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Evaluation and Testing of IONSIV IE-911 for the Removal of Cesium-137 from INEEL Tank Waste and Dissolved Calcines

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ABSTRACT

Development of waste treatment processes for the remediation of radioactive wastes is currently underway. A number of experiments was performed at the Idaho Nuclear Technology and Environmental Center (INTEC) located at the Idaho National Engineering and Environmental Laboratory (INEEL) with the commercially available sorbent material, IONSIV IE-911, crystalline silicotitanate (CST), manufactured by UOP LLC. The purpose of this work was to evaluate the removal efficiency, sorbent capacity and selectivity of CST for removing ^{137}Cs from actual and simulated acidic tank waste in addition to dissolved pilot-plant calcine solutions. The scope of this work included batch contact tests performed with non-radioactive dissolved Al and Run-64 pilot-plant calcines in addition to simulants representing the average composition of tank waste. Small-scale column tests were performed with actual tank WM-183 waste, tank waste simulant, dissolved Al and Run-64 pilot plant calcine solutions.

Batch contact experiments using simulated WM-183 tank waste with volume to mass ratios of approximately 25 and 100 displayed K_d values of 1225 and 1120, respectively. Batch contact experiments using dissolved Al pilot-plant calcine with volume to mass ratios of approximately 25 and 100 displayed K_d values of 1623 and 1487, respectively. Batch contact experiments using dissolved Run-64 pilot-plant calcine with volume to mass ratios of approximately 25 and 100 displayed K_d values of 4926 and 3694, respectively.

Small-scale column experiments using actual WM-183 tank waste resulted in fifty-percent ^{137}Cs breakthrough at approximately 589 bed volumes. Small-scale column experiments using the tank waste simulant displayed fifty-percent ^{137}Cs breakthrough at approximately 700 bed volumes. Small-scale column experiments using dissolved Al calcine simulant displayed fifty-percent ^{137}Cs breakthrough at approximately 795 bed volumes. Column experiments with dissolved Run-64, pilot plant calcine did not reach fifty-percent breakthrough throughout the test.

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Evaluation and Testing of IONSIV IE-911 for the Removal of Cesium-137 from INEEL Tank Waste and Dissolved Calcines

INTRODUCTION

Development of waste treatment processes for the remediation of radioactive waste is currently underway at the Idaho Nuclear Technology and Engineering Center (INTEC) located at the Idaho National Engineering and Environmental Laboratory (INEEL). INTEC, formerly known as the Idaho Chemical Processing Plant (ICPP), previously reprocessed nuclear fuel to retrieve fissionable uranium. Approximately 5000 m³ of radioactive liquid waste remains, and is being stored in underground concrete encased stainless steel tanks. This waste is acidic with significant concentrations of sodium and potassium, but the specific composition of the waste varies from tank to tank. The ICPP historically solidified tank waste by calcining in a fluidized bed operated at 500 °C. Approximately 4,000 m³ of calcine are presently stored in concrete encased stainless steel bins at the INTEC.¹

Radionuclide separation technologies are being evaluated for treating the tank waste and calcine. The purpose of this work was to evaluate IONSIV IE-911 for removing ¹³⁷Cs from acidic tank waste and dissolved pilot-plant calcine solutions. Batch contact tests were performed with non-radioactive dissolved Al and Run-64 pilot-plant calcines in addition to a simulant representing the average composition of tank waste. Small-scale column experiments were performed with actual tank WM-183 waste, tank waste simulant and dissolved Al and Run-64 pilot plant calcine simulants.

BACKGROUND

HISTORICAL DEVELOPMENT OF CST

The development of waste treatment processes for the remediation of radioactive wastes has led to the development of several ion-exchange technologies, including crystalline silicotitanates (CST's). Beginning about 1980, researchers from Sandia National Laboratories and Texas A&M University jointly discovered CST as the result of continued amorphous hydrous titanium oxide (HTO), development activities.

Initial experiments performed with the novel development materials, exhibited a high affinity for Cs, Sr and several other radionuclides from highly alkaline solutions (pH>14) containing high Na⁺ concentrations. In addition, the original development material showed excellent chemical and radiation stability. Together, the high selectivity and stability of CST's made them excellent candidates for treatment of radwaste solutions present at DOE facilities.²

A Sandia Laboratory Directed Research and Development (LDRD) project, in cooperation with Texas A&M, soon followed and CST's were developed for radwaste applications. Sandia National Laboratory and UOP teamed under a Cooperative Research and Development Agreement (CRADA) to develop CSTs in a powdered form and an engineered form suitable for column ion exchange use. UOP has developed this material into commercial products: IONSIV IE-910 (CST powder) and IONSIV IE-911 (engineered form) respectively.³

Small-scale laboratory experiments have been performed at various DOE facilities such as Idaho, Hanford, Savannah River and Oak Ridge.⁴ Recent column experiments performed at Oak Ridge National Laboratory with actual Melton Valley Storage Tank (MVST) W-27 waste, with an adjusted pH of 13.3, displayed 50% breakthrough at approximately 350 CV. Flowrates of both 3 and 6 CV/hr were used.⁵

PURPOSE AND SCOPE

The purpose of this study was to evaluate the removal of ^{137}Cs from acidic INEEL tank waste and dissolved pilot-plant calcine solutions using IONSIV IE-911 (CST). This study was completed by performing small-scale batch contact experiments in addition to small-scale dynamic column experiments.

Batch contact tests were performed with non-radioactive dissolved Al and Run-64 pilot-plant, calcine simulants in addition to a simulant representing the average composition of all tank waste. Small-scale column tests were performed with actual tank WM-183 waste, tank waste simulant and dissolved Al and Run-64 pilot plant calcine simulants.

EXPERIMENTAL PROCEDURE

FEED COMPOSITIONS

Three tank waste feed solutions were used in these experiments, actual tank WM-183 waste, WM-183 simulant and an average composition simulant. The average simulant was prepared to have an average composition of all tank wastes stored at the INTEC.

Two forms of dissolved calcine were utilized for testing, Al and Run-64. Run-64 calcine simulant is a Zr, Na blend as the result of blending Zr fuel reprocessing raffinates and incidental wastes containing sodium. Al calcine simulant is based on Al fuel reprocessing raffinates.

The simulant wastes utilized in this work have been developed based upon experience, which has been derived from many development projects. The complexity of the actual waste matrices has been reproduced as closely as possible in the simulant. The primary chemical components of the actual waste are present in the simulants, as well as many of the minor constituents. However, the simulated matrix does not account for some minor components.⁶

Each feed solution was filtered through a 0.45 micron filter prior to use. Simulants were spiked with ¹³⁷Cs to approximately 100 Bq/mL with a National Institute of Standards (NIST) ¹³⁷Cs tracer. Compositions of dissolved Al and Run-64 calcine feed solutions are shown in Table 1. The composition of actual WM-183, WM-183 simulant and average simulant feed solutions are shown in Table 2.

Table 1. Dissolved Al and Run 64 pilot-plant calcine feed compositions.

Component	Al Simulant	Run-64 Simulant
Acid (M)	1.5	1.18
Al (M)	1.00	0.987
Total Cs (M)	1.15E-4	7.90E-6
Na (M)	0.043	0.090
Sr (M)	5.23E-4	9.76E-4
K (M)	0.001	0.012
B (M)	0.0125	0.0046
Ca (M)	ND	0.501
Fe (M)	0.0016	0.0066
Zr (M)	ND	0.121
NO ₃ ⁻ (M)	4.83	~3.0
F ⁻ (M)	ND	0.73
¹³⁷ Cs (Bq/mL)	169.0	161.0

ND=no data

Table 2. Actual tank WM-183 waste, WM-183 simulant and average tank waste simulant compositions.

Component	Actual WM-183	WM-183 Simulant	Average Tank Waste Simulate
Acid (M)	1.77	1.70	1.31
Al (M)	0.64	0.62	0.59
B (M)	0.013	0.013	0.015
Ca (M)	0.040	0.029	0.033
Cl (M)	0.011	0.011	0.034
Cr (M)	0.014	0.017	0.006
Total Cs (M)	7.11E-5	9.8E-5	7.14E-5
Fe (M)	0.056	0.045	0.024
Hg (M)	0.0023	0.0013	0.0018
K (M)	0.094	0.086	0.13
Na (M)	0.68	0.69	1.04
NO ₃ (M)	5.24	4.80	4.2
Pb (M)	0.0012	0.0015	9.56E-4
SO ₄ (M)	0.066	0.066	8.85E-3
Sr (M)	ND	6.3E-4	5.57E-3
Zr (M)	4.2E-4	0.0065	5.78E-4
Alpha (nCi/g)	506	N/A	N/A
²⁴¹ Am (nCi/g)	34.9	N/A	N/A
²³⁸ Pu (nCi/g)	333.8	N/A	N/A
²³⁹ Pu (nCi/g)	123.3	N/A	N/A
U (mg/L)	114	N/A	N/A
²³⁷ Np (nCi/g)	<6.5	N/A	N/A
⁹⁹ Tc (Ci/m ³)	0.036	N/A	N/A
¹³⁷ Cs (Ci/m ³)	219	~100 Bq/mL	~100 Bq/mL
⁹⁰ Sr (Ci/m ³)	201	N/A	N/A
Density (g/mL)	1.25	ND	ND

ND=no data, N/A=not applicable

BATCH CONTACT EXPERIMENTS

Two contacts per simulant were performed, each containing approximately 0.4 and 0.1 grams of (Lot #999096810002) IONSIV IE-911. Twenty-two mLs of each simulant were prepared and 0.110 mLs of 5.4 $\mu\text{Ci}/5\text{ mL}$ tracer was added to each solution. Ten mLs of simulant were used for each batch contact.

All contacts had a mixing time of 24 hours. Mixing was constant throughout the test using a mechanical rotary mixer, adjusted to approximately 15 rotations per minute. All contacts were performed in 20 mL borosilicate glass test tubes. Batch contact solutions were filtered through 0.45 micron syringe filters prior to ^{137}Cs analysis. All contacts were performed at room temperature (21-25 C°). Batch contact experimental conditions are listed in Table 3.

Table 3. Batch contact experimental conditions.

Contact	Contact Time (Hrs)	Solution Volume (mLs)	Sorbent Weight (g)	Waste Type (All Simulants)
#1	24	10	0.40336	WM-183
#2	24	10	0.40168	AI
#3	24	10	0.40050	Run-64
#4	24	10	0.10036	WM-183
#5	24	10	0.10359	AI
#6	24	10	0.10161	Run-64

BATCH DISTRIBUTION COEFFICIENT (K_d)

The batch distribution coefficient (K_d) is an equilibrium measure of the overall ability of the solid phase ion exchange material to remove an ion from solution under the particular environmental conditions that exist during the contact. The batch distribution coefficient K_d is an experimental way of determining the affinity of a sorbent material for a specific ion. K_d can also be used as an indicator of the selectivity and affinity of an ion in the presence of a complex matrix of interfering ions. Larger K_d values indicate a greater amount of ions are concentrated onto the sorbent material.⁷

To ensure accurate comparison of K_d results, several factors need to be considered. Experimental conditions such as volume: mass ratio, temperature, solution composition, material pretreatment, etc can affect K_d results. Distribution coefficient (K_d) values were calculated according to the following formula:

$$K_d = \frac{(C_0 - C_e)}{C_e} * \frac{V}{M}$$

Where:

C_0 = initial concentration of the ion in solution before contacting sorbent.

C_e = final equilibrium concentration of the ion in solution after contacting sorbent.

V = mL of solution.

M = grams of sorbent material contacted.

COLUMN PREPARATION

A consistent procedure was used to load each column. The top of the column was removed and the column was filled with deionized water prior to loading. A polyethylene frit was placed at the bottom prior to sorbent addition to prevent particle loss. A piece of Nalgene tubing was then attached to the top of the column and a funnel or large syringe was secured to the other end of the tubing which was also filled with deionized water. A precisely measured dry sorbent weight was slurried into the funnel or syringe, and allowed to gravity-settle into the column. The column was gently tapped while the particles collected into a uniform column bed. Quantitative sorbent transfer was verified during each loading by inspecting the weighing dish, funnel or syringe to ensure all particles were transferred to, and remained in, the column. After sorbent preparation was completed, several mLs of deionized were processed through the column to flush unwanted fines.¹ It should be noted that (Lot #999096810002) IONSIV IE-911, with a mean size of 200 μ m, was used in these experiments. Particles were not screened or fractionated. In addition, the sorbent was not pretreated to equilibrate it to the pH of the feed solution.

COLUMN EXPERIMENTS

Two different sized columns were used for these experiments: 1 cm³ and 1.5 cm³ respectively. IONSIV IE-911 was tested using a 1 cm³ column with actual WM-183 tank waste and average tank waste simulant. The column was fabricated from stainless steel and was designed for downward flow through the column. The bed portion of the column was 35 mm high and 6.2 mm diameter.

IONSIV IE-911 was also tested using a 1.5 cm³ column with dissolved Al and Run-64 calcine simulants. The 1.5 cm³ column was fabricated from stainless steel and incorporated a Plexiglas bed section. The Plexiglas bed section allowed for visual inspection of bed material during operation. The bed section of the column was 21 mm high and 9.5 mm diameter. The column was designed for upward or downward flow. Downward flow was used for all experiments involving the 1.5 cm³ column. The process schematic of the assembled ion-exchange process is shown in Figure 1.

Figure 2 (Photo) displays the ion-exchange set-up installed at the Remote Analytical Laboratory (RAL). The column shown in Figure 2 is configured for up flow, however, all tests with IONSIV IE-911 were performed with downflow through the column.

An FMI valveless metering pump (Model QVG-50) was used to provide feed solution to the columns. Flow rates were controlled by controlling the pump with a ten-turn potentiometer FMI Stroke Rate Controller (Model V100). The appropriate tubing and fittings were used to connect equipment. Properties of the IONSIV IE-911 column experiments are listed in Table 4.

Table 4. Properties of the IONSIV IE-911 column experiments.

Property	Run-64	Al Simulant	Tank Waste Simulant	Actual Tank WM-183 Waste
Sorbent Wt.	1.49 g	1.50 g	1.05 g	1.02 g
Feed Flowrate	9 mL/hr	9 mL/hr	5.7 mL/hr	5.7 mL/hr
Superficial Vel.	11.5 cm/hr	11.5 cm/hr	18.9 cm/hr	18.9 cm/hr
BV/hr	6.0	6.0	5.4	5.5
Vol. Processed	1770 mLs	1567 mLs	800 mLs	800 mLs
Bed Volumes Processed	1187	1044	761	784

Figure 1. Process schematic of assembled ion-exchange process.

Figure 2. The ion-exchange set-up installed at the Remote Analytical Laboratory (RAL).

SAMPLING AND ANALYSIS

Column effluents from tests using dissolved Al and Run-64 calcine simulants were collected via an Eldex® fraction collector accompanied by a U-136 (9 mL) collection rack, containing 136 collection tubes. Fractions were collected in 45-minute intervals providing 6.75 mLs per collection tube, two hundred and ninety six (296) samples in all. Sample fractions were collected in factors of 10. Collection tubes directly proceeding and directly following the 10th tube were collected and combined with the amount of the 10th tube (20.25 mLs total) to provide adequate aliquots for analysis. One and 15 mL aliquots were collected and dispensed into 15-mL glass scintillation vials and 30 mL polypropylene bottles, respectively. After the aliquots were collected, the remaining volume was recorded. The recorded volume was used to calculate the cumulative volume through the column. Flow rate was recorded by measuring the volume of the collected sample and the time used to collect the sample.

Column effluents from the test using actual WM-183 SBW were collected in a glass beaker approximately every 3 to 5 hours. The effluent volume of each sample fraction was measured by pouring the sample into a clean graduated cylinder. The sample fraction was then poured into an unused polyethylene bottle, the beaker and graduated cylinder were thoroughly rinsed with deionized water and inverted to dry. Two beakers were used during actual waste testing, one of which was drying while the other was being used to collect effluent fractions. Each sample fraction required dilution with 3 % nitric acid prior to removing a sample aliquot from the shielded (hot) cell for ¹³⁷Cs analysis to reduce the radioactivity in the sample to safe handling limits. Each sample had to be diluted to less than 100 millirem total dose before it could be transferred from the hot cell. Typically, a 0.1 mL to 20.1 mL dilution was used. A 1 mL aliquot of the diluted fraction was taken with a 1 mL Eppendorf pipettor and dispensed into a 5 gram glass vial for ¹³⁷Cs analysis.¹

Column effluents from tests using the average simulant were collected in polyethylene bottles at specified time intervals. Sampling times changed during testing because continuous testing was attempted; therefore, the operation was not always attended. Those samples that were collected in the morning, after the experiment had been operating all night, were larger than those samples collected during the day and evening. Sampling frequency was also decreased during weekends, and the columns had to be shut down for the weekend occasionally.¹

¹³⁷Cs activities, for all experiments, were determined by Gamma Spectrometry using a high efficiency germanium detector. Sr, Al and Ca were analyzed using Inductively Coupled Plasma Atomic Emission Spectrophotometry (ICP-AES). Na, K and total Cs were analyzed separately by Atomic Absorption Spectrophotometry (AAS).

RESULTS AND DISCUSSION

BATCH CONTACT EXPERIMENTS

Results of batch contact (K_d) experiments are shown in Table 5. Batch contact experiments using simulated WM-183, with volume to mass ratios of approximately 25 and 100 displayed K_d values of 1225.43 and 1119.92, respectively. Batch contact experiments using dissolved Al pilot-plant calcine, with a volume to mass ratios of approximately 25 and 100, displayed K_d values of 1623.01 and 1487.44, respectively. Batch contact experiments using dissolved Run-64 pilot-plant calcine with volume to mass ratios of approximately 25 and 100, displayed K_d values of 4926.10 and 3694.34, respectively.

Table 5. Batch contact experimental conditions and results.

Contact	Contact Time (hrs)	Solution Volume (mLs)	Sorbent Weight (g)	Waste Type	K_d
#1	24	10	0.40336	WM-183	1225.43
#2	24	10	0.40168	Al	1623.01
#3	24	10	0.40050	Run-64	4926.10
#4	24	10	0.10036	WM-183	1119.92
#5	24	10	0.10359	Al	1487.44
#6	24	10	0.10161	Run-64	3694.34

COLUMN TESTS

Al Simulant

Figure 3 displays the ^{137}Cs , Al, Na and Sr breakthrough curves for dissolved, aluminum calcine simulant. The percent breakthrough ($C/C_0 \times 100$) is plotted against the bed volumes of solutions passed through the column. Initial ^{137}Cs breakthrough was observed at approximately 37.5 bed volumes. Fifty Percent ^{137}Cs breakthrough occurred at 756 bed volumes. Al, Na and Sr are not sorbed on the IONSIV IE-911, as evidenced by ~100% breakthrough for the duration of the test.

Figure 3. Cesium-137, Al, Na and Sr breakthrough curves for dissolved Al calcine simulant.

The slight decrease in ^{137}Cs breakthrough displayed at approximately 600 bed volumes was the result of a temporary (12 hour) shut down. During the shut down, equilibrium within the column was approached.

RUN-64 Simulant

Figure 4 displays the ^{137}Cs , Ca, Na, Sr and K breakthrough curves for dissolved, Run-64 pilot-plant calcine. The percent breakthrough ($\text{C}/\text{Co} \times 100$) is plotted against the bed volumes of solutions passed through the column. Initial ^{137}Cs breakthrough was observed at approximately 53 bed volumes. Fifty Percent ^{137}Cs breakthrough was never achieved throughout the test. Ca, Na, Sr and K are not sorbed on the IONSIV IE-911, as evidenced by 100% breakthrough for the duration of the test. Relatively high concentrations of Ca, Na, Sr and K observed in initial samples could possibly be the result of evaporation of the feed solution, which in turn increased initial concentrations.

Figure 4. Cesium-137, Ca, Na, Sr and K breakthrough curves for dissolved Run-64 pilot-plant, calcine simulant.

ACTUAL SBW-183 TANK WASTE AND AVERAGE TANK WASTE SIMULANT

Cesium breakthrough curves obtained from the actual WM-183 and average tank waste simulant are shown in Figure 5. Fifty percent breakthrough for Cs occurred at approximately 700 BV (700 mLs) for both wastes.

It is important to note that 50% breakthrough was achieved much sooner, compared to the Run-64 (1.0 ug/mL), due to concentrations of 10-13 ug/mL stable Cs within the feed solution.

Figure 5. Cesium-137 breakthrough curves for actual WM-183 tank waste and average tank waste simulant.

DYNAMIC CAPACITY

Data plots of throughput volume (liters) against column effluent Cs concentration (mmole/L) were generated using experimental column breakthrough data presented previously. A second order kinetic equation was fit to each of these data sets to obtain a relationship for Cs effluent concentration as a function of throughput volume. This equation for Cs concentration was then substituted into the following relationship for dynamic capacity (DC):

$$DC = \frac{\int_0^v (C_0 - C) dv}{M}$$

Where:

v = volume at a specified breakthrough, Liters

C_0 = initial Cs concentration, mmole/L

C = Cs concentration in the column effluent, mmole/L

M = mass of sorbent, grams (dry weight)

Dynamic capacity estimates were obtained by evaluating the integral numerically with upper limit volume values corresponding to approximately 50% and 100% Cs breakthrough. Dynamic capacities for the small-scale column experiments using actual tank WM-183 waste, tank waste simulant and dissolved Al and Run-64 pilot plant calcine simulants are shown in Table 6.

Table 6. Dynamic capacities for small-scale column experiments.

Feed Solution	Dynamic Capacity at 50% breakthrough	Dynamic Capacity at 100% breakthrough
Dissolved Al Calcine Simulant	7.55E-02 mmole/g	8.98E-02 mmole/g
Dissolved Run-64 Calcine Simulant	8.79E-03 mmole/g ¹	1.03E-02 mmole/g ¹
Actual Tank WM-183 Waste	3.76E-02 mmole/g	4.31E-02 mmole/g
Average Tank Waste Simulant	4.06E-02 mmole/g	5.02E-02 mmole/g

¹ estimated from breakthrough curve

CONCLUSIONS

- Batch contact experiments using simulated INEEL wastes indicate that IONSIV IE-911 has a high affinity for cesium at nitric acid concentrations up to 1.7 M.
- Column test data indicate that cesium is selectively sorbed over Al, Na, Sr, Ca and K.
- The slope of the breakthrough curves observed in this work were relatively low. The cause for this is unknown, but may be that at 6 BV/hr, the sorbent was limited by ion diffusion into the sorbent particle. No testing to establish sorption kinetics was performed as part of this study, but is currently in progress.

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EXPERIMENTAL DATA

INEEL TEST 2/16/98 TO 2/27/98
IONSIV IE-911 (CST) Bed Volume 1.426
Dissolved Al Pilot-Plant Calcine

Sample Fraction	Fraction Time (min)	Cumulative Time (min)	Volume mL	Cumulative Vol (mLs)	Cum. B Vol 1.4	Flowrate mL/hr	Pump Setting	Feed Concentration				
								Cs-137 dis/mL	Total Cs ug/mL	Aluminum ug/mL	Sodium ug/mL	Strontium ug/mL
Feed	0	0	0	0	0.0	0	0	169	15.4	2696.20	994.00	45.99
1	450	450	53.5	53.5	37.5	7.13	10% @ 0.72	0.192	0.04	24625.20	1070.00	44.35
2	983	1433	111	164.5	115.4	6.77	10% @ 0.72	0.524	0.04	27899.70	1030.00	47.21
3	450	228.6	61.1	228.6	158.2	8.14	10% @ 0.72	1.97	0.15	26033.00	984.00	46.88
4	987	2880	133.5	359.1	251.8	8.03	10% @ 0.75	7.32	0.57	29011.60	1060.00	47.33
5	450	3330	63	422.1	286.0	8.4	10% @ 0.82	11.3	0.94	30082.70	1080.00	45.12
6	990	4320	131	553.1	387.9	7.9	10% @ 0.88	22.8	1.79	28684.80	1060.00	46.72
7	450	4770	87	640.1	448.9	11.6	10% @ 100.0	37.5	3.14	29042.20	1070.00	46.24
8	900	5670	136.5	776.6	544.6	9.1	10% @ 0.82	44.5	3.95	29399.30	1010.00	47.98
9	420	6090	67	843.6	591.6	9.5	10% @ 0.82	62.9	4.75	28267.00	1040.00	47.47
10	480	6570	80.5	924.1	648.0	10	10% @ 0.82	46.3	3.97	28501.60	1060.00	48.18
11	960	7530	139.2	1063.3	745.7	8.7	10% @ 0.82	68.3	5.53	29817.50	1010.00	47.87
12	480	8010	72.5	1135.8	795.5	9.06	10% @ 0.76	87.3	7.95	28715.80	989.00	47.87
13	960	8970	143	1278.8	896.8	8.9	10% @ 0.76	90.6	8.25	28644.40	1140.00	46.16
14	480	9450	72	1350.8	947.3	9	10% @ 0.76	103	9.38	29225.90	1030.00	46.51
15	860	10410	139.2	1490	1044.9	8.7	10% @ 0.76	107	9.75	28593.40	1050.00	48.03
16	480	10890	73	1563	1096.1	9.12	10% @ 0.76	118	10.75	28399.60	1030.00	48.95
17	941	11831	141.1	1704.1	1195.0	8.9	10% @ 0.76	126	11.48	27818.10	1020.00	44.82
18	420	12251	65	1769.1	1240.6	9.2	10% @ 0.76	134	12.21	28695.40	1020.00	46.54

Percent Breakthrough (C/Co *100)			
Cs-137 C/Co *100	Aluminum C/Co *100	Sodium C/Co *100	Strontium C/Co *100
0.11	91.34	107.65	96.43
0.31	103.48	103.62	102.65
1.17	96.56	98.99	101.50
4.33	107.61	106.84	102.91
6.69	111.58	108.65	98.11
13.49	106.32	106.64	101.59
22.19	107.72	107.65	100.54
26.33	109.04	101.61	104.33
37.22	104.84	104.63	103.22
27.40	105.71	106.64	104.76
40.41	110.59	101.61	101.41
51.66	106.51	99.50	104.09
60.95	108.24	114.69	100.37
63.31	106.63	103.62	101.13
69.82	105.34	103.62	104.44
74.56	103.18	102.62	102.09
79.29	106.43	102.62	97.46
			101.20

INEEL TEST 3/19/98 TO 3/30/98
IONSIV IE-911 (CST) Bed Volume 1.499
Dissolved Run-64 Pilot-Plant Calcine

								Feed Concentration					
Sample Fraction	Fraction Time (min)	Cumulative Time	Volume mL	Cumulative Volume	Cumulative B Vol	Flowrate mL/hr	Pump Setting	Cs137 dps/mL	Total Cs ug/mL	Calcium ug/mL	Sodium ug/mL	Strontium ug/mL	Potassium ug/mL
Feed	0	0	16	16	1.5								
1	450	450	64	80	53.4	8.5	0.76 @ 10%	161	1.05	26645.0	2080.0	85.7	492.0
2	450	900	65	145	96.7	8.6	0.76 @ 10%	0.38	2.48E-03	26645.0	2080.0	85.7	492.0
3	450	1350	63	208	138.8	8.4	0.76 @ 10%	0.49	3.20E-03	29839.9	2340.0	103.9	552.0
4	450	1800	68	276	184.1	9	0.76 @ 10%	0.53	3.46E-03	29297.3	2360.0	102.4	565.0
5	450	2250	65	341	227.5	8.6	0.76 @ 10%	0.46	3.00E-03	28613.8	2280.0	96.9	535.0
6	450	2700	66.5	407.5	271.8	8.8	0.76 @ 10%	0.43	2.80E-03	28613.8	2280.0	96.9	535.0
7	450	3150	67	474.5	316.5	8.9	0.76 @ 10%	0.47	3.07E-03	28613.8	2280.0	96.9	535.0
8	450	3600	68	542.5	361.9	9	0.76 @ 10%	0.44	2.87E-03	28632.2	2250.0	93.4	510.0
9	450	4050	68	610.5	407.3	9	0.76 @ 10%	0.49	3.20E-03	28632.2	2250.0	93.4	510.0
10	450	4500	69	679.5	453.3	9.1	0.76 @ 10%	0.72	4.70E-03	26628.6	2170.0	92.3	538.0
11	450	4950	69	749.5	500.0	9.3	0.76 @ 10%	0.59	3.85E-03	26628.6	2170.0	92.3	538.0
12	450	5400	68.5	818	545.7	9.1	0.74 @ 10%	0.82	5.35E-03	26612.4	2120.0	92.6	515.0
13	450	5850	69	887	591.7	9.1	0.74 @ 10%	0.82	5.35E-03	26612.4	2120.0	92.6	515.0
14	450	6300	70	957	638.4	9.3	0.74 @ 10%	1.39	9.07E-03	26696.0	2100.0	91.1	522.0
15	450	6750	66	1023	682.5	8.8	0.74 @ 10%	2.24	1.46E-02	26696.0	2100.0	91.1	522.0
16	450	7200	66	1093	729.2	9.3	0.74 @ 10%	2.37	1.55E-02	26696.0	2100.0	91.1	522.0
17	450	7650	67	1160	773.8	8.9	0.74 @ 10%	3.42	2.23E-02	26073.8	2250.0	94.4	505.0
18	450	8100	69	1229	819.9	9.1	0.74 @ 10%	5.41	3.53E-02	27642.7	2230.0	91.9	520.0
19	450	8550	69	1298	865.9	9.1	0.74 @ 10%	7.48	4.88E-02	27642.7	2230.0	91.9	520.0
20	450	9000	73	1371	914.6	9.7	0.74 @ 10%	7.77	5.07E-02	26237.0	2160.0	87.6	508.0
21	450	9450	63	1434	956.6	8.4	0.74 @ 10%	9.82	6.40E-02	26237.0	2160.0	87.6	508.0
22	450	9900	68	1502	1002.0	9	0.74 @ 10%	16.2	1.06E-01	30297.0	2570.0	98.8	588.0
23	450	10350	65.5	1567.5	1045.7	8.7	0.74 @ 10%	16.6	1.08E-01	30297.0	2570.0	98.8	588.0
Percent Breakthrough C/Co *100													
Cs-137 C/Co *100	Calcium C/Co *100	Sodium C/Co *100	Strontium C/Co *100	Potassium C/Co *100									
0.24	112.4	112.0	121.3	112.2									
0.30	112.4	112.0	121.3	112.2									
0.33	110.0	112.9	119.5	114.8									
0.29	110.0	112.9	119.5	114.8									
0.27	95.6	96.6	93.2	96.9									
0.29	95.6	96.6	93.2	96.9									
0.27	97.4	95.3	91.2	90.3									
0.29	97.4	95.3	91.2	90.3									
0.45	93.8	96.0	95.2	100.6									
0.37	92.9	94.2	99.1	101.0									
0.51	92.9	94.2	99.1	101.0									
0.86	99.5	96.8	98.8	97.0									
1.39	98.3	96.8	98.8	97.0									
1.47	98.3	96.8	98.8	97.0									
2.12	98.3	96.8	98.8	97.0									
3.36	106.1	106.1	101.9	98.1									
4.65	106.2	106.2	100.9	99.6									
4.83	106.2	106.2	100.9	99.6									
6.10	100.6	96.0	92.9	100.6									
10.06	100.6	96.0	92.9	100.6									
10.31	110.0	115.2	107.5	115.0									
12.61	110.0	115.2	107.5	115.0									

INEEL TEST
IONSIV IE-911 (CST) Bed Volume 1.02
Actual WM-183 Waste

Sample	Volume mL	Cumulative Vol (mLs)	Cum. B Vol 1.4	Total Cs ug/mL	Cs-137 C/Co*100
feed	0	0	0.0	9.45	0.15
1	104.04	104.04	102	0.014	1.10
2	52.53	156.57	153.5	0.10	3.49
3	86.74	243.31	240.5	0.33	8.06
4	52.02	295.33	291.5	0.76	11.58
5	85.68	381.01	375.5	1.09	18.64
6	58.14	439.15	432.5	1.76	30.49
7	102	541.15	532.5	2.88	40.74
8	44.88	586.03	576.5	3.85	54.44
9	119.34	705.37	693.5	5.15	68.40
10	54.06	759.43	746.5	6.46	

INEEL TEST
IONSIV IE-911 (CST) Bed Volume 1.05
Average Tank Waste

Sample	Volume mL	Cumulative Vol (mLs)	Cum. B Vol 1.4	Total Cs ug/mL	Cs-137 C/Co*100
feed	0	0	0	9.49	0.11
1	103.95	103.95	99	0.01	0.11
2	49.35	153.3	146	0.01	0.45
3	70.35	223.65	213	0.04	1.08
4	29.4	253.05	241	0.10	4.09
5	92.4	345.45	329	0.39	10.30
6	49.35	394.8	376	0.98	21.80
7	143.85	538.65	513	2.07	44.80
8	162.75	701.4	668	4.26	61.80
9	101.85	803.25	765	5.86	73.60
10	122.85	926.1	882	6.98	69.9
11	144.9	1071	1020	7.06	74.4
12	156.45	1227.45	1169	7.01	73.9
13	58.8	1286.25	1225	7.92	83.5
14	238.35	1524.6	1462	7.98	84.1
15	214.2	1738.8	1656	8.20	86.4
16	225.75	1964.55	1871	8.95	94.3
17	60.375	2024.925	1928.5		