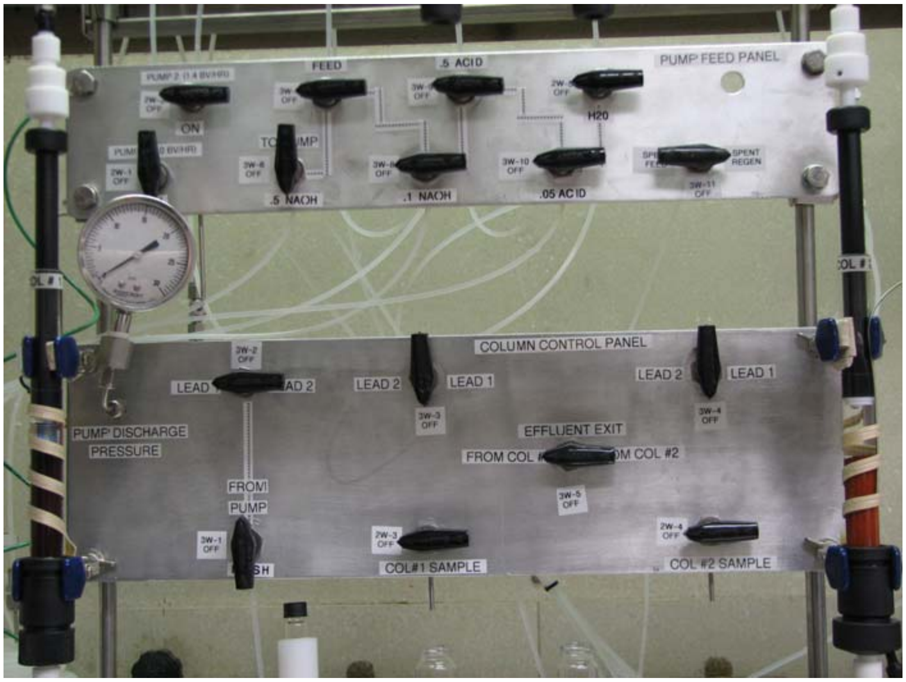

Fig.1. Valve controls and IX columns. The lighter colored resin to the right had been eluted (i.e., it was in H-form). The left column was still in Na-form and therefore darker in color.

Feed Solution

For this test the waste in SRS Tank 2F [2] was chosen because of its low concentration of potassium. A composite of real waste samples was made to match Tank 2F as shown in Table I.

Table I. Chemical Components of Feeds for Testing.

Species	Unit	Tank 2F a	SRS Actual Waste for Column Testing b
Na^{+1}	M	6.00	6.05
NO_3^{-1}	M	4.19	3.53
NO_2^{-1}	M	0.15	0.174
OH^{-1}	M	0.76	0.81
SO_4^{-2}	M	0.03	0.119
PO_4^{-3}	M	0.005	0.007
Al	M	0.29	0.32
F^{-1}	M	0.003	< 0.013
K^{+1}	M	0.007	0.0083
Cs^{+1}	M	1.70E-05	2.51E-05
P	M	0.005	0.011
S	M	0.03	0.129
Hg	M	-none-	3.24E-05
pH	-	14	14
density (25°C)	g/mL	1.306	1.300

a From [2]

b These measured values are accurate to ±10%

That is, the sample of actual waste dissolved saltcake closely matched Tank 2F waste, especially for the species important to ion exchange process performance. Na^+, Cs^+, K^+, and free OH concentrations have the most impact on performance of the RF resin.

Radioactive Dissolved Salt Solution

The radiochemistry of the SRS actual waste is given in Table II. Values outside of masses are accurate to ±10%. Mass concentrations from mass spectroscopy are accurate to ±20%.

Table II. Radiochemistry for Waste for Column Testing

Isotope	Unit	SRS Tanks Actual waste: Column Test	Major Isotope
Cs-137	dpm/mL	1.31E+08	
Sr-90	dpm/mL	na c	
Pu-238	dpm/mL	2.79E+04	
Pu-239/240	dpm/mL	5.82E+02	
Pu-241	dpm/mL	<1.62E+03	
Mass 59	μg/L	246	Stable Co
Mass 95	μg/L	1690	Mo
Mass 99	μg/L	1820	Tc-99 a
Mass 133	μg/L	2410	Stable Cs
Mass 137	μg/L	718	Cs-137 b
Mass 235	μg/L	72.5	U-235
Mass 237	μg/L	13.8	Np-237
Mass 238	μg/L	4590	U-238

a This mass would be 6.85E+04 dpm/mL Tc-99
b Cs-137 gamma activity implies 678 ug/L
c na = not available

Waste Tests with the Small-scale Columns

The IX Column test followed those of previous work [4,8-10]. Plant-typical aspects of the work included the chemical makeup of the waste, the flow rate in BV/h, and the resin media itself, i.e., sRF. The much smaller column size indicated smaller than plant-typical superficial velocities through the columns and smaller absolute volumes in BV.

The amount of waste planned to process in Cycle 2 (320 BV) was considerably less than what was processed in Cycle 1 (480 BV) because for Cycle 2 the new lead column, Column 2, already had a significant amount of cesium loaded from Cycle 1. Furthermore, the reduced volume of waste to process led to a reduced amount of time for the new lead column to become fully loaded. Besides waste processing a cycle contains several steps, which are listed in Table III.

Table III. Steps of a Cycle for an Ion Exchange Column in this Work.

IX Cycle Step	BV	BV/h	Solution Fed	Reason
1. Regeneration	6	3	0.5 M Sodium Hydroxide	Resin to Na+ form
2. Waste treatment	100's	1.4	Alkaline waste	Remove cesium
3. Waste displacement	5	3	0.1 M Sodium Hydroxide	Prevent Al precip
4. Caustic displacement	5	3	Deionized Water	Reduce alkalinity
5. Acid elution	30	1.4	0.5 M Nitric Acid	Remove resin Cs
6. Displacement of acid	5	1.4	Prepare resin for regen.	Reduce acidity

RESULTS AND DISCUSSION

Cesium Ion Exchange with SRS Waste

The test performed two complete IX cycles. The intention was to treat waste with Column 1 as the lead column and Column 2 as the lag column. Once the lead column reached a target cesium breakthrough, the treatment would stop in order to regenerate the resin in the lead column and then switch columns. The lag column, now partially loaded with cesium, is moved to the lead position and the newly regenerated lead column is moved to the lag position. Cycle 1 began with two columns of regenerated resin, and for Cycle 2, once the lead and lag columns were switched, the new lead column, Column 2, would begin partially loaded. Fig. 2 shows the lead-column results from both waste treatment cycles.

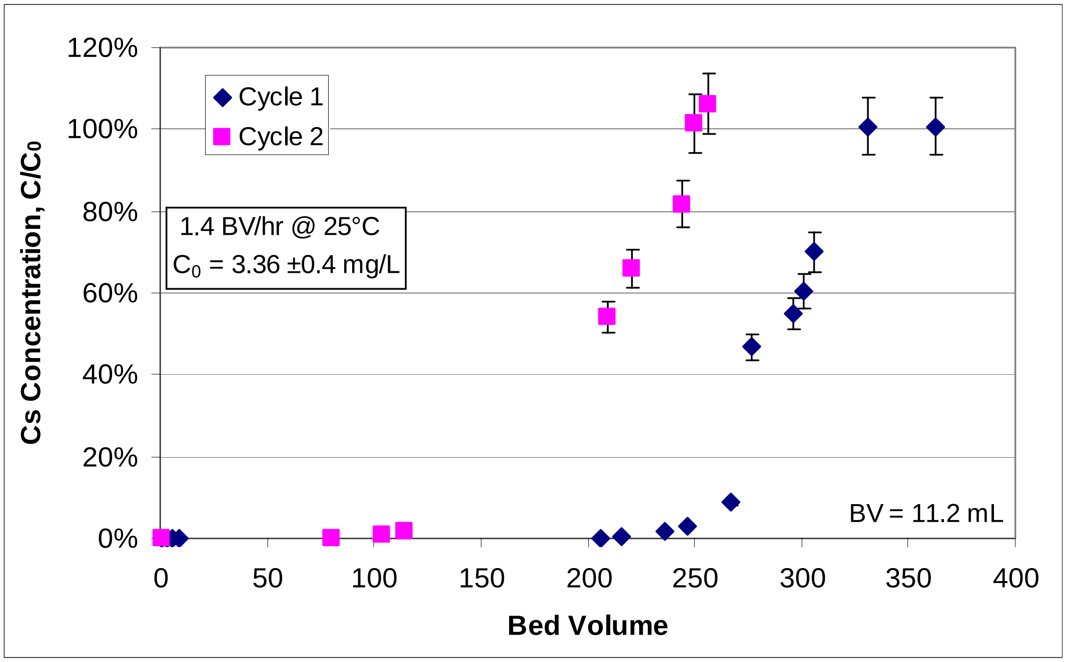

Fig. 2. Lead column effluent cesium for Cycle 2 with SRS actual waste feed

With the lead column of Cycle 1 switched to the lag-column position in Cycle 2, and without regenerating the resin in Cycle 2 lead column, the breakthrough curve initiates earlier, i.e., just after 100 BV. This breakthrough volume is about 100 BV sooner than if the resin in the lead column had started newly regenerated resin from Cycle 1. Once cesium was detected in the effluent, the slope of the breakthrough curve is identical to the curve for a freshly regenerated column of resin. In Cycle 2, the column attained 100% breakthrough at just before 250 BV. For Cycle 1, cesium was detected at 200 BV and ended at around 340 BV, resulting with a similar BV range of 140 BV to transition.

Fig. 2 shows that for both cycles the lead column, i.e., Column 1 for Cycle 1 and Column 2 for Cycle 2, the effluent stream reached 100% breakthrough. Further, the planned SCIX operation will not regenerate the lag column before it is switched to the lead position to begin the next IX cycle meaning it will have a certain preload of cesium, as previously explained. To estimate the cesium loading on the Cycle 1 lead column Table I showed the concentration of the cesium in the feed waste, i.e., 3.36 mg/L (~2.5E-05 M). With the total Cs concentration and the data in Fig. 2 the cesium adsorbed is estimated at 11.3 ±1.4 mg. For the lead column of Cycle 2 the estimate is

8.6 ±1.1 mg. In both cases, it appears that when a resin bed is taken to 100% breakthrough then approximately 85% of the cesium is adsorbed before showing up in the column effluent and the remaining 15% is loaded onto the bed as it reaches saturation.

Now, assuming that both Columns 1 and 2 have the same capacity of cesium loading when starting from the same state of regeneration, then this assumption should be good. That is, if the Cycle 2 lead column started with freshly regenerated resin then it should be able to adsorb approximately 11.3 mg when operated under the same flow conditions. If so, then the Cycle 2 lead column started with a cesium loading of 11.3 - 8.6 = 2.7 ±2.5 mg or in other words it was 24% preloaded. Note, that this preloaded value depends on when feed treatment stops after a certain level of breakthrough is realized. For the current test, after the Cycle 1 lead column effluent reached 100% breakthrough the feed continued for another approximate 80 BV through the lag column. This means the lag column received another 3.36 mg/L x 80 BV x 11.2 mL/BV / 1000 mL/L = 3.0 mg of cesium, which, when considering uncertainty, is the entire amount that was shown to be preloaded on the resin bed in the Cycle 1 lag column, i.e., 2.7 mg! This implies that if the treatment of feed is stopped at, or slightly before, the point when the lead column effluent is at 100% breakthrough, then the lag column still has most of its capacity to adsorb cesium.

A mass balance can be made by determining the amount of cesium that was eluted from the resin during the regeneration process. The majority, if not all, of the cesium elution occurred between 2 BV and 6 BV, with a steep peak, see Fig. 3.

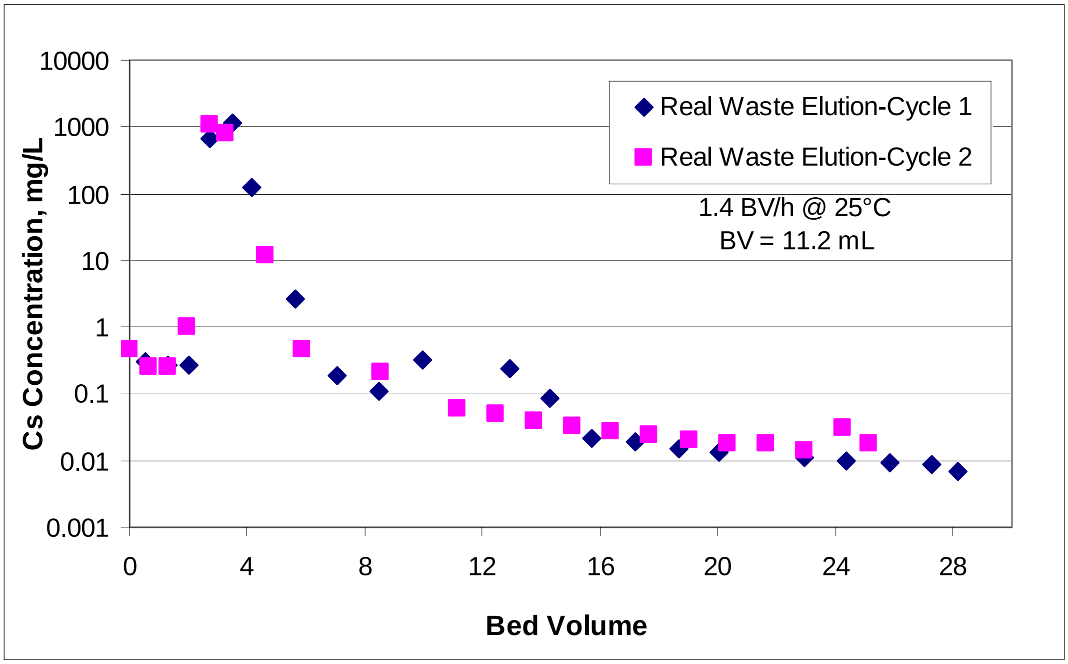

Fig. 3. Lead column Cs elution during Cycles 1 & 2 from the Actual Waste Test[3]

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[3] Fig. 3 uses semi-log format to illustrate the lower concentrations of cesium. The peaks seen past 8 BV may be real because the bed goes through settling as the resin shrinks. This phenomenon has been seen before [9], but it was not explained and the magnitudes are insignificant for overall elution.

For Cycle 1 that peak of cesium concentration occurred at approximately 3.5 BV and by 5.6 BV the effluent of Column 1, i.e., the Cycle 1 lead column that was regenerated, no longer had a measurable cesium concentration. By roughly estimating the area under the curve the cesium released during Cycle 1 elution was 15.2 ±2.3 mg. The cesium recovered from Cycle 2 elution was estimated to be 16.1 ±2.4 mg. While both estimates of the cesium recovered during elution are similar to each other they considerably higher than the Cycle 1 loading of 11.3 mg, even when considering the stated uncertainty of 1.4 mg. This discrepancy between the mass separated and then recovered indicates the difficulty in accurately estimating the cesium adsorbed during loading, desorbed during elution, or, which is more probable, the estimation of both quantities.

Not only was cesium recovered the same from both the Cycle 1 and Cycle 2 elutions, but the overall elution results shown in Fig. 3 were similar. Both cycles began releasing cesium at 2 BV and nothing significant was detected after 6 BV. Further, both elutions showed the same peak concentrations, i.e., 1155 mg/L for Cycle 1 and 1102 mg/L for Cycle 2, which is within the measurement uncertainty of ±15%.

Bed Changes that Occur during Elution of sRF resin

One of the well known [6] aspects of elutable RF resin is its change in volume and color when undergoing regeneration. When eluting cesium with acid, the pH of the resin drops from 14 to 1 and its volume decreases. When the resin is regenerated with sodium hydroxide the pH returns to 14 and the volume expands. This volume change has been found to be between 20 to 25%.

The other sRF resin feature that changes during elution is its color. In sodium form the sRF resin has a dark red/purple coloring throughout the cesium loading step. Once elution acid reaches the resin, not only does it begin to shrink but its dark color begins to change to a bright orange. Fig. 4 shows the color changing in the first hour of elution.

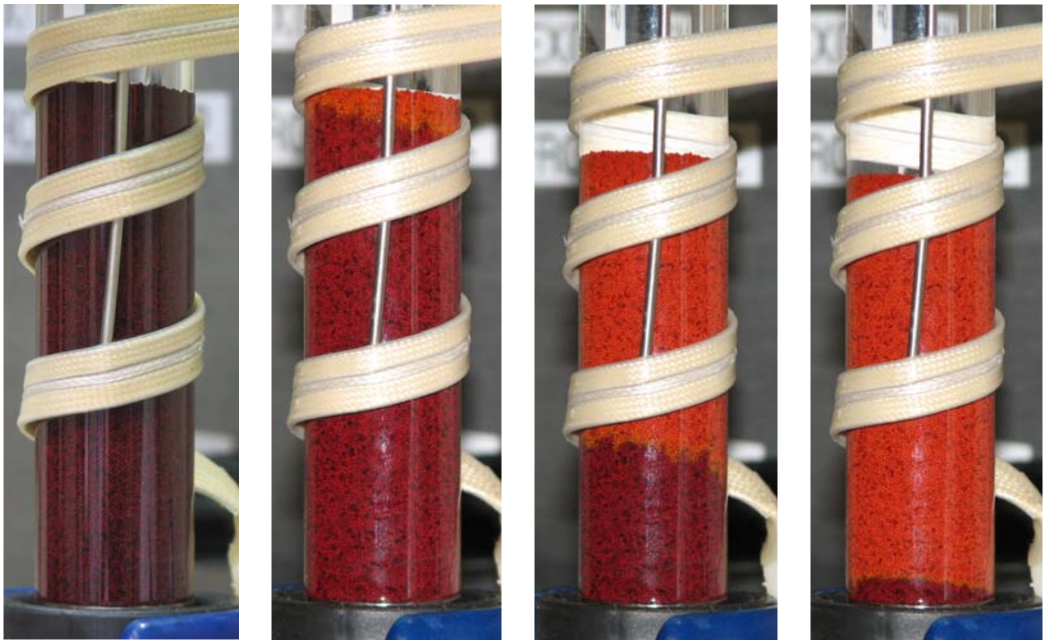

Fig. 4. sRF resin color and height shrinkage during elution as it changes from pH=14 to pH=1
[Approximate time progression from left to right: 0, 12, 45, 64 min. Note, the resin in all four pictures is the same; the much darker column to the left was due to the lighting difference as can be perceived by the darker color of the heating tape.]

Since the resin bed with started with a height of 6.5 cm this implies a velocity of 0.10 cm/min from the leading edge of the color wave. This velocity was slightly slower than the superficial velocity of the acid traveling through the resin bed, as was mentioned above to be 0.15 cm/min. This velocity difference is likely impacted by the kinetics of the proton exchange reaction.

TCLP Analyses

Two damp resin samples were sent to GEL Laboratories, LLC, of Charleston, SC for Toxic Leaching Protocol (TCLP) analyses. Samples were shipped in small glass vials with chain of custody. Each sample was extracted per the EPA TCLP method and extracts were analyzed by Volatile Organic Analysis (VOA, EPA method 8260B), CVAA for mercury, and ICP-ES for RCRA metals outside of mercury. Table IV provides the results.

Table IV. Summary of TCLP Results for the Column 1 and Column 2 resin beds

a, b	Result	DL	RL	units	DF
Column 1 – Volatile Organics					
Benzene	627	71.4	238	μg/kg	50
Column 1 – Metals Analyses					
Mercury	174	6.6	20	μg/L	10
Barium	189	10	50	μg/L	1
Chromium	194	10	50	μg/L	1
Column 2 – Metals Analyses					
Mercury	631	13.2	40	μg/L	20
Barium	145	10	50	μg/L	1
Chromium	162	10	50	μg/L	1

a Column 1 also had butanone and acetone at “J” levels
b Column 2 VOA reported no organic components at or above detection levels
c DL = Detection Limit. Minimum level of analyte that can be identified (not quantified) with 99% confidence
d RL = Reporting Limit. Lowest limit which a chemical may be accurately and reproducibly quantified. (How much is present?)
e DF = Dilution Factor

Ion Exchange Column Product Radiochemistry

Cesium levels in product liquid from the lag column were hard to measure and, in most cases, below 500 dpm/mL for Cycle 1 and below 5000 dpm/mL for Cycle 2. The feed level was 1.31E+08 dpm/mL in Cs-137, Table II. The cesium decontamination in a plant process depends on many things including flow rate, waste composition, and temperature. This work shows that the resin is effective in cesium decontamination work. The high level of Cs-137 removal allowed the gamma analysis to see antimony-126 gamma energy. Sb-126 activity was between 300 and 500 dpm/mL in the products of both actual waste cycles. Antimony probably existed as an oxyanion in the alkaline liquid. The resin did not appear to remove antimony from the waste stream.

Analysis of Eluate Composites from the Cycles

The acidic effluents from the Cycle 1 and Cycle 2 elution campaigns of the test were each collected in separate bottles so that these eluate composites could be characterized, with the results shown in Table V.

Table V. Stable Elements in Eluate Composites from Actual-Waste Testing

Analyte a ICP-ES, mg/L	**Cycle 1 Eluate**	**%RSD**	**Cycle 2 Eluate**	**%RSD**
Ag	<0.8		<0.9	
Al	101.0	0.9	20.4	0.9
B	<2.5		<1.5	
Ba	<0.2		<0.9	
Be	<0.2		<0.5	
Ca	0.6	0.55	1.4	0.55
Cd	<0.3		<0.4	
Ce	<4.0		<2.5	
Cr	1.3	4.2	1.2	4.2
Cu	0.7	11.2	<1.1	
Fe	2.3	2.3	<3.0	
Gd	<0.6		<0.8	
K	<18.1		<11.1	
La	<0.5		<0.7	
Li	<1.3		<0.8	
Mg	<0.1		<0.2	
Mn	<0.2		<0.3	
Mo	<1.4		<0.9	
Na	2155	0.1	754.4	0.1
Ni	<0.9		<1.5	
P	<7.5		<4.6	
Pb	<3.7		<2.3	
S	<73.4		<21.6	
Sb	<3.8		<4.3	
Si	<3.2		<2.0	
Sn	<1.8		<2.2	
Sr	<0.2		<0.6	
Ti	<0.1		<0.4	
U	<16.0		<9.8	
V	<0.3		<0.4	
Zn	0.6	8.9	0.5	8.9
Zr	<0.2		<0.9	
As by AA	<0.38		<0.46	

a AA is atomic absorption, all other values are from emission spectroscopy

Note that sampling was also done during these collections so while these composites have the bulk of elution volumes, they lack volumes taken in sample vials. They thus give an approximate composition of eluate to be expected from this process. Table V shows that aluminum, calcium, chromium, sodium, and zinc were consistently measurable. "%RSD" is percent relative standard deviation.

Table VI shows the plutonium concentration in eluate composites was about 3.5 times that of the feed. From previous work Fiskum et al. [8] found plutonium concentration in a composite eluate from a Hanford Tank AP-101 feed, but it was only 1 to 2 times the feed level. Fiskum et al. [9]

also found measurable plutonium in a composite eluate from processing a Hanford Tank AN-102 complexant feed, but it was less than one tenth the concentration of the feed. The form of plutonium on the resin is not clear. Fiskum et al. [12] found that significant plutonium from real waste was left on sRF resin after elution, strongly suggesting something other than trapping of suspended plutonium solids. The fact that significant plutonium is also found in eluate does not reveal whether solids trapping or ion exchange is also holding plutonium on the resin during loading. Table VI also shows that technetium was measurable, but was about 1% of the feed concentration.

Table VI. Radiochemistry of Eluate Composites

Isotope	**Cycle 1**	**%RSD**	**Cycle 2**	**%RSD**
dpm/mL	**Eluate**		**Eluate**	
Am-241	<194.		<176.	
Am-243	<29.0		<28.4	
Am-242m	<3.55		<3.78	
Cm-243	<106.		<104.	
Cm-245	<87.3		<85.8	
Cm-247	<139.		<143.	
Cf-249	<153.		<149.	
Cf-251	<95.3		<99.4	
Cm-242	<2.93		<3.13	
Cm-244	<11.2		258	23.5
Sr-90	7.66E+04		5.87E+04	
Tc-99	882	12.6	766	18.4
Pu-238	1.12E+05	6.3	9.07E+04	6.1
Pu-239-240	1940	69.4	3050	24.4
Pu-241	3720	16.9	4190	18.7

Spent Resin Analyses

A method using an excess of 8 M nitric acid in a Teflon™ sealed vessel was demonstrated with previously characterized nonradioactive sRF samples, then used on the radioactive resin bed samples. The resin was found to totally dissolve if held at 85°C for two hours. Table VII below provides elemental content on a dry basis. Major elements found are sodium, iron, aluminum, chromium, sulfur, and mercury. Sulfur is likely part of the resin as-manufactured. Potassium was on the edge of detection given the large relative standard deviation (%RSD).

Table VII. ICP-ES Results for Dissolution of Resin Samples

	Column 1 Resin			**Column 2 Resin**		
Element		**μg/g**	**%RSD**		**μg/g**	**%RSD**
Ag	<	5.07	N/A	<	5.48	N/A
Al		118.0	3.71		393.0	1.70
B		85.4	0.976		114.0	2.15
Ba	<	1.16	N/A	<	1.25	N/A
Be	<	0.34	N/A	<	0.37	N/A
Ca		22.3	2.18		46.5	1.74
Cd	<	2.51	N/A	<	2.73	N/A
Ce	<	20.2	N/A	<	22.0	N/A
Cr		1739.0	0.366		956.0	0.496
Cu	<	4.14	N/A	<	4.48	N/A
Fe		71.5	2.91		88.9	1.88
Gd	<	4.59	N/A	<	4.96	N/A
K	<	51.2	N/A		60.9	35.6
La	<	2.50	N/A	<	2.71	N/A
Li	<	4.23	N/A	<	4.59	N/A
Mg		4.86	0.98		9.85	0.588
Mn		1.27	0.672		2.29	3.92
Mo	<	8.87	N/A	<	9.59	N/A
Na		221.0	2.22		448.0	1.33
Ni	<	6.64	N/A	<	7.20	N/A
P	<	45.0	N/A	<	48.7	N/A
Pb	<	28.5	N/A	<	30.8	N/A
S		1019.0	9.55		1196.0	15.8
Sb	<	28.7	N/A	<	31.0	N/A
Si	<	24.6	N/A	<	26.6	N/A
Sn	<	13.5	N/A	<	14.6	N/A
Sr	<	0.22	N/A		1.03	5.02
Ti	<	5.03	N/A	<	5.42	N/A
U	<	119.0	N/A	<	128.0	N/A
V	<	2.50	N/A	<	2.71	N/A
Zn		5.35	5.06		11.6	4.66
K (AA)	<	31.0	N/A	<	34.4	N/A
Hg		4230.0	20		3720.0	20

Table VIII lists the major radioisotopes that were measured for the two resin samples. Pu-238 is the most active actinide found. Its activity is comparable to that of the Cs-137 that was measured. Very small activities of Am-241 and Cm-244 were detected, but with large deviations (%RSD). Plutonium is thus the actinide providing almost all of the actinide activity. If the Mass 238 value for the bed in Column 1 is converted to U-238 activity a value of 2.4 dpm/(g resin) results. Mass 235 (Uranium) was too low to detect.

Table VIII. Radiochemical Data for the Resins, dpm/(g resin)

Isotope	Column 1	%RSD	Column 2	%RSD
Sr-90	3.04E+05	14.8	3.73E+05	13.0
Cs-137	2.44E+06	5.0	7.95E+06	13.6
Pu-238	2.74E+06	7.24	3.12E+06	6.3
Pu-239/240	<2.7E+04	N/A	<1.5E+04	N/A
Pu-241	5.75E+04	11.5	8.56E+04	11.1
Am-241	56.1	17	120.3	17
Am-243	< 3.29	N/A	< 3.21	N/A
Am-242m	< 8.30	N/A	< 8.10	N/A
Cm-243	< 11.81	N/A	< 11.53	N/A
Cm-245	< 9.68	N/A	< 9.45	N/A
Cm-247	< 18.41	N/A	< 17.97	N/A
Cf-249	< 19.28	N/A	< 18.82	N/A
Cf-251	< 11.46	N/A	< 11.18	N/A
Cm-242	< 0.69	N/A	< 0.67	N/A
Cm-244	312	20	705	20

CONCLUSIONS

The sRF resin performance was tested with SRS Waste at a flow rate of 1.4 BV/h at 25 ±2°C to remove cesium. The following observations were made:

- For regenerated resin, breakthrough begins after processing between 200 and 250 BV, reaching 100% at around 400 BV, with an approximately linear slope from 5% to 100%.
- When a lag column has some level of cesium pre-loading and then put in the lead position, its breakthrough curve (as lead) has approximately the same slope as with regenerated resin.
- Most cesium desorption from the resin using 0.5 M nitric acid occurs from 2 to 6 BV.
- During elution the resin shrinks to about 80% of its fully working bed volume, or bed height, in sodium form. As 0.5 M nitric acid is used to elute cesium that changes the pH from 14 to 1 and approximately 90% of the bed height shrinkage occurs during the first 6 BV of acid.
- During elution the resin change color, from dark red while it is in sodium form, to a bright orange in hydrogen form. This color change occurs during the first 2 BV of acid processing. The color wave moves along the height of the resin bed at an estimated 60% of the superficial velocity of the acid moving through the column.
- Resin TCLP showed the resins passing except for a mercury point for one sample.
- The resin demonstrated significant affinity for mercury, chromium, boron, and plutonium. The ability to concentrate plutonium from non-complexing waste sends more plutonium to the eluate stream (high level waste). This has to be considered in criticality calculations.

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