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Effects of Resin Particle Size and Solution Temperature on SuperLig® 644 Resin Performance with AN-105 Simulant

SAVANNAH RIVER TECHNOLOGY CENTER

Neguib M. Hassan
Charles A. Nash

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Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

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Abstract

The performance of the SuperLig® 644 resin loading and elution was evaluated at 25, 35, and 45 °C using a single-column (1.54-cm i.d.) containing 2.25 g of oven-dry, hydrogen form of SuperLig® 664 resin. A simulated Envelope A solution was used to mimic the composition of low-activity waste solution from Tank 241-AN-105 supernate in the Hanford Site waste tank. The simulant was spiked with small quantities of trace metals (cadmium, chromium, iron, and lead) to evaluate the effects of these metals on cesium sorption. The results from column tests performed at 25, 35, and 45 °C showed that more than 100 BVs of simulated Envelope A solution could be processed at each temperature before 50% breakthrough of the cesium occurred. The breakthrough capacity of the resin at the breakthrough point (i.e. 50% C/Co) was 0.015, 0.013, and 0.011-mmole/g of oven-dry resin for the temperatures 25, 35, and 45 °C, respectively. The performance of the cesium column loading before and after resin exposure to elevated temperatures had not changed, thus showing no evidence of thermal degradation. Elution of the resin at elevated temperatures (35 and 35 °C) had not speeded up cesium elution or reduced eluent consumption. Elution of the resin with 0.5M nitric acid was generally effective at all temperaturs, requiring only 10 BV to reduce cesium concentration to below 1% of initial feed concentration.

Cesium uptake by SuperLig® 644 resin increased with increasing resin particle size. A 2.5-fold increase in cesium K_d value was observed for resin particle size range (590-840 μm) versus (250-420 μm) after 72-h contact with AN-105 simulant. Although the results were unexpected, the data agreed with results (cesium K_d values vs. particle size) reported by the resin manufacturer (IBC Advance d Technologies) for a different batch of SuperLig® resin.

The uptake of trace metals such as cadmium, chromium, iron, and lead by the SuperLig® 644 resin was noted. In the absence of cesium, SuperLig® 644 resin showed slight affinities for these trace metals. The affinity increased in the sequence iron> cadmium> lead> chromium. Since the concentrations of these minor competitors in the Hanford Site waste tanks are low, it is unlikely they will have a significant impact on cesium sorption of the resin.

The SuperLig® 644 resin degraded when stored in simulated Envelope A solution for 15 days at 45 °C and not protected from air; upto 50% mass loss of the resin was observed. The mass loss of the resin when protected from air oxidation (i.e. stored under nitrogen) was 5-10% under the same experimental conditions. The morphology of resin protected from air oxidation appeared to be unchanged. The resin retained characteristic sharp edges and rough surface normally observed for unexposed, but pretreated SuperLig® 644 resin. In contrast, resin stored in simulated Envelope A solution with air headspace showed damage to particle morphology as indicated by significant smoothing of the rough edges with signs of extensive cracking.

Nomenclature

AN-105	Hanford Site Tank 241-AN-105
ADS	Analytical Development Section
BV	Bed volume
C/Co	Metal concentration in the column effluent divided by the metal concentration in feed
DF	Decontamination factors
DI	De-ionized water
DLM	detection limit
F-Factor	Mass of oven-dry resin divided by the mass of air-dry resin
IV29	SuperLig® 644 batch # 991022SMC-IV29
IC	Ion chromatography
ICP-AES	Inductively coupled plasma/atomic emission spectroscopy
ICP-MS	Inductively coupled plasma/mass spectroscopy
K_d	Equilibrium distribution coefficient
na	not applicable
nm	not measured
PNNL	Pacific Northwest National Laboratory
RPP-WTP	River Protection Project – Waste Treatment Plant
RSD	Relative standard deviation
SRTC	Savannah River Technology Section
TAV	Total apparatus volume
TIC	Total inorganic carbon
TOC	Total organic carbon

1.0 Summary of Results

1.1 Objectives: The objectives of this work were to:

- Determine the cesium adsorption kinetics (K_d value versus time) for Envelope A simulant contacted with SuperLig® 644 resin of three different particle size distributions.

- Determine the cesium adsorption kinetics at 25, 35 and 45 ^oC to aid in the computer modeling effort at SRTC.

- Measure the distribution coefficients of chromium and several RCRA hazardous metals in Envelope A simulant.

- Determine the loading and elution profiles for a single column test with Envelope A simulant at 25, 35 ^oC and 45 ^oC. This is to determine the effect of temperature on column loading and elution performances.

- Measure the stability of the resin in 0.5M nitric acid and Envelope A simulant at elevated temperature to ensure experiment safety and efficacy.

1.2 Conduct of Tests

The experiments consisted of batch contact and column tests. Column tests were performed with Envelope A simulant (AN-105) at 25, 35, and 45 ^oC to examine the impact of operational temperature on the column loading performance. A single-column (1.54-cm i.d.) containing 2.25 g of oven-dry, hydrogen form of SuperLig® 664 resin was used for all the column tests. The simulant was spiked with small quantities of toxic metals (i.e. RCRA compounds) to evaluate minor competitor effects on the cesium sorption.

The batch contact tests fall into 4 categories: testing the effects of (1) temperature, (2) particle size, (3) metal competitor uptake in the absence of cesium and (4) degree of SuperLig® 644 resin degradation. The batch contact tests were performed to determine the distribution coefficients (K_d values) for cesium and metal competitors at three different temperatures (25, 35, and 45 ^oC) using unsieved SuperLig® 644 resin. The batch tests were also conducted at 25 ^oC with SuperLig® 644 resin sieved into three particle distributions: 20 to 30-mesh (0.6-mm to 0.841mm), 30 to 40-mesh (0.42-mm to 0.6-mm), and 40 to 60-mesh (0.25-mm to 0.42-mm). The resin batch used in both column and batch contact tests was # 991022SMC-IV29. The resin samples used in all tests were dry, hydrogen form.

The experimental investigations were performed according to the "Task Technical and Quality Assurance Plan for Evaluating Effects of Resin Particle Size and Solution Temperature on SuperLig® 644 and SuperLig® 639 Resins Performance with LAW Envelope A Simulant" (WSRC-TR-2001-00202, SRT-RPP-2000-00049, Rev. 0). The Task Plan was generated from the "Task Specification for Evaluating Effects of Resin Particle Size and Solution Temperature on

SuperLig® 644 and SuperLig® 639 Resins Performance with LAW Envelope A Simulant" (TSP-W375-01-00023, Rev. 0). This work was done in conformance with the scoping statement # S-105

1.3 Results and Performance against Objectives

The first test objective was to determine the cesium adsorption kinetics (K_d value versus time) for cesium on SuperLig® 644 resin of three different particle size distributions. The distribution coefficients (K_ds) of cesium were obtained at various contact times: 8, 24, 48, and 72 h. It was found that equilibrium was attained after 48-h contact with Envelope A simulant (AN-105) and the K_ds slightly dropped at contact times longer than 48 h. It was also found that the cesium uptake by SuperLig® 644 resin increased with increasing resin particle size. A 2.5-fold increase in cesium K_d value was observed for resin particle size range (590-840 μm) versus (250-420 μm) after 72-h contact with simulant. These results were unexpected because the mass transport in ion exchange is generally diffusion limited in the larger resin particles (i.e. small particles are better for kinetic). IBC Advanced Technologies reported similar trend of the particle size for a different batch of SuperLig® resin.

The second test objective was to determine the effect of temperature on cesium uptake by SuperLig® 644 resin. The results from batch contact experiments carried out at 25, 35, and 45 ^oC showed that cesium K_ds decrease with increasing temperature. The cesium K_ds for 48-h contact of the AN-105 simulant with SuperLig® 644 resin at 25, 35, and 45 ^oC were ~ 2300, 1635, and 1238 mL/g, respectively.

The third test objective was to measure the sorption of minor competitors, such as chromium, cadmium, iron, and lead, by SuperLig® 644 resin in the absence of cesium in Envelope A simulant. The concentrations of the minor competitors in the simulant were increased to examine their impact on the cesium sorption. The test results indicated SuperLig® 644 has some affinity for minor competitors. The affinity increases in the sequence iron> cadmium> lead> chromium. For example, the K_d values of iron, cadmium, chromium, and lead were in the order of 706, 193, 63,and 69 mL/g versus 1884 mL/g for cesium.

The fourth objective was to determine the effect of temperature on cesium loading and elution. The tests were performed at 25, 35, and 45 ^oC using a single-column (1.54-cm i.d.) containing 2.25 g of SuperLig® 664 resin (batch # 991022SMC-IV29). The results from this series of column tests showed that the solution temperature affects the cesium loading onto the resin. For instance, the breakthrough capacity of cesium at 25, 35, and 45 ^oC was 0.015, 0.013, and 0.011-mmole/g of resin, respectively**.** The cesium loading on the resin before and after resin exposure to elevated temperatures had not changed. Elution of the resin with 0.5M nitric acid was effective to reduce cesium concentration to below 1% of initial feed concentration after 10 BV of the eluent had passed through the column. Elevated temperatures had not speeded up cesium elution or reduced the eluent consumption.

1.4 Quality Requirements

This work was conducted in accordance with the RPP-WTP QA requirements specified for work conducted by SRTC as identified in DOE IWO MOSRLE60. SRTC has provided matrices to WTP demonstrating compliance of the SRTC QA program with the requirements specified by WTP. Specific information regarding the compliance of the SRTC QA program with RW-0333P, Revision 10, NQA-1 1989, Part 1, Basic and Supplementary Requirements and NQA-2a 1990, Subpart 2.7 is contained in these matrices. The QA requirements were specified in the Task Technical and Quality Assurance Plan for Evaluating Effects of Resin Particle Size and Solution Temperature on SuperLig® 644 and SuperLig® 639 Resins Performance with LAW Envelope A Simulant" (WSRC-TR-2001-00202, SRT-RPP-2000-00049, Rev. 0). Data verification was conducted through independent technical review of the final data report.

2.0 Introduction

The River Protection Project Waste Treatment Plant (RPP-WTP) has identified a process to pre-treat and vitrify Hanford tank waste into a low activity and high level waste glass. The pretreatment unit operations of the RPP-WTP process are sludge washing, filtration, precipitation, and ion exchange. Certain process units remove a portion of some radionuclides from the bulk of the waste and produce a relatively small volume of high-level waste (HLW) sludge. This sludge is vitrified with glass forming compounds as high activity level glass. The RPP has classified the LAW feed to the WTP into three envelopes: A, B, and C. Extensive testing with both radioactive and simulated waste for Envelopes A, B, and C was conducted for all unit processes.

The cesium removal is accomplished using SuperLig® 644 (Trademark of IBC Advanced Technologies, American Fork, Utah). This resin has been selected as the baseline ion exchange material for cesium removal from Hanford Site tank waste solutions. The resin contains proprietary polymerized ligands that have a high affinity for cesium ions in alkaline solutions, even in the presence of high concentrations of sodium and potassium. Extensive experimental investigations conducted at Savannah River Technology Center (SRTC) and Pacific Northwest National Laboratory (PNNL) over the last several years examined the resin capability for cesium removal from Hanford Site waste tank solutions. Experiments with SuperLig® 644 were carried out using three sizes of resin columns, small (~5 -10 mL), intermediate (~50-100 mL), and full-height (~1000 mL) pilot scale. Radioactive testing has been performed with small and intermediate scale columns to determine the loading and elution breakthrough profiles and to demonstrate the resin performance meets the WTP column design criteria for different Hanford Site Tank waste solutions. Simulant tests have been performed with intermediate and full-length columns to determine resin pre-conditioning requirements, buoyancy, swelling, and shrinking of resins, effects of column geometry, and superficial velocity on column scale-up. In experiments performed with simulated waste solutions, results suggest that SuperLig® 644 has adequate density and low-cycle physical durability[1], sufficient chemical stability[2], sufficient cesium sorption capacity and selectivity[3]. Radioactive Hanford Site tank waste samples tested with AN-

103[4] (Envelope A), AN-102[5,6] (Envelope C), and AZ-102 (Envelope B)[7] confirmed the simulant results.

All experimental investigations performed to date at SRTC and PNNL with SuperLig® 644 resin have been conducted at ambient temperature and nominal particle size (20-70 mesh) with resin batches initially in either sodium or potassium form. Thus, the effect of solution temperature has not been sufficiently assessed to understand the impact of temperature on the column performance. The resin will be used in the Richland/Tri-cities area of Washington State, where seasonal ambient temperatures can vary widely, and the RPP-WTP plant design engineers do not foresee capability for precise temperature control in the ion exchange columns. Thus, a possible equilibrium shift caused by elevated summer temperatures could severely impact the SuperLig® 644 resin's performance and durability. In addition, the minor competitors such as cadmium, chromium, silver, lead, and arsenic (arsenate) were often excluded from the simulant solutions due to the assumption that SuperLig® 644 is sufficiently selective against sodium and potassium with minimal co-sorption potential for toxic metal ions.

In this work, small-scale ion exchange column and batch equilibration tests were performed with simulated Envelope A simulant (Tank AN-105). The batch equilibration tests were performed to determine the equilibrium distribution coefficients (K_d values) for cesium and minor competitors at three temperatures (25, 35, and 45 ^oC) and three particle size ranges (20-30, 30-40, and 40-60 mesh). The column experiments were conducted using a single ion exchange column containing SuperLig® 644 resin. The experimental investigations were performed according to the "Task Technical and Quality Assurance Plan for Evaluating Effects of Resin Particle Size and Solution Temperature on SuperLig® 644 and SuperLig® 639 Resins Performance with LAW Envelope A Simulant" (WSRC-TR-2001-00202, SRT-RPP-2000-00049, Rev. 0).[8] The Task Plan was generated from the "Task Specification for Evaluating Effects of Resin Particle Size and Solution Temperature on SuperLig® 644 and SuperLig® 639 Resins Performance with LAW Envelope A Simulant" (TSP-W375-01-00023, Rev. 0).[9]

3.0 Experimental

3.1 Materials*:* Envelope A simulant was prepared based on the composition of Tank 241-AN-105 at Hanford Site. Five liters of the simulant at approximately 5.0M sodium concentration was prepared following the instructions provided by Eibling.[10] The simulant was spiked with the hazardous metals chromium, cadmium, lead, silver, and arsenic, then allowed to stand for 24 hours before filtering through a 0.45-µm filter. Duplicate sub-samples of the simulant were analyzed by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) to determine the concentrations of metal constituents. The cesium was replenished with cesium nitrate after the simulant preparation was complete and the concentration was determined by inductively coupled plasma mass spectroscopy (ICP-MS). The simulant composition is shown in Table 1.

Table 1. Composition of Simulant (AN-105)

Analyte	avg. (mg/L)
Cs, mg/L	8.10E+00
Total carbon, mg/L	
TIC, mg/L	3.26E+03
TOC, mg/L	1.20E+03
Free OH^-, M	8.44E-01
Total hydroxide (M)	2.29E+00
IC (anions), M	
Cl^-	1.04E-01
F^-	8.26E-03
$HCOO^-$	3.24E-02
NO_2^-	1.10E+00
NO_3^-	1.09E+00
$H(COO)_2^-$	2.88E-03
PO_4^{-2}	4.63E-03
SO_4^{-2}	7.44E-03
Specific gravity	1.23E+00
ICP-ES, mg/L	
Al	1.58E+04
B	2.35E+01
Ba	5.44E-01
Ca	2.99E+00
Cd	3.99E-01
Cr	5.92E+02
Cu	<1.0E-01
Fe	7.75E-01
Mo	3.62E+01
Na	1.14E+05
Ni	9.72E-01
P	7.17E+01
Pb	2.15E+01
Si	1.42E+02
Sr	1.20E-01
Zn	4.87E+00
K	3.43E+03
Na/Cs	1.40E+04
K/Cs	4.24E+02

The ion exchange resin used for cesium removal from the Envelope A simulant (Tank AN-105) was SuperLig® 644 (batch # 991022SMC-IV29). This resin is a polymerized proprietary organic material supplied by IBC Advanced Technologies, American Fort, Utah. The resin was received in potassium form as 20-70 mesh granules. It was pretreated to remove any impurities that may have been left from the resin manufacturing process and then converted into hydrogen form. A mass correction factor (F-factor) was then determined for the hydrogen form resin. The pretreatment and the F-factor measurement were performed as prescribed by the "Task Technical and Quality Assurance Plan for Evaluating Effects of Resin Particle Size and Solution Temperature on SuperLig® 644 and SuperLig® 639 Resins Performance with LAW Envelope A Simulant" (WSRC-TR-2001-00202, SRT-RPP-2000-00049, Rev. 0).[8]

3.2 Equipment

The equipment used for batch equilibration tests consisted of a benchtop incubator shaker (model C24) supplied by New Brunswick Scientific Co., Edison New Jersey, Nalgene® filter units supplied by Nalgene Nunc International, Rochester, New York, and an analytical balance, (model AG285) obtained from Mettler Toledo. The analytical balance was accurate to ± 0.001 g. A high precision (0.01 ^{o}C) thermometer traceable to NIST calibration was mounted in polyethylene bottles containing de-ionized water to record the temperature in the incubator shaker environment. A house-supplied vacuum and a trap assembly were used during sample filtration. All experiments were performed in a chemical hood.

The equipment for ion exchange column tests included a single column, a positive displacement pump, an automatic fraction collector, and a water circulator. The column was constructed from borosilicate glass tubing with 1.45-cm i.d., and a total length of 30 cm. The outside of the column walls was coated with a layer of clear polyvinylchloride to reduce hazards associated with potentially pressurizing the apparatus. The column top assemblies had a fill reservoir, a pressure gauge, a pressure relief valve, and a feed inlet port. The fill reservoir on column top assemblies also served as a vent. The top assembly was connected to the lower section by a glass ground joint and was tightly fitted by a screw cap. A ruler affixed to the column wall was used to allow observation of resin bed height and liquid level changes. All tubing connections were made of polypropylene lines that had Teflon® quick-connect fittings attached to each end. A 3-way, 6 mm bore Teflon® stopcock (#1) was attached to the bottom of the column. The column head was attached to the column using a Rudivis ground-glass joint. Two 2-way, 6 mm bore stopcocks (#2 and #3) were attached on opposite sides of the column head to serve as feed ports. The column head also contained a pressure gauge, a pressure relief valve, and a fill reservoir that also served as a vent. Stainless steel wire screens (200 mesh) were inserted into the columns to support the ion exchange resin. Quick-disconnect couplings supplied by Colder Products Company, St. Paul, Minnesota were used to connect low-density polyethylene tubing (11/64" i.d.) to the column. All solutions were passed as down flow through the column using a Fluid Metering Incorporated (FMI) positive displacement pump. Scilog Inc. Middletown, Wisconsin supplied the pump head (model RH00). It was made of a stainless steel (1/8" i.d.) piston that is displaced by a 450 rpm optically encoded, servo-controlled motor. The flow rate range for the pump head/piston configuration was 0-23 mL/min. Samples were collected either manually or using a Spectrum Chromatography IS-95 Interval Sampler.

3.3 Procedure

3.3.1 Resin Pretreatment & F-factor determination: To remove any water-soluble residues, or undesired cations remaining on the resin after the manufacturing process, the resin samples were subjected to pre-treatment. For this purpose the resin was converted by acid-caustic cycles from sodium or potassium to hydrogen form. Approximately 50 grams (± 0.01 g) of SuperLig® 644 (batch # 991022SMC-IV29) was weighed in a high density polyethylene (HDPE) bottle and soaked in a 10:1 phase ratio of 1.0M sodium hydroxide solution for 2 hrs. The resin and sodium hydroxide solution mixture was gently swirled several times. No magnetic bar or mechanical stirrer was used to shake the mixture. The sodium hydroxide solution and resin mixture was slurried into a 1-inch diameter glass column. The excess sodium hydroxide solution was drained and discarded. The resin in the column was washed with 3 bed volumes (BVs) of de-ionized water, followed by 15 BVs of 0.5M nitric acid and 10 BVs of de-ionized water. The resin was removed from the column and dried in a vacuum oven at 50 ± 5 ^{o}C and 24 in Hg. The dry mass of the pretreated resin in hydrogen form was approximately ~ 20 grams. A portion of the resin was sieved into three particle-size distributions, namely: 20 to 30-mesh (0.6-mm to 0.841mm), 30 to 40-mesh (0.42-mm to 0.6-mm), and 40 to 60-mesh (0.25-mm to 0.42-mm).

The resin moisture content (F-factor) was determined by storing a 0.3 g sub-sample of unsieved ion exchange resin in the hydrogen form in a screw-capped bottle for several days. The resin was then dried overnight in a vacuum oven at 50 ± 5 ^{o}C. After drying, the resin was cooled in a desiccator and weighed periodically to assure the attainment of a constant weight.

3.3.2 Resin Degradation Rate Tests: Resin degradation tests were performed to ensure the SuperLig® 644 resin does not significantly break down in process solutions, such as caustic simulant and dilute (0.5M) nitric acid solutions during extended exposure times. The tests consisted of exposing preconditioned SuperLig® 644 resin to simulated Envelope A and 0.5 M HNO_3 solutions in duplicate, withdrawing small aliquots (aqueous) every 3 days for cesium and total inorganic and organic (TIC/TOC) analysis. This was followed by a second test of exposing preconditioned SuperLig® 644 resin to single samples of Envelope A simulant and 0.5 M nitric acid in sealed containers of empty, air-filled, headspace. The samples from both tests were stored at 50 ± 5 ^{o}C for 15 days during which small aliquot (aqueous) of each solution was withdrawn every 3 days for analysis. The aliquots from the first test were analyzed for cesium and TIC/TOC and those from the second test were analyzed for vapor and liquid phase volatile and semivolatile organic analysis (VOA and SVOA. The phase ratio was maintained at 100. Changes in the morphology of the resin beads was examined, photographed, and recorded.

3.3.3 Batch Equilibration Tests: A known volume (~18 ml) of simulated Envelope A (AN-105) solution was added into polyethylene bottles containing a known quantity (~0.18 g) of pretreated SuperLig® 644 resin in hydrogen form with a narrow particle size distribution. Three particle size distributions were tested, namely: 20 to 30-mesh (0.59-mm to 0.84-mm), 30 to 40-mesh (0.42-mm to 0.59-mm), and 40 to 60-mesh (0.25-mm to 0.42-mm). All batch equilibration tests with different particle size distributions were conducted at 25 °C. Additional tests were conducted with unsieved SuperLig® 644 resin at 25, 35, and 45 °C. The phase ratio for all batch equilibration tests was maintained at 100. The bottles containing the solution and the resin were placed in an incubator- shaker. The shaking speed of the incubator was set at 275 rpm, and the temperature was set to the desired level (i.e. 25, 35, or 45 °C) and continuously monitored by placing de-ionized water bottles mounted with high precision thermocouples in a location adjacent to the simulant test bottles. The tests were all conducted in duplicate for 72 ± 1 hr. Laboratory control samples (~ i.e. 18 mL of simulant solution in which no resin was added) was treated in identical process steps as the simulant test samples. The concentrations of cesium and competing metal cations in the control samples were used as initial concentrations for determination of equilibrium distribution coefficient (K_d values). Sub-samples of the simulant in contact with the resin were removed from the solution using individual 0.45-micron filter syringes at intervals of 1, 4, 8, 24, 48, and 72-hours. The samples were analyzed by ICP-MS to determine the concentration of total cesium and by ICP-AES to determine the concentrations of sodium, potassium, and toxic metal competitors, such as cadmium, chromium, iron, lead, and calcium. The amounts of simulant solution withdrawn at each interval were higher than wanted, and this resulted in a gradual change of the phase ratio. Conducting a material balance on each sample mitigated the effect of this procedure on the results and the details are discussed later.

Additional testing was carried out with lower concentrations of chromium in the simulant in the absence of cesium. Duplicate samples of the pretreated resin in the H-form were contacted with Envelope A simulated solution containing ~ 100 mg/L of chromium, 0.84 mg/L cadmium, 3.56 mg/L iron, and 25 mg/L lead. Sequential batch contact tests were performed (3 contacts) to evaluate the effects of chromium and other minor competitor uptake in the absence of cesium. The sequential contact tests were conducted using fresh resin in each new contact with filtrate that had been separated from the resin in the preceding test. In the first contact, ~18 mL of the Envelope A simulant was added to HDPE bottles containing approximately 0.18 g of pretreated (unsieved) SuperLig® 644 resin. The bottles were placed in an incubator-shaker for 24 ±1 hours at 25 °C and a shaker speed of 275 rpm. Duplicate control samples (~18 mL of the simulant in which no ion exchange resin was added) were treated in identical process steps to the test samples. After equilibration, the solutions were separated from the resin using a 0.45-micron nylon filter unit.

In the second contact, approximately 12 mL of the filtrate that had been separated from the resin used in the first contact test was re-contacted with fresh resin (~0.12 g). The resin and the filtrate were gently shaken for 24 ±1 hours, then the solutions were separated from the resin using a 0.45-micron nylon filter unit. The third contact was carried in the same manner as the second contact test, except ~10 mL sample of the filtrate from the second test and ~ 0.1 g of fresh resin were equilibrated for 24 ±1 hours. After equilibration, the solutions were separated from the resin by filtration with a 0.45-micron nylon filter unit. Sub-samples (~ 1-mL) of each filtrate were analyzed for minor competitors (Cr, Cd, Fe, and Pb) by ICP-AES.

3.3.4 Small-Scale Column Tests: A known mass (2.25 g) of pretreated SuperLig® 644 (batch # 991022SMC-IV29) resin was slurried into a 1.45 cm (~0.6-inch) i.d. glass column using de-ionized water. The outside walls of the column were tapped while the resin was being slurried into column to ensure uniform packing of the resin bed. The initial height of the resin bed in de-ionized water was approximately 3.0-cm (~1.2-inches), yielding a column that contains ~5-mL of resin in the hydrogen form. The temperature of the water-bath circulator and the column jacket were adjusted at 25 ^{o}C. The temperature of the liquid above the resin bed was periodically measured and recorded during the tests. Six bed volumes (BVs) of 0.25M sodium hydroxide solution was pumped as down flow into the column at approximately 1 bed volume per hour (BV/h). The resin was stored overnight in the sodium hydroxide solution to allow for maximum swelling of the resin. After overnight storage, the NaOH liquid level was adjusted so that the volume of liquid above the resin bed was approximately 2 cm. The height of the resin bed was approximately 8-cm (3.1-inches), yielding a column that contained ~ 13-mL of swollen resin in sodium form. The preconditioning solution (0.25M NaOH) that remained above the resin bed and in the feed tubing was approximately 1 BV; the total apparatus volume (TAV) was equal to 2 BV. Therefore, the first 11.2-mL of simulant that was fed into the column at the beginning of the loading cycle was diluted by a factor of 2. Likewise, the post-feed water wash and the eluting solutions were allowed to mix with the liquid head left above the resin from the previous cycle. No attempt was made to correct for mixing of solutions in the column headspace when calculating the number of bed volumes of feed, wash, or eluate processed.

The loading cycle at 25 ^{o}C was considered to start at the moment that the simulant (AN-105) contacted the resin bed. The simulant was pumped as down flow through the column at ~ 3 BV/h. The first 3 BV of effluent was discarded to prevent dilution of the effluent by residual sodium hydroxide solution. Sub-samples of the column effluent were collected after 5 BV of solution had passed through the column and at intervals of approximately 10 BVs, until approximately 150-BVs of simulant had been processed. The samples were collected using a Spectrum Chromatography IS-95 Interval Sampler. Periodically (during sample collection except off-shift hours), the heights of the resin bed and the liquid above, the temperatures of the water-bath circulator and the resin bed, and the flow rate were measured and recorded. Each of the column effluent samples was analyzed to determine the concentrations of Na, K, and Cs.

At the conclusion of the loading cycle, the simulant was displaced from the column using 6 BVs (2 total apparatus volumes) of 0.1M sodium hydroxide solution. The dilute sodium hydroxide solution was pumped as down flow into the column at 3 BV/hr. The resin bed was then flushed with 6 BVs (2 total apparatus volumes) of de-ionized water at the same flow rate (3 BV/h). The dilute sodium hydroxide was used in order to prevent aluminum hydroxide precipitation that could foul the resin bed and the water rinse served to displace residual sodium hydroxide solution from the columns prior to elution. The column was eluted using 16BV of 0.5M nitric acid solution at 1.4 BV/hr. Sub-samples of the column eluate were collected in 2-BV increments and were analyzed for total cesium by ICP-MS; composite elute solution was analyzed for total cesium (ICP-MS) and the metal constituents by ICP-AES. Upon conclusion of the elution cycle, the residual nitric acid solution was displaced from the column by pumping 6 BVs (2 total apparatus volumes) of de-ionized water through the column at 1.4 BV/hr. The column was stored in the de-ionized water for 2 days before the second column test at 35 ^{o}C was initiated.

The second column test was carried out at 35 ^{o}C using a fresh batch of AN-105 simulant. The column was regenerated using a 0.25M NaOH solution. The regenerant solution, polypropylene tubing (feed line), and the resin bed were preheated to 35 ^{o}C. The resin was regenerated at 35 ^{o}C by pumping as down flow 6 BVs of 0.25M sodium hydroxide solution at 1.0 BV/hr through the column. The column was stored overnight in the regenerant solution at 35 ^{o}C to allow for maximum swelling of the resin. On the next day, the simulant and polypropylene feed line were preheated to 35 ^{o}C. The simulant was pumped as down flow through the column at ~ 3 BV/h and the first 3 BV of the effluent was discarded. Sub-samples of the column effluent were collected after 5 BVs of solution was processed and at intervals of approximately 10 BVs, until approximately of 150-BVs of the simulant had been processed.

Upon completion of the second loading cycle, 6 BVs of 0.1M sodium hydroxide at 3 BV/h was used to displace the simulant from the column. The dilute sodium hydroxide was rinsed from the column with 6 BVs of de-ionized water at 3 BV/h. The column was eluted at 35 ^{o}C using 16BV of 0.5M nitric acid solution at 1 BV/hr. The height of the resin bed after elution was 4.6-cm (1.8-inches), yielding a resin bed volume of 7.6-mL. Sub-samples of the column eluate were collected in 1-BV increments. The eluate sub-samples were analyzed for total cesium and the eluate composite was analyzed for both total cesium and other metal constituents. The column was stored in de-ionized water at ambient temperature for 2 days before a third column test was initiated.

The third column test was carried out at 45 ^{o}C. The height of the resin bed did not change during a 2-day storage period in de-ionized water. The temperatures of the regnerant solution (0.25M NaOH), polypropylene feed lines, and the column were raised to 45^{o}C. The column was regenerated (i.e. resin converted to sodium form) by transferring 6 BVs of 0.25M sodium hydroxide solution through the column at 1 BV/hr. The column was stored overnight in sodium hydroxide solution at 45 ^{o}C to allow maximum swelling. On the following day, the simulant and feed lines were again preheated to 45 ^{o}C and the simulant solution was pumped as down flow through the column at 3 BV/h. After discarding the first 3 BVs of the effluent, sub-samples were collected after 5 BVs of solution was processed, and at intervals of approximately 10 BVs thereafter, until approximately 150 BVs of simulant had been processed. At the conclusion of the loading cycle, the simulant was displaced from column by transferring 6 BVs of 0.1M sodium hydroxide at 3 BV/h, followed by 6 BVs of de-ionized water to rinse the dilute sodium hydroxide off the resin. The column was eluted at 45^{o}C using 16BV of 0.5M nitric acid solution at 1 BV/hr. Sub-samples of the column eluate were collected in 1-BV increments.

A fourth column test was carried at 25 ^{o}C to compare the column performance before and after the tests at elevated temperatures. This test was performed after storing the resin in de-ionized water for 2 days at ambient conditions. The column was regenerated at 25 ^{o}C by transferring 6 BVs of 0.25M sodium hydroxide as down flow at 1 BV/h. The conditions (i.e. flow rate, temperature) during column loading, displacement, rinsing, and elution were identical to that of the first column test at 25 ^{o}C. Sub-samples of the column effluent were collected after processing 5 BVs of simulant, and at intervals of approximately 10 BVs thereafter, until approximately 210 BVs of simulant had been processed.

4.0 Results and Discussion

4.1 Pretreatment and Particle Size Change: The SuperLig® 644 resin received from IBC Advanced Technologies (Fork, Utah) contained a significant quantity of impurities, which resulted from the manufacturing process. SRTC confirmed by X-ray diffraction that the impurity present in several "as-received" resin batches was primarily potassium bicarbonate. A very large fraction of the resin mass was removed during the pretreatment process; the percent mass loss of Superlig® 644 resin batch #IV-29 was nearly 47%. Approximately 5-10% of the resin mass was likely moisture content. Thus, less than 42% of the resin mass was "useable".

Figure 1 shows the mean particle size distribution as percentage of initial mass. Duplicate 20-gram samples of the resin (SuperLig® batch # 991022SMC-IV29) were used. The resin samples were pretreated and sieved for comparison. The calculated mean particle size decreased during pretreatment from approximately 0.74 to 0.51 mm based on the mass distributions. We estimated the mean particle size in the >0.841 mm range as 1.682 mm and the mean particle size range in the <0.25 mm range as 0.125 mm. These results show that pretreatment of the SuperLig® 644 (IV-29 batch) eliminated almost all of the largest particle size range and caused a significant shift towards smaller particle sizes. It is quite possible to speculate that the sodium bicarbonate may be acting as a binding agent to create those larger particles as agglomerates.

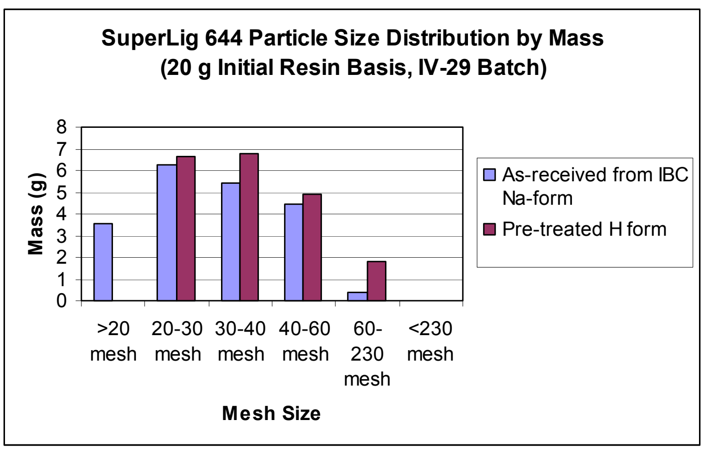

Figure 1. Particle Size Distribution of SuperLig® 644 Resin.

4.2 Batch Kinetic Results

Batch kinetic tests were based on measurement of distribution coefficient or K_d value of cesium and other metal ions at various contact times. The K_d value of an analyte or solute is defined as the ratio of the molal concentration of the solute in the resin to the molar concentration in the solution. The distribution coefficient (K_d value) is calculated using the following equation:

$$K_d = \left[\left(\frac{C_{init}}{C_{final}}\right) - 1\right]\left[\frac{V}{M * F}\right] \quad (1)$$

where C_{init} and C_{final} are the species concentration in the AN-105 simulant before and after contacting with resin, V is the volume of solution used, M is the mass of resin used (pre-treated here), and F is the resin dry weight correction factor (F-factor). Typically distribution coefficients are measured at equilibrium so the data represents one point on the equilibrium isotherm. The distribution coefficients determined at various contact times before attaining equilibrium were termed "Timed" K_d values and they describe the kinetic behavior of the resin during the adsorption process.

For this work, the distribution coefficients were obtained at different contact times (i.e. 8, 24, 48, and 72 h) to determine the concentration cesium and competing species. All K_d measurements were performed in duplicate, and the K_d values reported are the average of two separate measurements. The amount of test solution withdrawn at each interval (~ 1 mL) was higher than wanted and presumably the final solution weight differed slightly from that of the pre-withdrawal test solution. We made appropriate final corrections to account for the fact that the liquid-to-solid ratio and the remaining concentrations of the species decreased as successive assay portions were withdrawn. To determine corrected K_d values of sorbed species, the concentration of the species in the post-assay solution were compared with the concentrations in the pre-assay solution, then corrected for the amount and concentration of each species in the assay removed. Although the average K_d values for each pair of duplicate measurements were plotted, the average and associated relative standard deviation for every pair of measurements are given in Appendix A.

4.2.1 Effect of Temperature

Temperature is an important factor controlling the selectivity of ion exchange resin. The general data trends for various ion exchange resins suggest that an increase in temperature from 10 to 100 ^oC can lower the K_d values by as much as an order of magnitude. Previous studies showed that selectivity for cesium tends to decrease as the temperature increases for most ion exchangers. [11] In this study, batch contact experiments were carried out at 25, 35, and 45 ^oC to evaluate the effect of temperature on cesium sorption kinetics.

Figure 2 shows the distribution coefficients (K_d values) of cesium and minor competitors (chromium, cadmium, iron, and lead) as a function of contact time. In Fig. (2a), the temperature effect on the K_d values was negligible for contact times less than 20 h. This is significant in the operation of plant full-scale columns where a normal residence time of about 83 minutes is expected. Figure 2a also shows that K_d values appear to be significantly sensitive to contact time up to about 10 hours. This may mean that column loading performance is sensitive to changes in residence time over the planned operational residence time range of about 20 minutes to 3 hours and may merit further study. At contact times longer than 24 h, Fig. 2(a) shows a trend of cesium K_d decreasing with an increase in temperature from 25 to 45 ^oC. The cesium K_d values for a 48-h contact of the simulant (AN-105) with SuperLig® 644 resin at 25, 35, and 45 ^oC were ~ 2300, 1635, and 1238 mL/g, respectively. For 35 and 45 ^oC, equilibrium was generally attained after 48 hours, and the cesium K_d obtained at 45 ^oC slightly decreased for longer contact times.

Figure 2b shows the temperature dependence of chromium K_d as a function of contact time. It should be noted that chromium K_ds as a function of contact time increased as the temperature was raised. However, the K_d values were very low, generally averaging between 10 and 40 mL/g, respectively. Figures 2c, 2d and 2e show K_d results for lead, iron, and cadmium sorption on SuperLig® 644 resin. It is noted that lead, iron and cadmium behaved kinetically in similar fashion at 25 and 35 ^oC in such that equilibrium was attained after 24-h contact time and temperature had little effect in this range. At 45 ^oC, the K_ds for iron and cadmium increased with contact time, approaching approximately 500 mL/g after 72 h.

4.2.2 Effect of Particle Size

The resin particle size distribution has been shown to affect adsorption kinetics.[12] Therefore, information regarding the impact of resin particle size is important for the RPP-WTP plant design engineers to properly size and design full-scale ion exchange columns. The assessment and understanding of the impact of resin particle size on cesium uptake and kinetics will contribute to a better understanding of resin performance. The particle size influences the time required to establish equilibrium. A decrease in the particle size thus shortens the time required for equilibration. Large particles would mitigate high flow resistance and particle migration problems associated with small particles. However, exchange kinetics can become very slow. The particle size of the resin also affects the film diffusion (or the movement of ions from the surrounding solution to the particle surface) and internal diffusion (or movement of ions from the surface to the interior of the resin particle). Thus, a fine mesh particle presents more surface area for film diffusion and also contains less internal volume through which an ion must diffuse. Additionally, the greater surface area of the resin presented to the solution is more easily oxidized, or chemically degraded. Figure 3 shows that the distribution coefficients for cesium, iron, cadmium, lead, and chromium as a function of contact time and different particle size ranges. For small (40-60) and intermediate (30-40) mesh-size particles, the equilibrium cesium K_d values were ~ 1500 and 2800 mL/g, respectively. Equilibrium was attained for particles in these mesh-size ranges after 48-h contact with simulant (AN-105) and, the K_ds slightly dropped at longer times (> 48 h). However, it is also possible to speculate that this could be related to changes in surface area/volume ratio sites and not necessarily related to particle size.

The difference in K_d for Cr appears insignificnt with respect to particle size. However, the differences in K_d for Cd and Pb are as much as 40%. The particle size effects could not be discerned from the data in some cases due to detection limits. Figure 3c shows that the K_d values for iron behave in a manner opposite to that of cesium (i.e. the K_ds increased with decreasing particle size. Equilibrium for iron sorption on SuperLig® 644 resin was attained approximately after 24 hours and the K_ds slightly dropped at longer times. Although the data are preliminary, one explanation for the present observation is that cesium selective sites tend to be more abundant in the large particles, while the reverse is true for the iron-selective sites.

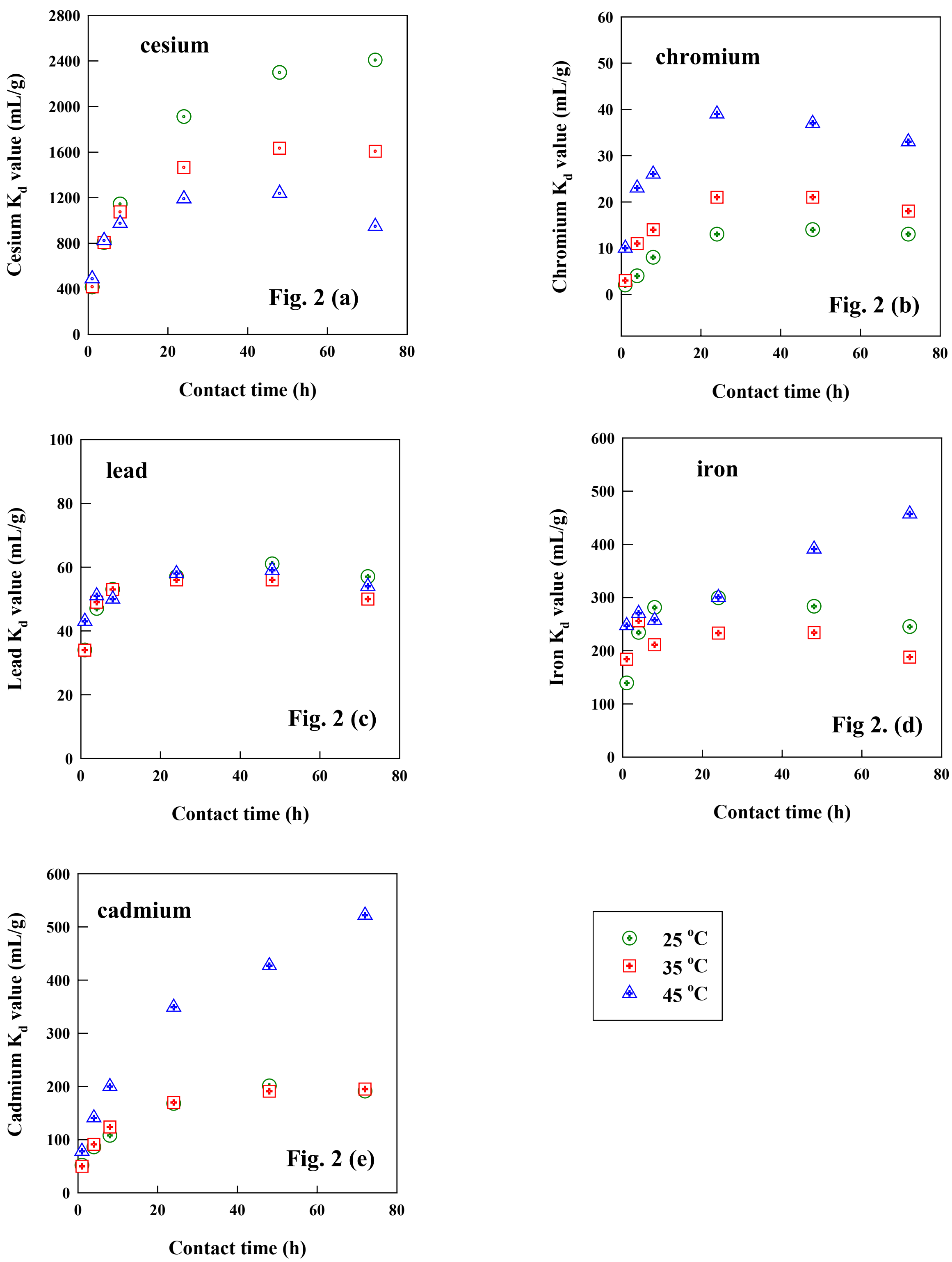

Figure 2. Temperature dependence of cesium and minor competitors

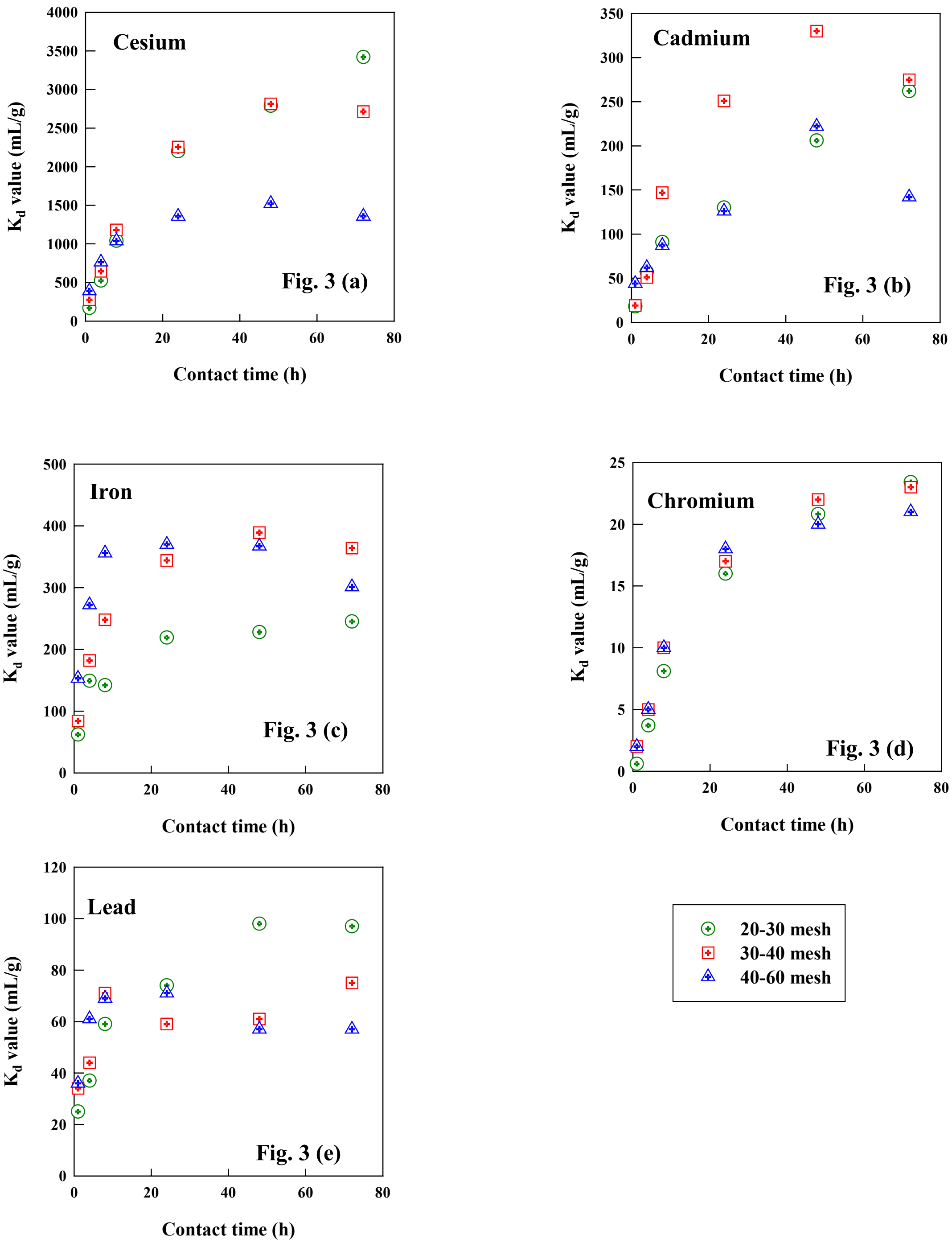

Figure 3. Particle size effect on cesium and minor competitors Kds

4.2.3 Competitor Metals Uptake Results

The purpose of this test was to examine the degree of the manufacturer's cited resin selectivity for cesium, and to see what other metals could be adsorbed during cesium ion exchange with actual Hanford waste. The uptake of chromium onto the resin is of particular interest to the RPP-WTP since this could present an oxidation hazard due to its presence as chromate in the waste. The presence of other RCRA hazardous metals (cadmium, chromium, silver, lead) in the ion exchange column eluate could also present eluate disposal difficulties. A simulant with no cesium was used to evaluate this scenario in its "worst case". The appearance of sodium and potassium as major competitors was expected as these are known by the manufacturer to compete with cesium for resin sites. The quantitative uptake experiments at a 10:1 liquid to solid phase ratio, where a $K_d > \sim 2$ is expected to be significant, shows these to be minor competitors, although the relatively large quantities of these ions may yield artificially low distribution coefficients.

Table 2 shows the loading and K_d values of minor competitors on SuperLig® 644 at 25 °C. The K_ds and loading of minor competitors were generated by a batch contact method using Envelope A (AN-105) simulant with no cesium in it. The K_d for cesium was obtained using Envelope A simulant containing ~ 600 mg/L chromium, 0.27 mg/L cadmium, 0.68 mg/L iron, and 24 mg/L lead. The resin's strong affinity for iron (present as a contaminant), cadmium, lead, and chrome was unexpected. Typically, competition with cesium for SuperLig® 644 resin sites would have been expected from mono-valent cations, such as sodium and potassium. Since sodium and potassium are present in the simulant in macro-quantities, the small change in their concentrations during the resin contact is barely detectable. While the K_d value of chrome is relatively small among minor competitors, it has the highest loading capacity. The impact of SL644 for RCRA hazardous cadmium, lead and chrome on RPP-WTP's ability to dispose of ion exchange column eluate should be carefully evaluated. As a result of these findings, further batch contact and ion exchange column experiments are needed with all minor competitors to re-evaluate the sorption and elution characteristics of the metal ions.

Table 2 (a). Minor Competitors K_ds and Loading on SuperLig® 644 Resin

Analyte	initial conc.	phase	final conc.	Kd	Loading
	(mg/L)	ratio	(mg/L)	(mL/g)	(mmole/g)
Chromium	101	100	62	63	7.48E-02
Cadmium	0.84	100	0.29	193	1.06E-03
Iron	3.56	100	0.44	708	5.99E-03
Lead	25.0	100	14.75	69	4.93E-03

Table 2 (b). Minor Competitors K_ds and Loading on SuperL® 644 resin

Analyte	initial conc.	phase	final conc.	K_d	Loading
	(mg/L)	ratio	(mg/L)	(mL/g)	(mmole/g)
Chromium	101	10	2.7	362	1.88E-02
Cadmium	0.84	10	0.14	50	1.34E-04
Iron	3.56	10	0.44	71	5.99E-04
Lead	25.0	10	6.90	26	8.72E-04

4.2.4 Resin Degradation Rates

Pilot-scale ion exchange column tests with SuperLig® 644 at Thermal Fluids Laboratory in the Savannah River Technology Center (SRTC) inadvertently discovered, through equipment malfunction that air flow through the resin bed resulted in severe resin damage. Generally attacks by acids and strong bases represent the most serious mode of resin degradation and thus it is important to ascertain whether SuperLig® 644 resin is capable of tolerating chemicals found in tank waste and other feed streams before use. To examine the rate at which resin degradation could occur under normal column operations, pretreated resin samples were stored in 0.5M nitric acid (used in elution cycles), de-ionized water, and Envelope A (Tank AN-105) simulant solution at 45°C for 15 days. Small aliquots of the solutions were withdrawn every 3 days, cooled, filtered, and analyzed for total organic carbon. After 15 days, the resin remaining in solution was filtered, washed with 0.5 M HNO3, and rinsed with de-ionized water before drying it in a vacuum oven (<10 mm Hg) at 45 °C.

Prior to the experiments, some scanning electron microphotographs were taken for samples of pretreated resin (Figure 4a). Similar microphotographs were taken for resin samples stored for 15 days in 0.5M nitric acid (Figure 4b) and AN-105 simulant that was inerted (Figure 4c) or unprotected from air (Figure 4d) under elevated temperature. The morphology of the resin samples was observed for evidence of physical degradation. The resin mass loss at various storage conditions was also measured. The results showed up to ~25% mass loss for samples stored in the nitric acid solutions for 15 days at 45 °C. In the AN-105, the mass loss was up to ~50%. Inerting the liquid headspace in the sealed bottles containing the resin resulted in a resin mass loss of 5-10%. The morphology of resin stored in 0.5M nitric acid solution at 45 °C did not change. Scanning electron microphotographs of the pretreated (unused) resin were compared with the resin stored in 0.5M nitric acid solution for 15 days at 45 ^{o}C. The appearance of the resin samples before and after the storage period had not changed and their morphology was not noticeably different. These two resin samples showed similar porous structure and rough surface. Resin stored in simulant solution with air in the headspace showed damage to particle morphology as indicated by significant smoothing of rough edges with signs of extensive cracking. Inerting the storage bottle headspace appears to have minimized damage to particle morphology.

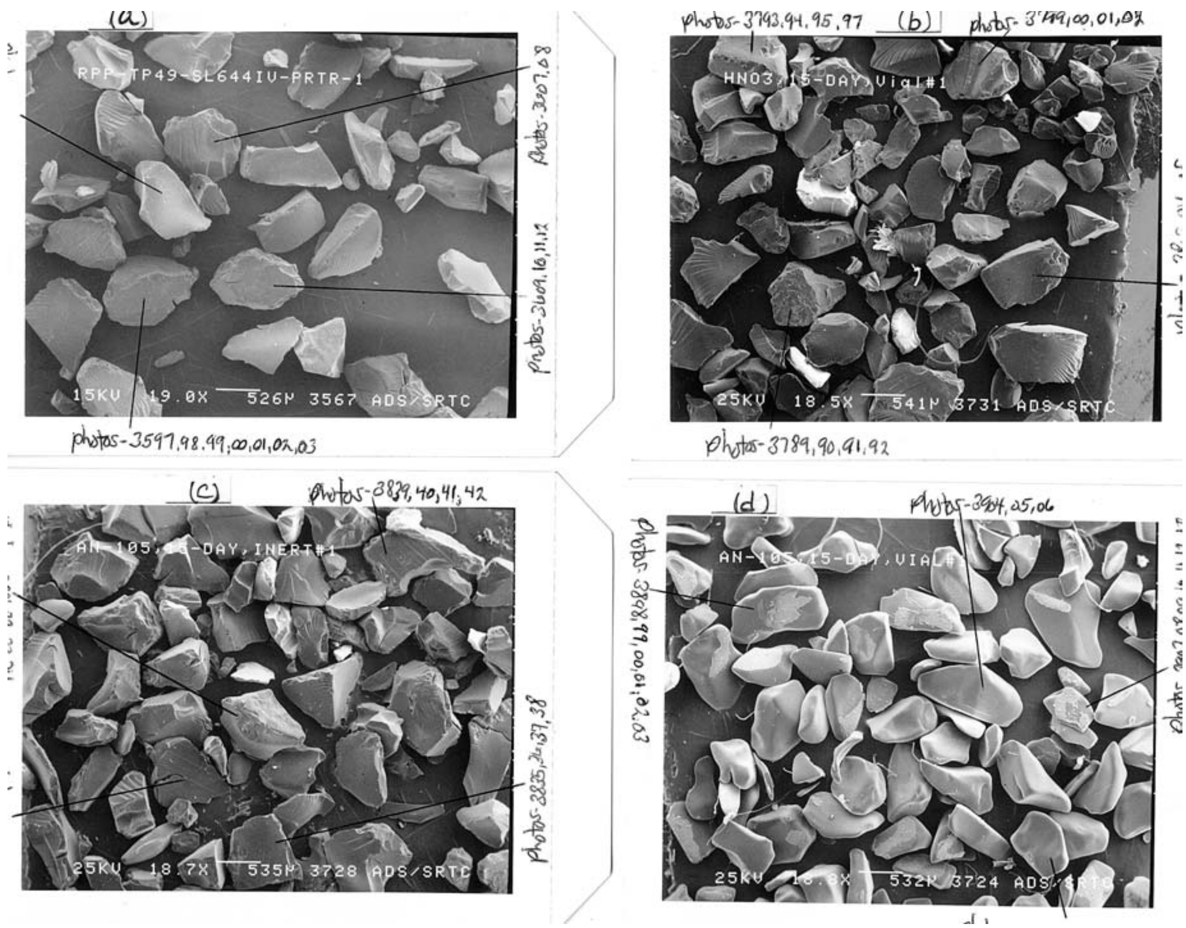

Figure 4. Scanning Electron Micrographs of SuperLig® 644 resin

Table 3 shows the distribution coefficients for cesium and minor competitors after 3, 6, 9, 12, and 15-day contact with SuperLig 644 resin at 45 ^{o}C. It is interesting to note that the K_d values generally increased in the following sequence: cesium > iron> cadmium> lead> chromium. The K_d values of metal species were quite variable over the 15-day storage period at elevated temperature. After 15 days, the K_ds for cesium, chromium, and lead decreased by ~ 22.8, 58.5, and 32.9%, respectively; and those of cadmium and iron increased by 61 and 36%, respectively. For the inert samples, the k_d values for cesium, cadmium, chromium, iron, and lead increased by 5, 150, 119, 131, 104%, respectively. These results suggest that the contact time (72-h) was not sufficient for these metal species to attain equilibrium at 45 ^{o}C. Chemical degradation does not clearly explain the lowering of K_d values for cesium, chromium and lead and corresponding increasing K_ds for iron and cadmium. The logical explanation for this finding is that new sites on the resin are being activated while some old sites destroyed. As a result, cations such as iron and cadmium prefer the newly activated sites, and the ability of cesium to compete for these new sites will decrease, and K_d should drop.

Table 3 . Cesium and Minor Competitors K_ds vs. Contact Time (45 ^oC)*

Time	cadmium	chromium	iron	lead	cesium
(days)	avg. K_d (mL/g)	avg. K_d (mL/g)	avg. K_d (mL/g)	avg. K_d (mL/g)	avg. K_d (mL/g)
3	175	53	281	79	1420
6	478	37	552	66	1272
9	332	48	507	75	1473
12	514	36	757	87	1481
15	282	22	383	53	1096
Solution purged with nitrogen					
15	437	116	648	147	1495

* air not purged from bottles headspace

Table 4 shows the total organic carbon leached into the simulant from the resin as a function of contact time. The data revealed that the resin stored in AN-105 simulant at 45 ^oC has gradually degraded due to dissolved oxygen in the simulant and in the headspace of sealed bottles. In this instance, total organic carbon leached from the resin after 15-day at 45 ^oC was 328 mg/g resin. In a parallel experiments where the simulant was purged with nitrogen, the total organic carbon leached was only ~ 42 mg/g resin. In 0.5M nitric acid at the same experimental condition, the total organic carbon leached from the resin was ~ 84 mg/g resin. Thus, the oxidative degradation was low for resin stored in simulant (caustic) solution with little or no oxygen present. The data are consistent with the mass losses observed for resins stored in dilute nitric acid and in simulant solution with and without oxygen present under elevated temperature. Therefore, the degradative force of oxygen cannot be ignored during the life of the resin. The oxidation of SuperLig® 644 resin in caustic solutions has already been documented.[14] The catalytic effect of traces of metals such as iron and copper along with oxygen may be quite important to determine the life expectancy of the resin.

Table 4. Total Organic Leachate from SuperLig 644 Resin at 45 ^{o}C

	AN-105 simulant		0.5M nitric acid		AN-105 simulant	AN-015 controls
Time (days)	avg. TOC (mg/L)	avg. TOC leached (mg/g of dry resin)	avg. TOC (mg/L)	avg. TOC leached (mg/g of dry resin)	avg. TOC (mg/L)	avg. TOC (mg/L)
3	1330	15	68	6	X	X
6	1830	66	69	7	X	X
9	2560	133	83	8	X	X
12	2630	145	82	8	X	X
15	4560	328	84	8	1590	1170

4.3 Column Performance Results

All experimental investigations performed to date at SRTC and PNNL with SuperLig® 644 resin have been conducted at ambient temperature and nominal particle size (20-70 mesh) with resin batches either in sodium or potassium form. The fact is that the resin will be used in the Richland/Tri-cities area of Washington State, where seasonal ambient temperatures can vary widely. Hence, the RPP-WTP plant design engineers do not foresee capability for precise temperature control in the ion exchange columns. A possible equilibrium shift caused by elevated temperatures consistent with summer temperatures could severely impact the SuperLig® 644 resin's performance and durability. The results for cesium loading on SuperLig® 644 resin at different temperatures are presented in Table 5. All column tests were carried out in 1.45-cm inside diameter column at ~ 3 BV/h (0.98 cm/min). The column contained 2.25 g of oven-dried resin, which was slurry-packed into the column with de-ionized water. The results in Table 5 show that more than 100 BVs of the AN-105 feed were processed for each of the three temperatures before 50% breakthrough of the cesium occurred. The breakthrough curves obtained at 25 ^{o}C before and after the elevated temperatures were nearly identical (see Figure 5), suggesting that the performance of the resin had not been affected by the high temperature exposures.

Table 5. Summary of Column Test Results

Test #	Temperature (^{o}C)	Resin bed* volume (mL)	Flow rate (BV/h)		Total # BV processed	# BV @ 50% bkth.
			Loading	Elution		
1	25	11.0	3.0	1.4	140	170 **
2	35	11.0	3.0	1.0	140	150 **
3	45	11.0	3.0	1.0	150	125
4	25	11.0	3.0	1.0	210	165

* mass of resin bed = 2.25 g

Table 6 shows a summary of the swelling and shrinking history of the resin bed during the column tests. The average specific volumes of the resin bed during regeneration, loading, and elution were 9.9, 8.1, and 5.5 ml/g, respectively. The swelling of the resin bed during regeneration with 0.25M sodium hydroxide was as much as 45% from the wet hydrogen form. The resin bed had shrunk about 18% during the column loading. This is due to exchange of large hydrated sodium ions on the resin with smaller hydrated cesium ions from the feed solution. When exchange occurs, the resin is able to contract. Swelling is desirable for the resin to undergo ion exchange with cesium. In addition, swollen resin allows for faster mass transfer by reducing intraparticle resistance. The resin swelling, however, can become undesirable from operation's point of view since swelling could potentially cause channeling. The swelling and shrinkage behavior of the resin was invariant with temperature under present experimental conditions.

Table 6. Resin Bed Swelling and Shrinking History (values in mL)

Test #	Temperature (^oC)	0.25M NaOH	5M Na+ simulant	0.1M NaOH	0.5M HNO3
1	25	13.2	11.2	13.7	8.1
2	35	14.1	11.2	13.2	7.6
3	45	13.7	10.9	12.7	7.1
4	25	12.9	10.9	13.2	7.4

Figure 5 shows the cesium breakthrough curves at three different temperatures. The plots show the concentration of cesium in the effluent divided by the initial concentration in the feed vs. the bed volume of simulant processed. As expected, the column loading decreased with increasing temperature. At 45 ^oC, 70% cesium breakthrough was observed after 150 BVs as compared to a 41% cesium breakthrough at 25 ^oC. However, the breakthrough capacity of the resin (defined as the amount of cesium that loaded per unit mass of resin in the column before being detected in the outlet of the column) was essentially the same for all temperatures. The breakthrough capacity observed at 25, 35 and 45 ^oC was 0.015, 0.013, and 0.011-mmole/g resin, respectively.

Figure 6 shows the elution curves of cesium from the SuperLig® 644 resin by using 0.5M nitric acid solution at ~1 BV/h (Note: the first column test was eluted at 1.4 BV/h). For the temperature ranges investigated, the cesium elution peak was observed in the first 5 BV of acid transferred into the column. Complete elution (i.e. less than 1% of the cesium remaining in the column) of the cesium from the resin was accomplished in ~14 BVs. In Figure 6, the concentration of cesium in the eluate reached its maximum between 4 and 6 BVs, then exponentially decayed to less than 1% of the initial feed concentration. Temperature did not show significant effect on cesium elution from SuperLig® 644 under conditions in the experimental range.

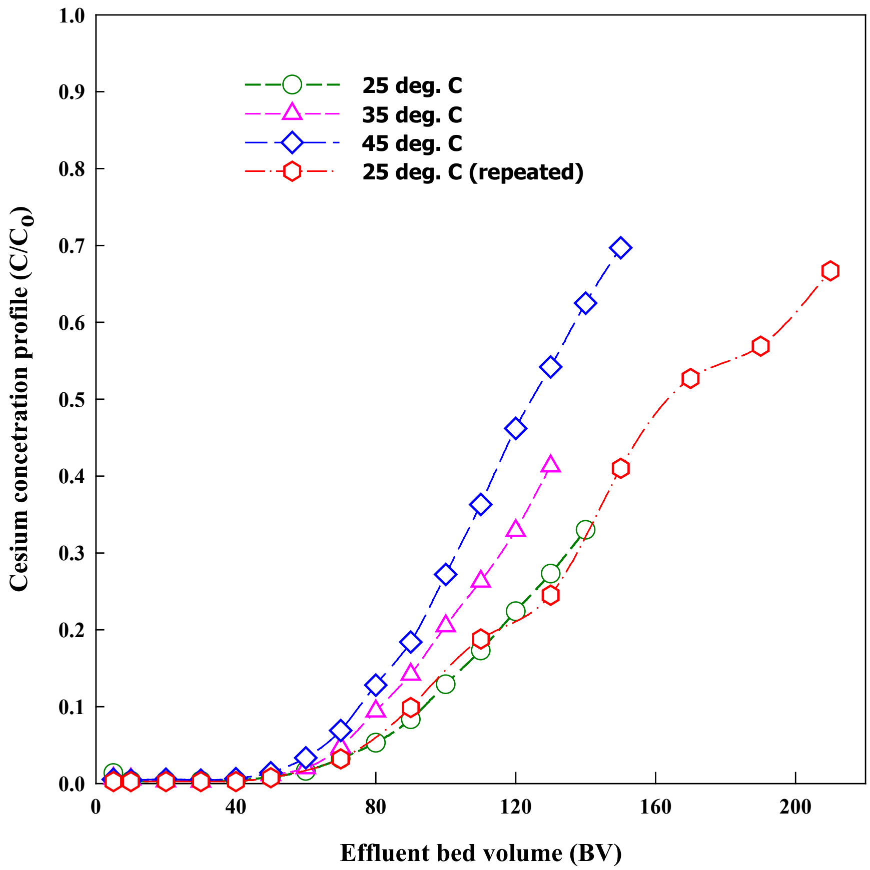

Figure 5. Cesium breakthrough curves

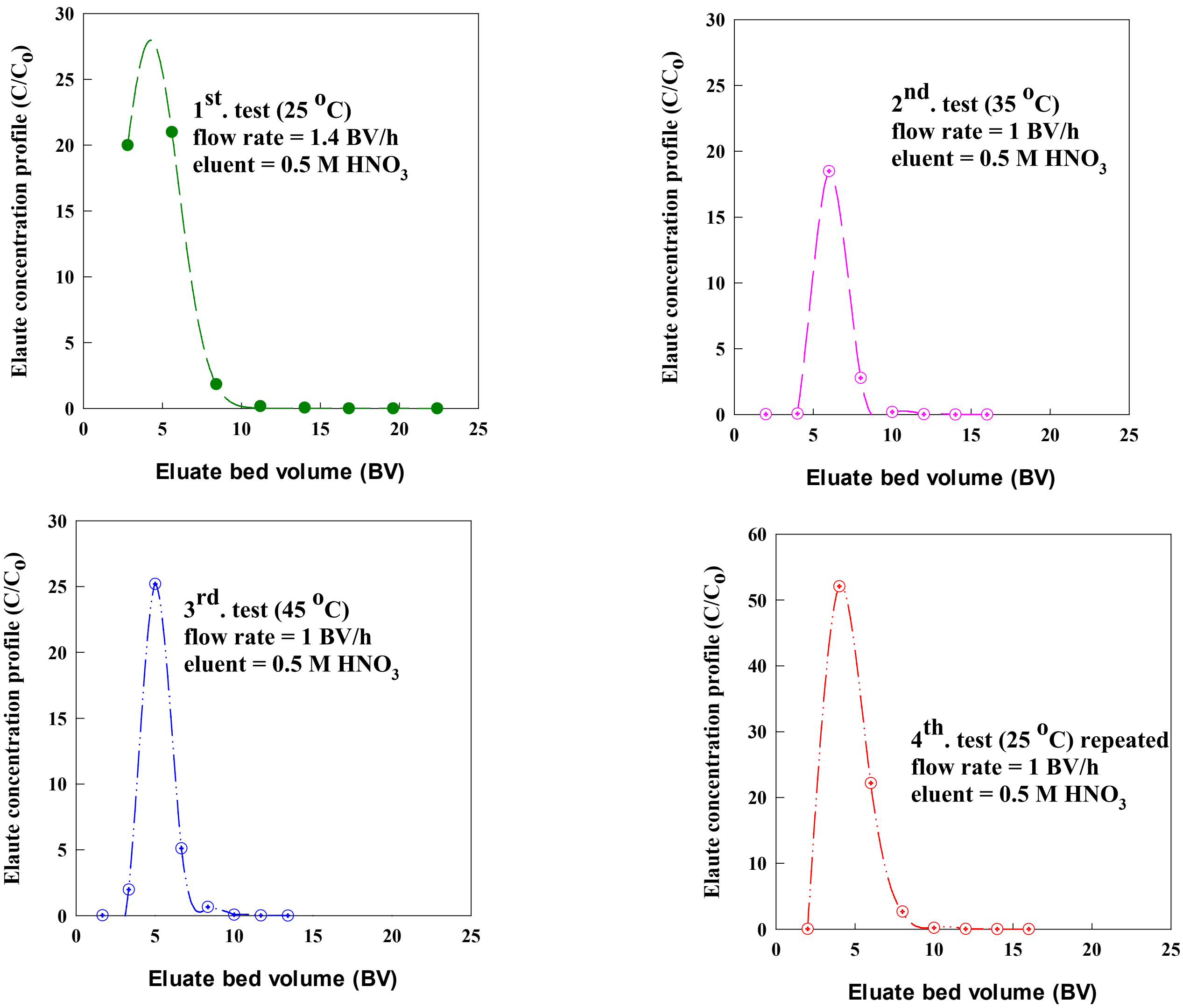

Figure 6. Cesium elution profiles

Figure 7 (a-d) shows the breakthrough curves of cadmium, chromium, iron, and lead at 25, 35, and 45 °C. The breakthrough curves of the metals are also shown after the resin was exposed to elevated temperatures (repeated test at 25 °C). The feed concentrations of cadmium, chromium, iron, and lead in the Envelope A simulant were 0.27, 596, and 0.68, and 24 mg/L, respectively. The breakthrough data for cadmium and iron at 35 and 45 °C (Figures 7 (a) and 7(b)) were erratic and the concentrations of these elements in the column effluent were higher than in the feed. The cause of this erratic behavior at the elevated temperatures is unknown. In

Figure 7a, there is an upward shift in the slope of the cadmium breakthrough curve obtained at 25 ^{o}C after the resin was exposed to elevated temperatures. In Figures 7 (c) and 7(d) the early breakthrough curve of chromium and lead could result from poor diffusion kinetics in the column.

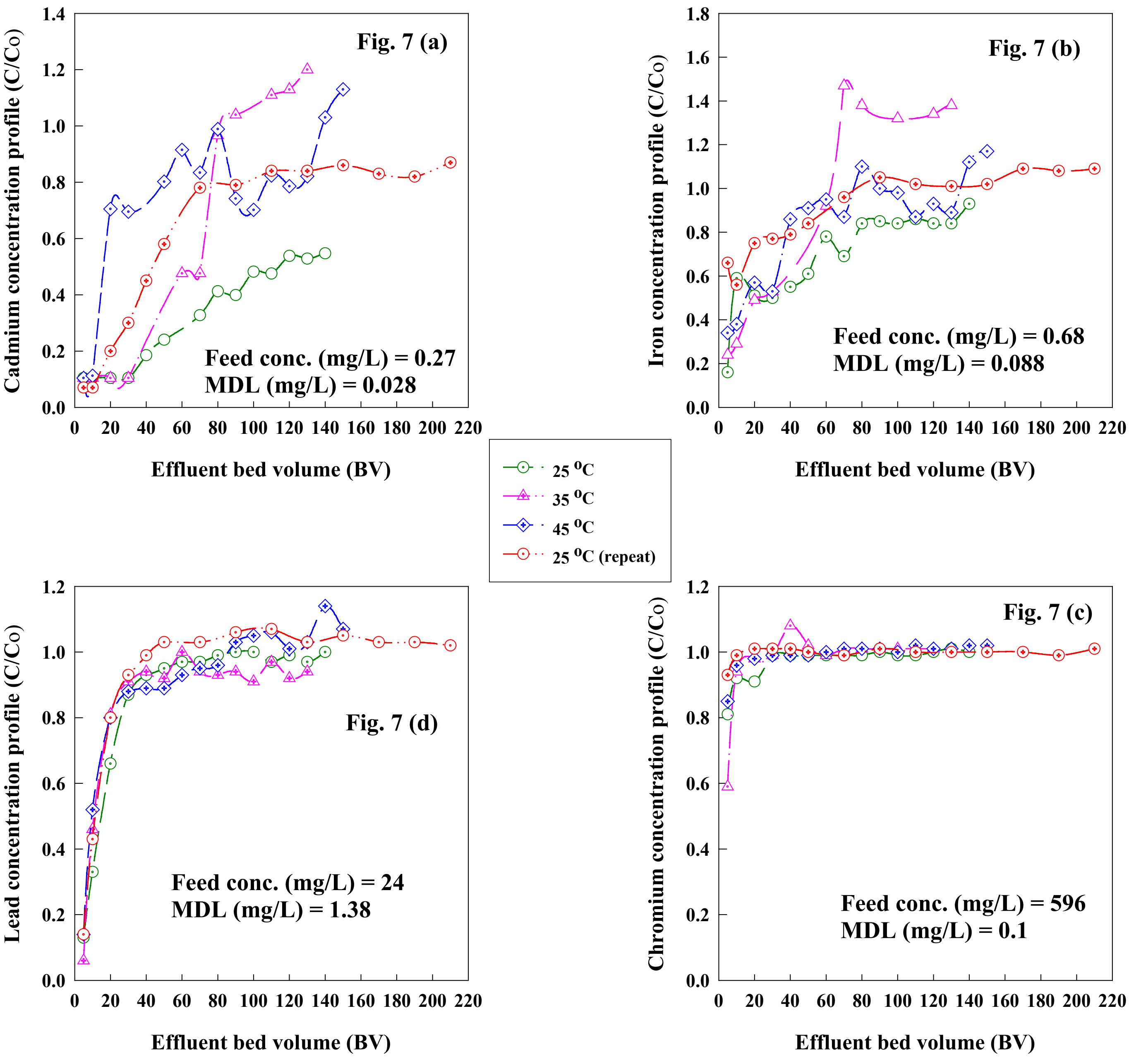

Figure 7. Minor Competitors loading profiles

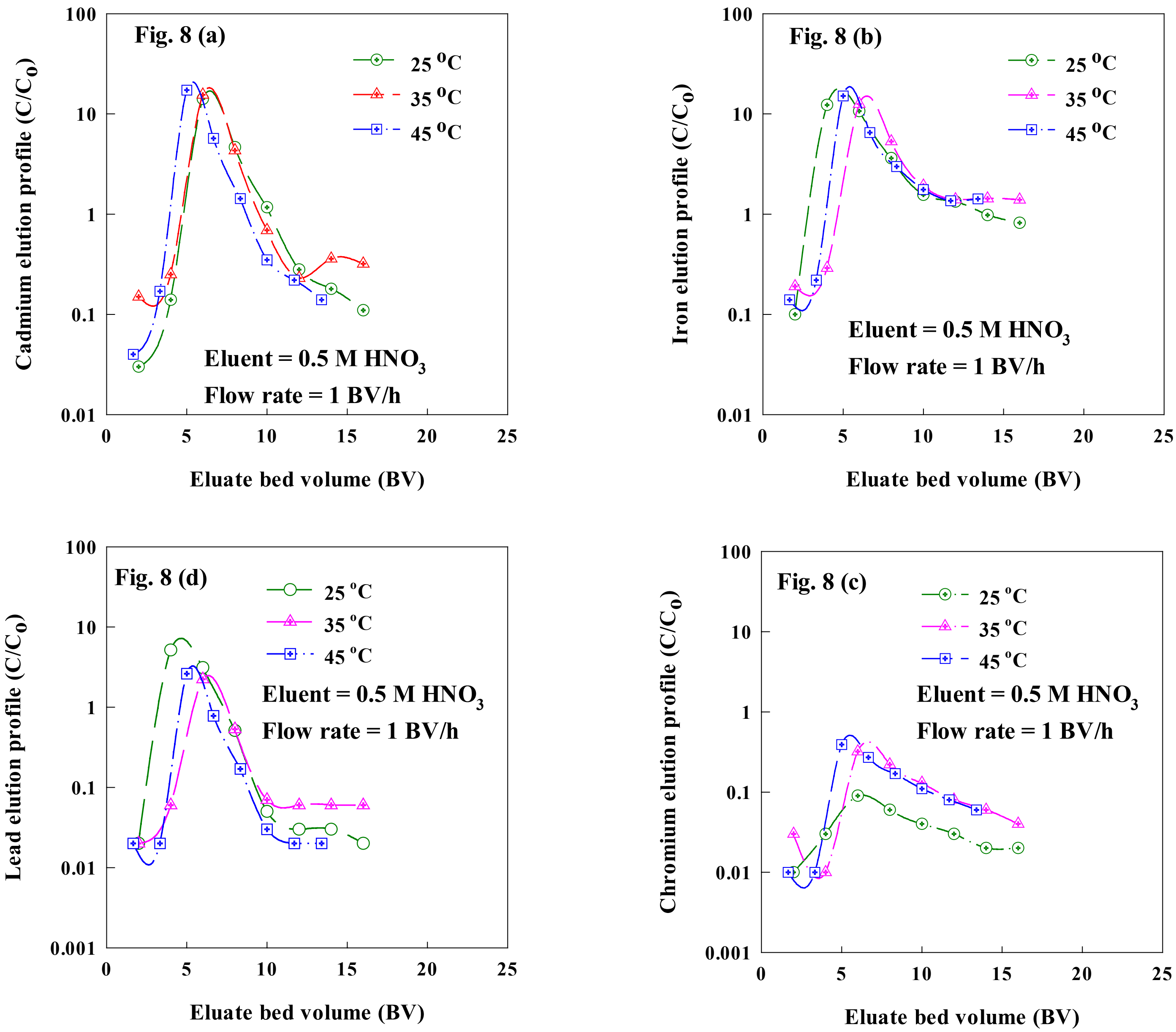

Figure 8. Elution profiles for minor competitors

Figure 8 (above) shows the elution of minor competitors from the resin at three temperatures using 0.5M nitric acid solution at ~ 1 BV/h. Elution of these elements during the first column test at 25 °C (before resin exposure to elevated temperatures) was carried out at 1.4 BV/h and the metals were not completely eluted (plot not shown). Figures 8 (a-d) show the elution profiles of the minor competitors from SuperLig® 644 resin at 25, 35 and 45 °C. It is clear that the metals (cadmium, iron, chromium, and lead) were retained on the resin during the loading cycle, but they were slowly removed during the elution cycle. The elution peaks of the elements were observed after 4 to 5 BVs of the acid had passed through the column.

Table 7 shows the concentration of chemical species in the effluent composite solutions from column tests performed at 25 ^{o}C before and after elevated temperatures. The concentrations of metals of interest such as barium, calcium, cadmium, and iron in the effluent composite solution before elevated temperatures (Table 7) were lower than the feed concentrations (Table 1) by as much as 47, 57, 84, and 35%, respectively. After elevated temperatures, the concentrations of the metals were lower by 30, 47, 34, and 28%. The chromium concentration in the feed and effluent composite solution was nearly the same, suggesting that chromium was not appreciably sorbed onto the resin. The change in anion concentrations between the feed and effluent composite solutions before and after elevated temperatures was within the expected range. The composition of the metals in the eluate composite solution is shown in Table 8. The SuperLig® 644 resin concentrated the metals such as barium, calcium, cadmium, and iron. A 4-fold increase of the metal concentrations in the eluate composite solution was noted. The mechanism in which the resin adsorbs these metals is unknown, but the presence of these metals in the eluate stream and the impact on the process flowsheet need to be addressed.

Table 7. Composition of Effluent Solutions before and after elevated temperatures

Temperature (25 °C)	Before	After
Analyte	avg. value	avg. value
Cs, mg/L	0.878	0.877
Total carbon, mg/L		
TIC, mg/L	X	4470
TOC, mg/L	X	792
Total hydroxide (M)	X	2.319
IC (anions), M		
Cl^-	1.15E-01	1.04E-01
F^-	6.89E-03	1.05E-03
$HCOO^-$	3.12E-02	3.10E-02
NO_3^-	7.51E-01	6.67E-01
NO_2^-	1.50E+00	1.24E+00
$H(COO)_2^-$	2.88E-03	2.52E-03
PO_4^{-2}	4.29E-03	5.28E-03
SO_4^{-2}	6.56E-03	6.64E-03
ICP-ES, mg/L		
Al	1.38E+04	1.59E+04
B	2.76E+01	2.54E+01
Ba	2.86E-01	3.80E-01
Ca	1.29E+00	1.58E+00
Cd	6.39E-02	2.62E-01
Cr	5.90E+02	5.84E+02
Cu	<1.0E-01	<1.0E-01
Fe	5.06E-01	5.59E-01
Mo	3.66E+01	3.67E+01
Na	1.10E+05	1.16E+05
Ni	6.13E-01	9.00E-01
P	8.36E+01	7.08E+01
Pb	2.10E+01	2.03E+01
Si	1.51E+02	1.53E+02
Sr	3.52E-02	6.38E-02
Zn	1.27E+00	4.53E+00
K	3.60E+03	3.55E+03
Na/Cs	1.25E+05	1.32E+05
K/Cs	4.09E+03	4.05E+03

Table 8. Composition of Eluate Solution before and after elevated temperatures

Temperature (25 °C)	Before	After
Analyte	avg. value	avg. value
Cs, mg/L	4.75E+04	6.41E+04
Total carbon, mg/L		
TIC, mg/L	9.57E+00	< 20
TOC, mg/L	1.55E+01	< 20
IC (anions), M		
Cl^-	5.71E-04	1.26E-03
F^-	1.05E-03	1.05E-03
$HCOO^-$	2.22E-03	2.22E-03
NO_2^-	1.61E-03	1.61E-03
NO_3^-	5.75E-01	4.67E-01
$H(COO)_2^-$	1.12E-03	1.12E-03
PO_4^{-2}	1.05E-03	1.05E-03
SO_4^{-2}	5.21E-04	2.40E-04
ICP-ES, mg/L		
Al	1.36E+01	5.66E+01
B	7.22E+00	8.64E+00
Ba	2.16E+00	1.21E+00
Ca	1.28E+01	1.33E+01
Cd	1.51E+00	1.34E+00
Cr	5.21E+01	2.30E+01
Cu	5.20E-01	2.63E-01
Fe	3.14E+00	2.71E+00
Mo	<1.0E-01	1.17E-01
Na	1.09E+03	1.40E+03
Ni	1.76E-01	1.25E-01
P	<6.8E-01	4.95E-01
Pb	2.11E+01	2.03E+01
Si	6.86E+00	9.32E+00
Sr	6.43E-01	4.47E-01
Zn	6.68E-01	5.16E-01
K	3.65E+01	5.26E+01

5. Conclusion

Batch contact and column tests were performed to evaluate the effects of temperature and resin particle size on cesium sorption SuperLig® 644 resin. The distribution coefficients of cesium were obtained as a function of contact times. Loading and elution profiles of cesium were also obtained. The rate of resin degradation in storage solutions was examined under elevated temperature. Additionally, the competition of trace metal ions in the simulant for sites in the resin was evaluated. The following conclusions were drawn from the test results:

1. The batch tests revealed that cesium uptake by SuperLig® 644 resin increased with increasing resin particle size. Although the data are preliminary, the general trend of increased resin Kd with smaller particle size was unexpected. Generally, small particles are better for kinetics, but they also present higher-pressure drop. Further kinetic testing of the particle size effects on cesium sorption for SuperLig® 644 resin will be conducted under separate task plan (resin batch- to-batch variability)

2. The results from column tests showed that more than 100 BVs of the simulated Envelope A (AN-105) feed were processed for the temperatures 25 ^{o}C, 35 and 45 ^{o}C before 50% breakthrough of the cesium occurred. The loading of cesium on the resin columns was slightly reduced at elevated temperatures. Cesium elution from SuperLig® 644 resin was complete after passing 15 BVs of 0.5M nitric acid into the columns. Temperature did not appear to have significant effect on elution under present experimental conditions.

3. The results from experiments designed to examine SuperLig® 644 resin degradation in alkaline solution under elevated temperatures revealed that significant mass loss of the resin (upto 50 % mass) occurred when the resin was stored in alkaline solution at 45 ^{o}C and not protected from air. Storing the resin in 0.5M nitric acid under the same experimental conditions did not show significant mass loss or degradation.

4. Trace metal (cadmium, chromium, iron, and lead) spiked into Envelope A simulant were adsorbed onto SuperLig® 644 resin. The uptake of the metal ions increased in the sequence iron >cadmium >lead >chromium. These metals were often omitted from simulant solutions due to the assumption that SuperLig® 644 was sufficiently selective for cesium and minimal co-sorption potential existed for these metal ions.

6.0 References

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Appendix-A

Envelope A (Tank 241-AN-105) Simulant Recipe

Appendix A-1: Composition of Tank AN-105 Simulant (at 5 M Na)

From Eibling Report (WSRC-TR-2000-00338, SRT-RPP-2000-00017)

Component	Moles/Liter	Target: mg/Liter	Actual: mg/Liter	Moles/Liter	% of Target Attained
Aluminum	1.47E+00	39700	18551	6.87E-01	90
Ammonium	6.65E-03	120	56	3.11E-03	
Boron	4.72E-03	51	24	2.21E-03	94
Cadmium	2.94E-05	3	1.4	1.37E-05	100
Calcium	9.98E-04	40	19	4.66E-04	<2
Carbonate	2.09E-01	12540	5860	9.77E-02	
Cesium	1.22E-04	16	7.5	5.70E-05	
Chromium	2.60E-02	1350	631	1.21E-02	107
Hydroxide	3.42E+00	58100	27149	1.60E+00	
Lead	2.56E-04	53	25	1.20E-04	87
Magnesium	2.22E-04	5	2.3	1.04E-04	<20
Molybdenum	8.55E-04	82	38	4.00E-04	109
Potassium	1.92E-01	7500	3505	8.97E-02	112
Selenium	1.25E-05	1	0.5	5.84E-06	
Silicon	7.51E-03	211	99	3.51E-03	61
Silver	1.51E-04	16	7.5	7.06E-05	
Sodium	1.07E+01	246000	114949	5.00E+00	104
Tin	1.83E-04	22	10	8.55E-05	
Zinc	1.54E-04	10	4.7	7.20E-05	158
TIC	2.09E-01	2510	1173	9.77E-02	
TOC	2.99E-01	3590	1678	1.40E-01	
Chloride	2.56E-01	9090	4248	1.20E-01	101
Fluoride	1.00E-02	190	89	4.67E-03	<50
Formate	6.40E-02	2880	1346	2.99E-02	103
Nitrate	2.66E+00	165000	77100	1.24E+00	104
Nitrite	2.41E+00	111000	51867	1.13E+00	108
Oxalate	6.93E-03	610	285	3.24E-03	<16
Phosphate	6.00E-03	570	266	2.80E-03	< 18
Sulfate	8.03E-03	771	360	3.75E-03	115
Acetate	3.51E-02	2070	967	1.64E-02	
Glycolate	1.53E-02	1150	537	7.15E-03	

Appendix-B

Batch Contact Data – Minor Competitors Effect

Appendix B-1:Chromium Uptake Data
No cesium in simulant
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Sample ID	Feed	Feed duplicate	1st. contact	1st. contact-D	2nd. contact	2nd. contact -D	3rd. contact	3rd. contact -D	Quanti-tative	Quanti-tative-D
Sample mass (g)	18.3195	18.3157	22.0277	21.968	18.2522	18.4371	14.1266	14.7984	12.251	12.205
Density (g/mL)	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
Resin mass (g)	na	na	0.1815	0.1789	0.1491	0.1542	0.1151	0.121	1.0094	1.0045
Phase ratio			99	101	100	98	101	100	10	10
Cr (mg/L)	101	100	61	62	36.2	34.1	20.6	19.4	2.7	1.9
K_d (mL/g)			64	63	70	80	76	76	360	517
Avg. K_d (mL/g)	na	101		63		75		76		439

Appendix B-2:Cadmium Uptake Data
No cesium in simulant
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Sample ID	Feed	Feed duplicate	1st. contact	1st. contact-D	2nd. contact	2nd. contact -D	3rd. contact	3rd. contact -D	Quanti-tative	Quanti-tative-D
Sample mass (g)	18.3195	18.3157	22.0277	21.968	18.2522	18.4371	14.1266	14.7984	12.251	12.205
Density (g/mL)	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
Resin mass (g)	na	na	0.1815	0.1789	0.1491	0.1542	0.1151	0.121	1.0094	1.0045
Phase ratio			99	101	100	98	101	100	10	10
Cr (mg/L)	0.81	0.86	0.25	0.32	0.14	0.14	0.14	0.14	0.14	0.14
K_d (mL/g)	na	na	233	162	79	126	0	0	49	49
Avg. K_d (mL/g)		0.84		197		102		0		49

Appendix B-3: Iron Uptake Data
No cesium in simulant
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Sample ID	Feed	Feed duplicate	1st. contact	1st. contact-D	2nd. contact	2nd. contact -D	3rd. contact	3rd. contact -D	Quanti-tative	Quanti-tative-D
Sample mass (g)	18.3195	18.3157	22.0277	21.968	18.2522	18.4371	14.1266	14.7984	12.251	12.205
Density (g/mL)	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
Resin mass (g)	na	na	0.1815	0.1789	0.1491	0.1542	0.1151	0.121	1.0094	1.0045
Phase ratio	na	na	99	101	100	98	101	100	10	10
Cr (mg/L)	3.50	3.61	0.44	0.44	< DLM	< DLM	< DLM	< DLM	< DLM	< DLM
K_d (mL/g)	na	na	704	713	nm	nm	nm	nm	nm	nm
Avg. K_d (mL/g)	3.56			708						

Appendix B-4:Lead Uptake Data
No cesium in simulant
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Sample ID	Feed	Feed duplicate	1st. contact	1st. contact-D	2nd. contact	2nd. contact -D	3rd. contact	3rd. contact -D	Quanti-tative	Quanti-tative-D
Sample mass (g)	18.3195	18.3157	22.0277	21.968	18.2522	18.4371	14.1266	14.7984	12.251	12.205
Density (g/mL)	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
Resin mass (g)	na	na	0.1815	0.1789	0.1491	0.1542	0.1151	0.121	1.0094	1.0045
Phase ratio	na	na	99	101	100	98	101	100	10	10
Cr (mg/L)	25.30	24.60	15.80	14	8.00	7.90	6.90	6.90	6.90	6.90
K_d (mL/g)	na	na	58	83	98	72	16	15	26	26
Avg. K_d (mL/g)	24.95			70		85		15		26

Appendix-C

Batch Contact Data – Particle Size Effect

Appendix C-1: Cesium Batch Data
Particle size 20-30 mesh
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cs]_i$ (mg/L)	$[Cs]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0489	0.1820	18.07	99	7.25	2.69	168	169	3.40E-03
I -h D	21.8889	0.1806	17.94	99	7.25	2.67	170		3.42E-03
4-h	20.8289	0.1820	17.07	94	7.56	1.18	507	523	4.50E-03
4-h D	20.6689	0.1806	16.94	94	7.56	1.12	540		4.54E-03
8-h	19.6089	0.1820	16.07	88	7.96	0.629	1029	1039	4.87E-03
8-h D	19.4489	0.1806	15.94	88	7.97	0.618	1050		4.88E-03
24-h	18.3889	0.1820	15.07	83	8.44	0.304	2217	2200	5.07E-03
24-h D	18.2289	0.1806	14.94	83	8.46	0.309	2182		5.07E-03
48-h	17.1689	0.1820	14.07	77	9.02	0.221	3079	2789	5.12E-03
48-h D	17.0089	0.1806	13.94	77	9.04	0.271	2499		5.09E-03
72-h	15.9489	0.1820	13.07	72	9.69	0.198	3445	3419	5.13E-03
72-h D	15.7889	0.1806	12.94	72	9.72	0.201	3394		5.13E-03

Appendix C-2: Cesium Batch Data
Particle size 30-40 mesh
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cs]_i$ (mg/L)	$[Cs]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	21.9977	0.1791	18.03	101	7.25	1.98	268	277	3.99E-03
I -h D	21.9738	0.1814	18.01	99	7.25	1.87	286		4.02E-03
4-h	20.7777	0.1791	17.03	95	7.60	0.974	647	645	4.74E-03
4-h D	20.7538	0.1814	17.01	94	7.61	0.968	643		4.68E-03
8-h	19.5387	0.1791	16.02	89	8.02	0.59	1126	1182	5.00E-03
8-h D	19.5394	0.1814	16.02	88	8.02	0.534	1238		4.97E-03
24-h	18.3201	0.1791	15.02	84	8.52	0.306	2250	2255	5.18E-03
24-h D	18.3193	0.1814	15.02	83	8.52	0.301	2260		5.12E-03
48-h	17.1105	0.1791	14.03	78	9.10	0.263	2630	2813	5.20E-03
48-h D	17.1181	0.1814	14.03	77	9.10	0.229	2995		5.16E-03
72-h	15.9171	0.1791	13.05	73	9.76	0.265	2610	2714	5.20E-03
72-h D	15.9162	0.1814	13.05	72	9.77	0.243	2819		5.15E-03

Appendix C-3: Cesium Batch Data
Particle size 40-60 mesh
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cs]_i$ (mg/L)	$[Cs]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	21.9668	0.1807	18.01	100	7.25	1.44	402	390	4.35E-03
I -h D	22.0538	0.1804	18.08	100	7.25	1.52	378		4.32E-03
4-h	20.7468	0.1807	17.01	94	7.63	0.829	773	760	4.82E-03
4-h D	20.8338	0.1804	17.08	95	7.63	0.857	748		4.82E-03
8-h	19.5422	0.1807	16.02	89	8.05	0.62	1063	1029	4.95E-03
8-h D	19.6344	0.1804	16.09	89	8.04	0.661	996		4.95E-03
24-h	18.335	0.1807	15.03	83	8.54	0.502	1332	1342	5.03E-03
24-h D	18.4214	0.1804	15.10	84	8.53	0.497	1352		5.05E-03
48-h	17.1427	0.1807	14.05	78	9.10	0.449	1499	1507	5.06E-03
48-h D	17.2102	0.1804	14.11	78	9.09	0.446	1516		5.08E-03
72-h	15.9521	0.1807	13.08	72	9.75	0.5	1338	1344	5.03E-03
72-h D	15.999	0.1804	13.11	73	9.75	0.498	1350		5.06E-03

Appendix C-4: Cesium Batch Data
Particle size: unsieved
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cs]_i$ (mg/L)	$[Cs]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0673	0.1832	18.09	99	7.25	1.37	424	397	4.37E-03
I -h D	22.0105	0.1822	18.04	99	7.25	1.53	370		4.26E-03
4-h	20.8473	0.1832	17.09	93	7.64	0.773	828	787	4.81E-03
4-h D	20.7905	0.1822	17.04	94	7.63	0.85	746		4.77E-03
8-h	19.6659	0.1832	16.12	88	8.05	0.551	1197	1147	4.96E-03
8-h D	19.6123	0.1822	16.08	88	8.04	0.598	1097		4.93E-03
24-h	18.4738	0.1832	15.14	83	8.53	0.338	2004	1917	5.09E-03
24-h D	18.4159	0.1822	15.10	83	8.52	0.369	1830		5.08E-03
48-h	17.2778	0.1832	14.16	77	9.10	0.291	2340	2304	5.12E-03
48-h D	17.2216	0.1822	14.12	77	9.08	0.3	2268		5.12E-03
72-h	15.7519	0.1832	12.91	70	9.95	0.276	2471	2414	5.13E-03
72-h D	16.0509	0.1822	13.16	72	9.72	0.289	2357		5.12E-03

Appendix C-5: Cadmium Batch Data
Particle size 20-30 mesh
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cd]_i$ (mg/L)	$[Cd]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0489	0.1820	18.07	99	0.747	0.641	16	18	9.36E-05
I -h D	21.8889	0.1806	17.94	99	0.747	0.621	20		1.11E-04
4-h	20.8289	0.1820	17.07	94	0.754	0.444	65	57	2.59E-04
4-h D	20.6689	0.1806	16.94	94	0.755	0.500	48		2.13E-04
8-h	19.6089	0.1820	16.07	88	0.773	0.418	75	91	2.79E-04
8-h D	19.4489	0.1806	15.94	88	0.771	0.350	106		3.31E-04
24-h	18.3889	0.1820	15.07	83	0.796	0.281	152	130	3.80E-04
24-h D	18.2289	0.1806	14.94	83	0.799	0.346	109		3.34E-04
48-h	17.1689	0.1820	14.07	77	0.833	0.242	189	206	4.07E-04
48-h D	17.0089	0.1806	13.94	77	0.832	0.214	223		4.24E-04
72-h	15.9489	0.1820	13.07	72	0.878	0.234	197	262	4.12E-04
72-h D	15.7889	0.1806	12.94	72	0.879	0.158	327		4.60E-04

Appendix C-6: Cadmium Batch Data
Particle size 30-40 mesh
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cd]_i$ (mg/L)	$[Cd]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	21.9977	0.1791	18.03	101	0.747	0.601	24	19	1.31E-04
I -h D	21.9738	0.1814	18.01	99	0.747	0.661	13		7.64E-05
4-h	20.7777	0.1791	17.03	95	0.756	0.482	54	51	2.32E-04
4-h D	20.7538	0.1814	17.01	94	0.752	0.498	48		2.12E-04
8-h	19.5387	0.1791	16.02	89	0.773	0.296	144	147	3.79E-04
8-h D	19.5394	0.1814	16.02	88	0.768	0.285	149		3.79E-04
24-h	18.3201	0.1791	15.02	84	0.805	0.186	279	251	4.62E-04
24-h D	18.3193	0.1814	15.02	83	0.800	0.216	224		4.30E-04
48-h	17.1105	0.1791	14.03	78	0.849	0.190	272	330	4.59E-04
48-h D	17.1181	0.1814	14.03	77	0.841	0.140	388		4.83E-04
72-h	15.9171	0.1791	13.05	73	0.898	0.190	271	275	4.59E-04
72-h D	15.9162	0.1814	13.05	72	0.894	0.184	278		4.55E-04

Appendix C-7: Cadmium Batch Data
Particle size 40-60 mesh
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cd]_i$ (mg/L)	$[Cd]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	21.9668	0.1807	18.01	100	0.747	0.515	45	44	2.06E-04
I -h D	22.0538	0.1804	18.08	100	0.747	0.526	42		1.97E-04
4-h	20.7468	0.1807	17.01	94	0.747	0.463	58	59	2.38E-04
4-h D	20.8338	0.1804	17.08	95	0.747	0.455	61		2.46E-04
8-h	19.5422	0.1807	16.02	89	0.764	0.443	64	84	2.53E-04
8-h D	19.6344	0.1804	16.09	89	0.764	0.355	103		3.25E-04
24-h	18.335	0.1807	15.03	83	0.784	0.314	125	121	3.48E-04
24-h D	18.4214	0.1804	15.10	84	0.789	0.327	118		3.44E-04
48-h	17.1427	0.1807	14.05	78	0.814	0.191	253	215	4.31E-04
48-h D	17.2102	0.1804	14.11	78	0.820	0.251	177		3.96E-04
72-h	15.9521	0.1807	13.08	72	0.857	0.278	151	136	3.73E-04
72-h D	15.999	0.1804	13.11	73	0.860	0.323	121		3.47E-04

Appendix C-8: Cadmium Batch Data
Particle size: unsieved
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cd]_i$ (mg/L)	$[Cd]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0673	0.1832	18.09	99	0.747	0.556	34	37	1.68E-04
I -h D	22.0105	0.1822	18.04	99	0.747	0.532	40		1.89E-04
4-h	20.8473	0.1832	17.09	93	0.759	0.434	70	69	2.69E-04
4-h D	20.7905	0.1822	17.04	94	0.760	0.440	68		2.67E-04
8-h	19.6659	0.1832	16.12	88	0.778	0.369	98	91	3.20E-04
8-h D	19.6123	0.1822	16.08	88	0.779	0.401	83		2.97E-04
24-h	18.4738	0.1832	15.14	83	0.804	0.294	144	145	3.75E-04
24-h D	18.4159	0.1822	15.10	83	0.804	0.291	146		3.78E-04
48-h	17.2778	0.1832	14.16	77	0.840	0.244	189	175	4.10E-04
48-h D	17.2216	0.1822	14.12	77	0.839	0.273	160		3.90E-04
72-h	15.7519	0.1832	12.91	70	0.898	0.251	181	166	4.05E-04
72-h D	16.0509	0.1822	13.16	72	0.881	0.285	151		3.83E-04

Appendix C-9: Chromium Batch Data
Particle size 20-30 mesh
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cr]_i$ (mg/L)	$[Cr]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0489	0.1820	18.07	99	463	462	0	1	1.53E-03
I -h D	21.8889	0.1806	17.94	99	463	458	1		9.17E-03
4-h	20.8289	0.1820	17.07	94	463	446	4	4	3.04E-02
4-h D	20.6689	0.1806	16.94	94	463	445	4		3.26E-02
8-h	19.6089	0.1820	16.07	88	464	424	8	8	6.78E-02
8-h D	19.4489	0.1806	15.94	88	464	426	8		6.51E-02
24-h	18.3889	0.1820	15.07	83	467	390	16	16	1.22E-01
24-h D	18.2289	0.1806	14.94	83	467	392	16		1.19E-01
48-h	17.1689	0.1820	14.07	77	472	372	21	21	1.49E-01
48-h D	17.0089	0.1806	13.94	77	472	372	21		1.49E-01
72-h	15.9489	0.1820	13.07	72	480	368	22	23	1.54E-01
72-h D	15.7889	0.1806	12.94	72	480	356	25		1.71E-01

Appendix C-10: Chromium Batch Data
Particle size 30-40 mesh
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cr]_i$ (mg/L)	$[Cr]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	21.9977	0.1791	18.03	101	463	454	2	2	1.70E-02
I -h D	21.9738	0.1814	18.01	99	463	455	2		1.49E-02
4-h	20.7777	0.1791	17.03	95	463	440	5	5	4.17E-02
4-h D	20.7538	0.1814	17.01	94	463	438	5		4.47E-02
8-h	19.5387	0.1791	16.02	89	464	420	9	10	7.61E-02
8-h D	19.5394	0.1814	16.02	88	464	417	10		8.04E-02
24-h	18.3201	0.1791	15.02	84	467	388	17	17	1.28E-01
24-h D	18.3193	0.1814	15.02	83	467	387	17		1.28E-01
48-h	17.1105	0.1791	14.03	78	473	369	22	22	1.56E-01
48-h D	17.1181	0.1814	14.03	77	473	367	22		1.58E-01
72-h	15.9171	0.1791	13.05	73	481	364	23	23	1.63E-01
72-h D	15.9162	0.1814	13.05	72	481	363	23		1.63E-01

Appendix C-11: Chromium Batch Data
Particle size 40-60 mesh
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cr]_i$ (mg/L)	$[Cr]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	21.9668	0.1807	18.01	100	463	457	1	2	1.11E-02
I -h D	22.0538	0.1804	18.08	100	463	454	2		1.70E-02
4-h	20.7468	0.1807	17.01	94	463	437	6	5	4.67E-02
4-h D	20.8338	0.1804	17.08	95	463	439	5		4.33E-02
8-h	19.5422	0.1807	16.02	89	464	420	9	10	7.55E-02
8-h D	19.6344	0.1804	16.09	89	464	417	10		8.09E-02
24-h	18.335	0.1807	15.03	83	467	386	17	18	1.30E-01
24-h D	18.4214	0.1804	15.10	84	467	386	18		1.31E-01
48-h	17.1427	0.1807	14.05	78	472	375	20	19	1.45E-01
48-h D	17.2102	0.1804	14.11	78	472	381	19		1.37E-01
72-h	15.9521	0.1807	13.08	72	479	371	21	21	1.50E-01
72-h D	15.999	0.1804	13.11	73	479	373	21		1.48E-01

Appendix C-12: Chromium Batch Data
Particle size: unsieved
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cr]_i$ (mg/L)	$[Cr]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0673	0.1832	18.09	99	463	437	6	7	4.90E-02
I -h D	22.0105	0.1822	18.04	99	463	431	7		6.06E-02
4-h	20.8473	0.1832	17.09	93	463	423	9	9	7.14E-02
4-h D	20.7905	0.1822	17.04	94	463	423	9		7.16E-02
8-h	19.6659	0.1832	16.12	88	465	407	13	13	9.82E-02
8-h D	19.6123	0.1822	16.08	88	465	406	13		1.00E-01
24-h	18.4738	0.1832	15.14	83	469	386	18	18	1.31E-01
24-h D	18.4159	0.1822	15.10	83	469	385	18		1.33E-01
48-h	17.2778	0.1832	14.16	77	474	379	19	19	1.41E-01
48-h D	17.2216	0.1822	14.12	77	474	379	19		1.42E-01
72-h	15.7519	0.1832	12.91	70	482	380	19	18	1.39E-01
72-h D	16.0509	0.1822	13.16	72	481	386	18		1.31E-01

Appendix C-13: Iron Batch Data
Particle size 20-30 mesh
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Fe]_i$ (mg/L)	$[Fe]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0489	0.1820	18.07	99	3.44	2.08	65	62	2.42E-03
I -h D	21.8889	0.1806	17.94	99	3.44	2.16	59		2.27E-03
4-h	20.8289	0.1820	17.07	94	3.52	1.41	140	149	3.53E-03
4-h D	20.6689	0.1806	16.94	94	3.51	1.31	158		3.70E-03
8-h	19.6089	0.1820	16.07	88	3.65	1.45	133	142	3.47E-03
8-h D	19.4489	0.1806	15.94	88	3.65	1.35	151		3.64E-03
24-h	18.3889	0.1820	15.07	83	3.79	1.03	222	219	4.10E-03
24-h D	18.2289	0.1806	14.94	83	3.80	1.06	215		4.07E-03
48-h	17.1689	0.1820	14.07	77	3.99	1.01	228	228	4.13E-03
48-h D	17.0089	0.1806	13.94	77	4.00	1.01	228		4.13E-03
72-h	15.9489	0.1820	13.07	72	4.22	1.02	224	245	4.11E-03
72-h D	15.7889	0.1806	12.94	72	4.23	0.90	266		4.28E-03

Appendix C-14: Iron Batch Data
Particle size 30-40 mesh
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Fe]_i$ (mg/L)	$[Fe]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	21.9977	0.1791	18.03	101	3.44	1.81	91	84	2.94E-03
I -h D	21.9738	0.1814	18.01	99	3.44	1.94	77		2.66E-03
4-h	20.7777	0.1791	17.03	95	3.53	1.23	178	182	3.92E-03
4-h D	20.7538	0.1814	17.01	94	3.52	1.18	185		3.93E-03
8-h	19.5387	0.1791	16.02	89	3.68	1.11	207	248	4.12E-03
8-h D	19.5394	0.1814	16.02	88	3.67	0.86	288		4.44E-03
24-h	18.3201	0.1791	15.02	84	3.85	0.78	331	344	4.61E-03
24-h D	18.3193	0.1814	15.02	83	3.86	0.73	356		4.64E-03
48-h	17.1105	0.1791	14.03	78	4.07	0.64	417	389	4.80E-03
48-h D	17.1181	0.1814	14.03	77	4.08	0.72	361		4.65E-03
72-h	15.9171	0.1791	13.05	73	4.32	0.72	366	364	4.70E-03
72-h D	15.9162	0.1814	13.05	72	4.33	0.72	363		4.65E-03

Appendix C-15: Iron Batch Data
Particle size 40-60 mesh
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Fe]_i$ (mg/L)	$[Fe]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	21.9668	0.1807	18.01	100	3.44	1.4	145	153	3.64E-03
I -h D	22.0538	0.1804	18.08	100	3.44	1.32	161		3.80E-03
4-h	20.7468	0.1807	17.01	94	3.52	0.87	287	267	4.47E-03
4-h D	20.8338	0.1804	17.08	95	3.51	0.97	248		4.31E-03
8-h	19.5422	0.1807	16.02	89	3.65	0.70	374	346	4.68E-03
8-h D	19.6344	0.1804	16.09	89	3.65	0.80	318		4.55E-03
24-h	18.335	0.1807	15.03	83	3.79	0.69	374	354	4.62E-03
24-h D	18.4214	0.1804	15.10	84	3.80	0.76	335		4.56E-03
48-h	17.1427	0.1807	14.05	78	3.99	0.70	365	352	4.58E-03
48-h D	17.2102	0.1804	14.11	78	4.00	0.75	339		4.55E-03
72-h	15.9521	0.1807	13.08	72	4.22	0.84	291	286	4.38E-03
72-h D	15.999	0.1804	13.11	73	4.23	0.87	281		4.37E-03

Appendix C-16: Iron Batch Data
Particle size: unsieved
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Fe]_i$ (mg/L)	$[Fe]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0673	0.1832	18.09	99	3.44	1.40	144	151	3.60E-03
I -h D	22.0105	0.1822	18.04	99	3.44	1.32	158		3.75E-03
4-h	20.8473	0.1832	17.09	93	3.44	0.87	275	257	4.29E-03
4-h D	20.7905	0.1822	17.04	94	3.44	0.97	239		4.14E-03
8-h	19.6659	0.1832	16.12	88	3.59	0.70	364	336	4.55E-03
8-h D	19.6123	0.1822	16.08	88	3.58	0.80	309		4.40E-03
24-h	18.4738	0.1832	15.14	83	3.76	0.69	370	349	4.55E-03
24-h D	18.4159	0.1822	15.10	83	3.75	0.76	328		4.44E-03
48-h	17.2778	0.1832	14.16	77	3.96	0.70	360	345	4.52E-03
48-h D	17.2216	0.1822	14.12	77	3.95	0.75	330		4.44E-03
72-h	15.7519	0.1832	12.91	70	4.19	0.84	281	278	4.23E-03
72-h D	16.0509	0.1822	13.16	72	4.17	0.87	275		4.27E-03

Appendix C-17: Lead Batch Data
Particle size 20-30 mesh
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Pb]_i$ (mg/L)	$[Pb]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0489	0.1820	18.07	99	25.8	22.3	15	25	1.66E-03
I -h D	21.8889	0.1806	17.94	99	25.8	19.0	35		3.23E-03
4-h	20.8289	0.1820	17.07	94	26.0	20.0	28	37	2.70E-03
4-h D	20.6689	0.1806	16.94	94	26.2	17.6	46		3.89E-03
8-h	19.6089	0.1820	16.07	88	26.3	15.6	61	59	4.58E-03
8-h D	19.4489	0.1806	15.94	88	26.7	16.3	56		4.43E-03
24-h	18.3889	0.1820	15.07	83	27.0	14.3	74	74	5.10E-03
24-h D	18.2289	0.1806	14.94	83	27.4	14.5	74		5.17E-03
48-h	17.1689	0.1820	14.07	77	28.0	12.7	93	98	5.70E-03
48-h D	17.0089	0.1806	13.94	77	28.3	12.2	102		6.01E-03
72-h	15.9489	0.1820	13.07	72	29.1	13.0	89	97	5.59E-03
72-h D	15.7889	0.1806	12.94	72	29.6	11.9	106		6.09E-03

Appendix C-18: Lead Batch Data
Particle size 30-40 mesh
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Pb]_i$ (mg/L)	$[Pb]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	21.9977	0.1791	18.03	101	25.8	18.4	40	34	3.58E-03
I -h D	21.9738	0.1814	18.01	99	25.8	20.2	27		2.65E-03
4-h	20.7777	0.1791	17.03	95	26.2	18.7	38	44	3.45E-03
4-h D	20.7538	0.1814	17.01	94	26.1	17.0	50		4.10E-03
8-h	19.5387	0.1791	16.02	89	26.7	14.6	74	71	5.20E-03
8-h D	19.5394	0.1814	16.02	88	26.7	15.1	67		4.91E-03
24-h	18.3201	0.1791	15.02	84	27.5	16.6	55	59	4.38E-03
24-h D	18.3193	0.1814	15.02	83	27.4	15.5	63		4.75E-03
48-h	17.1105	0.1791	14.03	78	28.2	17.3	49	61	4.12E-03
48-h D	17.1181	0.1814	14.03	77	28.3	14.5	73		5.12E-03
72-h	15.9171	0.1791	13.05	73	29.1	14.0	79	76	5.31E-03
72-h D	15.9162	0.1814	13.05	72	29.3	14.6	72		5.10E-03

Appendix C-19: Lead Batch Data
Particle size 40-60 mesh
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Pb]_i$ (mg/L)	$[Pb]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	21.9668	0.1807	18.01	100	25.8	20.9	23	36	2.36E-03
I -h D	22.0538	0.1804	18.08	100	25.8	17.3	49		4.08E-03
4-h	20.7468	0.1807	17.01	94	25.8	14.8	70	58	4.98E-03
4-h D	20.8338	0.1804	17.08	95	25.8	17.2	47		3.90E-03
8-h	19.5422	0.1807	16.02	89	26.4	15.8	60	66	4.55E-03
8-h D	19.6344	0.1804	16.09	89	26.3	14.5	72		5.06E-03
24-h	18.335	0.1807	15.03	83	27.1	14.5	72	68	5.04E-03
24-h D	18.4214	0.1804	15.10	84	27.0	15.2	64		4.74E-03
48-h	17.1427	0.1807	14.05	78	27.9	17.0	50	54	4.10E-03
48-h D	17.2102	0.1804	14.11	78	27.8	15.9	58		4.48E-03
72-h	15.9521	0.1807	13.08	72	28.6	18.2	42	54	3.65E-03
72-h D	15.999	0.1804	13.11	73	28.6	15.0	66		4.76E-03

Appendix C-20: Lead Batch Data
Particle size: unsieved
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Pb]_i$ (mg/L)	$[Pb]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0673	0.1832	18.09	99	25.8	17.4	48	48	4.01E-03
I -h D	22.0105	0.1822	18.04	99	25.8	17.3	48		4.03E-03
4-h	20.8473	0.1832	17.09	93	26.3	15.2	68	64	5.00E-03
4-h D	20.7905	0.1822	17.04	94	26.3	16.1	59		4.58E-03
8-h	19.6659	0.1832	16.12	88	26.9	14.8	72	72	5.15E-03
8-h D	19.6123	0.1822	16.08	88	26.9	14.9	71		5.11E-03
24-h	18.4738	0.1832	15.14	83	27.7	14.4	76	77	5.30E-03
24-h D	18.4159	0.1822	15.10	83	27.6	14.3	77		5.34E-03
48-h	17.2778	0.1832	14.16	77	28.6	13.8	83	81	5.54E-03
48-h D	17.2216	0.1822	14.12	77	28.6	14.1	79		5.39E-03
72-h	15.7519	0.1832	12.91	70	30.1	14.0	80	76	5.45E-03
72-h D	16.0509	0.1822	13.16	72	29.7	14.8	72		5.18E-03

Appendix-D

Batch Contact Data – Temperature Effect

Appendix D-1:Cesium Batch Data
Temperature: 25 °C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cs]_i$ (mg/L)	$[Cs]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0673	0.1832	18.09	99	7.25	1.37	424	397	4.37E-03
I -h D	22.0105	0.1822	18.04	99	7.25	1.53	370		4.26E-03
4-h	20.8568	0.1832	17.10	93	7.86	0.773	855	813	4.97E-03
4-h D	20.7729	0.1822	17.03	93	7.86	0.85	770		4.92E-03
8-h	19.6368	0.1832	16.10	88	7.92	0.551	1175	1153	4.87E-03
8-h D	19.5519	0.1822	16.03	88	8.29	0.598	1132		5.09E-03
24-h	18.4554	0.1832	15.13	83	8.39	0.338	1967	1926	5.00E-03
24-h D	18.3737	0.1822	15.06	83	8.79	0.369	1886		5.23E-03
48-h	17.2633	0.1832	14.15	77	8.95	0.291	2297	2317	5.03E-03
48-h D	17.1773	0.1822	14.08	77	9.37	0.3	2337		5.27E-03
72-h	16.0673	0.1832	13.17	72	9.59	0.276	2426	2427	5.03E-03
72-h D	15.983	0.1822	13.10	72	10.05	0.289	2429		5.28E-03

Appendix D-2: Cesium Batch Data
Temperature: 35 °C
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cs]_i$ (mg/L)	$[Cs]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.1183	0.1772	18.13	102	7.25	1.53	383	403	4.40E-03
I -h D	22.1358	0.1824	18.14	99	7.25	1.38	423		4.39E-03
4-h	20.9502	0.1772	17.17	97	7.83	0.844	802	814	5.09E-03
4-h D	20.9364	0.1824	17.16	94	7.85	0.803	826		4.99E-03
8-h	19.7399	0.1772	16.18	91	7.91	0.621	1071	1085	5.00E-03
8-h D	19.7259	0.1824	16.17	89	8.28	0.619	1098		5.11E-03
24-h	18.5019	0.1772	15.17	86	8.40	0.438	1555	1477	5.12E-03
24-h D	18.4672	0.1824	15.14	83	8.81	0.493	1399		5.19E-03
48-h	17.2948	0.1772	14.18	80	8.95	0.38	1804	1648	5.16E-03
48-h D	17.2488	0.1824	14.14	78	9.39	0.464	1492		5.20E-03
72-h	16.0842	0.1772	13.18	74	9.60	0.394	1738	1620	5.15E-03
72-h D	16.0344	0.1824	13.14	72	10.07	0.461	1502		5.21E-03

Appendix D-3: Cesium Batch Data
Temperature: 45 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cs]_i$ (mg/L)	$[Cs]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.1354	0.1791	18.14	101	7.25	1.14	543	474	4.65E-03
I -h D	19.1887	0.1814	15.73	87	7.25	1.28	404		3.89E-03
4-h	20.9238	0.1791	17.15	96	7.87	0.856	784	832	5.05E-03
4-h D	17.9764	0.1814	14.73	81	7.92	0.67	879		4.43E-03
8-h	19.6215	0.1791	16.08	90	7.94	0.715	908	983	4.88E-03
8-h D	16.6802	0.1814	13.67	75	8.48	0.564	1058		4.49E-03
24-h	18.3444	0.1791	15.04	84	8.44	0.575	1149	1200	4.97E-03
24-h D	15.4681	0.1814	12.68	70	9.10	0.482	1250		4.53E-03
48-h	17.1321	0.1791	14.04	78	9.00	0.566	1168	1248	4.97E-03
48-h D	14.2592	0.1814	11.69	64	9.83	0.455	1328		4.54E-03
72-h	15.9283	0.1791	13.06	73	9.64	0.557	1189	1123	4.98E-03
72-h D	13.0554	0.1814	10.70	59	10.70	0.565	1058		4.49E-03

Appendix D-4: Cadmium Batch Data
Temperature: 25 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cd]_i$ (mg/L)	$[Cd]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0673	0.1832	18.09	99	0.827	0.556	48	51	2.01E-04
I -h D	22.0105	0.1822	18.04	99	0.827	0.532	55		2.19E-04
4-h	20.8568	0.1832	17.10	93	0.843	0.434	88	87	2.87E-04
4-h D	20.7729	0.1822	17.03	93	0.845	0.440	86		2.85E-04
8-h	19.6368	0.1832	16.10	88	0.852	0.369	115	109	3.19E-04
8-h D	19.5519	0.1822	16.03	88	0.870	0.401	103		3.10E-04
24-h	18.4554	0.1832	15.13	83	0.882	0.294	165	169	3.65E-04
24-h D	18.3737	0.1822	15.06	83	0.900	0.291	173		3.78E-04
48-h	17.2633	0.1832	14.15	77	0.923	0.244	215	202	3.95E-04
48-h D	17.1773	0.1822	14.08	77	0.943	0.273	189		3.89E-04
72-h	16.0673	0.1832	13.17	72	0.974	0.251	207	192	3.90E-04
72-h D	15.983	0.1822	13.10	72	0.993	0.285	178		3.82E-04

Appendix D-5: Cadmium Batch Data
Temperature: 35 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cd]_i$ (mg/L)	$[Cd]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.1183	0.1772	18.13	102	0.827	0.576	45	51	1.93E-04
I -h D	22.1358	0.1824	18.14	99	0.827	0.528	56		2.24E-04
4-h	20.9502	0.1772	17.17	97	0.84	0.444	87	92	2.90E-04
4-h D	20.9364	0.1824	17.16	94	0.84	0.417	97		3.02E-04
8-h	19.7399	0.1772	16.18	91	0.87	0.407	103	125	3.15E-04
8-h D	19.7259	0.1824	16.17	89	0.87	0.327	147		3.62E-04
24-h	18.5019	0.1772	15.17	86	0.90	0.288	180	172	3.91E-04
24-h D	18.4672	0.1824	15.14	83	0.91	0.306	163		3.75E-04
48-h	17.2948	0.1772	14.18	80	0.94	0.265	204	192	4.05E-04
48-h D	17.2488	0.1824	14.14	78	0.95	0.285	181		3.88E-04
72-h	16.0842	0.1772	13.18	74	0.99	0.267	201	197	4.04E-04
72-h D	16.0344	0.1824	13.14	72	1.00	0.273	192		3.94E-04

Appendix D-6: Cadmium Batch Data
Temperature: 45 ^oC
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cd]_i$ (mg/L)	$[Cd]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.1354	0.1791	18.14	101	0.827	0.441	89	79	2.94E-04
I -h D	19.1887	0.1814	15.73	87	0.827	0.461	69		2.39E-04
4-h	20.9238	0.1791	17.15	96	0.85	0.337	145	142	3.69E-04
4-h D	17.9764	0.1814	14.73	81	0.85	0.316	138		3.27E-04
8-h	19.6215	0.1791	16.08	90	0.88	0.290	184	201	4.01E-04
8-h D	16.6802	0.1814	13.67	75	0.89	0.229	219		3.77E-04
24-h	18.3444	0.1791	15.04	84	0.92	0.166	383	352	4.79E-04
24-h D	15.4681	0.1814	12.68	70	0.95	0.169	321		4.08E-04
48-h	17.1321	0.1791	14.04	78	0.98	0.154	419	430	4.86E-04
48-h D	14.2592	0.1814	11.69	64	1.01	0.129	442		4.28E-04
72-h	15.9283	0.1791	13.06	73	1.04	0.123	546	526	5.03E-04
72-h D	13.0554	0.1814	10.70	59	1.09	0.114	506		4.34E-04

Appendix D-7: Chromium Batch Data
Temperature: 25 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cr]_i$ (mg/L)	$[Cr]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0673	0.1832	18.09	99	442	437	1	2	3.34E-03
I -h D	22.0105	0.1822	18.04	99	442	431	2		7.82E-03
4-h	20.8568	0.1832	17.10	93	442	423	4	4	1.32E-02
4-h D	20.7729	0.1822	17.03	93	442	423	4		1.34E-02
8-h	19.6368	0.1832	16.10	88	443	407	8	8	2.35E-02
8-h D	19.5519	0.1822	16.03	88	443	406	8		2.47E-02
24-h	18.4554	0.1832	15.13	83	445	386	13	13	3.66E-02
24-h D	18.3737	0.1822	15.06	83	446	385	13		3.77E-02
48-h	17.2633	0.1832	14.15	77	449	379	14	14	4.07E-02
48-h D	17.1773	0.1822	14.08	77	450	379	14		4.12E-02
72-h	16.0673	0.1832	13.17	72	454	380	14	13	4.01E-02
72-h D	15.983	0.1822	13.10	72	455	386	13		3.71E-02

Appendix D-8: Chromium Batch Data
Temperature: 35 °C
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cr]_i$ (mg/L)	$[Cr]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.1183	0.1772	18.13	102	442	423	4	3	1.42E-02
I -h D	22.1358	0.1824	18.14	99	442	431	2		7.85E-03
4-h	20.9502	0.1772	17.17	97	443	401	10	11	3.03E-02
4-h D	20.9364	0.1824	17.16	94	442	393	12		3.47E-02
8-h	19.7399	0.1772	16.18	91	445	390	13	14	3.78E-02
8-h D	19.7259	0.1824	16.17	89	445	378	16		4.47E-02
24-h	18.5019	0.1772	15.17	86	449	363	20	21	5.52E-02
24-h D	18.4672	0.1824	15.14	83	450	355	22		5.91E-02
48-h	17.2948	0.1772	14.18	80	455	359	21	21	5.76E-02
48-h D	17.2488	0.1824	14.14	78	456	358	21		5.73E-02
72-h	16.0842	0.1772	13.18	74	462	372	18	19	5.03E-02
72-h D	16.0344	0.1824	13.14	72	463	366	19		5.25E-02

Appendix D-9: Chromium Batch Data
Temperature: 45 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Cr]_i$ (mg/L)	$[Cr]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.1354	0.1791	18.14	101	442	393	13	10	3.69E-02
I -h D	19.1887	0.1814	15.73	87	442	408	7		2.18E-02
4-h	20.9238	0.1791	17.15	96	444	359	23	23	6.14E-02
4-h D	17.9764	0.1814	14.73	81	444	343	24		6.15E-02
8-h	19.6215	0.1791	16.08	90	450	352	25	26	6.61E-02
8-h D	16.6802	0.1814	13.67	75	452	332	27		6.78E-02
24-h	18.3444	0.1791	15.04	84	457	310	40	39	9.27E-02
24-h D	15.4681	0.1814	12.68	70	461	297	39		8.62E-02
48-h	17.1321	0.1791	14.04	78	467	314	38	38	9.03E-02
48-h D	14.2592	0.1814	11.69	64	475	301	37		8.42E-02
72-h	15.9283	0.1791	13.06	73	479	328	34	33	8.26E-02
72-h D	13.0554	0.1814	10.70	59	489	317	32		7.64E-02

Appendix D-10: Iron Batch Data
Temperature: 25 ^oC
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Fe]_i$ (mg/L)	$[Fe]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0673	0.1832	18.09	99	3.56	1.45	144	142	1.57E-03
I -h D	22.0105	0.1822	18.04	99	3.56	1.48	140		1.55E-03
4-h	20.8568	0.1832	17.10	93	3.69	0.99	253	236	1.89E-03
4-h D	20.7729	0.1822	17.03	93	3.69	1.10	219		1.81E-03
8-h	19.6368	0.1832	16.10	88	3.72	0.85	296	283	1.90E-03
8-h D	19.5519	0.1822	16.03	88	3.85	0.94	270		1.92E-03
24-h	18.4554	0.1832	15.13	83	3.91	0.82	312	302	1.92E-03
24-h D	18.3737	0.1822	15.06	83	4.03	0.89	291		1.95E-03
48-h	17.2633	0.1832	14.15	77	4.12	0.86	294	285	1.90E-03
48-h D	17.1773	0.1822	14.08	77	4.25	0.93	275		1.93E-03
72-h	16.0673	0.1832	13.17	72	4.36	0.98	248	247	1.83E-03
72-h D	15.983	0.1822	13.10	72	4.50	1.02	246		1.88E-03

Appendix D-11: Iron Batch Data
Temperature: 35 ^oC
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Fe]_i$ (mg/L)	$[Fe]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.1183	0.1772	18.13	102	3.56	1.40	158	184	1.66E-03
I -h D	22.1358	0.1824	18.14	99	3.56	1.14	211		1.81E-03
4-h	20.9502	0.1772	17.17	97	3.68	1.09	230	258	1.89E-03
4-h D	20.9364	0.1824	17.16	94	3.70	0.92	285		1.97E-03
8-h	19.7399	0.1772	16.18	91	3.84	1.03	249	212	1.93E-03
8-h D	19.7259	0.1824	16.17	89	3.87	1.29	176		1.72E-03
24-h	18.5019	0.1772	15.17	86	4.03	1.12	222	235	1.87E-03
24-h D	18.4672	0.1824	15.14	83	4.05	1.02	247		1.89E-03
48-h	17.2948	0.1772	14.18	80	4.23	1.06	239	236	1.91E-03
48-h D	17.2488	0.1824	14.14	78	4.26	1.06	233		1.86E-03
72-h	16.0842	0.1772	13.18	74	4.47	1.45	155	190	1.69E-03
72-h D	16.0344	0.1824	13.14	72	4.50	1.10	224		1.85E-03

Appendix D-12: Iron Batch Data
Temperature: 45 °C
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Fe]_i$ (mg/L)	$[Fe]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.1354	0.1791	18.14	101	3.56	0.95	278	249	1.99E-03
I -h D	19.1887	0.1814	15.73	87	3.56	1.01	219		1.66E-03
4-h	20.9238	0.1791	17.15	96	3.71	0.96	275	272	1.98E-03
4-h D	17.9764	0.1814	14.73	81	3.74	0.86	270		1.75E-03
8-h	19.6215	0.1791	16.08	90	3.90	1.01	258	259	1.95E-03
8-h D	16.6802	0.1814	13.67	75	3.96	0.89	260		1.74E-03
24-h	18.3444	0.1791	15.04	84	4.10	0.86	315	302	2.04E-03
24-h D	15.4681	0.1814	12.68	70	4.20	0.82	290		1.78E-03
48-h	17.1321	0.1791	14.04	78	4.33	0.69	410	394	2.14E-03
48-h D	14.2592	0.1814	11.69	64	4.49	0.65	378		1.86E-03
72-h	15.9283	0.1791	13.06	73	4.60	0.60	486	461	2.19E-03
72-h D	13.0554	0.1814	10.70	59	4.84	0.58	436		1.89E-03

Appendix D-13: Lead Batch Data
Temperature: 25 ^oC
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Fresh pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Pb]_i$ (mg/L)	$[Pb]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.0673	0.1832	18.09	99	23.1	17.4	33	33	4.29E-03
I -h D	22.0105	0.1822	18.04	99	23.1	17.3	33		4.32E-03
4-h	20.8568	0.1832	17.10	93	23.5	15.2	51	47	5.84E-03
4-h D	20.7729	0.1822	17.03	93	23.5	16.1	43		5.18E-03
8-h	19.6368	0.1832	16.10	88	23.6	14.8	52	53	5.84E-03
8-h D	19.5519	0.1822	16.03	88	23.9	14.9	54		6.00E-03
24-h	18.4554	0.1832	15.13	83	24.2	14.4	56	58	6.08E-03
24-h D	18.3737	0.1822	15.06	83	24.5	14.3	59		6.35E-03
48-h	17.2633	0.1832	14.15	77	24.9	13.8	62	61	6.44E-03
48-h D	17.1773	0.1822	14.08	77	25.2	14.1	61		6.44E-03
72-h	16.0673	0.1832	13.17	72	25.7	14.0	60	57	6.30E-03
72-h D	15.983	0.1822	13.10	72	26.0	14.8	54		6.03E-03

Appendix D-14: Lead Batch Data
Temperature: 35 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Pretreated, oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Pb]_i$ (mg/L)	$[Pb]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.1183	0.1772	18.13	102	23.1	18.0	29	34	3.97E-03
I -h D	22.1358	0.1824	18.14	99	23.1	16.7	38		4.79E-03
4-h	20.9502	0.1772	17.17	97	23.4	15.4	50	49	5.84E-03
4-h D	20.9364	0.1824	17.16	94	23.5	15.5	48		5.65E-03
8-h	19.7399	0.1772	16.18	91	23.9	15.3	52	54	5.92E-03
8-h D	19.7259	0.1824	16.17	89	24.0	14.7	56		6.21E-03
24-h	18.5019	0.1772	15.17	86	24.5	14.4	60	56	6.49E-03
24-h D	18.4672	0.1824	15.14	83	24.6	15.0	53		5.98E-03
48-h	17.2948	0.1772	14.18	80	25.2	14.0	64	57	6.73E-03
48-h D	17.2488	0.1824	14.14	78	25.3	15.4	50		5.77E-03
72-h	16.0842	0.1772	13.18	74	26.0	15.4	51	51	5.96E-03
72-h D	16.0344	0.1824	13.14	72	26.1	15.4	50		5.79E-03

Appendix D-15: Lead Batch Data
Temperature: 45 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Batch # 991022smc-IV29
Oven-dry (H-form)

Contact time (h)	Solution mass (g)	Resin mass (g)	Solution vol. (mL)	phase ratio	$[Pb]_i$ (mg/L)	$[Pb]_e$ (mg/L)	K_d (mL/g)	avg. K_d (mL/g)	loading, q (mmole/g)
I-h	22.1354	0.1791	18.14	101	23.1	15.7	48	43	5.66E-03
I -h D	19.1887	0.1814	15.73	87	23.1	16.1	38		4.59E-03
4-h	20.9238	0.1791	17.15	96	23.6	15.2	53	52	6.04E-03
4-h D	17.9764	0.1814	14.73	81	23.6	14.6	50		5.52E-03
8-h	19.6215	0.1791	16.08	90	23.7	15.9	44	51	5.24E-03
8-h D	16.6802	0.1814	13.67	75	24.3	13.8	58		5.96E-03
24-h	18.3444	0.1791	15.04	84	24.2	15.0	52	58	5.82E-03
24-h D	15.4681	0.1814	12.68	70	25.1	13.1	65		6.35E-03
48-h	17.1321	0.1791	14.04	78	24.9	14.5	56	59	6.13E-03
48-h D	14.2592	0.1814	11.69	64	26.2	13.4	62		6.20E-03
72-h	15.9283	0.1791	13.06	73	25.6	14.8	54	55	5.96E-03
72-h D	13.0554	0.1814	10.70	59	27.3	14.1	55		5.87E-03

Appendix-E

Cesium Column Loading and Elution data

Appendix E-1: Cesium Column Loading
Flow rate = 3 BV/h
Temperature = 25 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cs]_{eff}$ (ug/L)	Cs profile [C/Co]
RPP-AN105-Cr25-L5	3-170827	6.8	2.98	5	98	1.35E-02
RPP-TP00049-Cr25-L10	3-170828	6.8	2.98	10	25	3.44E-03
RPP-TP00049-Cr25-L20	3-170829	6.8	2.98	20	25	3.44E-03
RPP-TP00049-Cr25-L30	3-170830	6.8	2.98	30	25	3.44E-03
RPP-TP00049-Cr25-L40	3-170831	6.8	2.98	40	29	3.99E-03
RPP-TP00049-Cr25-L50	3-170832	6.8	2.98	50	61	8.40E-03
RPP-TP00049-Cr25-L60	3-170833	6.8	2.98	60	118	1.62E-02
RPP-TP00049-Cr25-L70	3-170834	6.8	2.98	70	234	3.22E-02
RPP-TP00049-Cr25-L80	3-170835	6.8	2.98	80	386	5.31E-02
RPP-TP00049-Cr25-L90	3-170836	6.8	2.98	90	605	8.33E-02
RPP-TP00049-Cr25-L100	3-170837	6.8	2.98	100	940	1.29E-01
RPP-TP00049-Cr25-L110	3-170838	6.8	2.98	110	1.26E+03	1.73E-01
RPP-TP00049-Cr25-L120	3-170839	6.8	2.98	120	1.63E+03	2.24E-01
RPP-TP00049-Cr25-L130	3-170840	6.8	2.98	130	1.98E+03	2.73E-01
RPP-TP00049-Cr25-L140	3-170841	6.8	2.98	140	2.40E+03	3.30E-01
RPP-TP00049-Cr25-L150	3-170842	6.8	2.98	150	2.61E+03	3.59E-01

Feed concentration = 7.40E+03 ug/L
Feed duplicate = 7.13E+03 ug/L

Appendix E-2: Cesium Column Elution
Temperature = 25 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV* processed	$[Cs]_{eff}$ (ug/L)	Cs profile [C/Co]
RPP-TP00049-Cr25-E2	3-170843	5.8	0.95	2.8	1.62E+05	2.23E+01
RPP-TP00049-Cr25-E4	3-170844	4.9	1.37	5.6	1.70E+05	2.34E+01
RPP-TP00049-Cr25-E6	3-170845	4.9	1.51	8.4	1.49E+05	2.05E+01
RPP-TP00049-Cr25-E8	3-170846	4.9	1.51	11.2	1.34E+05	1.84E+01
RPP-TP00049-Cr25-E10	3-170847	4.9	1.51	14	486	6.69E-02
RPP-TP00049-Cr25-E12	3-170848	4.9	1.51	16.8	70	9.64E-03
RPP-TP00049-Cr25-E14	3-170849	4.9	1.51	19.6	77	1.06E-02
RPP-TP00049-Cr25-E16	3-170850	4.9	1.51	22.4	70	9.64E-03

*** BV is based on loading resin bed height**

Appendix E-3: Cesium Column Loading
Flow rate = ~ 3 BV/h
Temperature = 35 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cs]_{eff}$ (ug/L)	Cs profile [C/Co]
RPP-AN105-SL644IV-Cr35-L5	3-171235	6.8	3.00	5	47	6.47E-03
RPP-AN105-SL644IV-Cr35-L10	3-171236	6.8	3.00	10	38	5.23E-03
RPP-AN105-SL644IV-Cr35-L20	3-171237	6.8	3.00	20	23	3.17E-03
RPP-AN105-SL644IV-Cr35-L30	3-171238	6.8	3.00	30	20	2.75E-03
RPP-AN105-SL644IV-Cr35-L40	3-171230	6.8	3.00	40	nm	nm
RPP-AN105-SL644IV-Cr35-L50	3-171240	6.8	3.00	50	81	1.11E-02
RPP-AN105-SL644IV-Cr35-L60	3-171241	6.8	3.00	60	146	2.01E-02
RPP-AN105-SL644IV-Cr35-L70	3-171242	6.8	3.00	70	342	4.71E-02
RPP-AN105-SL644IV-Cr35-L80	3-171243	6.8	3.00	80	684	9.42E-02
RPP-AN105-SL644IV-Cr35-L90	3-171244	6.8	3.00	90	1030	1.42E-01
RPP-AN105-SL644IV-Cr35-L100	3-171245	6.8	3.00	100	1490	2.05E-01
RPP-AN105-SL644IV-Cr35-L110	3-171246	6.8	3.00	110	1910	2.63E-01
RPP-AN105-SL644IV-Cr35-L120	3-171247	6.8	3.00	120	2390	3.29E-01
RPP-AN105-SL644IV-Cr35-L130	3-171248	6.8	3.00	130	3000	4.13E-01
RPP-AN105-SL644IV-Cr35-L140	3-171249	6.8	3.00	140	3420	4.71E-01

Appendix E-4: Cesium Column Elution
Temperature = 35 °C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cs]_{eff}$ (ug/L)	Cs profile [C/Co]
RPP-TP00049-Cr35-E2	3-171253	7.6	1.0	2	1.88E+02	2.59E-02
RPP-TP00049-Cr35-E4	3-171254	6.0	1.0	4	5.34E+02	7.35E-02
RPP-TP00049-Cr35-E6	3-171255	4.6	1.0	6	1.50E+05	2.06E+01
RPP-TP00049-Cr35-E8	3-171256	4.6	1.0	8	2.26E+05	3.11E+00
RPP-TP00049-Cr35-E10	3-171257	4.6	1.0	10	1.66E+03	2.28E-01
RPP-TP00049-Cr35-E12	3-171258	4.6	1.0	12	193	2.66E-02
RPP-TP00049-Cr35-E14	3-171259	4.6	1.0	14	65	8.95E-03
RPP-TP00049-Cr35-E16	3-171260	4.6	1.0	16	35	4.82E-03

Appendix E-5: Cesium Column Loading
Flow rate = ~ 2.5-3 BV/h
Temperature = 45 °C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cs]_{eff}$ (ug/L)	Cs profile [C/Co]
RPP-AN105-SL644IV-Cr45-L5	3-171549	6.7	2.5	5	39	5.37E-03
RPP-AN105-SL644IV-Cr45-L10	3-171550	6.7	2.5	10	31	4.27E-03
RPP-AN105-SL644IV-Cr45-L20	3-171551	6.6	2.8	20	40	5.51E-03
RPP-AN105-SL644IV-Cr45-L30	3-171552	6.6	2.8	30	31	4.27E-03
RPP-AN105-SL644IV-Cr45-L40	3-171553	6.6	2.8	40	46	6.33E-03
RPP-AN105-SL644IV-Cr45-L550	3-171554	6.6	2.8	50	102	1.40E-02
RPP-AN105-SL644IV-Cr45-L60	3-171555	6.6	2.8	60	243	3.34E-02
RPP-AN105-SL644IV-Cr45-L70	3-171556	6.6	2.9	70	501	6.90E-02
RPP-AN105-SL644IV-Cr45-L80	3-171557	6.6	2.9	80	932	1.28E-01
RPP-AN105-SL644IV-Cr45-L90	3-171558	6.6	3.0	90	1490	1.84E-01
RPP-AN105-SL644IV-Cr45-L100	3-171559	6.6	2.8	100	2200	2.72E-01
RPP-AN105-SL644IV-Cr45-L110	3-171560	6.6	2.8	110	2940	3.63E-01
RPP-AN105-SL644IV-Cr45-L120	3-171561	6.6	2.8	120	3740	4.62E-01
RPP-AN105-SL644IV-Cr45-L130	3-171562	6.6	2.8	130	4390	5.42E-01
RPP-AN105-SL644IV-Cr45-L140	3-171563	6.6	2.8	140	5060	6.25E-01
RPP-AN105-SL644IV-Cr45-L150	3-171565	6.6	2.8	150	5640	6.97E-01

Appendix E-6: Cesium Column Elution
Temperature = 45 °C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	*Resin bed* height (cm)	Flow rate (BV/h)	# BV processed	$[Cs]_{eff}$ (ug/L)	Cs profile [C/Co]
RPP-TP00049-Cr45-E2	3-171567	6.2	1.06	2	2.53E+02	3.48E-02
RPP-TP00049-Cr45-E4	3-171568	4.9	1.05	4	1.60E+04	2.20E+00
RPP-TP00049-Cr45-E6	3-171569	4.3	1.05	6	2.04E+05	2.81E+01
RPP-TP00049-Cr45-E8	3-171570	4.3	1.05	8	4.14E+04	5.70E+00
RPP-TP00049-Cr45-E10	3-171571	4.3	1.05	10	5.30E+03	7.30E-01
RPP-TP00049-Cr45-12	3-171572	4.3	1.05	12	608	8.37E-02
RPP-TP00049-Cr45-14	3-171573	4.3	1.05	14	109	1.50E-02
RPP-TP00049-Cr45-16	3-171574	4.3	0.98	16	47	6.47E-03

Appendix E-7: Cesium Column Loading
Flow rate = ~ 2.8 BV/h
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cs]_{eff}$ (ug/L)	Cs Profile [C/Co]
RPP-AN105-SL644IV-Cr25R-L5	3-171798	6.6	2.7	5	20	2.47E-03
RPP-AN105-SL644IV-Cr25R-L10	3-171799	6.6	2.7	10	20	2.47E-03
RPP-AN105-SL644IV-Cr25R-L20	3-171800	6.6	2.8	20	20	2.47E-03
RPP-AN105-SL644IV-Cr25R-L30	3-171801	6.6	2.8	30	20	2.47E-03
RPP-AN105-SL644IV-Cr25R-L40	3-171802	6.6	2.8	40	20	2.47E-03
RPP-AN105-SL644IV-Cr25R-L50	3-171803	6.6	2.8	50	61	7.54E-03
RPP-AN105-SL644IV-Cr25R-L70	3-171804	6.6	2.8	70	259	3.20E-02
RPP-AN105-SL644IV-Cr25R-L90	3-171805	6.6	2.9	90	800	9.88E-02
RPP-AN105-SL644IV-Cr25-L110	3-171806	6.6	2.9	110	1520	1.88E-01
RPP-AN105-SL644IV-Cr25-L130	3-171807	6.6	2.8	130	1980	2.45E-01
RPP-AN105-SL644IV-Cr25-L150	3-171808	6.6	2.8	150	3320	4.10E-01
RPP-AN105-SL644IV-Cr25-L170	3-171809	6.6	2.8	170	4270	5.27E-01
RPP-AN105-SL644IV-Cr25-L190	3-171810	6.6	2.9	190	4610	5.69E-01
RPP-AN105-SL644IV-Cr25-L210	3-171811	6.6	2.8	210	5400	6.67E-01

Appendix E-8: Cesium Column Elution
Temperature = 25 ^oC (repeat)
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cs]_{eff}$ (ug/L)	Cs profile [C/Co]
RPP-TP00049-Cr25R-E2	3-171816	4.5	1.5	2	284	3.91E-02
RPP-TP00049-Cr25R-E4	3-171817	4.6	1.3	4	4.22E+05	5.81E+01
RPP-TP00049-Cr25R-E6	3-171818	4.5	1.4	6	1.80E+05	2.48E+01
RPP-TP00049-Cr25R-E8	3-171819	4.5	1.3	8	2.16E+04	2.97E+00
RPP-TP00049-Cr25R-E10	3-171820	4.5	1.3	10	1.61E+03	2.22E-01
RPP-TP00049-Cr25R-12	3-171821	4.5	1.3	12	230	3.17E-02
RPP-TP00049-Cr25R-14	3-171822	4.5	1.3	14	87	1.20E-02
RPP-TP00049-Cr25R-16	3-171823	4.5	1.3	16	49	6.74E-03

Appendix-F

Cadmium Column Loading and Elution data

Appendix F-1: Cadmium Column Loading

Flow rate = 3 BV/h
Temperature = 25 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cd]_{eff}$ (mg/L)	Cd profile [C/Co]
RPP-AN105-Cr25-L5	3-170827	6.8	2.98	5	0.028	1.04E-01
RPP-TP00049-Cr25-L10	3-170828	6.8	2.98	10	0.028	1.04E-01
RPP-TP00049-Cr25-L20	3-170829	6.8	2.98	20	0.028	1.04E-01
RPP-TP00049-Cr25-L30	3-170830	6.8	2.98	30	0.028	1.04E-01
RPP-TP00049-Cr25-L40	3-170831	6.8	2.98	40	0.0499631	1.85E-01
RPP-TP00049-Cr25-L50	3-170832	6.8	2.98	50	0.0646516	2.39E-01
RPP-TP00049-Cr25-L60	3-170833	6.8	2.98	60	nm	nm
RPP-TP00049-Cr25-L70	3-170834	6.8	2.98	70	0.0880828	3.26E-01
RPP-TP00049-Cr25-L80	3-170835	6.8	2.98	80	0.1109276	4.11E-01
RPP-TP00049-Cr25-L90	3-170836	6.8	2.98	90	0.1075247	3.98E-01
RPP-TP00049-Cr25-L100	3-170837	6.8	2.98	100	0.1298894	4.81E-01
RPP-TP00049-Cr25-L110	3-170838	6.8	2.98	110	0.1280383	4.74E-01
RPP-TP00049-Cr25-L120	3-170839	6.8	2.98	120	0.1450288	5.37E-01
RPP-TP00049-Cr25-L130	3-170840	6.8	2.98	130	0.1421891	5.27E-01
RPP-TP00049-Cr25-L140	3-170841	6.8	2.98	140	0.1472407	5.45E-01
RPP-TP00049-Cr25-L150	3-170842	6.8	2.98	150	0.1719951	6.37E-01

Cadmium concentration in the simulant = 0.27mg/L

Appendix F-2: Cadmium Column Elution
Temperature = 25 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV* processed	$[Cd]_{eff}$ (mg/L)	Cd profile [C/Co]
RPP-TP00049-Cr25-E2	3-170843	5.8	0.95	2.8	6.1	22.70
RPP-TP00049-Cr25-E4	3-170844	4.9	1.37	5.6	4.4	16.15
RPP-TP00049-Cr25-E6	3-170845	4.9	1.51	8.4	0.58	2.13
RPP-TP00049-Cr25-E8	3-170846	4.9	1.51	11.2	0.07	0.27
RPP-TP00049-Cr25-E10	3-170847	4.9	1.51	14	0.06	0.22
RPP-TP00049-Cr25-E12	3-170848	4.9	1.51	16.8	0.02	0.06
RPP-TP00049-Cr25-E14	3-170849	4.9	1.51	19.6	0.03	0.10
RPP-TP00049-Cr25-E16	3-170850	4.9	1.51	22.4	0.04	0.14

Appendix F-3: Cadmium Column Loading
Flow rate = ~ 3 BV/h
Temperature = 35 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cd]_{eff}$ (mg/L)	Cd profile [C/Co]
RPP-AN105-SL644IV-Cr35-L5	3-171235	6.8	3.00	5	0.028	1.04E-01
RPP-AN105-SL644IV-Cr35-L10	3-171236	6.8	3.00	10	0.028	1.04E-01
RPP-AN105-SL644IV-Cr35-L20	3-171237	6.8	3.00	20	0.028	1.04E-01
RPP-AN105-SL644IV-Cr35-L30	3-171238	6.8	3.00	30	0.028	1.04E-01
RPP-AN105-SL644IV-Cr35-L40	3-171230	6.8	3.00	40	<DTL	DTL
RPP-AN105-SL644IV-Cr35-L50	3-171240	6.8	3.00	50	0.028	1.04E-01
RPP-AN105-SL644IV-Cr35-L60	3-171241	6.8	3.00	60	<DTL	<DTL
RPP-AN105-SL644IV-Cr35-L70	3-171242	6.8	3.00	70	0.088	3.26E-01
RPP-AN105-SL644IV-Cr35-L80	3-171243	6.8	3.00	80	0.260	9.64E-01
RPP-AN105-SL644IV-Cr35-L90	3-171244	6.8	3.00	90	0.280	1.04E+00
RPP-AN105-SL644IV-Cr35-L100	3-171245	6.8	3.00	100	<DTL	<DTL
RPP-AN105-SL644IV-Cr35-L110	3-171246	6.8	3.00	110	0.300	1.11E+00
RPP-AN105-SL644IV-Cr35-L120	3-171247	6.8	3.00	120	0.304	1.13E+00
RPP-AN105-SL644IV-Cr35-L130	3-171248	6.8	3.00	130	0.324	1.20E+00
RPP-AN105-SL644IV-Cr35-L140	3-171249	6.8	3.00	140	0.334	1.24E+00

Appendix F-4: Cadmium Column Elution
Temperature = 35 °C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cd]_{eff}$ (mg/L)	Cd profile [C/Co]
RPP-TP00049-Cr35-E2	3-171253	7.6	1.0	2	0.0	0.14
RPP-TP00049-Cr35-E4	3-171254	6.0	1.0	4	0.1	0.24
RPP-TP00049-Cr35-E6	3-171255	4.6	1.0	6	3.91	14.48
RPP-TP00049-Cr35-E8	3-171256	4.6	1.0	8	1.09	4.04
RPP-TP00049-Cr35-E10	3-171257	4.6	1.0	10	0.17	0.65
RPP-TP00049-Cr35-E12	3-171258	4.6	1.0	12	0.06	0.22
RPP-TP00049-Cr35-E14	3-171259	4.6	1.0	14	0.09	0.34
RPP-TP00049-Cr35-E16	3-171260	4.6	1.0	16	0.08	0.30

Appendix F-5: Cadmium Column Loading
Flow rate = ~ 2.5-3 BV/h
Temperature = 45 °C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cd]_{eff}$ (mg/L)	Cd profile [C/Co]
RPP-AN105-SL644IV-Cr45-L5	3-171549	6.7	2.5	5	0.03	1.04E-01
RPP-AN105-SL644IV-Cr45-L10	3-171550	6.7	2.5	10	0.03	1.12E-01
RPP-AN105-SL644IV-Cr45-L20	3-171551	6.6	2.8	20	0.19	7.05E-01
RPP-AN105-SL644IV-Cr45-L30	3-171552	6.6	2.8	30	0.19	6.95E-01
RPP-AN105-SL644IV-Cr45-L40	3-171553	6.6	2.8	40		
RPP-AN105-SL644IV-Cr45-L550	3-171554	6.6	2.8	50	0.22	8.02E-01
RPP-AN105-SL644IV-Cr45-L60	3-171555	6.6	2.8	60	0.25	9.15E-01
RPP-AN105-SL644IV-Cr45-L70	3-171556	6.6	2.9	70	0.28	8.34E-01
RPP-AN105-SL644IV-Cr45-L80	3-171557	6.6	2.9	80	0.33	9.89E-01
RPP-AN105-SL644IV-Cr45-L90	3-171558	6.6	3.0	90	0.30	7.42E-01
RPP-AN105-SL644IV-Cr45-L100	3-171559	6.6	2.8	100	0.28	7.02E-01
RPP-AN105-SL644IV-Cr45-L110	3-171560	6.6	2.8	110	0.33	8.24E-01
RPP-AN105-SL644IV-Cr45-L120	3-171561	6.6	2.8	120	0.31	7.86E-01
RPP-AN105-SL644IV-Cr45-L130	3-171562	6.6	2.8	130	0.33	8.21E-01
RPP-AN105-SL644IV-Cr45-L140	3-171563	6.6	2.8	140	0.41	1.03E+00
RPP-AN105-SL644IV-Cr45-L150	3-171565	6.6	2.8	150	0.45	1.13E+00

Appendix F-6: Cadmium Column Elution
Temperature = 45 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	*Resin bed* height (cm)	Flow rate (BV/h)	# BV processed	$[Cd]_{eff}$ (mg/L)	Cd profile [C/Co]
RPP-TP00049-Cr45-E2	3-171567	6.2	1.06	2	0.01	0.04
RPP-TP00049-Cr45-E4	3-171568	4.9	1.05	4	0.06	0.17
RPP-TP00049-Cr45-E6	3-171569	4.3	1.05	6	5.61	17.24
RPP-TP00049-Cr45-E8	3-171570	4.3	1.05	8	1.85	5.69
RPP-TP00049-Cr45-E10	3-171571	4.3	1.05	10	0.47	1.43
RPP-TP00049-Cr45-12	3-171572	4.3	1.05	12	0.11	0.35
RPP-TP00049-Cr45-14	3-171573	4.3	1.05	14	0.07	0.22
RPP-TP00049-Cr45-16	3-171574	4.3	0.98	16	0.04	0.14

Appendix F-7: Cadmium Column Loading
Flow rate = ~ 2.8 BV/h
Temperature = 25 oC (repeat)
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cd]_{eff}$ (mg/L)	Cd Profile [C/Co]
RPP-AN105-SL644IV-Cr25R-L5	3-171798	6.6	2.7	5	0.03	0.07
RPP-AN105-SL644IV-Cr25R-L10	3-171799	6.6	2.7	10	0.03	0.07
RPP-AN105-SL644IV-Cr25R-L20	3-171800	6.6	2.8	20	0.09	0.20
RPP-AN105-SL644IV-Cr25R-L30	3-171801	6.6	2.8	30	0.13	0.30
RPP-AN105-SL644IV-Cr25R-L40	3-171802	6.6	2.8	40	0.19	0.45
RPP-AN105-SL644IV-Cr25R-L50	3-171803	6.6	2.8	50	0.25	0.58
RPP-AN105-SL644IV-Cr25R-L70	3-171804	6.6	2.8	70	0.33	0.78
RPP-AN105-SL644IV-Cr25R-L90	3-171805	6.6	2.9	90	0.33	0.79
RPP-AN105-SL644IV-Cr25-L110	3-171806	6.6	2.9	110	0.35	0.84
RPP-AN105-SL644IV-Cr25-L130	3-171807	6.6	2.8	130	0.36	0.84
RPP-AN105-SL644IV-Cr25-L150	3-171808	6.6	2.8	150	0.36	0.86
RPP-AN105-SL644IV-Cr25-L170	3-171809	6.6	2.8	170	0.35	0.83
RPP-AN105-SL644IV-Cr25-L190	3-171810	6.6	2.9	190	0.35	0.82
RPP-AN105-SL644IV-Cr25-L210	3-171811	6.6	2.8	210	0.37	0.87

Appendix F-8: Cadmium Column Elution
Temperature = 25 ^{o}C (repeat)
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cd]_{eff}$ (mg/L)	Cd Profile [C/Co]
RPP-TP00049-Cr25R-E2	3-171816	4.5	1.5	2	0.01	0.03
RPP-TP00049-Cr25R-E4	3-171817	4.6	1.3	4	0.06	0.14
RPP-TP00049-Cr25R-E6	3-171818	4.5	1.4	6	5.61	14.08
RPP-TP00049-Cr25R-E8	3-171819	4.5	1.3	8	1.85	4.64
RPP-TP00049-Cr25R-E10	3-171820	4.5	1.3	10	0.47	1.17
RPP-TP00049-Cr25R-12	3-171821	4.5	1.3	12	0.11	0.28
RPP-TP00049-Cr25R-14	3-171822	4.5	1.3	14	0.07	0.18
RPP-TP00049-Cr25R-16	3-171823	4.5	1.3	16	0.04	0.11

Appendix G

Chromium Column Loading and Elution data

Appendix G-1: Chromium Column Loading

Flow rate = 3 BV/h
Temperature = 25 ^oC
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cr]_{eff}$ (mg/L)	Cr profile [C/Co]
RPP-AN105-Cr25-L5	3-170827	6.8	2.98	5	484	0.81
RPP-TP00049-Cr25-L10	3-170828	6.8	2.98	10	549	0.92
RPP-TP00049-Cr25-L20	3-170829	6.8	2.98	20	542	0.91
RPP-TP00049-Cr25-L30	3-170830	6.8	2.98	30	590	0.99
RPP-TP00049-Cr25-L40	3-170831	6.8	2.98	40	590	0.99
RPP-TP00049-Cr25-L50	3-170832	6.8	2.98	50	590	0.99
RPP-TP00049-Cr25-L60	3-170833	6.8	2.98	60	591	0.99
RPP-TP00049-Cr25-L70	3-170834	6.8	2.98	70	591	0.99
RPP-TP00049-Cr25-L80	3-170835	6.8	2.98	80	591	0.99
RPP-TP00049-Cr25-L90	3-170836	6.8	2.98	90	596	1.00
RPP-TP00049-Cr25-L100	3-170837	6.8	2.98	100	593	0.99
RPP-TP00049-Cr25-L110	3-170838	6.8	2.98	110	593	0.99
RPP-TP00049-Cr25-L120	3-170839	6.8	2.98	120	596	1.00
RPP-TP00049-Cr25-L130	3-170840	6.8	2.98	130	599	1.01
RPP-TP00049-Cr25-L140	3-170841	6.8	2.98	140	597	1.00
RPP-TP00049-Cr25-L150	3-170842	6.8	2.98	150	592	

Appendix G-2: Chromium Column Elution
Temperature = 25 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV* processed	$[Cr]_{eff}$ (mg/L)	Cr profile [C/Co]
RPP-TP00049-Cr25-E2	3-170843	5.8	0.95	2.8	601	1.01
RPP-TP00049-Cr25-E4	3-170844	4.9	1.37	5.6	599	1.01
RPP-TP00049-Cr25-E6	3-170845	4.9	1.51	8.4	604	1.01
RPP-TP00049-Cr25-E8	3-170846	4.9	1.51	11.2	601	1.01
RPP-TP00049-Cr25-E10	3-170847	4.9	1.51	14	604	1.01
RPP-TP00049-Cr25-E12	3-170848	4.9	1.51	16.8	602	1.01
RPP-TP00049-Cr25-E14	3-170849	4.9	1.51	19.6	601	1.01
RPP-TP00049-Cr25-E16	3-170850	4.9	1.51	22.4	332	0.56

Appendix G-3: Chromium Column Loading
Flow rate = ~ 3 BV/h
Temperature = 35 °C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cr]_{eff}$ (mg/L)	Cr profile [C/Co]
RPP-AN105-SL644IV-Cr35-L5	3-171235	6.8	3.00	5	353	0.59
RPP-AN105-SL644IV-Cr35-L10	3-171236	6.8	3.00	10	563	0.94
RPP-AN105-SL644IV-Cr35-L20	3-171237	6.8	3.00	20	584	0.98
RPP-AN105-SL644IV-Cr35-L30	3-171238	6.8	3.00	30	592	0.99
RPP-AN105-SL644IV-Cr35-L40	3-171230	6.8	3.00	40	646	1.08
RPP-AN105-SL644IV-Cr35-L50	3-171240	6.8	3.00	50	605	1.02
RPP-AN105-SL644IV-Cr35-L60	3-171241	6.8	3.00	60	593	0.99
RPP-AN105-SL644IV-Cr35-L70	3-171242	6.8	3.00	70	601	1.01
RPP-AN105-SL644IV-Cr35-L80	3-171243	6.8	3.00	80	599	1.01
RPP-AN105-SL644IV-Cr35-L90	3-171244	6.8	3.00	90	604	1.01
RPP-AN105-SL644IV-Cr35-L100	3-171245	6.8	3.00	100	601	1.01
RPP-AN105-SL644IV-Cr35-L110	3-171246	6.8	3.00	110	604	1.01
RPP-AN105-SL644IV-Cr35-L120	3-171247	6.8	3.00	120	602	1.01
RPP-AN105-SL644IV-Cr35-L130	3-171248	6.8	3.00	130	601	1.01
RPP-AN105-SL644IV-Cr35-L140	3-171249	6.8	3.00	140		

Appendix G-4: Chromium Column Elution
Temperature = 35 ^oC
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cr]_{eff}$ (mg/L)	Cr profile [C/Co]
RPP-TP00049-Cr35-E2	3-171253	7.6	1.0	2	18.4	0.03
RPP-TP00049-Cr35-E4	3-171254	6.0	1.0	4	3.2	0.01
RPP-TP00049-Cr35-E6	3-171255	4.6	1.0	6	192	0.32
RPP-TP00049-Cr35-E8	3-171256	4.6	1.0	8	130	0.22
RPP-TP00049-Cr35-E10	3-171257	4.6	1.0	10	76.3	0.13
RPP-TP00049-Cr35-E12	3-171258	4.6	1.0	12	48.8	0.08
RPP-TP00049-Cr35-E14	3-171259	4.6	1.0	14	33.8	0.06
RPP-TP00049-Cr35-E16	3-171260	4.6	1.0	16	26.7	0.04

Appendix G-5: Chromium Column Loading
Flow rate = ~ 2.5-3 BV/h
Temperature = 45 °C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cr]_{eff}$ (mg/L)	Cr profile [C/Co]
RPP-AN105-SL644IV-Cr45-L5	3-171549	6.7	2.5	5	509	0.85
RPP-AN105-SL644IV-Cr45-L10	3-171550	6.7	2.5	10	574	0.96
RPP-AN105-SL644IV-Cr45-L20	3-171551	6.6	2.8	20	587	0.98
RPP-AN105-SL644IV-Cr45-L30	3-171552	6.6	2.8	30	593	0.99
RPP-AN105-SL644IV-Cr45-L40	3-171553	6.6	2.8	40	592	0.99
RPP-AN105-SL644IV-Cr45-L550	3-171554	6.6	2.8	50	593	0.99
RPP-AN105-SL644IV-Cr45-L60	3-171555	6.6	2.8	60	598	1.00
RPP-AN105-SL644IV-Cr45-L70	3-171556	6.6	2.9	70	598	1.01
RPP-AN105-SL644IV-Cr45-L80	3-171557	6.6	2.9	80	597	1.01
RPP-AN105-SL644IV-Cr45-L90	3-171558	6.6	3.0	90	598	1.01
RPP-AN105-SL644IV-Cr45-L100	3-171559	6.6	2.8	100	592	1.00
RPP-AN105-SL644IV-Cr45-L110	3-171560	6.6	2.8	110	602	1.02
RPP-AN105-SL644IV-Cr45-L120	3-171561	6.6	2.8	120	600	1.01
RPP-AN105-SL644IV-Cr45-L130	3-171562	6.6	2.8	130	598	1.01
RPP-AN105-SL644IV-Cr45-L140	3-171563	6.6	2.8	140	603	1.02
RPP-AN105-SL644IV-Cr45-L150	3-171565	6.6	2.8	150	606	1.02

Appendix G-6: Chromium Column Elution
Temperature = 45 °C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	*Resin bed* height (cm)	Flow rate (BV/h)	# BV processed	$[Cr]_{eff}$ (mg/L)	Cr profile [C/Co]
RPP-TP00049-Cr45-E2	3-171567	6.2	1.06	2	5.97	0.01
RPP-TP00049-Cr45-E4	3-171568	4.9	1.05	4	3.20	0.01
RPP-TP00049-Cr45-E6	3-171569	4.3	1.05	6	231	0.39
RPP-TP00049-Cr45-E8	3-171570	4.3	1.05	8	161	0.27
RPP-TP00049-Cr45-E10	3-171571	4.3	1.05	10	100	0.17
RPP-TP00049-Cr45-12	3-171572	4.3	1.05	12	67.2	0.11
RPP-TP00049-Cr45-14	3-171573	4.3	1.05	14	47.0	0.08
RPP-TP00049-Cr45-16	3-171574	4.3	0.98	16	36.8	0.06

Appendix G-7: Chromium Column Loading
Temperature = 25 °C (repeat)
Flow rate = ~ 2.8 BV/h
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cr]_{eff}$ (mg/L)	Cr Profile [C/Co]
RPP-AN105-SL644IV-Cr25R-L5	3-171798	6.6	2.7	5	548	0.93
RPP-AN105-SL644IV-Cr25R-L10	3-171799	6.6	2.7	10	587	0.99
RPP-AN105-SL644IV-Cr25R-L20	3-171800	6.6	2.8	20	594	1.01
RPP-AN105-SL644IV-Cr25R-L30	3-171801	6.6	2.8	30	599	1.01
RPP-AN105-SL644IV-Cr25R-L40	3-171802	6.6	2.8	40	594	1.01
RPP-AN105-SL644IV-Cr25R-L50	3-171803	6.6	2.8	50	593	1.00
RPP-AN105-SL644IV-Cr25R-L70	3-171804	6.6	2.8	70	587	0.99
RPP-AN105-SL644IV-Cr25R-L90	3-171805	6.6	2.9	90	597	1.01
RPP-AN105-SL644IV-Cr25-L110	3-171806	6.6	2.9	110	591	1.00
RPP-AN105-SL644IV-Cr25-L130	3-171807	6.6	2.8	130	591	1.00
RPP-AN105-SL644IV-Cr25-L150	3-171808	6.6	2.8	150	591	1.00
RPP-AN105-SL644IV-Cr25-L170	3-171809	6.6	2.8	170	590	1.00
RPP-AN105-SL644IV-Cr25-L190	3-171810	6.6	2.9	190	587	0.99
RPP-AN105-SL644IV-Cr25-L210	3-171811	6.6	2.8	210	594	1.01

Appendix G-8: Chromium Column Elution
Temperature = 25 ^{o}C (repeat)
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Cr]_{eff}$ (mg/L)	Cr profile [C/Co]
RPP-TP00049-Cr25R-E2	3-171816	4.5	1.5	2	5.98	0.01
RPP-TP00049-Cr25R-E4	3-171817	4.6	1.3	4	19.3	0.03
RPP-TP00049-Cr25R-E6	3-171818	4.5	1.4	6	55.4	0.09
RPP-TP00049-Cr25R-E8	3-171819	4.5	1.3	8	37.7	0.06
RPP-TP00049-Cr25R-E10	3-171820	4.5	1.3	10	24.7	0.04
RPP-TP00049-Cr25R-12	3-171821	4.5	1.3	12	18.1	0.03
RPP-TP00049-Cr25R-14	3-171822	4.5	1.3	14	14.3	0.02
RPP-TP00049-Cr25R-16	3-171823	4.5	1.3	16	11.4	0.02

Appendix-H

Iron Column Loading and Elution data

Appendix H-1: Iron Column Loading
Flow rate = 3 BV/h
Temperature = 25 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Fe]_{eff}$ (mg/L)	Fe profile [C/Co]
RPP-AN105-Cr25-L5	3-170827	6.8	2.98	5	0.11	0.16
RPP-TP00049-Cr25-L10	3-170828	6.8	2.98	10	0.40	0.59
RPP-TP00049-Cr25-L20	3-170829	6.8	2.98	20	0.35	0.51
RPP-TP00049-Cr25-L30	3-170830	6.8	2.98	30	0.34	0.50
RPP-TP00049-Cr25-L40	3-170831	6.8	2.98	40	0.37	0.55
RPP-TP00049-Cr25-L50	3-170832	6.8	2.98	50	0.42	0.61
RPP-TP00049-Cr25-L60	3-170833	6.8	2.98	60	0.53	0.78
RPP-TP00049-Cr25-L70	3-170834	6.8	2.98	70	0.47	0.69
RPP-TP00049-Cr25-L80	3-170835	6.8	2.98	80	0.57	0.84
RPP-TP00049-Cr25-L90	3-170836	6.8	2.98	90	0.58	0.85
RPP-TP00049-Cr25-L100	3-170837	6.8	2.98	100	0.58	0.84
RPP-TP00049-Cr25-L110	3-170838	6.8	2.98	110	0.59	0.86
RPP-TP00049-Cr25-L120	3-170839	6.8	2.98	120	0.57	0.84
RPP-TP00049-Cr25-L130	3-170840	6.8	2.98	130	0.57	0.84
RPP-TP00049-Cr25-L140	3-170841	6.8	2.98	140	0.64	0.93
RPP-TP00049-Cr25-L150	3-170842	6.8	2.98	150		

Appendix H-2: Iron Column Elution
Temperature = 25 ^oC
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV* processed	$[Fe]_{eff}$ (mg/L)	Fe profile [C/Co]
RPP-TP00049-Cr25-E2	3-170843	5.8	0.95	2.8	1.0	1.47
RPP-TP00049-Cr25-E4	3-170844	4.9	1.37	5.6	0.94	1.38
RPP-TP00049-Cr25-E6	3-170845	4.9	1.51	8.4	1.46	2.13
RPP-TP00049-Cr25-E8	3-170846	4.9	1.51	11.2	0.90	1.32
RPP-TP00049-Cr25-E10	3-170847	4.9	1.51	14	1.21	1.78
RPP-TP00049-Cr25-E12	3-170848	4.9	1.51	16.8	0.92	1.34
RPP-TP00049-Cr25-E14	3-170849	4.9	1.51	19.6	0.95	1.38
RPP-TP00049-Cr25-E16	3-170850	4.9	1.51	22.4	0.45	0.65

Appendix H-3: Iron Column Loading
Flow rate = ~ 3 BV/h
Temperature = 35 °C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Fe]_{eff}$ (mg/L)	Fe profile [C/Co]
RPP-AN105-SL644IV-Cr35-L5	3-171235	6.8	3.00	5	0.17	0.24
RPP-AN105-SL644IV-Cr35-L10	3-171236	6.8	3.00	10	0.20	0.29
RPP-AN105-SL644IV-Cr35-L20	3-171237	6.8	3.00	20	0.34	0.49
RPP-AN105-SL644IV-Cr35-L30	3-171238	6.8	3.00	30	0.36	0.53
RPP-AN105-SL644IV-Cr35-L40	3-171230	6.8	3.00	40	0.09	
RPP-AN105-SL644IV-Cr35-L50	3-171240	6.8	3.00	50	0.09	
RPP-AN105-SL644IV-Cr35-L60	3-171241	6.8	3.00	60	0.63	0.92
RPP-AN105-SL644IV-Cr35-L70	3-171242	6.8	3.00	70	1.0	1.47
RPP-AN105-SL644IV-Cr35-L80	3-171243	6.8	3.00	80	0.94	1.38
RPP-AN105-SL644IV-Cr35-L90	3-171244	6.8	3.00	90	1.46	
RPP-AN105-SL644IV-Cr35-L100	3-171245	6.8	3.00	100	0.90	1.32
RPP-AN105-SL644IV-Cr35-L110	3-171246	6.8	3.00	110	1.21	1.78
RPP-AN105-SL644IV-Cr35-L120	3-171247	6.8	3.00	120	0.92	1.34
RPP-AN105-SL644IV-Cr35-L130	3-171248	6.8	3.00	130	0.95	1.38
RPP-AN105-SL644IV-Cr35-L140	3-171249	6.8	3.00	140		

Appendix H-4: Iron Column Elution
Temperature = 35 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Fe]_{eff}$ (mg/L)	Fe profile [C/Co]
RPP-TP00049-Cr35-E2	3-171253	7.6	1.0	2	0.13	0.19
RPP-TP00049-Cr35-E4	3-171254	6.0	1.0	4	0.20	0.29
RPP-TP00049-Cr35-E6	3-171255	4.6	1.0	6	8.57	12.54
RPP-TP00049-Cr35-E8	3-171256	4.6	1.0	8	3.63	5.31
RPP-TP00049-Cr35-E10	3-171257	4.6	1.0	10	1.31	1.92
RPP-TP00049-Cr35-E12	3-171258	4.6	1.0	12	0.96	1.40
RPP-TP00049-Cr35-E14	3-171259	4.6	1.0	14	0.97	1.43
RPP-TP00049-Cr35-E16	3-171260	4.6	1.0	16	0.95	1.39

Appendix H-5: Iron Column Loading
Flow rate = ~ 2.5-3 BV/h
Temperature = 45 °C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Fe]_{eff}$ (mg/L)	Fe profile [C/Co]
RPP-AN105-SL644IV-Cr45-L5	3-171549	6.7	2.5	5	0.24	0.34
RPP-AN105-SL644IV-Cr45-L10	3-171550	6.7	2.5	10	0.26	0.38
RPP-AN105-SL644IV-Cr45-L20	3-171551	6.6	2.8	20	0.39	0.57
RPP-AN105-SL644IV-Cr45-L30	3-171552	6.6	2.8	30	0.36	0.53
RPP-AN105-SL644IV-Cr45-L40	3-171553	6.6	2.8	40	0.59	0.86
RPP-AN105-SL644IV-Cr45-L550	3-171554	6.6	2.8	50	0.62	0.91
RPP-AN105-SL644IV-Cr45-L60	3-171555	6.6	2.8	60	0.65	0.95
RPP-AN105-SL644IV-Cr45-L70	3-171556	6.6	2.9	70	0.63	0.87
RPP-AN105-SL644IV-Cr45-L80	3-171557	6.6	2.9	80	0.80	1.10
RPP-AN105-SL644IV-Cr45-L90	3-171558	6.6	3.0	90	0.77	1.00
RPP-AN105-SL644IV-Cr45-L100	3-171559	6.6	2.8	100	0.76	0.98
RPP-AN105-SL644IV-Cr45-L110	3-171560	6.6	2.8	110	0.68	0.87
RPP-AN105-SL644IV-Cr45-L120	3-171561	6.6	2.8	120	0.72	0.93
RPP-AN105-SL644IV-Cr45-L130	3-171562	6.6	2.8	130	0.69	0.89
RPP-AN105-SL644IV-Cr45-L140	3-171563	6.6	2.8	140	0.87	1.12
RPP-AN105-SL644IV-Cr45-L150	3-171565	6.6	2.8	150	0.91	1.17

Appendix H-6: Iron Column Elution
Temperature = 45 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	*Resin bed* height (cm)	Flow rate (BV/h)	# BV processed	$[Fe]_{eff}$ (mg/L)	Fe profile [C/Co]
RPP-TP00049-Cr45-E2	3-171567	6.2	1.06	2	0.10	0.14
RPP-TP00049-Cr45-E4	3-171568	4.9	1.05	4	0.16	0.22
RPP-TP00049-Cr45-E6	3-171569	4.3	1.05	6	11.0	15.09
RPP-TP00049-Cr45-E8	3-171570	4.3	1.05	8	4.75	6.52
RPP-TP00049-Cr45-E10	3-171571	4.3	1.05	10	2.17	2.98
RPP-TP00049-Cr45-12	3-171572	4.3	1.05	12	1.28	1.76
RPP-TP00049-Cr45-14	3-171573	4.3	1.05	14	0.99	1.36
RPP-TP00049-Cr45-16	3-171574	4.3	0.98	16	1.04	1.42

Appendix H-7: Iron Column Loading
Temperature = 25 ^{o}C (repeat)
Flow rate = ~ 2.8 BV/h
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Fe]_{eff}$ (mg/L)	Fe Profile [C/Co]
RPP-AN105-SL644IV-Cr25R-L5	3-171798	6.6	2.7	5	0.54	0.66
RPP-AN105-SL644IV-Cr25R-L10	3-171799	6.6	2.7	10	0.46	0.56
RPP-AN105-SL644IV-Cr25R-L20	3-171800	6.6	2.8	20	0.62	0.75
RPP-AN105-SL644IV-Cr25R-L30	3-171801	6.6	2.8	30	0.63	0.77
RPP-AN105-SL644IV-Cr25R-L40	3-171802	6.6	2.8	40	0.64	0.79
RPP-AN105-SL644IV-Cr25R-L50	3-171803	6.6	2.8	50	0.69	0.84
RPP-AN105-SL644IV-Cr25R-L70	3-171804	6.6	2.8	70	0.79	0.96
RPP-AN105-SL644IV-Cr25R-L90	3-171805	6.6	2.9	90	0.86	1.05
RPP-AN105-SL644IV-Cr25-L110	3-171806	6.6	2.9	110	0.84	1.02
RPP-AN105-SL644IV-Cr25-L130	3-171807	6.6	2.8	130	0.83	1.01
RPP-AN105-SL644IV-Cr25-L150	3-171808	6.6	2.8	150	0.84	1.02
RPP-AN105-SL644IV-Cr25-L170	3-171809	6.6	2.8	170	0.89	1.09
RPP-AN105-SL644IV-Cr25-L190	3-171810	6.6	2.9	190	0.89	1.08
RPP-AN105-SL644IV-Cr25-L210	3-171811	6.6	2.8	210	0.89	1.09

Appendix H-8: Iron Column Elution
Temperature = 25 ^{o}C (repeat)
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Fe]_{eff}$ (mg/L)	Fe profile [C/Co]
RPP-TP00049-Cr25R-E2	3-171816	4.5	1.5	2	0.08	0.10
RPP-TP00049-Cr25R-E4	3-171817	4.6	1.3	4	9.51	12.28
RPP-TP00049-Cr25R-E6	3-171818	4.5	1.4	6	8.26	10.66
RPP-TP00049-Cr25R-E8	3-171819	4.5	1.3	8	2.80	3.61
RPP-TP00049-Cr25R-E10	3-171820	4.5	1.3	10	1.21	1.56
RPP-TP00049-Cr25R-12	3-171821	4.5	1.3	12	1.03	1.33
RPP-TP00049-Cr25R-14	3-171822	4.5	1.3	14	0.76	0.98
RPP-TP00049-Cr25R-16	3-171823	4.5	1.3	16	0.64	0.82

Appendix-I

Lead Column Loading and Elution data

Appendix I-1: Lead Column Loading
Flow rate = 3 BV/h
Temperature = 25 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Pb]_{eff}$ (mg/L)	Pb profile [C/Co]
RPP-AN105-Cr25-L5	3-170827	6.8	2.98	5	3.2	0.13
RPP-TP00049-Cr25-L10	3-170828	6.8	2.98	10	7.9	0.33
RPP-TP00049-Cr25-L20	3-170829	6.8	2.98	20	15.9	0.66
RPP-TP00049-Cr25-L30	3-170830	6.8	2.98	30	21.0	0.87
RPP-TP00049-Cr25-L40	3-170831	6.8	2.98	40	22.3	0.93
RPP-TP00049-Cr25-L50	3-170832	6.8	2.98	50	22.8	0.95
RPP-TP00049-Cr25-L60	3-170833	6.8	2.98	60	23.3	0.97
RPP-TP00049-Cr25-L70	3-170834	6.8	2.98	70	23.2	0.97
RPP-TP00049-Cr25-L80	3-170835	6.8	2.98	80	23.8	0.99
RPP-TP00049-Cr25-L90	3-170836	6.8	2.98	90	23.9	1.00
RPP-TP00049-Cr25-L100	3-170837	6.8	2.98	100	24.0	1.00
RPP-TP00049-Cr25-L110	3-170838	6.8	2.98	110	23.3	0.97
RPP-TP00049-Cr25-L120	3-170839	6.8	2.98	120	23.8	0.99
RPP-TP00049-Cr25-L130	3-170840	6.8	2.98	130	23.4	0.97
RPP-TP00049-Cr25-L140	3-170841	6.8	2.98	140	24.0	1.00
RPP-TP00049-Cr25-L150	3-170842	6.8	2.98	150	23.8	

Appendix I-2: Lead Column Elution
Temperature = 25 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV* processed	$[Fe]_{eff}$ (mg/L)	Fe profile [C/Co]
RPP-TP00049-Cr25-E2	3-170843	5.8	0.95	2.8	22.5	0.94
RPP-TP00049-Cr25-E4	3-170844	4.9	1.37	5.6	22.3	0.93
RPP-TP00049-Cr25-E6	3-170845	4.9	1.51	8.4	22.6	0.94
RPP-TP00049-Cr25-E8	3-170846	4.9	1.51	11.2	21.9	0.91
RPP-TP00049-Cr25-E10	3-170847	4.9	1.51	14	23.2	0.97
RPP-TP00049-Cr25-E12	3-170848	4.9	1.51	16.8	22.0	0.92
RPP-TP00049-Cr25-E14	3-170849	4.9	1.51	19.6	22.5	0.94
RPP-TP00049-Cr25-E16	3-170850	4.9	1.51	22.4	10.4	0.44

Appendix I-3: Lead Column Loading
Flow rate = ~ 3 BV/h
Temperature = 35 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Pb]_{eff}$ (mg/L)	Pb profile [C/Co]
RPP-AN105-SL644IV-Cr35-L5	3-171235	6.8	3.00	5	1.4	0.06
RPP-AN105-SL644IV-Cr35-L10	3-171236	6.8	3.00	10	11.1	0.46
RPP-AN105-SL644IV-Cr35-L20	3-171237	6.8	3.00	20	19.4	0.81
RPP-AN105-SL644IV-Cr35-L30	3-171238	6.8	3.00	30	21.9	0.91
RPP-AN105-SL644IV-Cr35-L40	3-171230	6.8	3.00	40	22.54	0.94
RPP-AN105-SL644IV-Cr35-L50	3-171240	6.8	3.00	50	22.1	0.92
RPP-AN105-SL644IV-Cr35-L60	3-171241	6.8	3.00	60	24.1	1.00
RPP-AN105-SL644IV-Cr35-L70	3-171242	6.8	3.00	70	22.5	0.94
RPP-AN105-SL644IV-Cr35-L80	3-171243	6.8	3.00	80	22.3	0.93
RPP-AN105-SL644IV-Cr35-L90	3-171244	6.8	3.00	90	22.6	0.94
RPP-AN105-SL644IV-Cr35-L100	3-171245	6.8	3.00	100	21.9	0.91
RPP-AN105-SL644IV-Cr35-L110	3-171246	6.8	3.00	110	23.2	0.97
RPP-AN105-SL644IV-Cr35-L120	3-171247	6.8	3.00	120	22.0	0.92
RPP-AN105-SL644IV-Cr35-L130	3-171248	6.8	3.00	130	22.5	0.94
RPP-AN105-SL644IV-Cr35-L140	3-171249	6.8	3.00	140		

Appendix I-4: Lead Column Elution
Temperature = 35 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Pb]_{eff}$ (mg/L)	Pb profile [C/Co]
RPP-TP00049-Cr35-E2	3-171253	7.6	1.0	2	0.39	0.02
RPP-TP00049-Cr35-E4	3-171254	6.0	1.0	4	1.4	0.06
RPP-TP00049-Cr35-E6	3-171255	4.6	1.0	6	53.6	2.23
RPP-TP00049-Cr35-E8	3-171256	4.6	1.0	8	12.7	0.53
RPP-TP00049-Cr35-E10	3-171257	4.6	1.0	10	1.6	0.07
RPP-TP00049-Cr35-E12	3-171258	4.6	1.0	12	1.4	0.06
RPP-TP00049-Cr35-E14	3-171259	4.6	1.0	14	1.4	0.06
RPP-TP00049-Cr35-E16	3-171260	4.6	1.0	16	1.4	0.06

Appendix I-5: Lead Column Loading
Flow rate = ~ 2.5-3 BV/h
Temperature = 45 ^oC
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Pb]_{eff}$ (mg/L)	Pb profile [C/Co]
RPP-AN105-SL644IV-Cr45-L5	3-171549	6.7	2.5	5	3.3	0.14
RPP-AN105-SL644IV-Cr45-L10	3-171550	6.7	2.5	10	12.6	0.52
RPP-AN105-SL644IV-Cr45-L20	3-171551	6.6	2.8	20	19.3	0.80
RPP-AN105-SL644IV-Cr45-L30	3-171552	6.6	2.8	30	21.0	0.88
RPP-AN105-SL644IV-Cr45-L40	3-171553	6.6	2.8	40	21.3	0.89
RPP-AN105-SL644IV-Cr45-L550	3-171554	6.6	2.8	50	21.4	0.89
RPP-AN105-SL644IV-Cr45-L60	3-171555	6.6	2.8	60	22.2	0.93
RPP-AN105-SL644IV-Cr45-L70	3-171556	6.6	2.9	70	21.7	0.95
RPP-AN105-SL644IV-Cr45-L80	3-171557	6.6	2.9	80	21.9	0.96
RPP-AN105-SL644IV-Cr45-L90	3-171558	6.6	3.0	90	22.2	1.03
RPP-AN105-SL644IV-Cr45-L100	3-171559	6.6	2.8	100	22.7	1.05
RPP-AN105-SL644IV-Cr45-L110	3-171560	6.6	2.8	110	22.7	1.06
RPP-AN105-SL644IV-Cr45-L120	3-171561	6.6	2.8	120	21.7	1.01
RPP-AN105-SL644IV-Cr45-L130	3-171562	6.6	2.8	130	22.1	1.03
RPP-AN105-SL644IV-Cr45-L140	3-171563	6.6	2.8	140	24.6	1.14
RPP-AN105-SL644IV-Cr45-L150	3-171565	6.6	2.8	150	23.0	1.07

Appendix I-6: Lead Column Elution
Temperature = 45 ^{o}C
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	*Resin bed* height (cm)	Flow rate (BV/h)	# BV processed	$[Pb]_{eff}$ (mg/L)	Pb profile [C/Co]
RPP-TP00049-Cr45-E2	3-171567	6.2	1.06	2	0.3	0.02
RPP-TP00049-Cr45-E4	3-171568	4.9	1.05	4	0.3	0.02
RPP-TP00049-Cr45-E6	3-171569	4.3	1.05	6	59.4	2.61
RPP-TP00049-Cr45-E8	3-171570	4.3	1.05	8	17.7	0.78
RPP-TP00049-Cr45-E10	3-171571	4.3	1.05	10	3.8	0.17
RPP-TP00049-Cr45-12	3-171572	4.3	1.05	12	0.7	0.03
RPP-TP00049-Cr45-14	3-171573	4.3	1.05	14	0.3	0.02
RPP-TP00049-Cr45-16	3-171574	4.3	0.98	16	0.3	0.02

Appendix I-7: Lead Column Loading
Flow rate = ~ 2.8 BV/h
Temperature = 25 ^{o}C (repeat)
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	Resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Pb]_{eff}$ (mg/L)	Pb Profile [C/Co]
RPP-AN105-SL644IV-Cr25R-L5	3-171798	6.6	2.7	5	3.0	0.14
RPP-AN105-SL644IV-Cr25R-L10	3-171799	6.6	2.7	10	9.4	0.43
RPP-AN105-SL644IV-Cr25R-L20	3-171800	6.6	2.8	20	17.2	0.80
RPP-AN105-SL644IV-Cr25R-L30	3-171801	6.6	2.8	30	20.2	0.93
RPP-AN105-SL644IV-Cr25R-L40	3-171802	6.6	2.8	40	21.6	0.99
RPP-AN105-SL644IV-Cr25R-L50	3-171803	6.6	2.8	50	22.4	1.03
RPP-AN105-SL644IV-Cr25R-L70	3-171804	6.6	2.8	70	22.3	1.03
RPP-AN105-SL644IV-Cr25R-L90	3-171805	6.6	2.9	90	22.9	1.06
RPP-AN105-SL644IV-Cr25-L110	3-171806	6.6	2.9	110	23.3	1.07
RPP-AN105-SL644IV-Cr25-L130	3-171807	6.6	2.8	130	22.4	1.03
RPP-AN105-SL644IV-Cr25-L150	3-171808	6.6	2.8	150	22.8	1.05
RPP-AN105-SL644IV-Cr25-L170	3-171809	6.6	2.8	170	22.2	1.03
RPP-AN105-SL644IV-Cr25-L190	3-171810	6.6	2.9	190	22.3	1.03
RPP-AN105-SL644IV-Cr25-L210	3-171811	6.6	2.8	210	22.0	1.02

Appendix I-8: Lead Column Elution
Temperature = 25 ^{o}C (repeat)
Envelope A (Tank 241-AN-105) simulant
Resin batch # 991022smc-IV29
Column size = 1.45 cm

Sample ID	ADS #	resin bed height (cm)	Flow rate (BV/h)	# BV processed	$[Pb]_{eff}$ (mg/L)	Pb profile [C/Co]
RPP-TP00049-Cr25R-E2	3-171816	4.5	1.5	2	0.35	0.02
RPP-TP00049-Cr25R-E4	3-171817	4.6	1.3	4	111	5.15
RPP-TP00049-Cr25R-E6	3-171818	4.5	1.4	6	66.9	3.10
RPP-TP00049-Cr25R-E8	3-171819	4.5	1.3	8	11.0	0.51
RPP-TP00049-Cr25R-E10	3-171820	4.5	1.3	10	1.09	0.05
RPP-TP00049-Cr25R-12	3-171821	4.5	1.3	12	0.69	0.03
RPP-TP00049-Cr25R-14	3-171822	4.5	1.3	14	0.69	0.03
RPP-TP00049-Cr25R-16	3-171823	4.5	1.3	16	0.35	0.02