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IONSIVÒ IE-911 Performance in Savannah River Site Radioactive Waste

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Abstract

This report describes cesium sorption from high-level radioactive waste solutions onto IONSIVÒ IE-911 at ambient temperature. Researchers characterized six radioactive waste samples from five high-level waste tanks in the Savannah River Site tank farm, diluted the wastes to 5.6 M Na^+, and made equilibrium and kinetic measurements of cesium sorption. The equilibrium measurements were compared to ZAM (Zheng, Anthony, and Martin)[1-2] model predictions. The kinetic measurements were compared to simulant solutions whose column performance has been measured. The test results indicate the following.

- The ZAM model adequately predicts loading of cesium from a variety of Savannah River Site wastes.
  - Measured values were mostly within 33% of the predicted values and were both higher and lower than predicted.
  - Wastes from both F and H Areas and with high and low K/Cs ratios showed good agreement with predictions.
- Kinetics of sorption were nearly identical in all tests with SRS radioactive waste and simulated SRS waste, suggesting current modeling parameters are adequate for predicting radioactive waste performance.

Further work recommended in this area includes performing identical tests with waste obtained by dissolving salt cake and development of a more sensitive test for comparing sorption kinetics.

Introduction

The Salt Disposition Systems Engineering Team identified non-elutable ion exchange as one of the preferred alternatives to decontaminate soluble radioactive waste at the Savannah River Site (SRS).[3] Crystalline silicotitanate (CST) in the engineered form (UOP IONSIVÒ IE-911) serves as the ion-exchange sorbent in this process option. The performance of IONSIVÒ IE-911 in three simulated wastes has received extensive study. However, data on the performance in radioactive waste from the Savannah River Site

(SRS) tank farm is limited. In 1999, researchers completed batch equilibrium tests and a column test using Tank 44F waste.[4] Previously, D. J. McCabe tested an early batch of the engineered sorbent (called Batch 38B) using Tank 22H waste for an application of CST to the DWPF recycle stream.[5] The sorbent performed as expected based on modeling. The current set of tests extends the data to a variety of waste tanks.

Waste management personnel provided samples from Tanks 30H, 32H, 33F, 34F, and 35H. Two samples from Tank 32H were obtained on different sampling dates approximately two months apart. Between the two sampling dates, a waste transfer was made into Tank 32H so the solution compositions were expected to differ. The tanks were chosen for the following reasons.

- Compare H Area and F Area waste.

  Tanks 33F and 34F, along with the previous work on Tank 44F, can be compared to Tanks 30H, 32H, and 35H to determine if minor component differences between the two tank farms affect IONSIVÒ IE-911performance.

- Investigate the effect of alkaline earth metal ions.

  Evidence from groundwater processing indicated that alkaline earth metals are sorbed by IONSIVÒ IE-911 and displace cesium.[6] Tank samples were selected to provide a variety of alkaline earth metal concentrations. Based on the tank farm corrosion inhibitor data base, Tank 33 was identified as containing high carbonate concentration compared to Tanks 30H, 32H, 34F, and 35H. Because of the low solubility of alkaline earth carbonates, it was inferred that this would provide a variation in alkaline earth concentration. Subsequently, work with simulants showed that alkaline earths are virtually insoluble in highly alkaline wastes and have no significant effect on cesium sorption.[7]

- Compare low and high potassium/cesium ratios.

  IONSIVÒ IE-911 sorbs potassium in addition to cesium. The selected tanks provide a range of K/Cs ratios that span above and below the average ratio expected during processing.

This work partially fulfills a request from R. A. Jacobs, "Chemical and Thermal Stability," Technical Task Request #HLW-SDT-TTR-99-38.1, Rev. 0, December 20, 1999. The work complies with the following plan: D. D. Walker, "Task Technical and Quality Assurance Plan for Non-Elutable Ion Exchange Process Waste Stability and IONSIVÒ IE-911 Performance Tests," WSRC-RP-99-01079, Rev.0, December 20, 1999.

Results and Discussion

Tests investigated the equilibrium and kinetics of cesium sorption from radioactive waste onto IONSIVÒ IE-911 sorbent. The following sections describe the result of the characterization of the radioactive waste, equilibrium tests to determine the extent of cesium sorption, and kinetic tests to determine the rate of cesium sorption. Appendix A describes experimental details of the tests.

Characterization of Radioactive Wastes

The SRS tank farm personnel obtained samples of supernatant liquid from six waste tanks in 100-mL steel bottles, commonly known as dip bottles. Two or three of the dip bottles from the same tank were combined and characterized for this study. Table A-1 in Appendix A lists details of the origin of the composite samples. Shielded Cells personnel made 100-fold water dilutions of aliquots of each waste for routine analysis by the SRTC Analytic Development Section personnel. Based on sodium ion concentrations determined for the diluted aliquots, researchers diluted the radioactive waste with water to achieve 5.6 M sodium ion. In one case (Tank 33H), the "as-received" sample was not diluted with water because the initial concentration was less than the desired 5.6 M Na^+. In a second case (Tank 32H, date 4/17/00), the dilution in the cell yielded a final sample containing only 4.4 M Na^+. The error likely occurred in the original analysis of the sodium ion concentration of the concentrated sample. Table I lists the analytical results for the diluted samples.

The waste compositions are generally typical of tank supernates. Crystallization of less soluble salts leaves the supernate highly concentrated in sodium hydroxide. In these solutions the free hydroxide accounts for half or more of the total sodium concentration. Cesium also tends to concentrate in the supernate and this is reflected in the high activity of the samples (Cs-137 $>1x10^9$ d/m/mL). The Tank 33F sample is unusual in several aspects. First, it was low in Na^+ indicating that it is fresh waste from canyon operations and has not been through an evaporator. The Cs-137 activity ($4x10^7$ d/m/mL) is low compared to most high-level waste solutions and

the uranium concentration is unusually high.

Alkaline earth metal concentrations were all below detection limits (typically 1-4 mg/L) except for Mg in Tank 33F. The appearance of Mg at 1.7 mg/L in Tank 33F exceeds the expected solubility of <0.1 mg/L.[7] Since the result is very close to the detection limit, it may be a false positive.

The ratio of K to Cs (in molar units) in average waste is 106.[8] The ratios in the waste samples in this study vary from a low of 42 in Tank 32H (2/8) to a high of 220 in Tank 34F. The high value in Tank 34F is of particular interest since the presence of large amounts of potassium (relative to cesium) decrease the ability of IONSIVÒ IE-911 to sorb cesium.

TABLE I. Composition of Radioactive Waste Samples

Component				Concentration		
	Tk 30	Tk 32 (2/9)	Tk 32 (4/17)	Tk 33	Tk 34	Tk 35
Na+ (M)	5.5	5.7	4.4	3.4	5.8	5.5
K+ (M)	0.028	0.013	0.013	0.0034	0.029	0.012
Rb+ (mM)	0.14	<0.4	<0.4	5.4	5.5	4.6
Cs+ (mM)	0.36	0.31	0.24	0.051	0.13	0.17
Free OH-	2.57	1.69	1.86	1.51	3.36	2.34
NO3	1.49	2.04	1.42	1.31	1.14	1.49
NO2	0.57	0.76	0.57	<.24	0.46	0.71
AlO2-	0.36	0.48	0.36	0.024	0.20	0.31
SO4	<.05	0.028	<.05	0.035	0.010	0.016
CO3	0.29	0.29	0.05	0.332	0.218	0.359
PO4	0.0049	0.0023	0.0032	0.0018	0.0044	0.0043
F	<.1	<.1	<.1	<.1	<.1	<.1
Cl	<.06	<.06	<.06	<.06	<.06	<.06
Oxalate	<.12	<.12	<.12	<.12	<.12	<.12
Formate	<.23	<.23	<.23	<.23	<.23	<.23
			Concentration (mg/L)			
Ag	<10	<10	<10	<6	<12	<9
As	0.15	0.18	0.07	0.13	0.38	0.31
Ba	<4	<3	<4	<2	<4	<3
Ca	<2	<2	<2	<1	<2	<2
Cd	<5	<4	<5	<3	<6	<5
Cr	600	192	320	49	510	180
Hg	4.9	25	14	0.69	0.66	15
Mg	<2	<2	<2	1.7	<2	<2
Pb	88	61	<50	<30	61	<40
Se	<0.5	0.6	0.4	0.3	0.4	0.06
Sr	<2	<2	<2	<1	<2	<2
Y	0.016	0.017	0.012	<0.002	<0.002	0.13
			Concentration (d/m/mL)			
Cs-137	3.01E+09	2.91E+09	2.22E+09	4.27E+07	1.04E+09	1.63E+09
Sr-90	3.0E+06	2.1E+07	1.7E+07	1.3E+06	<3.7E4	2.6E+07
Tc-99	5.2E+05	6.7E+05	4.9E+05	9.4E+03	1.5E+05	3.3E+05
Pu-238	4.6E+05	1.1E+05	7.8E+05	4.4E+03	1.1E+03	3.6E+05
Pu-239/240	1.2E+04	1.8E+04	1.4E+04	3.3E+04	<5E+02	7.1E+03
			Concentration (mg/L)			
M-235	0.45	0.72	0.54	1.7		0.62
M-236	0.20	0.44	0.26	0.07		0.27
M-237	<.05	<.05	<.05	0.69		0.053
M-238	1.8	1.7	1.3	69	1.8	6.0
M-239	0.06	0.093	0.066	0.28		0.10
Density	1.242	1.251	1.212	1.145	1.232	1.231
pH	>14	>14	>14	>14	>14	>14

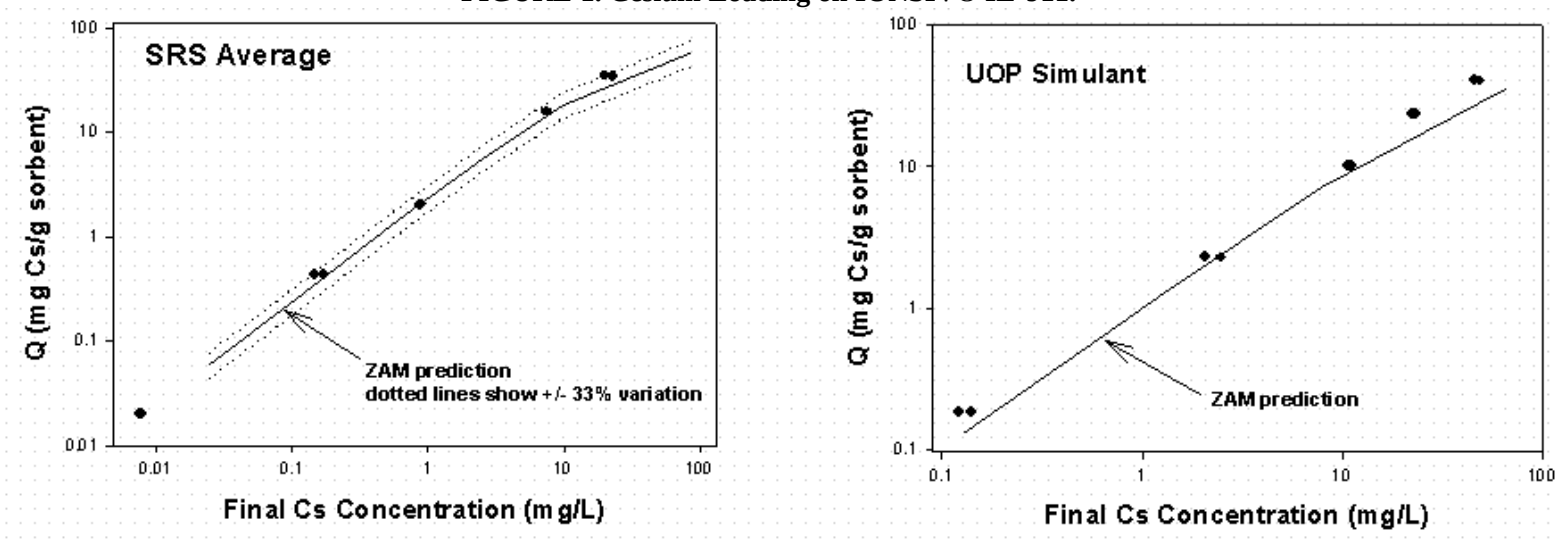
Equilibrium Tests

Equilibrium tests measure the amount of cesium sorbed onto IONSIVÒ IE-911 over a range of final cesium concentrations. The resulting data provide a loading curve for cesium on the sorbent. The loading curve is used to predict the amount of sorbent required

to process different wastes. The purpose of these tests was to compare the expected performance (i.e., ZAM-predicted loading curve) to the measured performance in radioactive waste and ascertain whether or not the ZAM model provides a good prediction. Two factors may cause deviations between ZAM predictions and measured values. First, IONSIVÒ IE-911 contains approximately 20 wt % inert binder in addition to the crystalline silicotitanate sorbent. The ZAM model was built from data for the hydrogen-form of CST without the binder. Second, in the measurements reported here, IONSIVÒ IE-911 was converted to the sodium form, dried, and then tested. Although the water content was corrected for, no correction was made for the change in density due to the replacement of hydrogen by sodium. To offset these biases, the ZAM model predictions are adjusted with a 30% "dilution" factor (Appendix B).

Figure 1 shows the results of the loading tests and compares them to the ZAM predictions for each of the six tank wastes and two simulant solutions. Measured and predicted values agree within ± 33% except in a few cases. There appears to be a tendency for the measured values at low cesium concentrations to fall below the ZAM model prediction. This means that the sorbent does not absorb as much cesium as predicted at low cesium concentrations. This discrepancy is most noticeable for the Tank 33F and Tank 34F samples. Deviations from the ZAM model in this concentration region will not impact the usage rate for crystalline silicotitanate since loading at higher concentration typical of column breakthrough are adequately predicted. However, performance that is poorer than predicted at low concentrations could lengthen the mass transfer zone in column operations. One interpretation of the discrepancy is that F Tank Farm wastes contain a component that affects cesium sorption. However, this is not a general conclusion for all F Area waste since previous testing with Tank 44F waste showed excellent agreement between ZAM predictions and measured values.[4] Figure 2 shows previously published data[4] and the ZAM prediction for the Tank 44F salt solution. Neither does it seem likely that the Tank 34F discrepancy is due to the high K/Cs ratio since a similar discrepancy occurs with Tank 33F waste in which the ratio is below average. The authors think that the discrepancy is due to contamination of the low activity samples during handling in the Shielded Cells. Random contamination required repeating the low activity simulant tests outside of the Shielded Cells. The cesium activities at the low end of the loading curves for Tanks 33F and 34F are of the same magnitude as the contamination found in the simulant tests (approximately 10^5 d/m/mL).

FIGURE 1. Cesium Loading on IONSIVÒ IE-911.



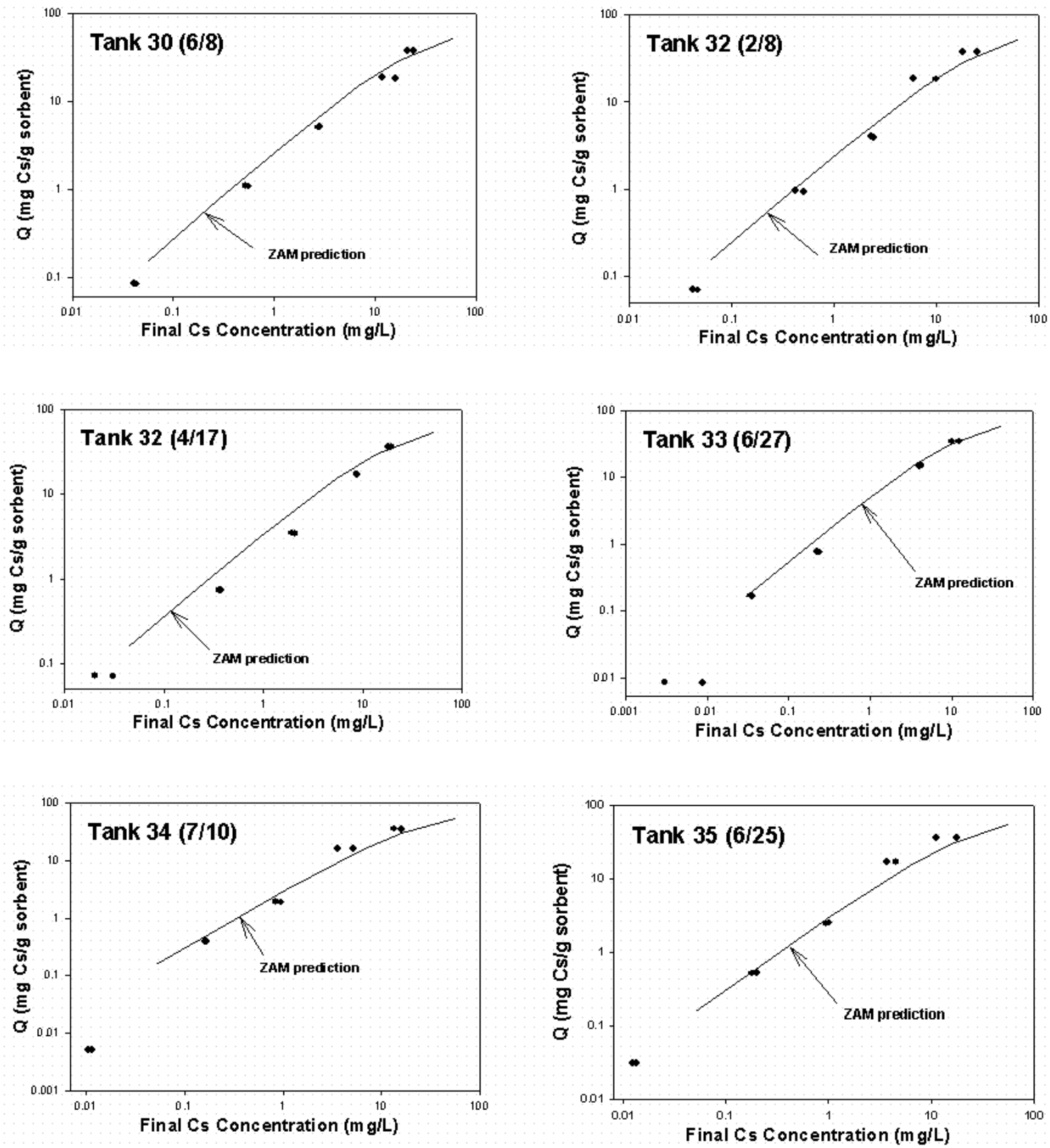
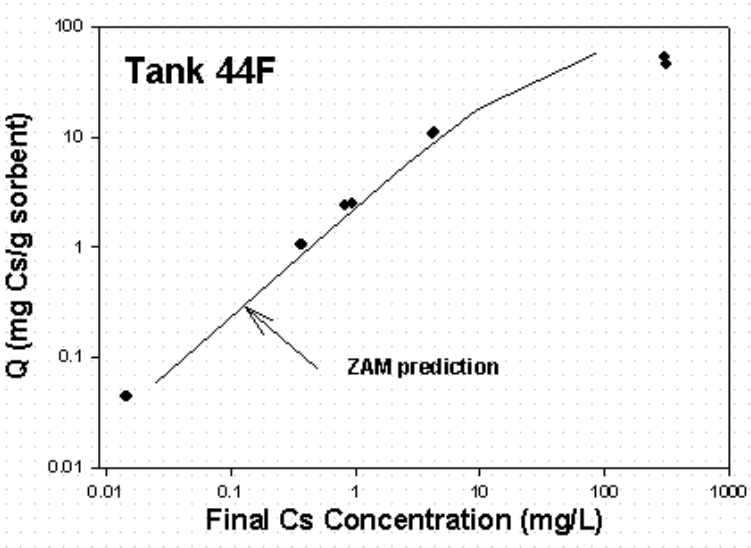


FIGURE 2. Tank 44F Cesium Loading on IONSIVÒ IE-911*



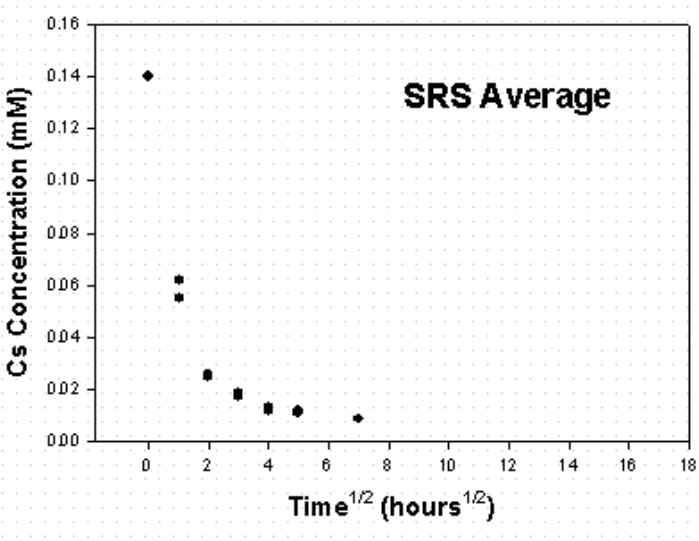
*See Reference 4.

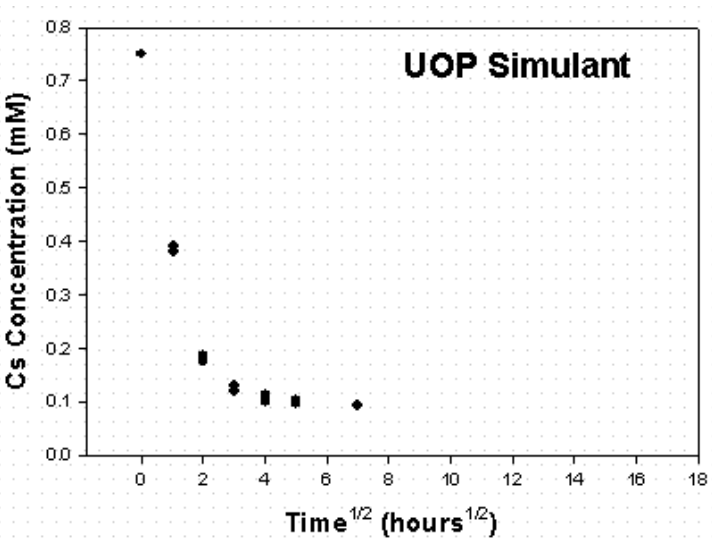
Kinetic Tests

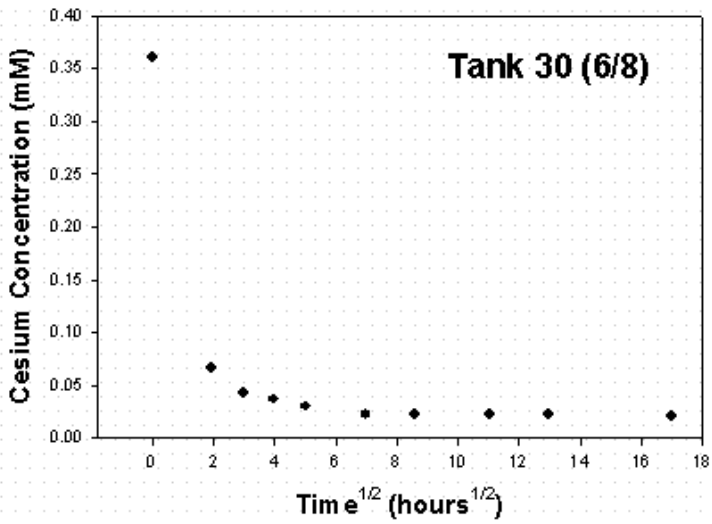
Researchers measured sorption of Cs on IONSIVÒ IE-911 as a function of time. The tests examine whether cesium sorbed more slowly from the radioactive waste solutions compared to SRS average simulant or UOP simulant. Slower sorption rates could indicate that the process ion-exchange columns need to be longer than currently designed. The six waste samples and two simulants were compared under similar conditions of temperature, mixing, sample size, and container shape. Mixing was achieved by shaking the samples in an orbital shaker. The decrease in the cesium concentration in solution was measured for 288 hours, although the cesium appeared to reach the equilibrium concentration after 48 hours. Figure 3 shows graphs of the data for each solution. The numerical values are listed in Table A-4 in Appendix A.

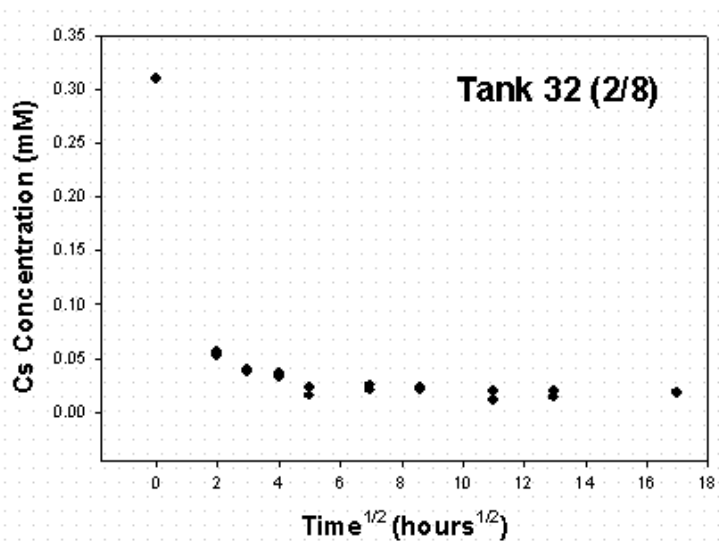
FIGURE 3. Rate of Cesium Sorption on IONSIVÒ IE-911 from Simulated and Radioactive Waste Solutions

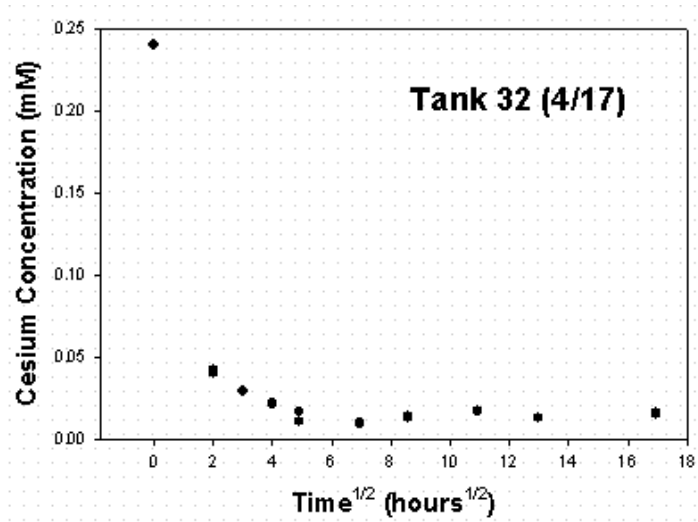
(Note: The cesium concentration is plotted against the square root of the elapsed time to emphasize the curvature at short time periods.)

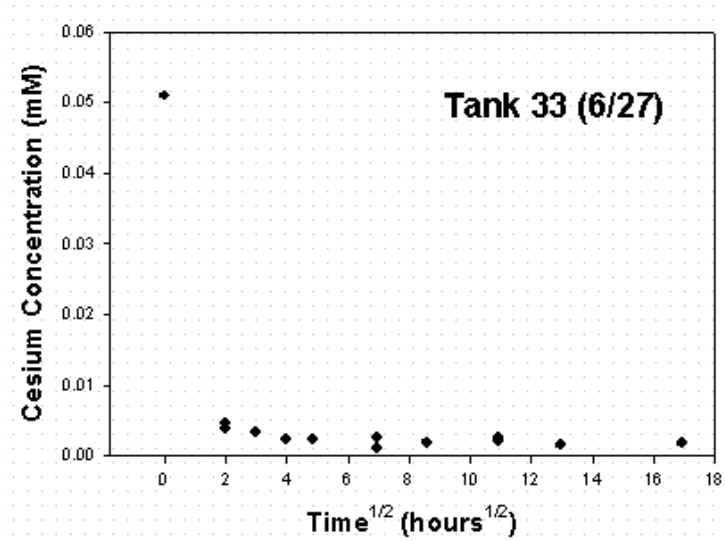


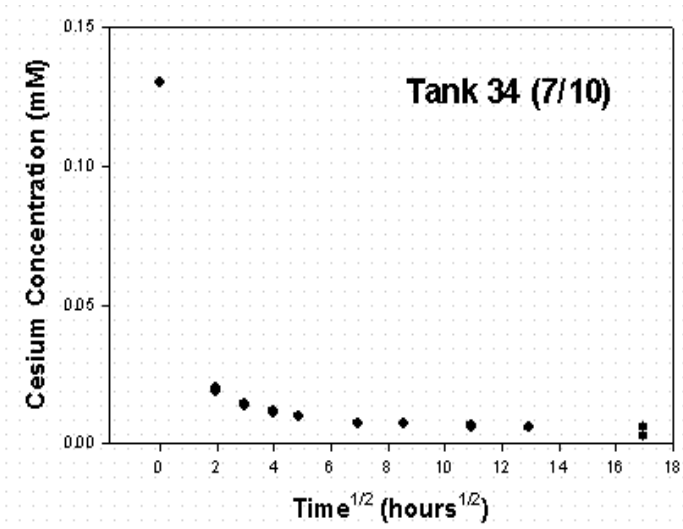


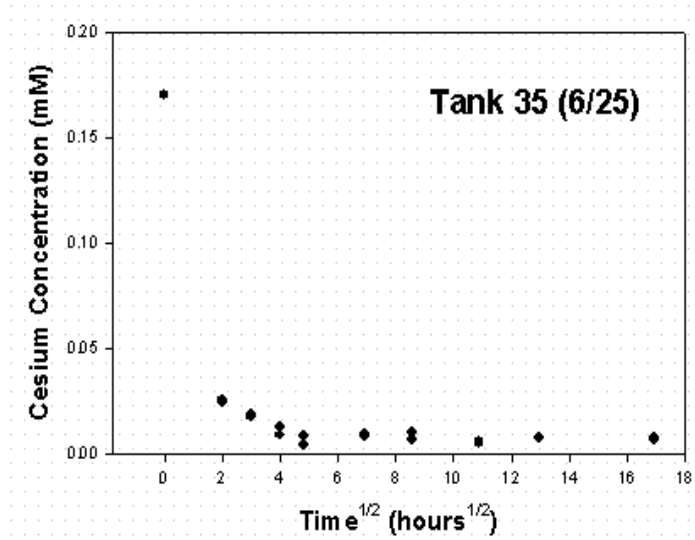












The shapes of the graphs show no significant differences in sorption rate. Table II lists the initial slopes calculated from the data in Fig. 3. The calculations used the following equation.

$$\text{Initial Slope} = [(C_o-C_t)/(C_o-C_f)]/t$$

Where C_o = initial Cs concentration

C_t = Cs concentration at the 4-hour sampling time
C_f = final Cs concentration (average of all data at 48 hours and later)
t = exact time for the 4-hour sample

As shown in Table II, the initial slopes for the radioactive wastes are equal to or greater than the slopes for the SRS average simulant. Thus, it is concluded that, within the limitations of the test method, the rates of cesium sorption from radioactive wastes are equal to the rate for the SRS simulant.

Researchers at Texas A&M University use a similar test but mix using a stir bar and impeller.[9] The amount of solution required for the Texas A&M procedure (~1 L) exceeds the amount of radioactive waste available for the SRS tests. Under the test conditions employed by Texas A&M, film mass transfer is negligible and apparent intraparticle diffusivity data can be extracted from the test data. In the test method used for the SRS wastes, both film mass transfer and intraparticle diffusivity affect the rate of cesium sorption. Values for each cannot be extracted from the data.

TABLE II. Calculated Initial Slopes for Cesium Sorption from Simulated and Radioactive Waste Solutions*

Solution	Initial Slope (h^{-1})
SRS Average	0.22
UOP simulant	0.23
Tk 30H	0.23
Tk 32(2/8)	0.23
Tk 32 (4/17)	0.22
Tk 33F	0.24
Tk 34F	0.24
Tk 35H	0.22

*Based on initial 4-hour interval.

Summary and Conclusions

Researchers investigated sorption of cesium from six radioactive waste samples from the SRS tank farms. The experiments included both equilibrium and kinetic measurements. The radioactive waste results were compared to results from two simulated waste solutions. The equilibrium results were also compared to predictions by the ZAM model The equilibrium measurements indicate that the distribution of cesium in the presence of wastes is similar to simulant solutions and to ZAM model predictions. This data supports the continued use of the ZAM model for predictions of process performance. Perform-ance for waste from F and H area tanks farms is adequately predicted. The time-dependent data suggests that kinetic parameters for simulants are similar for radioactive waste and column-modeling parameters (such as intraparticle diffusivity) need not change.

Although these results greatly extend the performance data-base for IONSIV IE-911 in SRS wastes, additional measurements are recommended. The waste samples tested to date are all high-hydroxide supernate solutions. Samples of dissolved salt cake which will have higher nitrate-ion concentrations and lower hydroxide concentrations have not been tested for any of the three Salt Alternative processes. Also, dissolution of salt cake may add additional trace contaminants to the waste. Future tests with radioactive waste should also emphasize accurate measurements of the distribution at low cesium concentrations.

The kinetic test procedure used in this study did not reveal significant differences in sorption kinetics between different waste samples. However, the test protocol did not allow derivation of the apparent diffusivity used in column-modeling calculations. It is recommended that a protocol be developed for evaluating this aspect of sorption kinetics.

Acknowledgements

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Appendix A
Experimental

Characterization of Radioactive Waste

The SRS tank farm personnel provided samples of liquid radioactive waste from five waste tanks. One waste tank (Tank 32H) was sampled twice about 3 months apart. The samples were received, stored, and processed in the Shielded Cells facility in Bldg. 773-A. The samples were received in 100-mL stainless-steel dip bottles. The contents of the bottles were combined and stored in polyethylene bottles. The densities were measured in 50-mL volumetric flasks and weighed on a balance that reads to ± 1 mg. Unfiltered portions (1 mL) were diluted in 99 grams of water or 0.2 M nitric acid and sent to the SRTC Analytical Development Section for routine analyses. The exact dilution factors were calculated from the density, weight of the nominally 1-mL sample, and weight of the water assuming ideal mixing of the waste and water. Table A-1 lists the origin of the samples. Table I (p. 8) lists the results of the analyses.

IONSIVÒ IE-911

Researchers used pretreated IONSIVÒ IE-911 (UOP, LLC; Lot # 8999-020-81-000009). The sorbent (100 g) was pretreated in four steps. First, it was washed with water (2 L) to remove fines. Second, it was loaded into a column and rinsed continuously with 7 liters of 3.0 M NaOH at a flow rate of 5 mL/min for 24 hours. Third, the sorbent was washed with a continuous flow of water for 24 hours (5 mL/min for a total of 7 L). The pH of the water exiting the column at the end of the 24-hour rinse was 11.3. Finally, the washed sorbent was dried at 35 ° C. The water content (14.3 wt %) was measured by loss of weight upon heating to 400 ° C for 4 hours.

TABLE A-1. Origin and Initial Concentrations of the Radioactive Waste Samples from the SRS Tank Farms

Tank of origin:	Tank 30H	Tank 32H	Tank 32H	Tank 33F	Tank 34F	Tank 35H
Date of sample	6/8/00	2/8/00	4/17/00	6/27/00	7/10/00	6/25/00
Sample number	HTF-212 HTF-213 HTF-214	SS1* SS2* VDS1* VDS2*	#1 #2 #3	#1 #2 #3 (#4)** (#5)**	#1 #2 #3	HTF-219 HTF-220 HTF-221 HTF-222
Volume received (mL)	178	213	224	385	191	296
Density (g/mL)	1.410	1.303	1.324	1.145	1.413	1.310
Na+ (M)	10.4+/-.5	7.1+/-.2	8.9+/-.5	3.6+/-.2	11.1+/-.7	7.7+/-.2

* W. R. Wilmarth provided these samples from the 3H Evaporator program.
** No sample identification number was present.

Simulant Solutions

Researchers tested two simulated waste solutions for comparison to the radioactive wastes. Table A-2 lists the compositions of the simulants.[10] The simulants were prepared from reagent-grade chemicals in volumetric flasks. The weighing errors using analytical balances were less than 1%. Accurate cesium concentrations were obtained by preparing a 10,000 mg Cs/L stock solution from CsCl. Researchers added tracer amounts of Cs-137 stock solution (Isotope Products Laboratory, >99% radionuclidic purity).

Cesium-Loading Tests

Cesium-loading tests measured the sorption of Cs-137 from five radioactive waste and two simulant solutions onto pretreated IONSIVÒ IE-911 over a range of cesium concentrations. Table A-3 lists the results. The cesium concentrations in the wastes or simulants were varied by adding CsCl stock solution to obtain higher concentrations or by pretreating the solution with IONSIVÒ IE-911 to remove cesium for lower concentrations. Sorbent (0.1 or 0.5 grams) was weighed into polyethylene bottles, placed into the Shielded Cells, and treated with 10 mL of the appropriate radioactive waste or simulant solution. All samples were prepared in duplicate. The bottles were shaken for 12 days at ambient temperature on a New Brunswick Model C24 orbital incubator shaker at 150 rpm. The temperature averaged 23 ± 2 ° C, but varied with a high of 30 ° C and a low of 18 ° C. The cell air temperature was measured with two thermocouples located in the incubator.

TABLE A-2 Composition of Simulated Waste Solutions

Component	Concentration (M)	
	SRS Average	UOP Simulant
Na^+	5.6	5.7
K^+	0.015	--
Cs^+	0.00014	0.00075
OH^-	1.91	0.60
NO_3^-	2.14	5.1
NO_2^-	0.52	--
AlO_2^-	0.31	--
CO_3^{2-}	0.16	--
SO_4^{2-}	0.15	--
Cl^-	0.025	0.00075
F^-	0.032	--
PO_4^{3-}	0.010	--
$C_2O_4^{2-}$	0.0080	--
SiO_3^{2-}	0.0040	--
MoO_4^{2-}	0.0002	--

Kinetic Tests

Kinetics tests followed the same method as the equilibrium tests, except samples were removed from the shaker after 4, 9, 16, 25, 48, and 72 hours, and 5, 7, and 12 days. Table A-4 lists the results. In all cases, 0.1 gram of IONSIVÒ IE-911 was placed in 10 mL of the radioactive or simulanted waste with cesium concentrations shown in Tables 1 and A-2. The temperatures varied as described above. In the 4-hour test, the average temperature of 27 ° C was significantly higher than in the other tests.

The Cs-137 activities in samples from the simulant solutions were irregular and higher than expected. In some cases results for samples in which cesium had been adsorbed were higher than the original solution. This was attributed to random contamination during sample handling in the Shielded Cells. The simulants contained tracer levels of Cs-137 of approximately 10^5 d/m/mL. The contamination levels were of comparable magnitude. Contamination did not appear to affect the majority of the results from the radioactive waste tests where the Cs-137 activity was usually $>10^6$ d/m/mL . The simulant tests were repeated in radiochemical hoods outside of the Shielded Cells where contamination was avoided. The temperature of the repeated tests was 25 ± 0.5 ° C.

TABLE A-3 Cesium-Loading Test Data

Solution	[Cs] solution (mg/L)	Q (mg Cs/g sorbent)		Solution	[Cs] solution (mg/L)	Q (mg Cs/g sorbent)
UOP	48.6	40.4		**Tk 32H**	19.3	36.6
	46.0	40.6		**(4/17)**	18.0	36.5
	22.4	23.3			8.6	17.3
	23.5	23.3			8.7	17.3
	10.7	10.2			2.07	3.46
	11.2	10.1			1.94	3.50
	2.51	2.27			0.358	0.736
	2.06	2.28			0.375	0.735
	0.123	0.182			0.0308	0.0709
	0.142	0.182			0.0203	0.0717
SRS Avg	22.8	34.2		**Tk 33F**	10.1	34.5
	20.0	34.7			12.5	34.3
	7.6	15.7			4.2	14.9
	7.47	15.8			4.1	14.9
	0.90	2.04			0.240	0.75
	0.87	2.03			0.225	0.77
	0.170	0.43			0.036	0.168
	0.148	0.43			0.035	0.169
	0.0078	0.0205			0.0088	0.0083
	0.0076	0.0205			0.0030	0.0086
Tk 30H	24.0	37.7		**Tk 34F**	15.9	35.2
	21.2	38.0			13.4	35.4
	16.0	18.3			5.1	16.0
	11.7	18.8			3.6	16.2
	2.81	5.1			0.96	1.87
	2.75	5.1			0.84	1.89
	0.56	1.08			0.167	0.38
	0.52	1.10			0.162	0.39
	0.041	0.085			0.0105	0.0051
	0.043	0.084			0.0115	0.0050
Tk 32H	25.1	37.0		**Tk 35H**	11.3	36.4
(2/8)	18.2	37.7			17.8	35.6
	10.0	18.2			3.7	16.8
	6.0	18.7			4.6	16.6
	2.46	3.9			1.01	2.50
	2.34	4.0			0.95	2.48
	0.51	0.92			0.182	0.51
	0.42	0.95			0.200	0.52
	0.042	0.069			0.0135	0.030
	0.047	0.068			0.0124	0.031

TABLE A-4. Cesium-Sorption Kinetic Data

Solution	Time (hours)	[Cs] (mM)	Solution	Time (hours)	[Cs] (mM)	Solution	Time (hours)	[Cs] (mM)
UOP	0.0	0.75	Tank 32H	0.0	0.31	Tk 33H	48.3	0.0026
	1.1	0.38	(2/9)	3.80	0.056		48.3	0.0022
	1.1	0.39		3.80	0.053		73.5	0.00190
	4.0	0.189		8.8	0.039		73.5	0.00182
	4.0	0.176		8.8	0.038		119.6	0.0025
	9.0	0.121		16.0	0.036		119.6	0.00201
	9.0	0.132		16.0	0.033		168.2	0.00156
	16.2	0.102		25.1	0.0151		168.2	0.00143
	16.2	0.113		25.1	0.022		287.7	0.00180
	25.0	0.103		48.8	0.025		287.7	0.00168
	25.0	0.098		48.8	0.020			
	49.2	0.093		74.4	0.021	Tank 34F	0.0	0.13
	49.2	0.095		74.4	0.022		3.80	0.0190
				120.8	0.0187		3.80	0.0200
SRS Avg	0.0	0.140		120.8	0.0106		9.0	0.0139
	1.1	0.055		168.4	0.0195		9.0	0.0146
	1.1	0.062		168.4	0.0134		16.1	0.0121
	4.0	0.025		289.0	0.0176		16.1	0.0110
	4.0	0.026		289.0	0.0184		23.4	0.0098
	9.0	0.0175					23.4	0.1020
	9.0	0.0186	Tank 32H	0.0	0.24		48.1	0.0076
	16.2	0.0118	(4/17)	4.05	0.042		48.1	0.0072
	16.2	0.0134		4.05	0.040		73.4	0.0074
	25.0	0.0109		9.0	0.029		73.4	0.0074
	25.0	0.0119		9.0	0.029		118.8	0.0059
	49.2	0.0088		15.9	0.021		118.8	0.0070
	49.2	0.0088		15.9	0.022		168.1	0.0057
				24.0	0.0163		168.1	0.0060
Tank 30H	0.0	0.36		24.0	0.0107		286.8	0.0029
	3.75	0.066		48.4	0.0090		286.8	0.0062
	3.75	0.066		48.4	0.0099			
	9.0	0.043		73.6	0.0129	Tank 35H	0.0	0.17
	9.0	0.047		73.6	0.0136		4.00	0.026
	16.0	0.037		119.2	0.0165		4.00	0.025
	16.0	0.038		119.2	0.0169		9.0	0.0175
	25.2	0.030		168.4	0.0123		9.0	0.0190
	25.2	0.027		168.4	0.0126		16.1	0.0091
	48.9	0.023		287.8	0.0156		16.1	0.0130
	48.9	0.017		287.8	0.0146		23.2	0.0089
	74.2	0.022					23.2	0.0047
	74.2	0.022	Tank 33F	0.0	0.051		48.0	0.0086
	121.6	0.023		3.93	0.0039		48.0	0.0095
	121.6	0.023		3.93	0.0046		73.2	0.0070
	168.5	0.022		8.9	0.0033		73.2	0.0102
	168.5	0.021		8.9	0.0033		118.4	0.0052
	289.4	0.021		15.9	0.0023		118.4	0.0059
	289.4	0.021		15.9	0.0023		168.2	0.0079
				23.7	0.0023		168.2	0.0078
				23.7	0.0022		286.3	0.0076
							286.3	0.0072

Appendix B
ZAM Model Calculations

R. A. Jacobs calculated cesium distributions for the six radioactive wastes and two simulants using the ZAM (Zheng, Anthony, and Martin) equilibrium model.[1-2] Distributions were calculated at 25 ° C assuming 25 mL of liquid and 0.1 gram of sorbent. The weight of sorbent was not adjusted to account for binder in the IONSIVÒ IE-911. Table B-1 lists the results of the calculations.

TABLE B-1. Calculated Cesium Distributions

Solution	[Cs] solution (mg/L)	Q (mg Cs/g sorbent)		Solution	[Cs] solution (mg/L)	Q (mg Cs/g sorbent)
UOP	65.0	35.5		**Tank 32H**	50.6	54.4
	7.93	7.20		**(4/17)**	13.7	30.1
	1.29	1.30			5.37	15.4
	0.64	0.64			0.909	3.12
	0.127	0.128			0.221	0.782
	0.0127	0.0128			0.0438	0.157
SRS Avg	83.9	55.7		**Tank 33F**	39.3	57.2
	9.71	17.80			9.42	31.1
	2.53	5.59			3.61	15.9
	0.61	1.44			0.604	3.2
	0.122	0.289			0.147	0.801
	0.0242	0.0580			0.0291	0.160
Tank 30H	58.7	52.3		**Tank 34F**	55.8	53.1
	17.2	29.2			15.9	29.5
	6.83	15.0			6.28	15.2
	1.17	3.06			1.07	3.08
	0.284	0.767			0.260	0.773
	0.0563	0.1530			0.0516	0.155
Tank 32H	61.9	51.5		**Tank 35H**	55.1	53.2
(2/9)	18.6	28.9			15.6	29.6
	7.45	14.9			6.16	15.2
	1.28	3.03			1.05	3.09
	0.310	0.760			0.254	0.774
	0.0616	0.152			0.0505	0.155